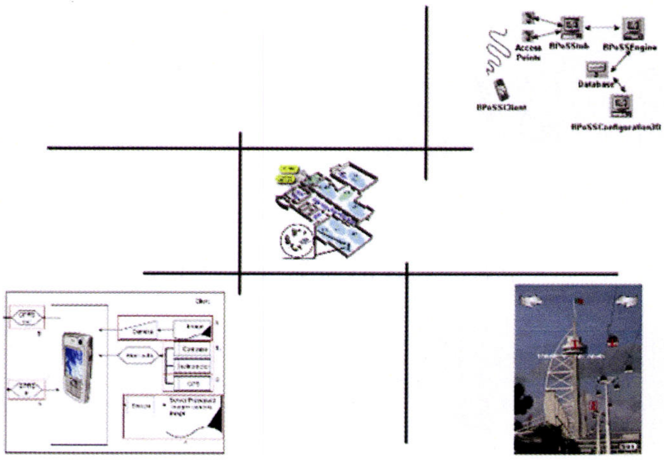
Empowering the user with contextual information

From location infrastructures to augmented reality interfaces



Research Dissertation presented for the Degree of Doctor in Computer Science Engineering by the University of Évora

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April, 2007

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iv. Abreviations and Definitions

3G	Third Generation
8 PSK	Eight-Phase-Shift Keying
AES	Advanced Encryption Standard
A-FLT	Advanced Forward Link Trilateration
A-GPS	Assisted GPS
AMC	Adaptive Modulation and Coding
AOA	Angle of Arrival
AP	Access Point
ATM	Asynchronous Transfer Mode
BT	Bluetooth
BS	Base Station
BSSID	Basic Service Set ID
BTAP	Bluetooth Access Point
CCK-OFDM	Complimentary Code Keying/Orthogonal FDM
CS	Coding Schemes
DEM	Digital Elevation Map
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data rates for GSM Evolution
EDR	Enhanced Data Rate
E-FLT	Enhanced Forward Link Triangulation
E-FLT	Enhanced Forward Link Trilateration
FFD	Full Function Device
FHS	Frequency Hop Synchronization
FHSS	Frequency Hopping Spread Spectrum
FIPS	Federal Information Processing Standards
GMSK	Gaussian minimum-shift keying

GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Request
HMD	Head-Mounted Display
HSCSD	high-speed, multi-slot data
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IQD	Inquiring Device
IQSD	Inquiry Scanning Device
ISM	Industrial Scientific and Medical
L2CAP	Logical Link Control and Adaptation Protocol
LOS	Line of Sight
LP	Local Positioning Profile Specification
MAC	Medium Access Control Layer
MIMO	Multiple-Input Multiple-Output
MS	Mobile Station
MSC	Modulation Coding Schemes
Mte	Mobile Cellular Terminals
NIC	Network Interface Card
NIST	National Institute of Standards and Technology
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
OS	Operating System
OTDOA	Observed Time Difference of Arrival
OTDOA-IPDL	Observed Time of Arrival-Idle Period Down Link
PAN	Personal Area Network
PBCC-22	Packet Binary Convolutional Coding - 22
PDA	Personal Digital Assistant
PHY	Physical Layer
PSM	Phase-shift keying
QoS	Quality of Service
RF	Radio Frequency
RFD	Reduced Function Device
RNBP	Reference Node Based Positioning
RTT	Round-Trip Time
SDP	Service Discovery Protocol

SMS	Short Message Service
TA	Timing Advance
TDOA	Time Difference of Arrival
TGn	New Task Group
TOA	Time-of-Arrival
ToC	Track-on-a-Chip
TOF	Time of Flight
TTFF	Time-To-First-Fix
UI	User Interface
UMTS	Universal Mobile Telephone System
W-CDMA	Wideband Code Division Multiple Access
WEP	Wireless Encryption Protocol
WGS84	World Geodetic System 1984
WiMax	Worldwide Interoperability for Microwave Access
WIMP	Windows, Icons, Menus and Pointers
WPA	Wi-Fi Protected Access
ZigBee	IEEE 802.15.4 Standard

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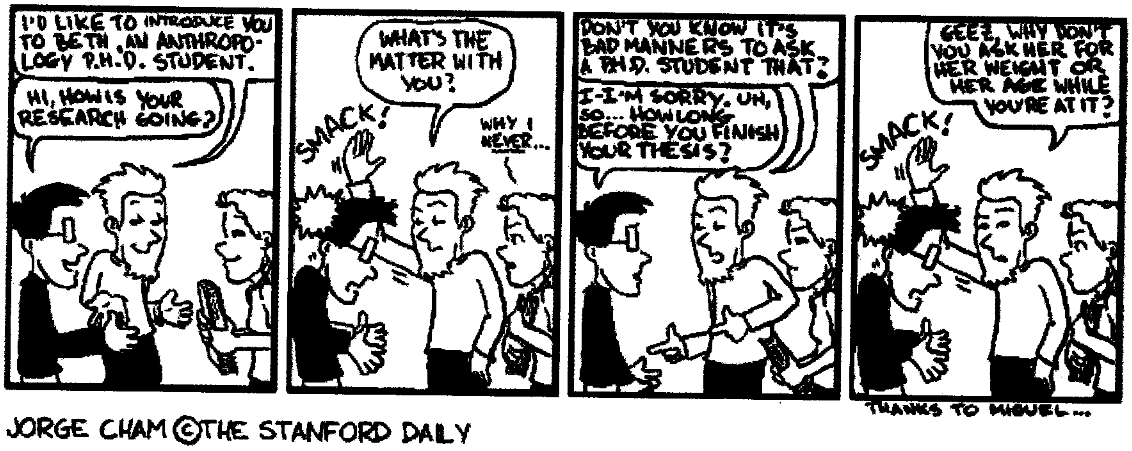

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

v. Resumo alargado

Sumário

O trabalho apresentado nesta dissertação envolve a utilização de realidade aumentada como uma interface ubíqua no mundo real. A tese discute ainda diferentes aspectos associados aos diferentes módulos necessarios para o desenvolvimento de um sistema de computação ubíqua, nomeadamente a aquisição de contexto e a apresentação de informação ao utilizador. No contexto da tese, são ainda discutidas novas arquitecturas, métodos e técnicas para melhorar os sistemas de computação ubíqua. Esta secção apresenta uma breve descrição da tese, assim como as questões e objectivos que levaram à sua realização.

v.1. Introdução

Computação ubíqua compreende um mundo onde os computadores fornecem informações e serviços, onde e quando forem necessários. Desta forma, poderemos ter dispositivos computacionais nas coisas mais triviais: nas etiquetas da roupa (para analisar a lavagem), nas chávenas de café (para alertar a equipa de limpeza para uma lavagem mal realizada), interruptores de luz (para poupar energia se ninguém estiver numa determinada divisão), e canetas (para digitalizar tudo o que escrevemos). Num universo onde tal seja possível, devemos viver com os computadores e não nos limitarmos a interagir com eles [1].

A ideia principal é ter computadores no nosso dia a dia, escondidos no ambiente e a ajudar as pessoas nas suas tarefas mais comuns. A computação ubíqua envolve diferentes areas de pesquisa, tais como redes de sensors, computação móvel, realidade aumentada, interacção humano-máquina e inteligência artificial. Contudo, a computação ubíqua é uma área de pesquisa, ainda numa fase muito recente do seu desenvolvimento.

Tomemos em conta um exemplo para o desenvolvimento de interfaces. Billinghurst et al. [3] afirma que o desenvolvimento de uma nova forma de interacção tipicamente passa por quarto fases:

1. Demonstração do protótipo;
2. Adopção de técnicas de interacção a partir de outras metáforas de interacção;
3. Desenvolvimento de uma nova metáfora apropriada ao problema;
4. Desenvolvimento dos modelos formais teóricos para previsão e modelação das interacções do utilizador.

Apesar de terem sido realizados grandes avanços na áreas que envolvem a computação ubíqua, ainda existe um grande caminho a percorrer até se atingir a quarta fase. O sistema de tabs, pads, e boards desenvolvido no Xerox-Parc é um exemplo de um protótipo do que poderá ser um sistema de computação ubíqua [25]. Ainda assim, podemos considerar que esta nova interface ainda se encontra na primeira fase de desenvolvimento.

Em grande utilização, as interfaces baseadas em Janelas, Ícones, Menus e Apontadores (WIMP) possuem algumas limitações quando aplicadas à grande mobilidade das actividades decorrentes do dia-a-dia. Para uma utilização eficiente de interfaces WIMP é necessário desenvolver e actualizar as aptidões do utilizador. Na verdade, a experiência diária mostra-nos que as pessoas funcionam maioritariamente num mundo onde as experiências são partilhadas e existem algumas falhas nas aptidões tecnológicas de cada um.

A interface WIMP, tal como é conhecida nos nossos dias, isola as pessoas; requerendo atenção permanente por parte do utilizador, retirando-lhe ainda uma visão global do ambiente envolvente. Contudo, deixar as interfaces WIMP não é fácil. Apesar das suas ineficiências, os utilizadores já absorveram o seu contexto de utilização e a sugestão das suas propriedades físicas, quer se trate de teclados, ratos ou monitores.

Para além disto, para que se possa focar a atenção das pessoas na tarefa em curso, em vez de focar a atenção das mesmas num dispositivo informático, existe a necessidade de criar redes de sensores. Estas redes de sensores são necessárias para capturar e identificar o contexto em que as tarefas são executadas ou, alternativamente, solicitar ao utilizador que indique esse mesmo contexto. Este último caso é um compromisso entre um sistema totalmente automatizado e as interfaces WIMP amplamente utilizadas.

Quando o contexto pode ser capturado por sensors na vizinhança do utilizador, as tarefas podem ser executadas de uma forma proactiva, tal como se de um agente autónomo se tratasse, realizando este os objectivos previstos para o utilizador [14]. Desta forma, diferentes variáveis podem ser avaliadas para identificar o contexto em questão. Como tal, é necessário que um sistema de computação ubíqua seleccione as variáveis que melhor descrevem o contexto de uma situação em particular.

A localização é uma das variáveis que permite a um sistema de computação ubíqua identificar o contexto em que uma tarefa está a ser executada. A aplicação de sistemas de localização a sistemas de computação ubíqua é um requisito importante, tornando-os aplicáveis a diferentes situações. Como tal, diferentes avanços têm sido realizados na área dos sistemas de localização. Ainda assim, diversas melhorias serão necessarias para que se consiga atingir um sistema que seja fácil, familiar e que forneça valor acrescentado na sua utilização.

Borriello et al. [5] refere que as aplicações baseadas na localização estão destinadas a ser as primeiras aplicações reais dos sistemas de computação ubíqua. As aplicações "buddy finder e product finder" são exemplos de aplicações que têm direccionado os laboratórios de pesquisa e a indústria a desenvolver um grande número de sensores e aplicações baseadas na localização.

As tecnologias desenvolvidas, para este fim, têm uma grande influência nos parâmetros de performance dos sistemas de localização e nas aplicações desenvolvidas para os utilizar. Para que um dispositivo móvel possa capturar a sua localização, podem ser utilizadas técnicas como: escutar emissões, procurar padrões na cena ou, ainda, medir parâmetros do sinal de rádio, ver tabela 0-1.

Método	Descrição
Escutar emissões	São colocados, no ambiente, pequenos dispositivos que divulgam a sua localização no espaço. Habitualmente, recorrendo à infra-estructura, estes são colocados em locais desobstruidos, nomeadamente satélites, tectos ou paredes, denominando-se emissores. Do outro lado, os receptores são pequenos dispositivos que recebem as mensagens dos emissores e utilizam estas mensagens para inferirem a sua localização. Posteriormente, uma API é desenvolvida para que os programas desenvolvidos nos receptores possam aprender onde estão e possam utilizar esta informação para descreverem a sua localização para os serviços que lhes estão associados. Nestes sistemas, os receptores monitorizam a posição do dispositivo através da monitorização de sinais dos emissores e, posteriormente, questionar uma base de dados central para obtenção da sua localização. Alternativamente, os receptores podem questioner uma base de dados local para obter a sua localização.
Procurar padrões na cena	São procurados padrões na cena, com recurso a um sistema de localização, e a localização é calculada com base na posição conhecida de cada um destes padrões. Num sistema de localização com base em visão, o cálculo da localização é realizado com base na busca de padrões [17] ou característivas naturais [2], tais como a análise da linha do horizonte na linha de visão e comparação com uma base de dados. Posteriormente, a imagem pode ser comparada com um modelo ou mapa [4], definindo um conceito em que o conhecimento do ambiente pode ser utilizado para resolver problemas de outros sistemas de

	localização.
Medir parâmetros de rádio	A localização pode ainda ser obtida através da análise de sinais de rádio, o que é maioritariamente utilizado nas redes de rádio celulares. Nestes casos, os terminais móveis conseguem calcular a sua posição, muitas vezes com suporte da própria rede, sem grandes alterações nos próprios dispositivos.

Table 0-1 - Métodos para análise da localização

Contudo, o facto destes sistemas terem uma forte base em pesquisa ou terem ainda reduzido desenvolvimento revela a falta de uma infra-estrutura comum. Como tal, é difícil utilizar diferentes tipos de sensors e formatos de localização, levando ainda a uma divulgação lenta da utilização dos sistemas baseados na localização. Os desafios para a especificação e desenho desta infra-estructura surgem de diferentes fontes, com base na especificidade de cada uma das tecnologias, assim como na especificidade de cada uma das aplicações envolvidas.

A precisão necessária, a modelação da localização e o formato da informação de localização são variáveis que devem ser consideradas durante o desenho de tal infra-estructura. Como exemplo, poderemos ter um sistema de realidade aumentada que requer um elevado nivel de precisão; contudo, para a maioria das aplicações baseadas em localização informação de proximidade é suficiente. Com o recurso a variáveis adicionais, a infra-estructura pode ser mais complexa.

Consequentemente, é importante modelar a informação de forma a optimizar os requisitos dos sistemas de localização. Os modelos de localização podem influenciar e melhorar a qualidade da informação de localização, assim como sistemas com base na localização. Os modelos básicos de localização, nomeadamente simbólicos ou geométricos, podem servir diferentes serviços ou aplicações. Os modelos simbólicos podem fornecer relações entre os espaços, faltando-lhes a precisão encontrada nos modelos geométricos. Como tal, uma infra-estructura comum para sistemas de localização deve ter todos estes detalhes em consideração.

Para além disto, os sistemas de computação ubíqua têm forte base em informação que lhes é fornecida remotamente. Sendo necessário o transporte dos dados através de redes sem fios para suportar uma experiência ubíqua. Como tal, diferentes tecnologias podem ser utilizadas para o transporte dos dados entre dispositivos. Estas tecnologias permitem o acesso a diferentes recursos, logo a escolha da melhor tecnologia para um problema específico deve ter em consideração a largura de banda necessárias e o alcance desejado. Chen e Kotz descreveram alguma destas tecnologias em três categorias [7]:

- Redes celulares sem fios são a solução mais comum para a cobertura de uma grande área, normalmente utilizadas por telefones celulares. O seu alcance pode ser a nível global.
- Redes locais sem fios, baseadas na familia de standards IEEE 802.11, são soluções que permitem a mobilidade ao nível de um campus universitário, um edifício, ou até mesmo de uma cidade como New York [18]. Estas redes permitem maiores larguras de banda que as redes celulares.
- Redes pessoais sem fios são redes que operam ao nível da esfera pessoal. Tipicamente, os seus pontos fortes são baixo consumo, curto alcance e conexão com até 16 outros dispositivos. Em alguns casos, estas redes estão desenhadas para substituir os fios. O Bluetooth é um standard de radio, IEEE 802.15.1, este

grupo de trabalho procura ainda o desenvolvimento de outros standards para redes de curta distância.

Mais recentemente, a quarta geração de redes wireless foca o seu desenvolvimento numa infra-estructura de redes heterogéneas, assim como no desenvolvimento de redes mais rápidas e mais eficientes. O exemplo deste foco é o crescente suporte por parte de dispositivos móveis em diferentes redes sem fios.

Desta forma, a crescente necessidade de redes mais rápidas continua. A companhia japonesa, NTT DoCoMo, e a Samsung encontram-se a testar redes de comunicação 4G a 100 Mbit/s, em movimento, e a 1 Gbit/s, para dispositivos fixos [21]. Em consequência, existe a necessidade de adaptar o comportamento dos dispositivos e aplicações de acordo com os recursos disponíveis, mudanças do ambiente e objectivos do utilizador. Adicionalmente, a descoberta e análise destes factores permite fornecer uma melhor experiência ubíqua.

De modo idêntico, objectivos semelhantes são aplicados aos sistemas de realidade aumentada. Realidade Aumentada é uma tecnologia em que a visão do utilizador do mundo real é melhorada com informação virtual que parece coexistir no mesmo espaço que os objectos reais. Azuma et al. [1] definiram realidade aumentada como possuindo três propriedades:

- Combina os objectos reais e virtuais no ambiente real;
- Corre interactivamente e em tempo real; e
- Regista os objectos virtuais e reais entre eles.

Computação Ubíqua e a realidade aumentada são áreas de pesquisa fortemente ligadas. Os sistemas de computação ubíqua fornecem suporte aos utilizadores sem alterar os seus comportamentos. Ainda assim, quando são adicionadas novas funcionalidades aos dispositivos, estes tendem a ser mais complicados. Como tal, aumentar o ambiente com informação adicional pode facilitar o uso de dispositivos complexos.

O foco é na busca de um paradigma mais intuitivo, não apenas no provimento de informação virtual adicional ao utilizador. A informação adicional fornecida ao utilizador não se restringe à visão. Qualquer sentido, incluindo o cheiro, o paladar, a audição ou o tacto podem ser aumentados. De igual forma, os objectos reais podem ser retirados da cena, um processo designado por alguns investigadores como realidade mediata ou diminuida.

A realidade aumentada pode ser aplicada a areas como gestão ambiental, cirúgia assistida por computador, reparação e manutenção de sistemas complexos, modificação de ambientes, desenho de interiores ou ainda entretenimento. Todas as áreas de pesquisa mencionadas influenciaram esta dissertação. Como tal, esta dissertação explora diferentes interfaces para os sistemas de computação ubíqua, com especial foco em realidade aumentada como uma interface ubíqua, fornecendo ainda contribuições no desenvolvimento de outros módulos pertencentes a um sistema de computação ubíqua.

v.2. Domínio do problema

As interfaces computacionais evoluiram ao longo dos tempos, sendo que algumas foram embutidas no ambiente e actividades da vida diária, operando na periferia da atenção dos utilizadores. Alguns dispositivos foram integrados nesse ambiente e desapareceram da atenção dos utilizadores [25][6]. Esta era computacional, designada por computação ubíqua, trouxe dispositivos computacionais mais pequenos, baratos e mais rápidos embebidos em dispositivos do dia a dia, chamados objectos "inteligentes".

Recentemente, Adam Greenfield utilizou o termo "everyware" para descrever tecnologias de computação ubíqua, computação pervasiva, ambientes informáticos e interfaces tangíveis [15]. Com pontos de pesquisa comuns, "everyware" e realidade aumentada têm vários problemas por resolver. Felizmente, a pesquisa tem evoluido à medida que o tempo passa, deixando aos investigadores várias opções, tecnologias e aplicações.

Este número de opções leva a diferentes soluções para o mesmo problema, nomeadamente o desenvolvimento e aplicação de diferentes sistemas de localização. Contudo, cada sistema tem apenas em conta restrições específicas para o problema e, no seu conjunto, encontramos grandes inovações para o problema de uma forma global. Frequentemente, os custos envolvidos nestas soluções são a restrição principal; reduzindo o número de opções. Em resultado, alguns compromissos são tomados levando a soluções mais acessíveis.

Este conjunto de soluções criou, ainda, a necessidade de juntar todo numa solução comum, facilitando o seu uso. Este requisito tem importância crescente à medida que aumenta o número de tecnologias e plataformas comuns, nomeadamente standards, são necessários para melhorar e facilitar o desenvolvimento de aplicações e serviços. Ainda assim, a localização é apenas uma variável capaz de caracterizar um âmbito maior, o contexto.

Também para um âmbito maior, o contexto, existe a necessidade de pesquisa e desenvolvimento de sistemas com base no contexto. A falta de uma infra-estructura comum, assim como para os sistemas de localização, existe. Também de igual forma, é necessário especificar a infra-estructura assim como o formato da informação a utilizar pelas aplicações e serviços.

Perante a necessidade de transferir dados entre os diferentes dispositivos levanta-se ainda outra questão. Como é que os diferentes dispositivos móveis comunicam com a infra-estructura? As tecnologias de comunicação são importantes, serão ainda mais na medida em que podem ser utilizadas para detecção da localização. Como tal, o modo como se usam estas tecnologias e se melhora o seu uso para outras tarefas, nomeadamente detecção do contexto, é uma área de pesquisa interessante.

Estas tecnologias e infra-estructuras podem ainda servir de base a outras áreas de pesquisa. Entre elas, a realidade aumentada, como uma interface ubíqua, pode criar um novo motivo de entusiasmo na sua utilização. Ainda assim, diferentes arquitecturas, métodos e tecnologias têm de ser discutidos e testados, assim como novos campos de aplicação onde os sistemas de realidade aumentada possam ser aplicados para melhorar o desempenho dos utilizadores nas suas actividades.

A gestão ambiental é um dos campos onde a realidade aumentada pode melhorar a percepção do ambiente na vizinhança dos utilizadores. A informação recolhida por diferentes métodos e processos pode ser integrada num sistema de realidade aumentada, assim como modelos de previsão para fornecer uma aproximação mais realista de como os problemas ambientais podem afectar o ambiente em redor.

A realidade aumentada tem ainda a capacidade de fornecer esses requisitos sem exigir o foco de atenção do utilizador num dispositivo em particular. O utilizador pode caminhar no ambiente e ainda receber informação adicional sobre o ambiente que o rodeia.

Até agora, apenas os aspectos técnicos têm sido abordados mas será que os utilizadores irão realmente utilizar estes sistemas? Os aspectos sociais também devem ser considerados. A tecnologia deve ser desenvolvida com os utilizadores em mente. Uma vez encontrada a tecnologia ideal, várias questões devem ser tidas em conta para que essa tecnologia possa entrar na vida das pessoas. Muitas vezes, a tecnologia para um determinado problema já existe, deve então ser adaptada para ir de encontro às necessidades das pessoas.

v.2.a) Questões para a pesquisa

Nesta dissertação, alguns problemas relacionados com a utilização de realidade aumentada como uma interface ubíqua são investigados, principalmente aplicando a realidade aumentada a problemas de gestão ambiental e situações da vida real. Durante a pesquisa, as questões levantadas foram consideradas no desenvolvimento, de forma a produzir protótipos de aplicação a problemas reais como demonstração. Diferentes problemas foram então tidos em conta nesta dissertação e formulados em questões a pesquisar:

- Como recolher e utilizar informação sobre localização? Que tecnologias se aplicam melhor a cada cenário de utilização?
- Como utilizar o Bluetooth em sistemas de localização para interiors, dado que um grande número de dispositivos móveis já suportam esta tecnologia?
- Como estructurar e desenvolver uma infra-estructura comum de localização? Que modelos de localização devem ser utilizados para cada um dos propósitos e como os integrar?
- Como criar um sistema de localização simples e de baixo custo que possa ser utilizado sem necessidade de complicadas configurações e calibrações?
- Que dispositivos devem ser desenvolvidos e integrados num sistema de realidade aumentada aplicado a gestão ambiental?
- Como melhorar a arquitectura anterior para que possa integrar simulações de dispersões de poluentes?
- Que dispositivos devem ser desenvolvidos e integrados em dispositivos móveis de uso comum de forma a serem utilizados num sistema móvel de realidade aumentada para exteriores, aplicados a cenários de entretenimento?

v.2.b) Objectivos da pesquisa

O principal objectivo desta dissertação é discutir, melhorar e/ou responder às questões formuladas anteriormente e contribuir com soluções para a resolução desses problemas. Dirigindo, essas soluções, para o uso de sistemas de realidade aumentada como uma interface ubíqua. Os objectivos desta pesquisa são os seguintes:

- Sistemas de localização utilizando Bluetooth – O objectivo é desenvolver um sistema com base no servidor por forma a controlar as emissões de rádio produzidas no sistema e não exigir alterações nos dispositivos móveis.

- Infraestructura de localização – O objectivo é identificar os principais módulos de uma infraestructura de localização e os seus papéis. Os modelos de localização são ser tidos em consideração para avaliar a sua utilização em sistemas de localização ou melhorar os sistemas baseados no contexto.
- Sistemas de localização de baixo custo – O objectivo é a obtenção de um sistema de baixo custo que encorage a utilização de aplicações com base na localização por um maior número de pessoas, nomeadamente visitantes de um museu. O sistema proposto é fácil de manter, configurar e instalar.
- Realidade aumentada para gestão ambiental – O objectivo é uma configuração de RA adequada ao uso por engenheiros do ambiente. O sistema é composto por um modelo geo-referenciado e um módulo de visualização. Alternativamente, pode ser utilizado um modelo 3D do ambiente, uma base de dados geo-referênciada e um módulo de visualização, permitindo aos utilizadores visualizar informação adicional sobre o ambiente.
- Realidade aumentada móvel aplicada em entretenimento – O objectivo é o desenvolvimento de um sistema de realidade aumentada móvel aplicado ao entretenimento, com recurso a uma bússula digital sem fios, um GPS sem fios, um telefone móvel e um servidor de jogo. O processamento do jogo é realizado no servidor, recorrendo a tecnologias sem fios para melhorar a experiência de utilização de um sistema de realidade aumentada.

v.3. Declaração da dissertação

De acordo com Thomas Kuhn, as alterações no paradigma de iteracção são revoluções no conhecimento científico [22]. Na curta história das ciências da computação, foram encontrados quarto paradigmas de interacção (Batch, Time-Sharing, Desktop, Networked). Esta nova éra traz-nos uma nova mudança de paradigma. Em vez de ferramentas centradas na utilização do computador pessoal, é sugerido que se criem ferramentas centradas no utilizador.

Prevê-se que os dispositivos computacionais possam estar em todo o lado, com diferentes tamanhos e aplicados a diferentes tarefas. A interacção com os utilizadores tende a ser de forma natural e intuitiva, com os vários utilizadores a utilizar diferentes dispositivos computacionais. Em consequência, os utilizadores focam a sua atenção na tarefa, em vez de focarem a sua atenção nas ferramentas utilizadas.

Adicionalmente, o desenho dos dispositivos deve sugerir a sua utilização. Permitindo ainda aos dispositivos informáticos captar o contexto dos utilizadores de forma automática. Desta forma, a computação ubíqua e a realidade aumentada são campos de pesquisa que podem fornecer um contributo significativo para esta visão do mundo.

O contexto é um elemento importante tanto para a computação ubíqua como para realidade aumentada. Como captar o contexto? Como modelar o contexto? Estas e outras questões necessitam de pesquisa adicional e mais desenvolvimento.

A localização é, reconhecidamente, uma importante variável de contexto. Como tal, muitos serviços baseados em localização estão a ser desenvolvidos e a ser instalados para resolver problemas comuns do dia a dia, utilizando localização. Novas ferramentas, novas tecnologias e requisitos dos utilizadores dão lugar aos avanços que têm sido realizados. Apesar disso, existe ainda a necessidade de uma infraestructura comum, incluindo modelação da localização e serviços para melhorar os serviços baseados na localização.

Tal como referido anteriormente, no mundo real a informação não está facilmente acessível a todos os indivíduos. Como tal, a realidade aumentada pode fornecer as ferramentas necessárias para aceder a informação que não é detectada pelos sentidos dos utilizadores. Esta informação pode ajudar os utilizadores a melhorarem a realização de algumas tarefas, assim como diminuir os tempos de execução.

Estas ferramentas poderão ser muito úteis em gestão ambiental, assim como em tarefas do dia a dia. Consequentemente, novas arquitecturas de realidade aumentada e novas interfaces são necessárias para melhorar a execução dessas tarefas, fornecendo informação virtual adicional aos utilizadores, nomeadamente engenheiros do ambiente ou ainda cidadãos comuns.

Finalmente, não se deve esquecer a aceitação social das tecnologias desenvolvidas em ambientes de pesquisa. Assim, é necessário desenvolver e estudar interfaces amigáveis para que o seu uso possa facilmente ser integrado no dia a dia de cada um dos utilizadores alvo. Para tal, o desenvolvimento baseado em tecnologias de ampla aceitação pode ser um passo para a aceitação de novos desenvolvimentos. Contudo, estudos e desenvolvimentos adicionais devem ser realizados para validar cada uma das soluções.

v.4. Contribuições

Esta dissertação efectua um conjunto de contribuições para o presente estado da arte nos campos da computação ubíqua e realidade aumentada. Algumas das contribuições incluidas nesta dissertação requerem o desenvolvimento de dispositivos e programas necessários para que possam ser desenhadas e desenvolvidas.

A lista completa de contribuições é:

- A análise de métodos, procedimentos e técnicas para construir um sistema de realidade aumentada para uso de engenheiros do ambiente quando no exterior. Os engenheiros do ambiente podem beneficiar da utilização de um sistema de realidade aumentada deixando as suas mãos livres para a tarefa que estão a realizar à medida que vão recebendo informação sobre o ambiente na sua vizinhança. Uma arquitectura modular foi desenhada e direccionada para a sua aplicação em gestão ambiental [8,9,12,13,19,20]
- Desenvolvimento de uma arquitectura modular de realidade aumentada permitindo a visualização de modelos ambientais ao longo do tempo e avaliar as alterações ambientais [9,12,13]. Esta arquitectura pode ainda ser utilizada pelos decisores para avaliar o impacto de alterações ambientais.
- Desenvolvimento de uma interface de utilizador especificamente desenhada para a tarefa em questão, considerando questões de mobilidade e familiaridade da interface. São utilizados agentes como modelos prédefinidos, facilitando a interacção com modelos ambientais [9,12,13].
- Desenvolvimento e análise de um sistema de localização com base na tecnologia Bluetooth, tendo em conta diferentes variáveis da tecnologia para inferir distância e calcular a localização com base em triangulação. [11]

- Análise de uma infraestructura de localização a aplicar a sistemas de localização para interiors, assim como os modelos de localização utilizados nessa infraestructura [16]
- Desenvolvimento de um sistema de localização de baixo custo a aplicar em museus, permitindo uma instalação fácil e com o mínimo impacto no ambiente. Este sistema de localização tem em conta perfis de utilizadores e utilizadores com deficiência de visão ou audição. [10]
- Desenvolvimento de um sistema de realidade aumentada móvel direccionado para telefones móveis. O sistema faz recurso a redes sem fios, uma arquitectura cliente-servidor e um desenho que sugere a sua utilização para melhorar a experiência dos utilizadores.

v.5. Estrutura da dissertação

A presente dissertação encontra-se redigida em inglês, iniciando a sua discussão através de um capítulo introdutório, semelhante a este resumo alargado. Em seguida, é apresentada uma discussão genérica sobre os conceitos e tecnologias associados às comunicações sem fios. Esta discussão genérica permite fundamentar a pesquisa baseada em redes sem fios. Os capítulos seguintes contêm, de igual modo, informação adicional quando relevante.

O capítulo três fornece uma discussão genérica sobre os conceitos e tecnologias associados aos sistemas de localização. Este capítulo tem em conta todos os aspectos referentes à detecção da localização, referindo as vantagens e desvantagens das tecnologias estudadas. Esta discussão genérica serve de base para o desenvolvimento e selecção de tecnologias de localização para outros capítulos da dissertação.

O capítulo quarto discute o desenvolvimento de um sistema de localização para interiores recorrendo à tecnologia Bluetooth. Um grande número de dispositivos móveis está a ser desenvolvido com suporte para esta tecnologia. Desta forma, o Bluetooth pode ser adoptado para utilização em serviços baseados na localização aplicados a espaços interiores. Desta forma, esta tecnologia pode ser utilizada para serviços baseados na localização, nomeadamente publicidade baseada na localização.

O sistema explora os sinais de rádio do Bluetooth para calcular a localização, revela um backoffice intuitivo para gerir a infraestructura e apresenta uma infraestructura que pode crescer independentemente de qual o fabricante dos circuitos Bluetooth. O capítulo cinco foca a falta de uma infraestructura comum para os serviços com base na localização. Este capítulo fornece ainda uma visão geral dos módulos que constituem essa infraestructura, assim como discute os diferentes modelos de localização que podem servir de base para essa mesma infraestructura.

O capítulo seis foca um âmbito mais prático dos sistemas de localização. Muitos projectos de investigação estão a ser desenvolvidos de forma a utilizarem a localização dos utilizadores para lhes dar informação com base no contexto em que se encontram. Contudo, a complexidade desses sistemas pode desviar a atenção dos utilizadores dos benefícios decorrentes da utilização destes sistemas.

Adicionalmente, os custos associados na instalação destes sistemas desencorajam os decisores a adoptar estes sistemas. Como tal, este capítulo é discutido um sistema que tem em conta estas questões permitindo fornecer informação baseada na localização. No capítulo sete é realizada uma pesquisa sobre os sistemas de realidade aumentada que serviram de inspiração para os sistemas desenvolvidos no âmbito desta dissertação.

As principais contribuições de cada sistema são destacadas de forma a servirem de base para pesquisas futuras. No capítulo oito é discutido um sistema de realidade aumentada aplicado a gestão ambiental. Este sistema foca um requisito dos engenheiros do ambiente, nomeadamente a capacidade de executar tarefas podendo receber informação adicional do sistema.

Desta forma, a realidade aumentada fornece as ferramentas a estes profissionais para explorar o ambiente na sua vizinhança através de duas arquitecturas distintas. No capítulo nove, este sistema de realidade aumentada é extendido para incorporar um modelo de dispersão de poluentes permitindo aos engenheiros do ambiente e decisores avaliar o impacto de alterações ambientais no ambiente real. Este sistema visa facilitar a percepção do impacto real da dispersão de poluentes em recursos aquáticos.

O capítulo décimo discute um sistema de realidade aumentada sem fios, como trabalho em curso. A arquitectura deste sistema pretende ser simples e completamente baseada em tecnologias sem fios, libertando o utilizador da tarefa de conexão de todos os cabos necessários. O corpo da dissertação termina com uma discussão dos objectivos alcançados e pesquisas futuras. Depois da conclusão e trabalho futuro seguem-se os anexos.

v.6. Referências

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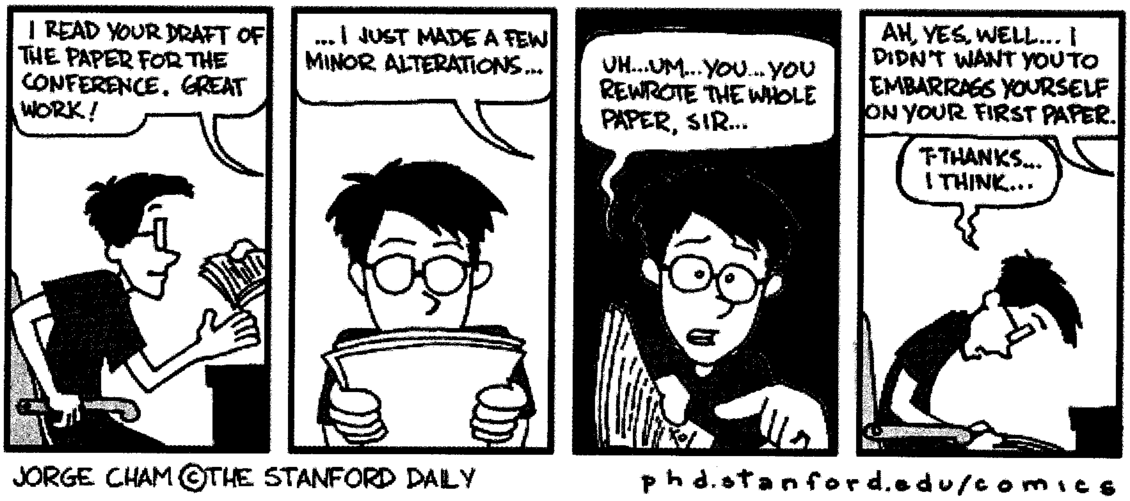

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vi. Summary

Augmented Reality and Ubiquitous Computing are evolving topics in computer science. In this dissertation, augmented reality is discussed as a ubiquitous interface applied to several events in the real world, namely environmental management, every day's life and entertainment. Throughout the dissertation, different aspects of the development of augmented reality systems for ubiquitous computing are presented, such as a number of architectures, methods and techniques to ubiquitously locate persons and objects and visualize related information.

There are several technologies used to track persons and object, however their capabilities and limitations make each technology more suitable for specific purposes. One example is the limitation presented by GPS, used to track users or objects outdoor. However, GPS sensors have problems when used indoor due to the required line-of-sight with the satellites.

Thus, different sensors need to be used to track people and objects indoor. Bluetooth is a technology explored in this dissertation to track persons and objects indoor. However, Bluetooth still reveals some limitations, namely due to the cost of Bluetooth development kits and hardware. In the dissertation, a custom radio tracking system is purposed, reducing costs and augmenting the functionality of the system.

Nevertheless, a new challenge rose: How to model location? In this dissertation the agents involved in a location system are discussed as well as how to model location

information, whether using symbolic information or geometric information. In a wider spectrum, context is also discussed, taking advantage of the actions performed in the environment and the previous knowledge of user's characteristics.

In the first chapters, the infrastructure required in an augmented reality system is discussed, mainly considering indoor scenarios. Afterwards, the complete system is considered to fully develop augmented reality applications. As stated before, augmented reality is also applied as a ubiquitous interface to be used by environmental engineers while in the field of observation.

This work was developed in the scope of the ANTS project, where laptop computers with a head-mounted display and PDAs were used, allowing environmental engineers to grasp information about the surrounding environment. The system explores the capacities and constrains of both approaches to improve the interface with the user. As a proof of concept, three applications were developed.

Two applications, one for buildings visualization and another for subsoil structure visualization, use a 3D model and a database in the server side, for the purposes of content and user positioning, and use presentation components to superimpose virtual information over real images in the client side. The remaining application, for pollution dispersion simulation, uses a dispersion pollution model for the purposes of tracking and providing content, in the server side. In the client side, presentation components are used, similarly to the two previous applications.

Finally, a mobile wireless augmented reality system for mobile phones is presented. The system uses mobile phones and wireless sensors to supply a seamless augmented experience, without bulky and cumber equipment augmented experience. The system presented also explores two different methods to update the augmented experience in the mobile phone.

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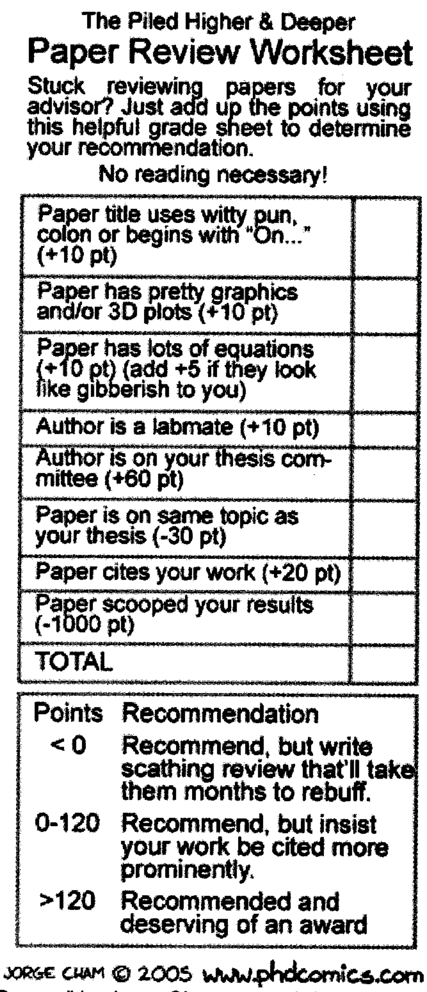
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vii. Declaration

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

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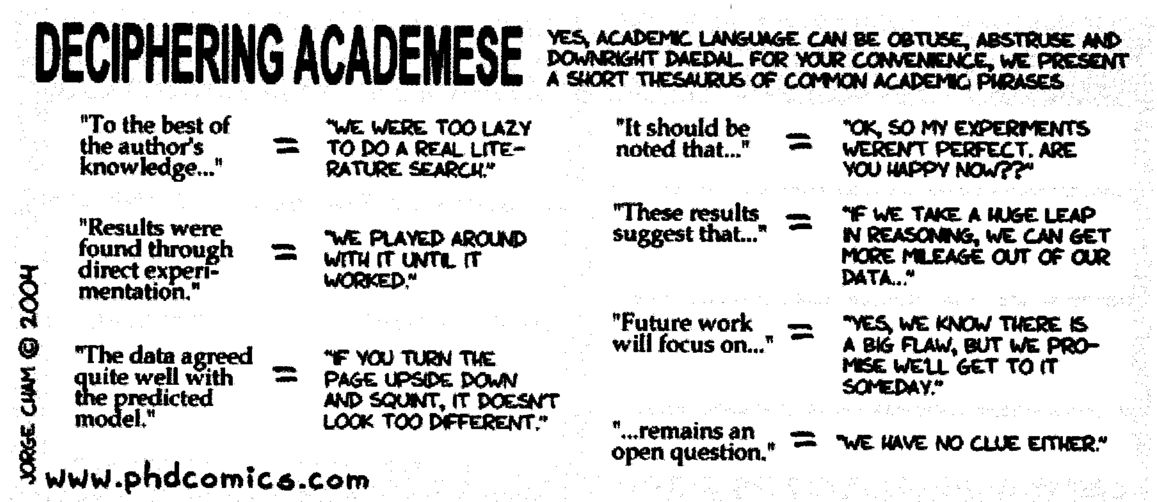

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viii. Acknowledgements

I was expecting for a dissertation in the chimney for Christmas but without success. Therefore I tried to write it myself, and although it is supposed to be a contribution by one person for a PhD, there are still a lot of people who have helped me out over the years. I have been fortunate enough to have had the support of so many people and without them this would not have been possible. While most people did not help directly on the dissertation or contributed to some of the related projects, every one of them contributed in some way towards helping me to get where I am today, even things like just helping me in daily things, being a friend, going out and having fun. Others were responsible for giving me a push in the right direction in life, and for everyone listed here I am eternally grateful for their help.

Firstly, I would like to thank all the persons from Grupo de Análises de Sistemas Ambientais (GASA) for all their help and directions towards the many subjects regarding my dissertation and their extraordinary friendship helping me on everyday tasks that I couldn't have performed otherwise. The lunch time with all of you was excellent. Numerous members of the group have entered and leaved for other projects but all have helped in some way, namely Manuel Costa, João Serpa, Cristina Gouveia, Sofia Simões, Joana Hipólito and everyone that joined the group.

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I should also thank my uncle Delfino and my cousin Susana for their support and friendship. When I was 8 my uncle bought a ZX Spectrum with only 48 KB of memory. Can you imagine that nowadays? Rapidly, I was invaded with the informatics bug. I needed one of those things. In my following birthday, my mum bought one ZX Spectrum for me. It was way outside her possibilities but she bought it. Who would imagine that it would lead me towards this path? Thanks mum.

Also supportive through all my life was my cousin, António Joaquim. He has some crazy ideas, sometimes, but he is also the best friend a person can ever wish. Whenever I needed, most of the times without a previous request, he was there helping me in everything and supporting me.

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In summary, I would like to thank everyone for putting up with me. I believe that this dissertation has made a real contribution to the field of computer science and I hope that everyone that reads this dissertation finds it useful in their work. It has been a fun journey so far, and I look forward to catching up with everyone and having lots of fun and good times, because that is the most important thing of all. Thanks.

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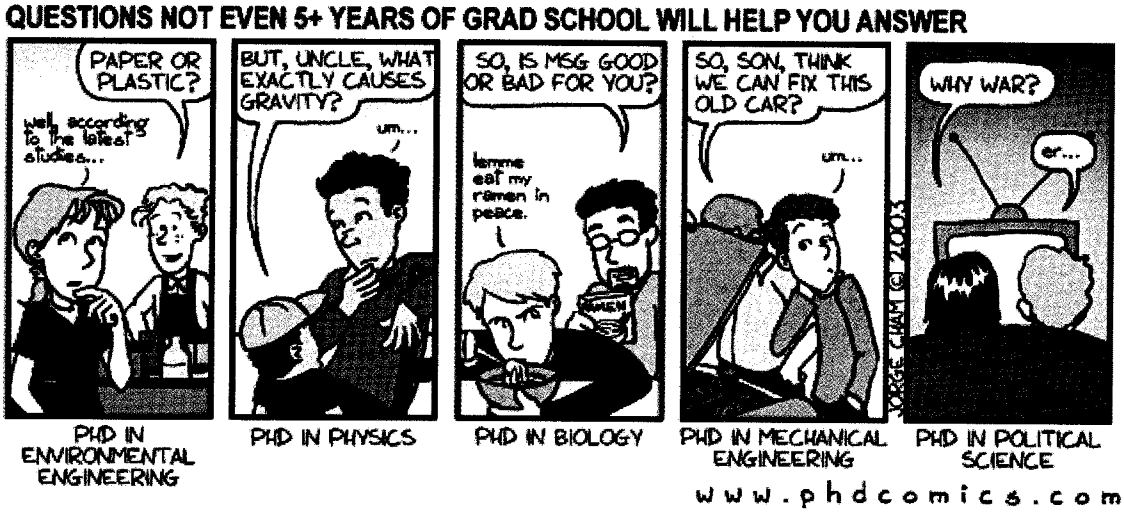

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ix. Inspiration

The work presented in this dissertation has been inspired by the excellent work performed by so many men and women that I've meet through my life seeking to improve their work and performance. Therefore, I've made their path a guideline for my own life.

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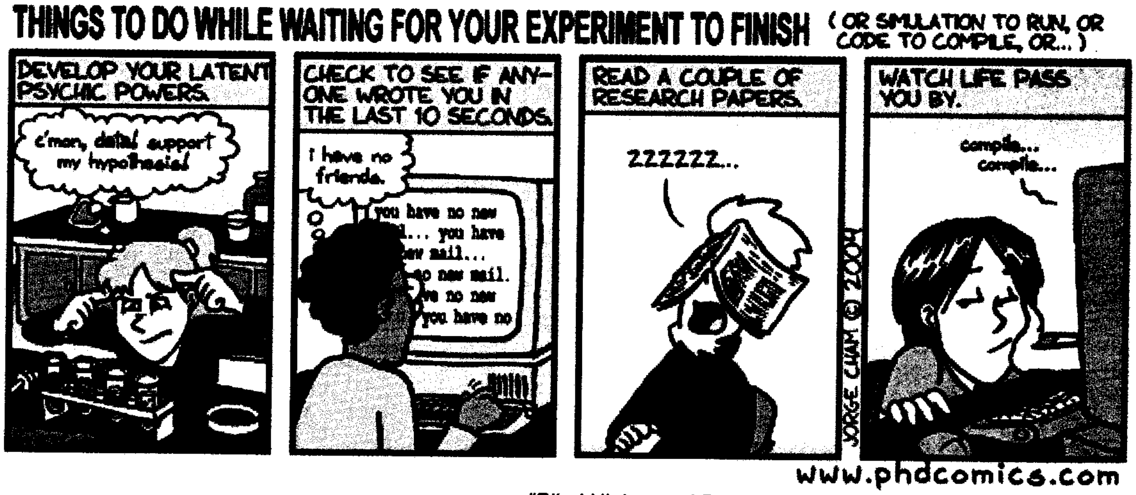

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1. Presentation

Abstract

The work presented in this thesis discusses the usage of augmented reality as a ubiquitous interface in the real world. The thesis discusses several elements required to build a ubiquitous system, namely grab context and present related information to the user. New architectures, methods and techniques were explored to enhance usage of such systems. In this chapter the structure of this thesis is presented as well as the research questions and goals that lead to the research performed in the context of the thesis.

1.1. Introduction

Ubiquitous computing is about computers inhabiting our everyday's environment. Therefore, computers can be found in the most trivial things: cloth labels (to track washing), coffee cups (to alert cleaning staff to moldy cups), light switches (to save energy if no one is in the room), and pencils (to digitize everything we draw). In such a world, we must dwell with computers, not just interact with them [1].

The main idea is to have computers crossing our daily lives, hidden in the environment and helping persons in common tasks. Ubiquitous computing involves several areas of research such as sensor networks, mobile computing, augmented reality, human-computer interaction, and artificial intelligence. However, ubiquitous computing is still in its infancy.

To clear the presented idea, Billinghurst et al. [3] states that the development of a new interface medium, typically progresses through four stages:

1. Prototype demonstration;
2. Adoption of interaction techniques from other interface metaphors;
3. Development of new interface metaphors appropriate to the medium;
4. Development of formal theoretical models for predicting and modelling user interactions.

Although great advances have been performed in Ubiquitous Computing, there is an enormous path to go over until the fourth stage. The tabs, pads, and boards system developed at Xerox-Parc are an example of a prototype of what ubiquitous computing systems could be [25]. However, we can state this project as being in the first stage of interface development.

The desktop computer metaphor with Windows, Icons, Menus and Pointers (WIMP) interfaces hardly fits in mobile activities of our everyday life. To comfortably manage WIMP interfaces, skills have to be developed and constantly updated in order to manage the interface. In fact, the world shows that people primarily work in a world of shared situations and unmanaged technological skills.

The WIMP interface, as experienced today, isolates persons, requiring full attention to be managed and taking the user apart from the overall situation. Nevertheless, dropping WIMP interfaces is not easy. Besides its inefficiencies, users have already absorbed the context of usage and the affordances of its physical properties: keyboards, mice and displays.

WIMP interfaces limit the availability of users to focus in the task being performed, rather than in a computing device. This leads to the need for sensor networks. These sensor networks need to be able to capture and identify the context where tasks are being performed, or alternatively, request the user to enter the context [14]. The later, is a compromise between a fully automatic system and WIMP interfaces to which users are already adapted.

When the context can be fetched by sensors in user's neighborhood, tasks can be performed in a proactive mode, as an autonomous agent, that tries to reach user's goals. Therefore, several variables can be sensed in order to identify context. It is up to a ubiquitous system to select the variables that best describe the context in a particular situation.

Location is one of such variables that allow a ubiquitous system to identify the context where a task is being performed. Applying location systems in ubiquitous computing is a major request, making them practical for several uses. Several advances have been performed in the field of location-awareness. Nevertheless, additional steps should be performed to achieve a system that is effortless, familiar and rewarding to use.

Borriello et al. [5] claims that location-enhanced applications are poised to be the first real-world example of ubiquitous applications. The "buddy finder and product finder" applications are examples of such applications that have driven research labs and industry to develop a plethora of sensors and location-aware applications.

The sensor's technology used has major influence in the goals of the location systems and the applications developed to use them. A mobile device can be aware of its position listening to beacons, searching for cues in the scene, or measuring radio signal parameters while in a radio-based network, see table 1-1.

Method	Description
Listening to beacons	Small devices advertise their location in a spatial location, usually placed in unobtrusive locations like satellites, ceilings or walls, by location owner, also named beacons. On the other side, listeners are small devices that listen to messages from beacons, and use these messages to infer their location. Indeed, listeners, attached to a mobile device or static node, receive the advertised information. Then, an API is provided by listeners so that programs running on the node can learn where they are, and use this information to appropriately advertise themselves and their location to other services. In these systems listeners can track its attached mobile device position by monitoring beacons while the mobile device queries a central database to get the current location. Alternatively, listeners passively listen to beacons and query a local database for its current location.
Searching for cues in the scene	Cues are searched in the scene with a vision-based tracking system and position is calculated based on known position of this cues. In vision-based tracking systems, location is done by searching for fiducials [17] or natural features [2], like horizon silhouettes, in the field of view and querying a local or remote database. Furthermore, vision can be used for model matching or map-based positioning [4] defined as a concept where knowledge about the environment and restrictions it imposes on navigation can be used to correct imprecisions in chosen tracking systems. When a tracking system relies in itself to collect and calculate position data from the environment, privacy can be better achieved. In this case, advertisement of system position can be done to the world or just to selected third parties based on system goals.
Measuring radio signal parameters	Position can be attained measuring radio signals and is mainly used in radio-based cellular networks. Mobile cellular terminals, PDA's, and other mobile devices using radio-based wireless networks will be able to calculate their position with network support allowing deployment of location based systems without major changes in user devices.

Table 1-1 - Location sensing methods

However, the research nature or infancy of such systems lacks a common infrastructure. Thus, it's difficult to use different sensors and location formats seamlessly, also leading to a slower spread of location systems. The challenge in designing such an infrastructure comes from the different aspects that deal with each sensor technology and location-aware applications, namely the accuracy required.

The required accuracy, location modeling and location information format are issues that should be considered while designing such an infrastructure. For example, an augmented reality application may require as much accuracy as possible; however, for the majority of location-based applications proximity is enough. This can get even more complicated when additional variables are added.

Consequently, it is important to model information to best fit the requirements of location systems. Location models can enhance and influence the quality of location and context-aware systems. Basic location models, namely symbolic or geometric, can serve different purposes and applications. Symbolic models can supply relations between spaces lacking the accuracy found in geometric models. Consequently, a common infrastructure for location systems should also account for these details.

Apart from that, ubiquitous systems also rely in remote information, where several data must be carried over a wireless network to support the ubiquitous experience. Thus, different technologies are available to carry data between devices. Those technologies give access to remote resources, and the choice of the best solution for a specific problem must account for the necessary bandwidth and range of network. Therefore, Chen and Kotz described some of these technologies [7]:

- Wireless cellular network is a common solution in mobile devices, such as mobile phones, and their range can be almost worldwide.
- Wireless LANs, based in IEEE 802.11 specification family are other solutions to supply mobility in building or campus range, and can be extended to supply mobility in some cities, like New York [18]. These networks allow for superior network bandwidth, transferring data with higher transfer rates then other technologies.
- Wireless PANs or BANs are networks operating in a personal sphere, and typical issues among these networks are low consumption, short range, low cost and a range of 8 to 16 nodes. Indeed, wireless PAN or BAN are intended to replace cables. To illustrate, Bluetooth is a promising RF-based standard, and IEEE 802.15 working group is setting consensus standards for other short distance wireless networks, namely Zigbee.

More recently, the fourth generation of wireless networks are setting the pace to develop an infrastructure and devices that can access different wireless technologies (heterogeneous networks) as well as developing better and faster wireless technologies. Recent mobile devices are supporting a growing number of wireless networks, setting the path towards this direction.

Nevertheless, the need for faster networks still exists. The Japanese company NTT DoCoMo and Samsung are testing 4G communications at 100 Mbit/s while moving and 1 Gbit/s while stationary [21]. From the exposed, there is a request for an adaptive behavior for devices and applications, according to available resources, environment changes and user goals. Consequently, accurate discovery and analysis of these issues allows for a better ubiquitous experience.

Similar goals are also set for augmented reality systems. Augmented Reality (AR) is a technology in which a user's view of the real world is enhanced with virtual objects that appears to coexist in the same space as real objects. Azuma et al. [1] define an augmented reality system to have three properties:

- Combines real and virtual objects in a real environment;
- Runs interactively, and in real time; and
- Register real and virtual objects with each other.

Ubiquitous computing and augmented reality are strongly connected. Ubiquitous systems provide smart support for users without changing their behavior. Nevertheless, when more functionality is added to a device, it tends to be more complicated. Therefore, augmenting the environment with additional information can ease the usage of complex devices.

The focus is on the achievement of an intuitive paradigm, not just providing virtual information to the user. Enhancements are not limited to our sense of vision. All senses, like touch, hearing and smell can also be enhanced. Moreover, real objects can be removed from the scene adding virtual ones, a process called mediated or diminished reality by some researchers.

AR can be applied to target application areas such as environmental management, computer-aided surgery, repair and maintenance of complex engines, facilities modification, interior design or entertainment. All of the above mentioned research areas have influenced the research goals of this thesis. Thus, this dissertation explores different interfaces and systems for ubiquitous systems, focusing in mobile augmented reality as a ubiquitous interface, as well as performing contributions towards location-aware systems.

1.2. Problem Statement

Computational interfaces have evolved over time being embedded in our environment and daily lives, and operating in the periphery of our attention. Several devices can be seamlessly integrated in the world and almost disappear from the user's attention [25][6]. This new computational era, named ubiquitous computing, brought us smaller, cheaper, and faster computational devices embedded in common everyday objects, "smart" objects.

More recently, Adam Greenfield has coined the term "everyware" to describe technologies of ubiquitous computing, pervasive computing, ambient informatics and tangible media [15]. With overlapping research topics, "everyware" and augmented reality have several unsolved problems. Fortunately, things have evolved as time goes by, leaving researchers with a plethora of options, technologies and applications.

This number of options leads to different solutions for a common problem; namely, different location systems being developed and deployed. However, each system may address specific restrictions to the problem that, as a whole, constitute major innovations. Frequently, the costs involved in the development of these solutions are the main restriction, shortening the options. Compromises are then taken into account leading to more balanced solutions.

This plethora of solutions has raised the need to merge them into a common platform, also easing its usage. This requirement is increasing in importance as the number of technologies increase and common platforms, namely standards, are needed to enhance and ease the development of applications and services. Nevertheless, location is only one variable able to characterize a wider issue, the context.

Therefore, there is a major request for development and deployment of context-aware systems. The lack of a common infrastructure still exists, as for location systems. Considering location has an important variable to recognize users' context, there is a request to specify an infrastructure that can provide such information in a format that fits applications and services requests.

Therefore, a question is raised: how would mobile devices communicate with the required infrastructure? Communications technologies are important in a global manner, since they can be further used for location. Indeed, how to use such technologies and enhance their usage for further tasks, namely to gather context about users' environment, is a vivid research goal.

Augmented reality, as a ubiquitous interface, can create a new sense of enthusiasm in its usage. Nevertheless, different setups, methods, and technologies need to be discussed and tested as well as new fields need to be identified where augmented reality systems can be applied and enhance user's activities.

Environmental management is one of the fields where augmented reality can enhance users' perception of the environment in their vicinity. The information already gathered by different methods and process can be integrated in an augmented reality system, as well as predictive models to gather a more realistic approach of the problems that can affect the environment in our vicinity.

Augmented reality has the capacity to perform the required tasks without requesting the user to focus on a particular device. The user can roam throughout the environment and still receive all the needed information as if it was really there.

Until now, only technical aspects have been addressed but will users use these systems? Social issues also need to be considered. Technology must be developed with users' in mind. Once found the ideal technologies, security, privacy and social issues are raised so that technology can enter into users' life. For many problems, the technology is already in the field, it should then be adapted to fit users' in their every day's life.

1.2.a) Research questions

In this dissertation, a number of different unsolved problems related to the usage of augmented reality as a ubiquitous interface and context-aware applications have been investigated, mainly applied to environmental management and every day's life situations. During research, presented questions were considered to develop and produce real world applications as demonstrations. Different problems were then addressed by this dissertation and formulated into research questions:

- How to gather and use location information? Which technologies best addresses each particular scenario?
- How to use Bluetooth for indoor location systems, since a majority of mobile devices are already in the pockets of final users embedded with Bluetooth technology?
- How to structure and develop a common location infrastructure? Which location models to use for each purpose and how to integrate them?

- How to create a simple and low cost location system that can be used and deployed without a complex setup?
- What hardware must be developed and integrated into an augmented reality system that can be used for environmental management?
- How to enhance the previous setup to be used for pollution dispersion simulations?
- What hardware must be developed and integrated with common mobile devices that can be used in a mobile outdoor augment reality gaming scenario?

1.2.b) Research goals

The main goal of this dissertation is to discuss, enhance and/or answer the questions discussed previously and contribute with solutions to solve the problems facing ubiquitous computing and augmented reality as a ubiquitous interface. The specific research goals of this dissertation are as follows:

- Bluetooth location systems – The goal is a server side system addressing Bluetooth limitations, also not requiring special software to be installed in the user's device to track him or her.
- Location infrastructure – The goal is to identify the main modules in a location infrastructure and discuss their roles. Locations models are discussed in order to evaluate how they can be used in location, and context-aware systems.
- Low cost location systems – The goal is a low cost system that encourages the usage of location aware applications by wider audiences, namely museum visitors. The proposed system is easy to maintain, configure and deploy.
- Augmented reality for environmental management – The goal is an AR setup suitable to be used by environmental engineers. This setup uses a geo-referenced model and an 2D/AR composition module, or alternatively a geo-referenced database, an AR composition module and a 3D model, enabling several users to interact and share experiences during system usage.
- Mobile Augmented reality gaming – The goal is a mobile augmented reality system directed towards gaming through the use of a wireless digital compass, a wireless GPS, a mobile phone and a game server. Main game processing is performed in the server and wireless technologies are used to provide an augmented reality gaming experience less cumbersome than current systems.

1.3. Thesis Statement

According to Thomas Kuhn, changes in the paradigm are revolutions in scientific knowledge [22]. In the short history of computer science, there were already four paradigms (Batch, Time-Sharing, Desktop, Networked). This new century, brings us a new shift in the paradigm. Instead of tools centered in the personal computer, trends suggest that tools should be centered in the user.

Computers are envisioned to be everywhere, with different sizes and tailored to specific tasks. Interaction with users tends to be natural and intuitive, with every users interrelating with several computational devices. Consequently, users can focus in the task, in opposite to focus in the tools being used.

Additionally, the design should also afford the usage, as well as allowing computing devices to grasp users' context, automatically. Therefore, ubiquitous computing and augmented reality are research fields that can significantly contribute to this vision of the world.

Context is also an important issue for both Augmented Reality and Ubiquitous computing. How to grasp context? How to model context? What variables best describe an individual's context? These and so many other questions require further studies and development.

Position is already known to be an important context variable. Thus, location-based services are being developed and deployed at larger steps each day. New tools, new technologies, and a huge requirement, by users, give the motto for recent advances. Despite all that, there is a lack for a common infrastructure, including position modeling and services to further improve location based services.

Nevertheless, the physical environment and all the information in it are not easily available to every individual. Augmented reality can easily supply the tools to access information not detectable by an individual's senses. This information helps the individual to better perform the task at hand, minimizing execution times.

Augmented Reality tools can be very helpful in the field of environmental engineering or entertainment. Consequently, new augmented reality architectures and interfaces are required to perform the task, supplying virtual information to environmental engineers and gamers.

Finally, social acceptance of the technologies developed in the research field is also important. Therefore, friendly interfaces should be developed and studied so that the usage of recent developments could be easily and seamlessly integrated into an individual's everyday life. Development over widely spread technologies can be a plus to achieve user's acceptance. However, further studies and developments should be performed.

1.4. Contributions

This dissertation makes a number of research contributions to the current state of the art in ubiquitous computing and augmented reality fields of research. Some of the contributions included in this dissertation also require a number of supporting hardware and software artifacts to be designed and developed.

The full list of contributions is:

- The analysis of methods, procedures and techniques to build a modular augmented reality system architecture for usage by environmental engineers while outdoors. Environmental engineers can benefit from the usage of augmented reality systems leaving their hands free for the task in hands while receiving additional information. A new modular architecture was designed and directed towards environmental management addressing these issues [8,9,12,13,19,20]
- Development of a modular augmented reality architecture allowing the visualization of environmental models across time and assessment of environmental changes [9,12,13]. This architecture can also be used by decision makers to assess the impact of environmental changes.

- Development of a user interface specifically designed for the task, also considering mobility and a familiar interface. Agents are used as templates with predefined values to easier the interaction with environmental models [9,12,13].
- Development and analysis of an indoor Bluetooth location system, considering several Bluetooth variables to infer distance and calculate location using triangulation. [11]
- The analysis of the location infrastructure for indoor location systems and also the models used in such infrastructure [16]
- Development of a low cost radio frequency location system to be applied in museums and easily deployed with minimal impact in the environment. This location system also addresses different user profiles and users with visual or hearing handicap. [10]
- Development of a mobile augmented reality system targeting mobile phones; exploring wireless networks, client-server architecture and the affordances of the system to enhance users experience.

1.5. Dissertation structure

After this introduction chapter, an overall background discussion is presented, introducing the concepts and technologies concerning wireless networks. This overview provides a general discussion of related research. The following chapters also include specific background information when relevant.

Chapter three provides an overview of the location concepts and technologies that can be used in location systems. This chapter addresses all the aspects of sensing location identifying the advantages and disadvantages of each technology. The overview sets the basics related to the development and selection of location systems.

Chapter four sets an overview of some augmented reality systems that have be used as an inspiration for mobile augmented reality systems described in this thesis are shown. Major contributions in each system are presented in a way that can be used to guide future developments.

Chapter five discusses the development of an indoor location system using Bluetooth. A growing number of mobile devices are being deployed with support for Bluetooth. Therefore, Bluetooth is a technology that can be used to develop indoor location-based services, namely location-based advertising. The system explores Bluetooth radio signals to calculate the location, shows an intuitive back office to manage the system and presents an infrastructure that can grow independently of the Bluetooth manufacturer.

Chapter six addresses the lack of a common infrastructure for location services. This chapter also provides a brief overview of the modules that constitute the infrastructure, as well as discuss the different location models that can be used as a basis for the location infrastructure.

Chapter seven addresses a more practical level for location systems. Several research projects are being developed that exploit users' location to supply them with location-aware information or, even more, context aware information. However, the complexity of such systems may not draw the users' attention to the benefits that such applications can offer. Moreover, the costs of deploying such systems also discourage decision makers to adopt those systems. Therefore, in this chapter a solution is presented that address these issues and can be used to easily supply users with location aware information.

In chapter eight, a mobile augmented reality system for environmental management is discussed. Indeed, exploration of the environment while receiving additional information is a major request for environmental engineers. Therefore, augmented reality can provide the tools for those professionals to explore the environment in their vicinity with two different augmented reality setups.

In chapter nine, the augmented reality system for environmental management is further extended to incorporate a pollution dispersion model allowing environmental engineers and other decision makers to perform pollution simulation in the field. The system easies the perception of the real impact of pollution dispersion in common water resources.

In chapter ten, a lighter and wireless augmented reality system is discussed, as work in progress, supplying a wireless and simpler setup for augmented reality systems, releasing the users of trying to connect all the cables to operate the system. The last chapter of this dissertation performs a comprehensive view of the contributions performed in this thesis as well as future directions for the research. Finally, annexes for the work in this dissertation are presented.

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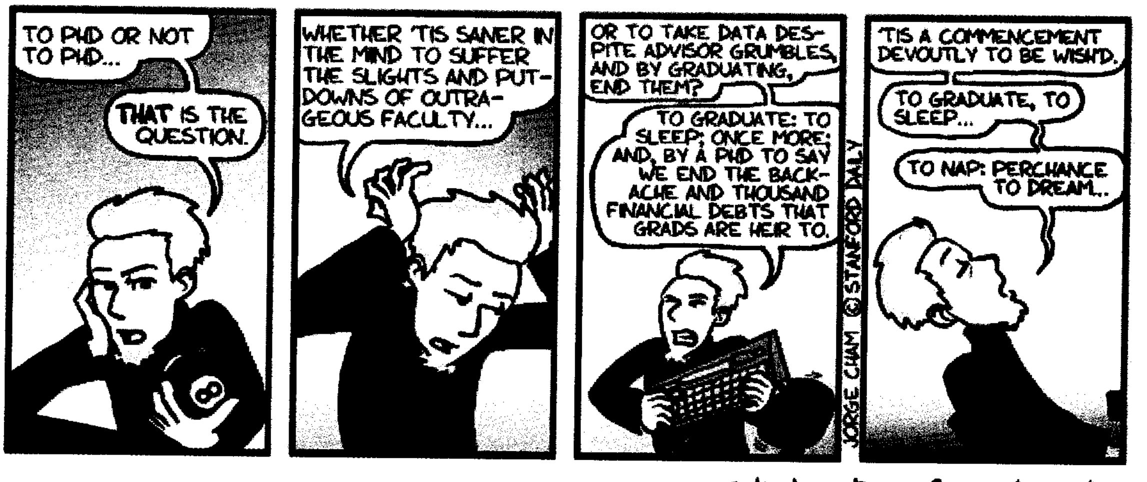

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2. Wireless Technologies

Abstract

The need for data anywhere, anytime, has challenged developers in the tricky feat of handling data on wireless and mobile devices. Add ever-shortening development and technological cycles and, suddenly, the process of getting data wirelessly is plagued with mistakes. However, this chapter was written to help researchers and developers in the selection of the technology that best fits the requirements of the problem in hands.

2.1. Introduction

Technologies, such as IEEE 802.15.4, IEEE 802.15.1, and UMTS can be used to transfer information between devices in a wireless environment. In a fast growing industry of wireless technologies, the task of choosing the best one to use in each case is far from easy. The user's search for a quick and easy technology able to add value to their lives should always be remembered.

Two main reasons constrain user's wireless experience:

- The physical interface: the size and weight of the device should be suitable to be used on the move and also to be carried in the pocket;
- The network topology: Mobility requires a good range of coverage, seamless handover between access points, as well as a connection experience similar to wired devices.

After naming a few reasons that will attract user's to go mobile, a brief description of what is required from the technological counterpart will be presented. The focus is directed into ubiquitous, location and augmented reality systems that can be used and carried everywhere, searching for what is required in such systems.

Some of such systems can rely on their own resources to sense context, and no network resources are needed. However, when additional context information is needed, an information carrier is required to transport context information and other data between devices. Wireless technologies can also be used to sense context, namely location, thus enhancing the usage of wireless technologies.

Therefore, wireless technologies play an important role when users go mobile. Bellow, a list and description of some of the most known and used technologies is presented and can be used to perform a conscious choice of the wireless technology to use in each case.

2.2. Technologies

In a personal sphere, and when low bandwidth is needed, natural electrical conductivity of human body conductivity can be used to transfer electronic data. So, Zimmerman [16] developed a Personal Area Network (PAN) using a small prototype transmitter embedded with a microchip, and a slightly larger receiving device. Thus, to illustrate the concept, researchers can transmit a pre-programmed electronic business between two people via handshake.

As described in [16], natural salinity of human body makes it an excellent electrical conductor, and data can be sent by creating an external electrical field that passes an incredibly tiny current through the body, see figure 2-1. PAN can achieve speeds up to 2400 bps. However, theoretically, Zimmerman refers that it can achieve speeds up to 400 Kbps. Consequently, PAN can be used for personal authentication and identification.

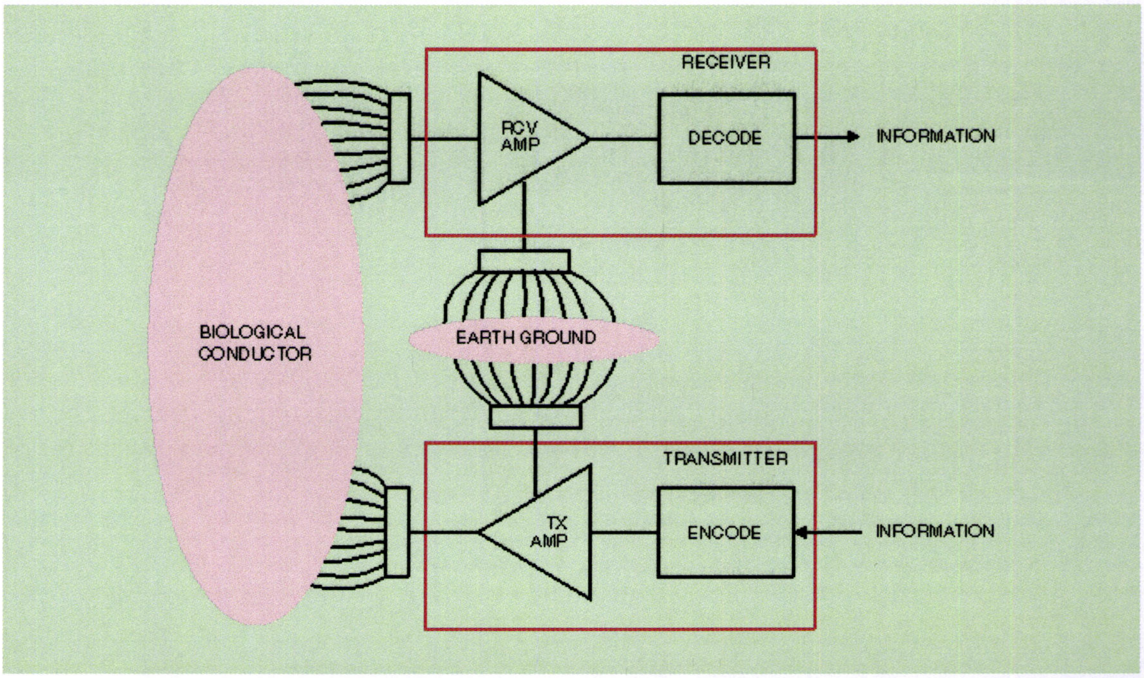

Figure 2-1: PAN Concept

ZigBee is a set of specifications built around the IEEE 802.15.4 wireless protocol. In the same group, there is also the IEEE 802.15.1 wireless protocol, commonly known as Bluetooth. The main difference between both protocols is that ZigBee is designed for highly efficient connectivity between small devices. Communication between small devices and a central computer, or low-power household devices, is possible as well as centralized lighting control. Bluetooth focus on connectivity between larger devices, namely laptops, PDAs, and other major peripherals.

Another major difference between both protocols is the throughput. ZigBee is actively-limited to a through-rate of 250 Kbps, while Bluetooth with Enhanced Data Rate (EDR) can reach up to a peak of 3 Mbps (2.1 Mbps of real throughput). Moreover, ZigBee has simplified operations; up to two orders of magnitude less complex then Bluetooth operations. This, in fact, reduces prices for ZigBee chips.

ZigBee has been developed to meet the requirements of low-power wireless networking devices, with a radio range of up to 76 meters. Therefore, due to its low-power consumption, ZigBee devices can sustain with a small battery from a few months up to a few years, making this technology ideal for devices with install and forget purposes.

There are three types of ZigBee devices. Bellow, a small description of each type is presented given that the first requires more memory, consequently is the most expensive; and the latter requires less memory, thus having reduced costs.

- ZigBee coordinator: Only one coordinator exists in each network. It is the root of the network with the ability to bridge to other networks. The coordinator is also able to store information about the network.
- Full function device (FFD): It can act as an intermediate router, passing data from other devices.
- Reduced function device (RFD): It is just smart enough to talk to the network; it cannot relay data from other devices.

Kasten et al. [9] in the Smart-Its project intends to attach small, unobtrusive computing devices to real objects giving them some sense of smartness. Each device must be able to perceive context information from its integrated sensors. Consequently, numerous of such devices connected can gain collective awareness by sharing this information. Moreover, Smart-Its intends to connect them with no central authority help, in an ad hoc fashion, i.e., without knowing each other and without a background infrastructure. Therefore, the selected technology was Bluetooth.

Bluetooth address some of these issues, such as:

- Operates in a license-free frequency;
- Uses frequency hopping spread spectrum to minimize interference problems;
- Has low energy consumption;
- Has worldwide availability; and
- Low-price.

However, Bluetooth has problems handling densely connected sensor networks because it is only able to connect up to eight Bluetooth devices in a piconet (figure 2-2), controlled by a master that manages all slaves' communications. Therefore, handling more than eight devices requires at least one common device between two or more piconets, also known as a scatternet (figure 2-3).

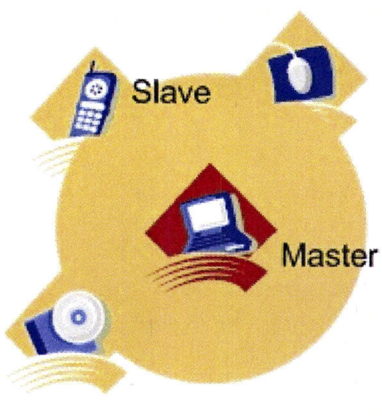

Figure 2-2: Piconet

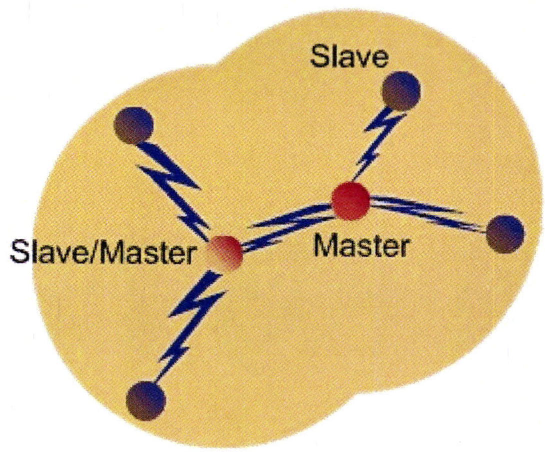

Figure 2-3: Scaternet

Bluetooth also supports the paradigm of spontaneous networking, no previous knowledge of each device is required, see chapter 5 - introduction. Another problem with Bluetooth may appear in mobile devices, because inquiry process (the process to search for devices in vicinity) may take several seconds in real-live settings. Indeed, a Smart-Its device can become out of range even before a connection could be established if their relative speeds are faster then the inquiry process. Power consumption is another issue related to the inquiry procedure that has to be considered when using Bluetooth as an information carrier.

Another wireless carrier technology is the IEEE 802.11 family of protocols. A brief description of some of the protocols in this family of protocols is presented bellow.

IEEE 802.11b specification is an international standard for wireless networking that operates in the 2.4 GHz frequency range (2.4 GHz to 2.4835 GHz) and provides a throughput of up to 11 Mbps. The IEEE 802.11a specification is applied to wireless ATM systems and is used in access hubs, operating at radio frequencies between 5 GHz and 6 GHz.

It uses a modulation scheme known as orthogonal frequency-division multiplexing (OFDM) that makes possible data speeds as high as 54 Mbps, but most commonly, communications takes place at 6 Mbps, 12 Mbps, or 24 Mbps. Comparing with Bluetooth and ZigBee, IEEE 802.11b and 802.11a standard have the advantage of allowing for seamless roaming across access points.

IEEE 802.11g specification operates in the same 2.4-GHz band as 802.11b does and has mandatory support for the 802.11b modes, meaning that an 802.11g network interface card (NIC) can work with an 802.11b access point (AP), and vice versa. The other mandatory mode for 802.11g is to use 802.11a OFDM, meaning that 802.11g will be able to support the same data rate provided by 802.11a (54 Mbps) in the 2.4-GHz band, and optional modes CCK-OFDM or PBCC-22 enabling data rates up to 22 Mbps.

In January 2004, IEEE announced the creation of a new Task Group (TGn) to develop a new amendment to the 802.11 standard for local-area wireless networks. The primary feature that will be offered by this standard is speed. Indeed, IEEE 802.11n is being designed to offer up to 600 Mbps of raw data. 802.11n is also being designed to be backward compatible with previous IEEE 802.11 protocols, adding two techniques to improve the throughput and capacity: OFDM and multiple-input multiple-output (MIMO).

OFDM is regarded as an efficient method for high data rates due to its robustness to multipath channels and high bandwidth efficiency [2][8]. Conversely, the capacity of MIMO systems approximately grows linearly with the minimum number of transmit and receive antennas [4][14]. Thus, IEEE 802.11n wisely combines OFDM and MIMO techniques to achieve higher data rates. IEEE 802.11n is also projected to have a better operating distance than other networks.

However, power consumption is still an issue to solve in all IEEE 802.11 protocols. The free space radio propagation model states that the propagation of wavelengths obeys the inverse square law. Thus, the signal strength is proportional to $\mathbf{K * P_t / r^2}$ where K is a constant factor, P_t is the transmitter power and r is the distance from the source. Therefore, to reach longer distances with a good signal power it is required to also augment the transmission power, also increasing consumption.

While using IEEE 802.11 standards security and privacy of data is also an issue. Known flaws in Wireless Encryption Protocol (WEP), and even required improvements in Wi-Fi Protected Access (WPA) lead to the development of WPA2. WPA2 is based on the final IEEE 802.11i amendment to the IEEE 802.11 standard. Security and privacy has taken a large step with WPA2 providing government grade security by implementing the National Institute of Standards and Technology (NIST) FIPS 140-2 compliant AES encryption algorithm. Consequently, wireless connections, using IEEE 802.11 standard, are becoming more secure [12].

WiMax stands for Worldwide Interoperability for Microwave Access. All products that pass conformity and interoperability tests with the IEEE 802.16 standards have WiMax as a certification mark. The IEEE 802.16 Working Group on Broadband Wireless

Standards develops standards and recommended practices to support the development and deployment of broadband Wireless Metropolitan Area Networks. An important purpose for IEEE 802.16 is to be a wireless substitute for the last mile cable system, which introduces major costs for telecom operators.

IEEE 802.16 can have a bandwidth of up to 134 Mbps in 28 MHz channels; operating between 10 to 66 GHz frequency spectrum. The scope of the standard is to specify the air interface, including the medium access control layer (MAC) and physical layer (PHY), of fixed point to multipoint broadband wireless access systems providing multiple services. The MAC layer is capable of supporting multiple physical layer specifications optimized for the frequency bands of the application. A physical layer is also specified in the standard and can be applied to systems operating between 10 to 66 GHz.

The service area range of IEEE 802.16 can reach up to 50 Km of linear service allowing connectivity between users without a direct line of sight. However, practical limits stay between 5 and 8 Km. To provide an efficient use of spectrum, IEEE 802.16 uses ODFM and Orthogonal Frequency Division Multiplexing Access (OFDMA) for non line of sight applications. IEEE 802.16 guaranties flexible QoS, in MAC layer, enabling different services as well as guarantying independent QoS [10][11]. Previously, IEEE 802.16 standard only allowed for fixed connections. However, since December, 2005 the IEEE 802.16e amendment to the standard introduced the possibility to have roaming users.

The delay experienced in a GSM-Internet connection, according to Greenhalgh et al. [5], is about 1s in GSM900 and 0.5s in GSM1800 [13], nevertheless this delay can be decreased moving closer to the base station (in GSM protocol), but it can be a big delay for some applications. To illustrate, in GSM bit rate can be up to 9.6 Kbps.

General Packet Radio Service (GPRS) is another carrier technology with a theoretical maximum speed of up to 171.2 Kbps, achievable when GPRS is using all eight timeslots at the same time, see figure 2-4. GPRS eases for instant connections whereby information can be sent or received immediately, only subject to radio coverage, and also gives the sense of always being connected overlaying a packet based air interface on the existing circuit switched GSM network. Hence, in GPRS networks, the information is split into separate but related "packets" before being transmitted and reassembled when received.

Additionally, packet switching means that GPRS radio resources are used only when users are sending or receiving data. Thus, supporting virtual connectivity, and, as a result, concurrently sharing radio resources with several users. The use of network resources is maximized in a dynamic and flexible way [6].

HSCSD is a high-speed, multi-slot data communication platform for GSM networks, also removing the barrier to mobile data communication of low network performance, bringing phone users better performance connections. Indeed, HSCSD can offer data transfer speed up to 57.6 Kbps or higher if combined with compression and filtering products. However, the effective transmission speed is 40 Kbps, depending on the terminal.

In addition, EDGE is a method to increase data rates over GSM radio link, and so, introduces a new modulation technique, the 8 PSK, and a new channel coding that can be used to transmit both packet-switched and circuit-switched voice and data services.

While GPRS uses four different coding schemes named CS1 to CS4, with different amounts of error-correcting coding optimized for different radio environments.

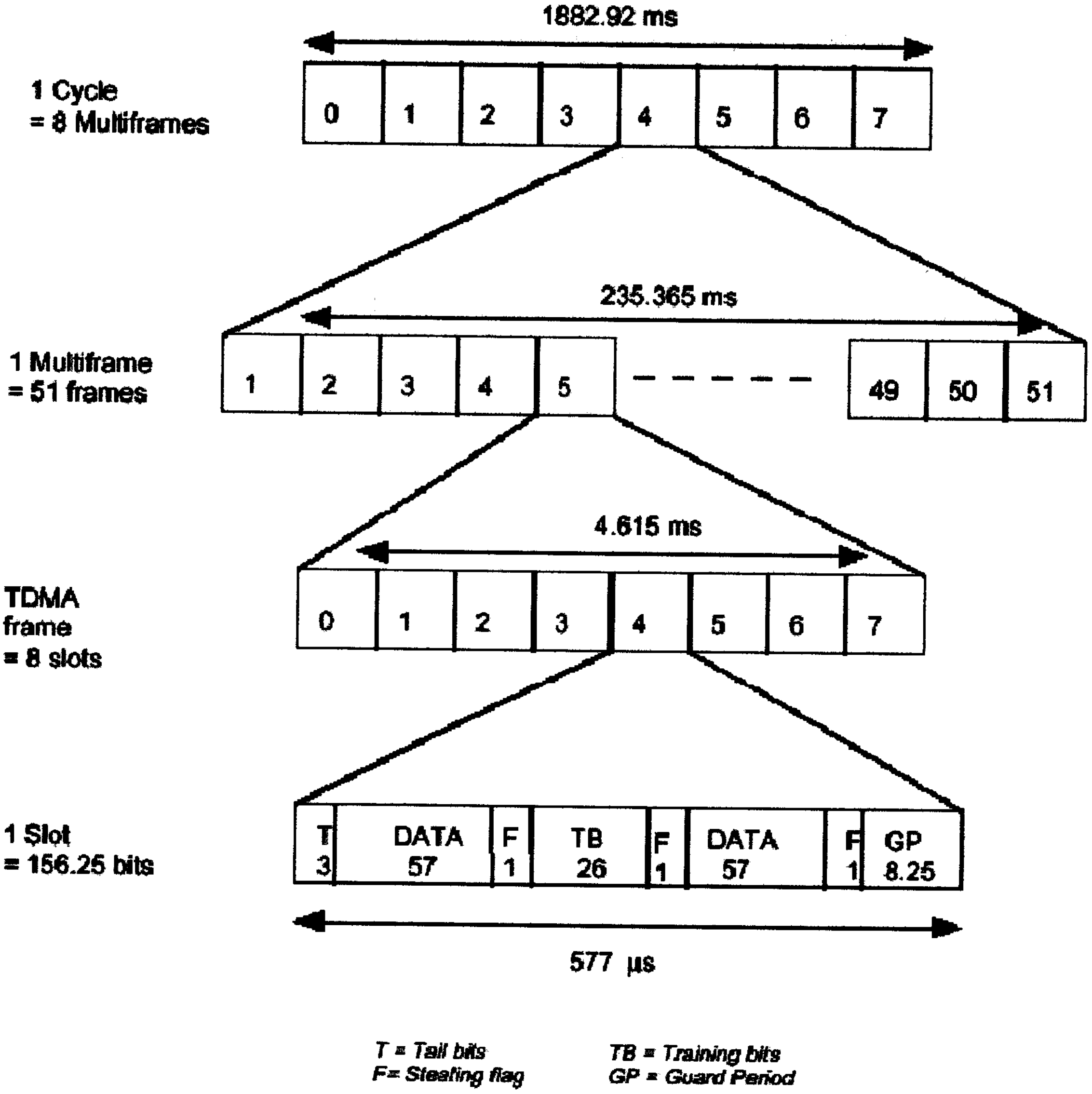

Figure 2-4: GPRS Time Slots

EDGE uses nine modulation coding schemes, named MSC1 through MSC9, where the first modulation coding schemes, MSC1 through MSC4, uses GMSK, and remaining modulation coding schemes use 8 PSK. EDGE has a slightly bigger throughput using GMSK then GPRS, because EDGE allows packets that were not properly received to be retransmitted over a lower coding scheme (more error correction) if the radio environment requires it, also requiring changes in the payload size of the radio blocks, and allowing better performance over GPRS [3].

In 3G networks, Universal Mobile Telephone System (UMTS) provide packet switch connections with data rates of up to 2 Mbps, when user mobility is lower, and 384 Kbps over circuit-switched connections. Moreover, UMTS supplies an important feature, compared with GSM and other existing mobile networks: it allows for negotiation of the properties of the radio bearer. Thus, UMTS networks work mainly as an infrastructure that supplies facilities, appropriate bandwidth and quality for end-users and their applications. In addition, UMTS will be widely available, allowing global roaming [15].

High-Speed Downlink Packet Access or HSDPA [7] is a new mobile telephony protocol, also called 3.5G (or "3½G"). HSDPA is a packet-based data service with data transmission up to 8-10 Mbps (and 20 Mbps for MIMO systems) over a 5MHz bandwidth in W-CDMA downlink. HSDPA implementations includes Adaptive Modulation and Coding (AMC), MIMO, Hybrid Automatic Request (HARQ), fast scheduling, fast cell search, and advanced receiver design.

HSUPA, High-Speed Uplink Packet Access [1], is a data access protocol for mobile phone networks with extremely high upload speeds up to 5.8 Mbps. Similar to HSDPA, HSUPA is considered 3.75G or sometimes 4G. HSUPA is expected to use an uplink enhanced dedicated channel (E-DCH) on which it will employ link adaptation methods similar to those employed by HSDPA, namely:

- Shorter Transmission Time Interval enabling faster link adaptation;
- HARQ with incremental redundancy making retransmissions more effective.

Table 2-1 - Overview of wireless carriers (ordered by range and data throughput)

Technology	Description	Bandwith	Range	Advantages	Disadvantages
Body Net	Uses natural electrical conductivity of human body conductivity to transfer electronic data	2400 bps	0 meters	Allow for data transfer between two persons handshaking.	Low data transfer rates – 2400 bps
ZigBee (IEEE 802.15.4)	Designed for highly efficient connectivity between small low-power devices.	Up to 250 kbit/s	Up to 76 meters	Up to 76 meter radio range. Low power consumption. Ideal for small household appliances Operates in a free ISM band with a global technology specification. Simple operations	Low data transfer rates

Bluetooth **(IEEE 802.15.1)**	Revolutionize personal connectivity giving freedom from wired connections – enabling links between mobile computers, mobile phones, handheld devices, and connectivity to the Internet	Up to 2.1 Mbit/s	Up to 100 meters	Low price wireless solution, both voice and data, for short distance. Operates in a free ISM band with a global technology specification. Works in stationary and mobile environments. Low power consumption. Uses frequency hopping spread spectrum to minimize interference problems. Up to 100 meters range	Only allows for a master and seven slaves in a piconet. Slow discover of neighbor devices. Does not allow for slave-to-slave communications in standard.
IEEE 802.11b	An international standard for wireless networking	Up to 11 Mbit/s	Up to 150 meters	Easy to add new clients good bandwith, up to 11 Mbps Up to 150 meters	Easy access to non-secure access points, even WEP can be cracked with de-algorithmic programs Power consumption
IEEE 802.11a	is applied to wireless ATM systems and is used in access hubs	Up to 54 Mbit/s	Up to 150 meters	Avoid crowded 2.4 GHz frequency band Bigger bandwidth than IEEE 802.11b, up to 54 Mbps Greatly enhanced network capacity and comparable coverage range	Not compatible with 802.11b Power consumption
IEEE 802.11g	Specification compatible with IEEE 802.11b to suply faster data transfer rates	Up to 54 Mbit/s	Up to 150 meters	Compatible with existing IEEE 802.11b offering higher speeds Theoretically, Operating in lower frequency band can provided higher speeds at a higher range than 802.11a. Possibility to use firmware to upgrade newer IEEE 802.11b access points to 802.11g. Possibility of using the same channel assignment with newer IEEE 802.11g as with IEEE 802.11b devices.	IEEE 802.11g has the same system capacity has IEEE 802.11b. Higher speeds can only be used with access points and network identification cards compatible with IEEE 802.11g. Uses the crowded 2.4 GHz frequency, subject to interferences from other technologies. Power consumption.

IEEE 802.11n	Specification backward compatible with IEEE 802.11a/b/g to supply up to 500 Mbps	Up to 500 Mbit/s	Up to 400 meters	Compatible with existing IEEE 802.11a/b/g offering higher speeds Uses OFDM and MIMO techniques to improve throughput.	Higher speeds can only be used with access points and network identification cards compatible with IEEE 802.11n. Uses the crowded 2.4 GHz frequency, subject to interferences from other technologies. Power consumption.
GSM	Global System for Mobile Communications	Up to 9.6 Kbit/s	Up to a few kilometres	international roaming capability. Up to few kilometres	Low transfer rate, up to 9.6 Kbps
GPRS	General Packet Radio Service ease for instant connections whereby information can be sent or received immediately, only subject to radio coverage, and also gives the sense of always being connected overlaying a packet based air interface on the existing circuit switched GSM network	Up to 171.2 Kbit/s	Up to a few kilometres	theoretical maximum speed up to 171.2 Kbps Ease for instant connections Gives the sense of always being connected packet switching means that GPRS radio resources are used only when users are sending or receiving data, so supporting virtual connectivity	Limited cell capacity for all users Lower speed than 171.2 Kbps Suboptimal modulation technique, uses GMSK Transit delays Need for GPRS compatible terminals
HSCSD	High Speed Circuit Switch Data Moreover is a high-speed, multi-slot data communication platform for GSM networks.	Up to 56.7 Kbps	Up to a few kilometres	enables higher rates (up to 56.7 Kbps) by using multiple channels	Need for HSCSD compatible terminals Uses circuit-switching
EDGE	Enhanced Data for Global Evolution intends to increase data transmission rates and spectrum efficiency and to facilitate new applications and increased capacity for mobile use.	Up to 473.6 Kbit/s with 8 timeslots	Up to a few kilometres	Introduces a new modulation technique, the 8 PSK, and a new channel coding that can be used to transmit both packet-switched and circuit-switched voice and data services	Need for EDGE compatible terminals

UMTS	Universal Mobile Telephone System is one of the 3G mobile systems being developed within the ITU's IMT-2000 framework capable of offering broadband multimedia mobile telecommunications technology	Up to 2 Mbit/s	Up to a few kilometres	The coverage area provision is to be worldwide, comprising both terrestrial and satellite components Higher speech quality that current networks Advanced data and information services Above 2G mobile systems, being capable to support 2Mbit/s data rates Consistent service environment even when roaming via "Virtual Home Environment" (VHE).	New network communications system and new terminals to take advantage of this technology Not currently available worldwide
HSDPA	High Speed Downlink Packet Access (HSDPA) is a packet-based data service in W-CDMA downlink with data transmission up to 8-10 Mbps (and 20 Mbps in MIMO systems)	Up to 20 Mbit/s downlink and 384 Kbit/s uplink	Up to a few kilometres	HSDPA evolved from and backward compatible with Release 99 WCDMA systems. Standardised as part of UMTS Release 5	New network communications system and new terminals to take advantage of this technology Uplink is reduced Not currently available worldwide
HSUPA	HSUPA stands for High Speed Uplink Packet Access and describes an extremely efficient procedure for sending data in a great performance way through UMTS devices	Up to 20 Mbit/s downlink and up to 5.76 Mbits/s uplink	Up to a few kilometres	HSUPA should be also inexpensive, it is based on software. No new infrastructure must be developed by the mobile network carriers. Standardised as part of UMTS Release 6	Not currently available. Availability is predicted up to 2 years after HSDPA.

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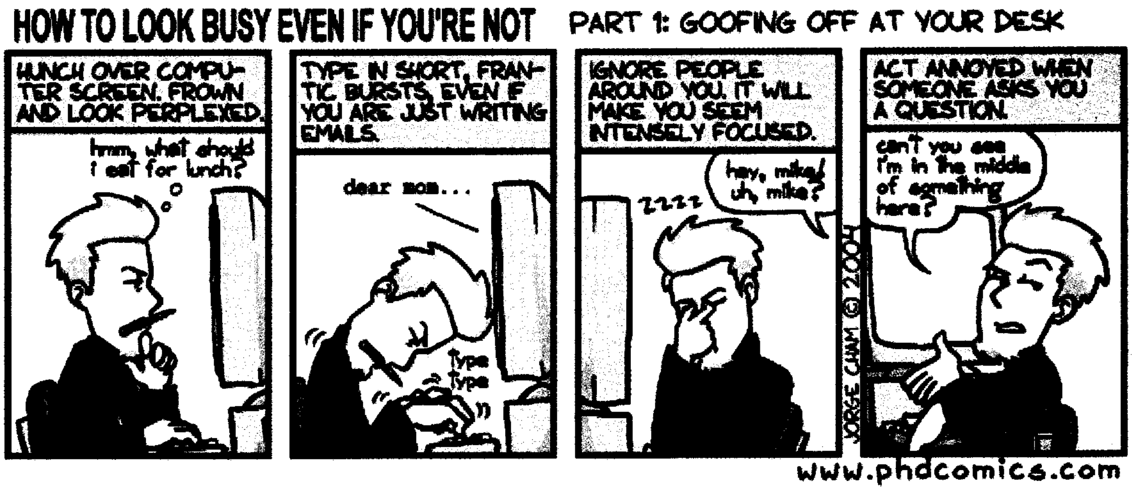

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

3. Tracking Systems

Abstract

Location is required for a growing number of location-based applications. Consequently, a plethora of sensors has invaded research labs making the decision of what sensors to use in each project a difficult problem. This chapter performs an overview of some of the sensors used. Pros and cons for each technology are also presented.

3.1. Introduction

An increase in mobile devices' availability and users' mobility has raised the need for location-aware computing. Thus, there is an incremental importance in geospatial data to assist users to accomplish many every day tasks. Taking advantage of geospatial data, several applications have already been developed [24], as seen on the following table:

Applications	Description
Office Applications	Namely, nearest printer services and mobile desktop control to increase workplace productivity
Tour and Museum Guides	Help people navigate in unfamiliar spaces
Friend Finder Utilities	Link with instant messaging for social or business purposes
Conference Aids	Track presentation attendance and facilitate note taking and discussion
Medical Facilities	Track staff and monitor patients for emergency response
Home Applications	Help with household management and home entertainment, as well as aid the aged and disabled in performing everyday tasks

Table 3-1 - Examples of location-based applications

GPS has been, for long, the widely used technology to retrieve user's location [16][21]. Indeed, while outdoors, GPS is almost ubiquitous, mainly requiring line of sight to the sky. However, when there is no clear line of sight to the sky, GPS can overcome such problems using newer methods, such as A-GPS, controlled by mobile operators, or, instead, high sensibility GPS receivers.

Another alternative is to use GSM Cell ID or IEEE 802.11 Mac Address as beacons to locate people and objects [31]. This alternative has been validated in urban areas where a clear line of sight to the sky isn't possible and the proposed technologies are widely deployed. In fact, a major number of daily life applications won't require much accuracy, and the accuracy supplied by those technologies can be sufficient, varying from tens of meters to a few kilometres.

Undeniably, mobile phones are becoming ubiquitous in our daily lives and GSM cells are widely deployed in urban areas, where most of these applications can be used. Moreover, commercial location systems, such as Ekahau [15], are in use, supplying accuracies of up to a meter using IEEE 802.11 Access Points (AP). Nevertheless, more accurate systems exist claiming accuracies of up to the centimetre level, namely Ubisense [41].

Indeed, the high cost and complex configuration procedures of some of these systems inhibit their usage in a more wide scale where a numerous persons could benefit from it. Namely, indoor events, shopping centres and museums can benefit from location information to supply more detailed descriptions of their content to visitors. Therefore, their visitors will fell free to visit the space on their own while receiving contextual information related to what they are looking at.

Apart from costs and configuration procedures, different and more intuitive schemas can be used to present geospatial data to users, other than the geometric geospatial data that we are used to. In fact, several location scales and different sensors may be used, where a wide range of applications may also have different specifications.

Geometric geospatial data, such as WGS84, may not be adequate in such spaces, raising the need to combine geometric models with others models that may provide more suitable features for this kind of environments. Symbolic, hybrid and semantic models are location models that may be more suitable for some applications. Consequently, applications can be more easily developed and deployed when such models are used. Chapter six addresses the location infrastructure and location models.

3.2. Tracking Environments

3.2.a) Outdoor

Several tracking systems have been developed for outdoor environments; nevertheless the required accuracy for some systems, namely augmented reality, has not been achieved yet. For example, Global Positioning System (GPS), gyroscopes, accelerometers, compass, pedometers and image recognition are the main tracking sensors for outdoor environment. Nevertheless, satellite-based positioning systems are widely used in outdoor tracking systems.

GPS [20] has its origin in a military system; however, despite its broad use, there are other solutions. The Russian GLONASS System [19] is an alternative although fragile; with few satellites to offer a reliable service. Europe is also developing a new global navigation satellite system called GALILEO [10]. GALILEO is designed to be a stand-alone, global system, but it may inter-operate with other services, such as GPS, and it has been declared open for international co-operation. Thus, GALILEO intends to provide a state-of-the-art positioning and timing services with adequate guarantees and availability.

As discussed previously, satellite-based positioning systems are the chosen tracking systems while outdoors, but different situations such as sky occlusion, tall buildings or trees can reduce their availability or accuracy. Therefore, other tracking systems may be used. Indeed, using hybrid tracking technologies will result in better accuracy. You et al. [51] developed a hybrid inertial and vision tracking system for augmented reality registration that combines inertial orientation data with vision feature tracking. In this case, inertial orientation is used to predict and reduce search space of 2D vision feature-motion, which will be corrected by vision sensor.

It is not always possible to prepare the environment for tracking purposes, and tracking systems must handle unknown features. Therefore, Azuma et al. [6] refers three reasons why it is difficult to track objects or persons in unprepared environments:

- If the user operates outdoors and cross long distances, available resources may be limited due to mobility constraints;
- The range of operating conditions is greater than in prepared environment; and
- The designer cannot control the environment.

To overcome these difficulties, Azuma et al. [6] developed two tracking systems. The first one represents an initial base system, combining a compass and a tilt sensor with three rate gyroscopes to stabilize the apparent motion of the virtual objects. The last one adds input from a video tracker, which looks for 10 to 40 features in the scene that can be robustly tracked to reduce errors to a few pixels.

Both tracking systems focus their potentialities in orientation tracking. For the last tracking system, with video input, two different simulations were developed:

- a 5-DOF simulation that also keeps tracking of relative motion direction in addition to rotation, based on observed 2D motions, and

- a 6-DOF simulation that keeps tracking of 3D positions of natural features or uncalibrated fiducials.

In addition, other natural features can be tracked, like horizon natural silhouettes, to supply information about orientation. Horizon silhouettes, in a well-structured terrain, define visual frontiers between earth and sky. Therefore, cues for visual human navigation and orientation can be supplied. Moreover, a digital elevation map (DEM) database can be used to compute a 360 degrees silhouette, based on the known observer position (from GPS).

Behringer [9] developed a system that can exploit horizon silhouettes to improve the orientation precision of a camera that is aligned with the user's view. Registration is achieved by matching predicted silhouette from a DEM with horizon silhouette segment extracted from the camera. In addition, to improve accuracy, other visual features can be used has cues to provide hypothesis for matching.

3.2.b) Indoor

While indoor it is possible to have controlled environments and small tracking spaces, therefore solving some of the problems of outdoors' location systems. However, building an indoor location sensor to provide mobile devices with fine-grain spatial information has several additional problems, in order to have high update rate, be unobtrusive, cheap, scalable and robust.

Yokokohji et al. [50] proposed a method for accurate registration of images on Head-Mounted Display (HMD) using image recognition and accelerometers. This method is based in an Extended Kalman Filter designed for video-see through HMD. The acceleration information is used to predict head motion and to compensate end-to-end system delay, making the vision-tracking system robust. In experimental results, measured errors were of 6 pixels on average and 11 pixels at maximum, even if the user moves her or his head quickly. So, adding more landmarks to the environment allows a bigger viewing range.

Another alternative for indoor environments is to use a combination of RF and ultrasound hardware. Priyantha et al. [35] developed Cricket Location-Support System, which enable a listener to determine the distance from a beacon, see figure 3-1. In such system, the closest beacon can be inferred measuring the one-way propagation time of the ultrasonic signals emitted by a beacon. The basis of the system relies in the fact that sound speed is lower than light speed over the air. Therefore, each transmission is filled with RF information, altogether with an ultrasonic pulse.

When the first bits of the RF signal are received the ultrasonic receiver is turned on and, a few instants after, the ultrasonic pulse is received. Afterwards, the listener uses time difference between receipt of the first bit of RF information and the ultrasonic signal to determine the distance to the beacon.

GPS pseudolites can also be used indoor, making GPS navigation possible. A pseudolite is a signal generator that transmits GPS-like signals to users in neighbourhood. Indeed, GPS is used mainly outdoors because indoor GPS does not have line of sight to satellites, making its usage difficult. This way, in 1999, Seoul National University GPS Lab (SNUGL) [30] developed a centimetre-accuracy indoor GPS navigation system using asynchronous pseudolites, see figure 3-2.

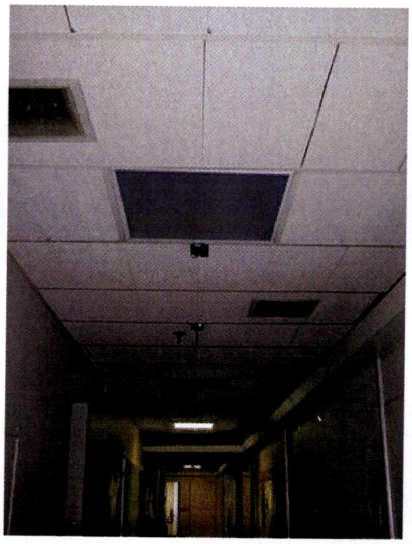

Figure 3-1 - Cricket Location-Support System "Image courtesy MIT Laboratory for Computer Science Cambridge, (c) 2003, used with permission"

This navigation system was recently updated to include carrier phase cycle-slip recovery and automatic cycle ambiguity-resolution functions, and through a position and attitude sensor, this system could achieve 1-2 centimetre control errors implemented in a control vehicle system. In future, SNUGL will direct their efforts to mobile European standard GSM, U.S. digital cellular CDMA standard IS-95, and 3G mobile phones where GPS modules may be included. Furthermore, SNUGL also intends to make seamless indoor/outdoor navigation possible by upgrading receivers and pseudolites.

Finally, Smart Floor is another approach for indoor tracking systems, developed by Orr et al. [34]. Smart Floor identifies people based on their footstep profiles. Indeed, footstep profiles are modeled allowing a system accuracy of about 93%. So, relying on uniqueness of footstep profiles within a small group of up to 15 persons, Smart floor overcomes many problems of other biometric user identification techniques, like shadows and lightning in face recognition. This tracking technique is unobtrusive but has disadvantages like poor scalability and high incremental cost due to the fact that Smart Floor requires physical installation of pressure sensor grids on the floor.

3.2.c) Indoor and Outdoor Interaction

Several applications require tracking objects outdoor and indoor without a transition between both environments. Such an example is the navigation system developed by Baus et al. [7] with indoor and outdoor components that adapt presentation of route directions to different output devices and modalities, named REAL project. The REAL project accounts for varying tracking accuracy according to available technical resources in the current situation, and consists of 3 major components:

- Information booth, based on a graphical workstation, where a virtual presenter, which uses spatial utterances and meta-graphics, shows a virtual walk-through across the environment;
- Indoor navigational system, based in strong infrared transmitters and PDA's as presentation devices; and

- Outdoor navigational system, which uses a laptop computer and a HMD, as well as a GPS receiver to determine current user location and an electronic compass to determine user orientation.

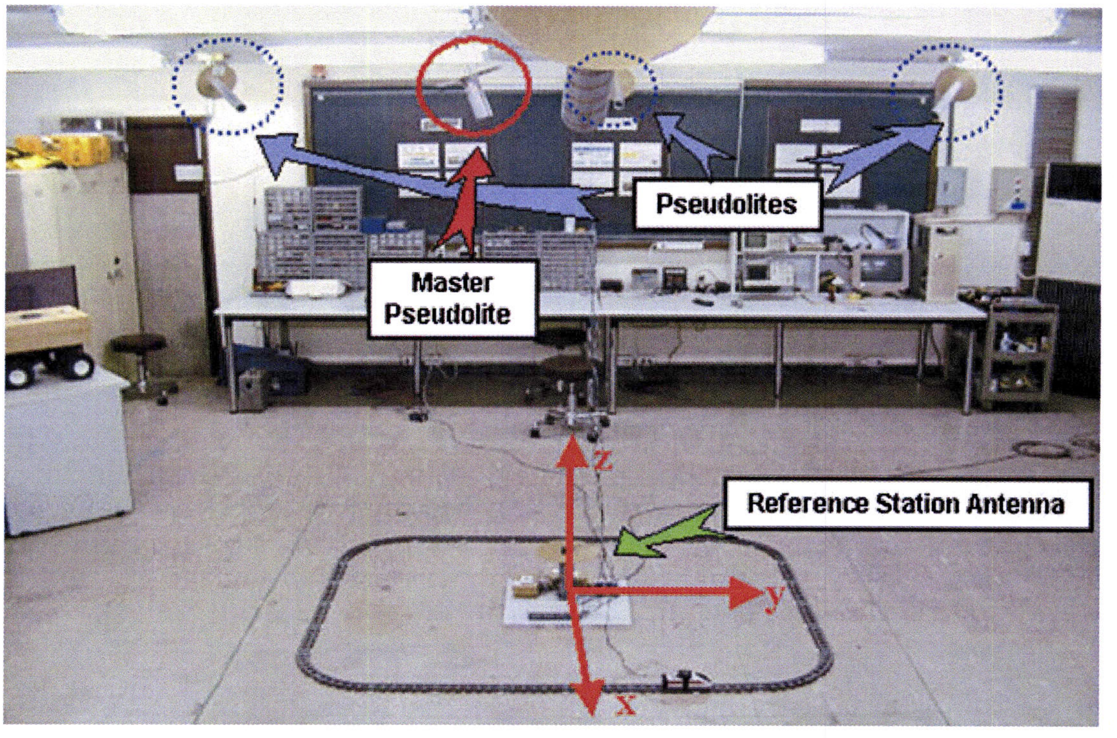

Figure 3-2 - Indoor Centimeter-Accuracy Navigation Using GPS-Like Pseudolites "Image courtesy Changdon Kee, (c) 2002, used with permission"

In REAL, all graphic descriptions are generated from scratch, according to user cognition and technical constrains of output device. Indeed, in different situations, user cognition resources can be limited. Thus, REAL accounts for user walking speed, spatial familiarity and time pressure; avoiding complex redirections along the way at costs of a slightly longer route, and also minimizing additional user cognitive load.

While indoor, in IRREAL, the information is sent in cycles, resembling videotext, and giving a higher priority nodes are sent at higher rates, also adapting presentation to the user walking speed. Hence, user information becomes more complex when she or he stays in the same location. Outdoors', ARREAL uses a sub-notebook for relevant calculations, special clip-on glasses for text and graphics output, a GPS receiver and a magnetic tracker to actively determine user's position and orientation. The magnetic tracker has been prepared to act like a 3D pointing device with the addition of buttons, also providing orientation information to the system.

3.2.d) Node-Based Sensing

Other tracking systems are not specially designed for indoor or outdoor usage, namely systems based in network domains with radio cells.

3.2.d.i) General Node-Based Positioning Sensing

Machida et al. [32] proposed a system where Bluetooth beacons provide precise location services, in a town scenario. The system goal is to provide town information and location to pedestrians. Their experimental system showed the effective function of the location platform and potential of the town information system.

Hallberg et al. [23] developed another positioning system with Bluetooth where the theoretical worst-case error scenario is 10 meters. In Hallberg positioning system, when a Bluetooth device wants to know its position it queries all devices in its range for a positioning service. If a positioning service is found, that device will return its position, otherwise the current device will query a database for the position of the found device. Finally, triangulation is performed in order to achieve current device position.

In fact, mobile positioning importance was foreseen in future cellular systems. Thus, usage of position assistance data allows for advanced location based services and radio system performance optimization. To illustrate, commercial location based applications are being used in several areas like fleet management, buddy finder, traffic information management, transportation, nearest services, emergency services and follow me services. Additionally, location information can be used for network performance optimization, improving network performance through an optimized planning process.

Consequently, mobile cellular terminals (Mte) can use several positioning methods. Some of the most use positioning methods are [13], [28] (see also the radio sensing section):

- Cell ID based positioning
- Round-Trip Time (RTT) based positioning
- Time-of-Arrival (TOA) positioning
- Time Difference of Arrival (TDOA) positioning
- Angle of Arrival (AOA) positioning
- Multipath Fingerprinting
- Timing Advance (TA)
- Enhanced Forward Link Triangulation (E-FLT)
- Reference Node Based Positioning (RNBP)
- Global Positioning System (GPS)
- Assisted GPS (A-GPS)

3.2.d.ii) UMTS specific positioning methods

UMTS networks may supply:

- Cell ID based positioning
- Observed Time Difference of Arrival (OTDOA) positioning
- Assisted GPS positioning

These methods may be network based, network based and mobile assisted or mobile-based and network assisted. The main difference is where calculations take place. Cell ID based method maps a cell ID into a corresponding Service Area Identifier, where Cell ID is seen as an internal reference, not be seen outside the core network. In Observed Time of Arrival-Idle Period Down Link (OTDOA-IPDL), the terminal uses idle periods of the serving BS to measure the signals of neighboring BSs, therefore estimating distance to each one and calculating its location.

In the last mentioned method, assisted GPS can overcome problems found in conventional GPS solutions, achieving higher location accuracy and reasonable costs. In such cases, mobile phones are assisted by the network over the air-interface, whilst determining their own location. This distributed approach leads to a better performance than conventional GPS.

In fact, wireless network will use its own GPS receivers, as well as an estimate of the mobile's location down to cell/sector, to predict GPS signal that the mobile phone will receive and send that information to mobile phone. This assistance allows for a great reduction of search space and time-to-first-fix (TTFF) is reduced from a minute to a second or less. Additionally, assisted GPS receivers in the handset can detect and demodulate signals that are weaker than those required by conventional GPS receivers.

In more detail, assisted GPS is divided in two subcategories: terminal based and terminal assisted. In terminal based position calculation, the network sends assisted GPS data to terminal including:

- Measurements assistance data, like GPS reference time, visible satellite list, satellite signal Doppler and code phase search window. Valid for 2-4 hours, or 30s when differential GPS is used.
- Assistance data for position calculation, like reference time, reference position, satellite ephemeris and clock corrections. Valid for 4 hours, or 30s when differential GPS is used.

In a terminal assisted position calculation, the terminal has a reduced GPS receiver and just performs pseudo-range measurements. After that, realized measurements are sent to a calculation unit in the network, which carries out the rest of the GPS operation. Djuknic et al. [13] refers that assisted GPS is accurate within 50 meters while users are indoor and 15 meters while users are outdoor.

3.3. Ideal location sensing

While developing location sensing technologies, the designer has to think of what type of location sensing technology is more suitable for the scenario where the system will be deployed; considering calibration procedures, related infrastructure to support the system, costs, robustness, latency, and so many other factors. The result is the best compromise between an ideal location sensing technology and specific problems found for that system. Thus, it is important to illustrate what an ideal location sensing system would be.

According to Welch et al. [47] the ideal location sensing system would be a device called "track-on-a-chip" (ToC). The ToC would be:

- Tiny—the size of an 8-pin DIP (dual in-line package) or even a transistor;
- Self-contained—with no other parts to be mounted in the environment or on the user;
- Complete—tracking all six degrees of freedom (position and orientation);
- Accurate—with resolution better than 1 mm in position and 0.1 degree in orientation;

- Fast—running at 1,000 Hz with latency less than 1 ms, no matter how many ToCs are deployed;
- Immune to occlusions—needing no clear line of sight to anything else;
- Robust—resisting performance degradation from light, sound, heat, magnetic fields, radio waves, and other ToCs in the environment;
- Tenacious—tracking its target no matter how far or fast it goes;
- Wireless—running without wires for three years on a coin-size battery; and
- Cheap—costing $1 each in quantity.

At the moment, there is no such magical device; encouraging the development of many location sensing systems based on different technologies as presented bellow.

3.4. Optical-based location sensing

Optical-based tracking systems search for cues in the scene to track persons and objects. Wang [44] defined optical tracking methods in two categories: outside-in and inside-out. Outside-in requires all sensors to be attached to a fixed reference. In inside-out category, sensors are attached to the mobile target. Outside-in are useful for tracking objects and persons in a room, reducing the sense of mobility. On the other hand, inside-out configuration allows the mobile target to roam across a controlled environment.

Usually, optical tracking systems can have high update rates since interaction with the environment occurs at the speed of light. However, such systems are highly influenced by image quality, and the distance to tracked features which may compromise resolution and accuracy. When an object is far away from the optical sensor, the number of pixels to define it is reduced also reducing the ability to track that object. Moreover, optical noise, spurious light, and ambiguity of sensed surfaces are also sources of errors.

In addition, optical-based location systems are also influenced by occluded/missing features in the scene increasing the sources of error for these systems. In order to overcome these problems, correct placement of sensors must be achieved. Finally, update rates and accuracy of the estimation process is also dependent on the number of features to track [38].

3.4.a) Outside-in

In outside-in methods, video-cameras are placed in the coordinate reference to locate the target person or object. These methods can be further sub-classified in multiscopy, and pattern recognition. Multiscopy is referred to as a technique to provide depth cues using multiple optical sensors. Mainly, multiscopy is employed using two cameras, so called stereoscopy, were depth cues are collected using two slightly different images. Stereoscopy tries to resemble the human eye, where two different images are supplied to the left and right eye enabling human to perceive a 3D view [38].

Multiscopy is used with two or more optical sensors to perceive the spatial position of the tracked object using triangulation. By tracking several features in the image, it is possible to evaluate the orientation of the tracked object. In the process, blobs features, clusters of the image with similar characteristics, are perceived in different views and, through the use of a non linear modelling, and the combination of iterative and recursive estimation methods, the 3D geometry is recovered from blob correspondences [3].

Pattern recognition uses a single camera to track known patterns from a set of features in the tracked object. The tracked pattern is a function of the position and orientation of the tracked object. Commonly, an object model is used to estimate a match between the model and the image captured by the camera, minimizing the image-based error to estimate object position and orientation. The 3D parameters of each object, such as motion parameters, shape deformation parameters, and joint parameters for articulated objects, can influence the image-based error [38].

Examples of usage of these methods can be found in Martin and Horaud [33] work. They have implemented a method for tracking rigid objects using one or several cameras. In the tracking process, a previously defined 3D model of the object is aligned to match the contours of the object in the gathered images. Alternatively, pattern matching can be used to reconstruct body motion.

Remondino [36] has developed a process were a sequence of images is captured and afterwards calibrated and oriented. In the following step, correspondences of the body are extracted using a least square matching algorithm. Finally, a reconstruction of the 3D body model is performed in point cloud form.

3.4.b) Inside-out

In inside-out methods sensors are attached to the tracking object and fixed beacons are placed on the coordinate reference. These methods can be further classified into videometric, and beam scanning. Videometric methods use optical sensors placed on the target object, while beam scanning system uses rotating beams emitted from the reference and detected by the sensors located in the target [38].

Videometric methods are based in several cameras mounted in the target, which are able to track pattern features, previously installed features with known locations. Triangulation is then performed using at least three vectors calculated from the sensors to the acquired patterns. Welch et al. [46] developed the HiBall tracking system. The HiBall uses a looser-tolerance panels grid-cell of LEDs installed in the ceiling and a small sensor installed in the target user. For increased accuracy the HiBall tracking system also uses an unusual Kalman filter based algorithm that generates very accurate pose estimates at a high rate with low latency and simultaneously self calibrates the system.

Beam scanning is mainly used to track head orientation through synchronized detection, but can also be used to track the position of a target object. Sensors located on the target detect the time of sweep of the beam across their surfaces. The time of sweep is used with angular velocity to determine the angle from the reference axis to each sensor. The angle from the reference axis to each sensor is then used to determine the position and the orientation of the tracker [38].

Chinthammit et al. [11] purpose a system where the optical aperture of a Virtual Retinal Display (VRD) is shared between image display and the scanning beam to track position and orientation of the user. Instead of using a relative stationary reference, the reference beam is placed in a robot arm system.

Inside-out systems can also search for cues in the scene to retrieve position and orientation of the target object based on the known positions of these cues. The environment is perceived as the reference, using landmarks, object models and maps, whether in two or three dimensions. Thus, cameras are used to capture geometric features or regions that match that of the landmarks, models or maps. When the matching is performed the location of reference objects is retrieved and the position and orientation of the target can be estimated. The features used as references should be easily sensed in the environment, in order to improve the performance and accuracy of these systems.

The pin-hole camera model is commonly used to translate location information between the real world (3D), the captured image (2D), and the point of view of the camera in the 3D virtual world, see figure 3-3. The correct identification of the parameters to translate location information between all co-ordinate systems reduces the associated error. In addition, the location-error associated with the estimation strongly depends on the sensors, sensing schemes, and representations of the environment.

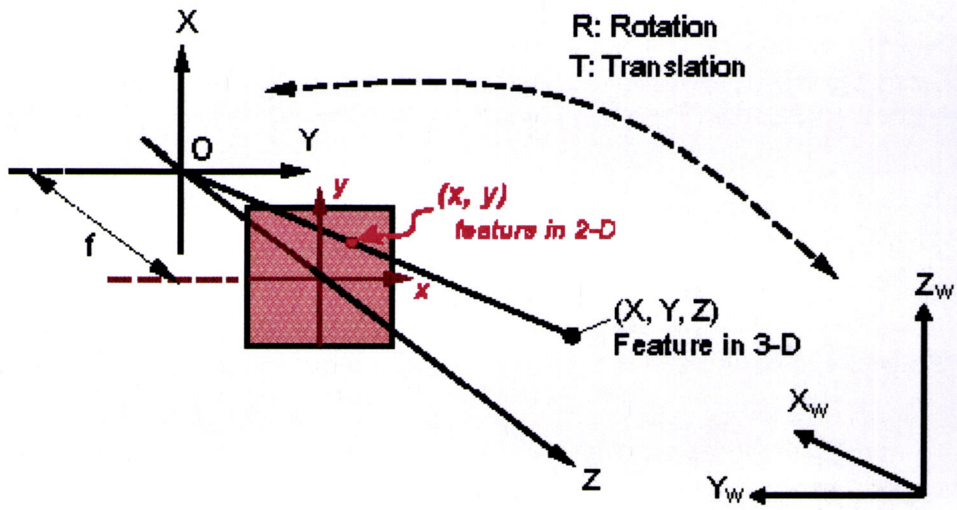

Figure 3-3 – Pin-hole camera model

Location estimation can use landmark-based positioning, model-based positioning, or feature-based visual map building positioning. Landmark-based methods search for simple features, namely points and lines, or more complex patterns, used as reference, to estimate the location of the target object.

After uniquely identify features and their positions, the position and orientation of the pin-hole camera and the target object, can be estimated. It is not always possible to uniquely identify a sufficient number of features. Mainly, three landmarks are needed to estimate the position of the target object.

In such cases, OpenCV is a good tool to retrieve and identify landmarks from the visual scene. OpenCV is a library aimed at real-time computer vision. Developed by Intel Research, OpenCV has excellent tutorials and courses to fasten the development of applications using the libraries. A huge array of computer vision operations can be performed using OpenCV, from contour processing, distance transforms, gesture recognition to 6DOF model based estimate from one 2D view.

In a model-based positioning method, previous knowledge about the environment needs to be gathered in a more comprehensive way than simple features such as in landmark-based positioning. 2D or 3D models of the environment structure, or even digital elevation maps (DEM) can be used as a priori knowledge of the environment.

Geometric models commonly include 3D models of buildings, floor maps, or objects. To correctly estimate the position of the target object, the capture image should retrieve the tracking features used to match with the model, reducing uncertainty. However, the captured feature in 2D may have a different shape then the 3D model. By using a 3D model two problems can be solved: objects identification and pose estimation for identified objects.

Therefore, a two dimensional projection of the model in matched against the captured lines from the image, see figure 3-4. A best match is achieved considering all possible sets of three landmarks. When the correspondence between the model and the captured image is found the spatial relation between the target object and the reference is achieved. The relation is express has the translation and orientation that match target object and reference co-ordinate system.

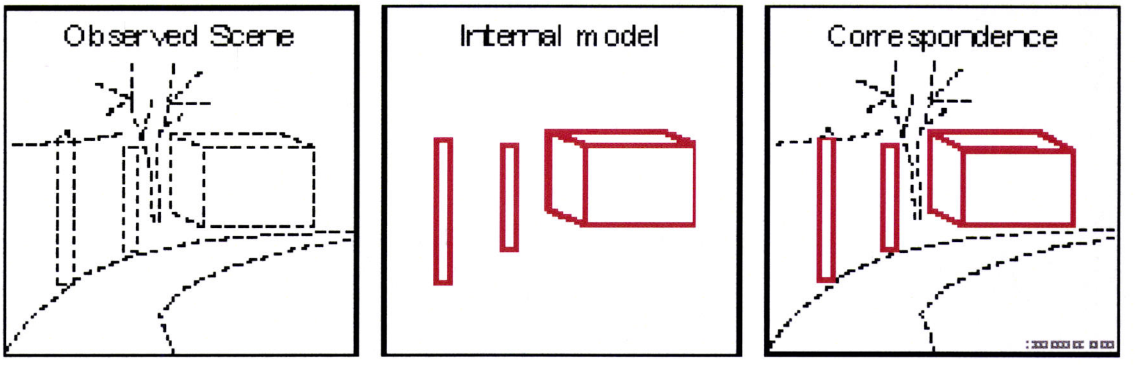

Figure 3-4 - Finding correspondence between an internal model and an observed scene

The location estimation can be relative to the reference, when the reference is also a moving object, or absolute, when estimation is performed related to a known co-ordinate system. Several AR applications take advantage of this kind of methods to accurately estimate the relation between the reference and the target object. ARToolkit takes advantage of relative location to surpass calibration issues [2].

ARToolKit is the most used software library to build AR applications. The library is being developed by Dr. Hirokazu Kato of Osaka University, Japan, and is being supported by the Human Interface Technology Laboratory (HITLab) at the University of Washington, and HIT Lab NZ at the University of Canterbury, New Zealand. The ARToolKit video libraries calculate the real camera position and orientation relative to the fiducials in real time.

Taking advantage of the ARToolKit library a new framework to ease its use was also developed, AMIRE [1]. AMIRE is an AR project sponsored by the European Union IST-programme aimed to create an efficient way to create and modify Mixed Reality (MR) applications. Authoring tools are also in development in order to efficiently use MR in applications, to conceive new MR methodologies and exploit synergies when combining MR technologies in the AMIRE framework, and to establish authoring as a new application domain for MR.

On-going research concerning the use of model-based feature tracking with the reduced processing power of mobile phone includes the Visual Code Recognition for Camera-

Equipped Mobile Phones project is using off-the-shelf mobile phones to track geometric patterns, fiducials [37].

In addition, while using model-based positioning methods, others sensors can be used for positioning purposes. The information collected from them can be used to fasten the process of matching landmarks found in the scene and the 2D projection of the model, also using the translation and orientation parameters from these sensors. Furthermore, DEMs are another model-based positioning approach. However, DEMs are mainly used for outdoor positioning. The basis is a hierarchical system comparing features in the visual scene to that found in a DEM, see figure 5.

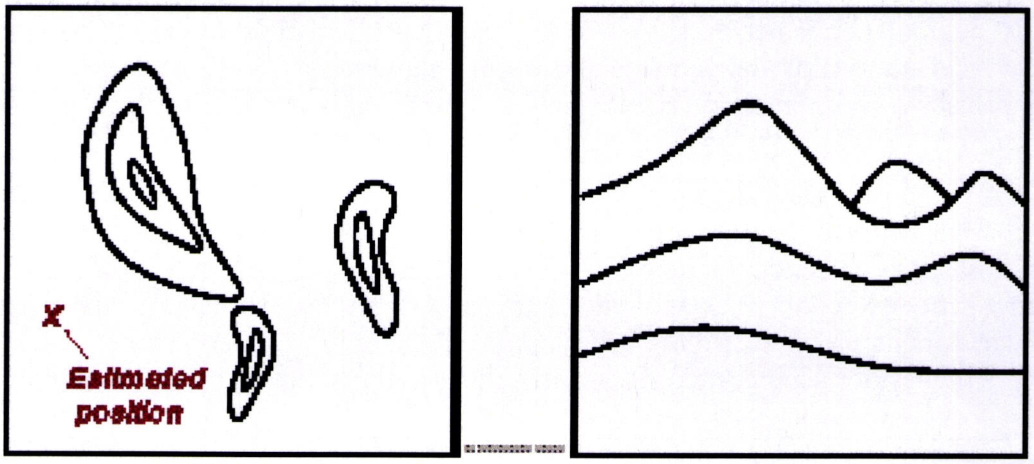

Figure 3-5 - Finding a location on a digital elevation map (DEM) that matches a visual scene observed from apart. The 'X' marks a possible location in the DEM that could generate the observed visual scene to the right.

Between such features, peaks, saddles, junctions, and endpoints can be identified in the visual scene and used to find the correspondence. From the DEM, features such as contours and ridges, are gathered. When a correspondence between visual scene and DEM features is found, the target object position and orientation can be estimated. Behringer [8] uses horizon silhouettes, while querying a local or remote DEM database to retrieve orientation.

In some cases, a priori knowledge of the environment is not possible. In such situations, the target object has to rely in its sensors. Thus, the sensor captures visual features to construct the environment model as the target object moves through different locations. Captured features in a location became relative references for future locations. Thus, model construction engages in a learning process of the environment.

When a correct correspondence is established, vision systems can perform better then odometry or inertial navigational systems. However, odometry and inertial sensors can be more reliable up to a certain degree. Therefore, information from these sensors can be used to narrow the search space for feature matching. A model based in the features captured by vision sensors may not describe adequately the environment structure for some applications.

3.5. Radio-based location sensing

Regarding location-based sensing, location estimation can be performed in the mobile terminal or in the network. Some methods perform location estimation in several steps involving the mobile terminal and the network. Finally, there are location estimation methods that can be performed either in the mobile terminal or in the network, depending on the resources available.

Terminal-based location estimation collects information from one or more sensors and performs all calculations to estimate its location. Sensors can be part of a network, or built-in the terminal. In terminal-based locations systems, privacy is better preserved since the user has full control of the location information. Thus, it is up to his or her decision to forward that information to third party services, namely LBS.

Opposed to terminal-based location methods, there are network-based location methods were no computation is performed in the terminal. All calculations are performed in the network and afterwards delivered to the service requesting for the location. In such cases, privacy issues can be raised since the user has to rely in the network to correctly handle sensitive information, such as his or her location.

Network-based location estimation relies on the infrastructure to perform all operations, thus no transformation is required in the terminal. Mainly, mobile phone operators prefer this approach, since it requires no client-side configuration, modules, or software to allow the network to track mobile terminals. A main disadvantage is the need to deploy and maintain an additional infrastructure for mobile location estimation. When there is a request for accuracy also requiring specialized equipment may be required.

There are also location methods requiring the cooperation between the network and the terminal to estimate location. In such cases, the terminal collects information from sensors. Afterwards, some previous calculations can be performed in the device and the result is sent to the network to estimate the location of the terminal. Finally, to overcome problems in location methods, they can be combined to improve accuracy. Based in Djuknic and Richton [14] classification, table 1 gives an overview of how each location method works and where location estimation is performed.

Network based positioning	**Cell ID Based Positioning**	Terminal position can be estimated based on current or recent terminal's camping radio cell information. Thus, every cell has a cell ID or cell coverage co-ordinates. Given cell ID or cell coverage, co-ordinates of the fixed known position of base station, terminal position is estimated.
	Round Trip Time (RTT) Based Positioning	RTT can increase cell ID based positioning accuracy. So, RTT is the propagation delay time of the signal traveling from the terminal to the base station and back. Furthermore, calculation of terminal position can be made using RTT measurements of the signal branches from several base stations. Finally, accuracy improves with additional base stations.
	Time of Arrival (TOA) Positioning	TOA calculates position based on the propagation delay of the radio signal from the transmitter to the receiver. So, when there are at least three TOA measurements available, terminal position accuracy can be improved by applying a triangulation technique, minimizing the least square distances between the terminal and corresponding TOA circles. However, TOA has problems with Non-Line-of-Sight, signal fading, reflection and shadowing. So, in measurements, an error margin must be taken into account. In addition, TOA method also requires very accurate base station synchronization.
	Time Difference of Arrival (TDOA) Positioning	Terminal observes TDOA of the radio signals from the neighboring base stations. Then, unknown terminal position is estimated by processing TDOA measurements between terminal and at least three base stations of known co-ordinates. TDOA terminal measurements are based in two components: TDOA = RTD + GTD Where GTD stands for Geometric Time Difference and is the actual quantity containing information related to the terminal position, since it defines a hyperbola between the two BSs. RTD is the transmission difference between the signals of the neighboring BSs.

	Angle of Arrival Positioning (AOA)	Terminal position is determined by calculating the intersection of two lines of pilot signal branches, each formed by an angle from the BSs to the mobile terminal. Thus, a single measurement angle forms pairs of lines and provides terminal position. Moreover, when LOS between terminal and two BSs, and measurements of AOA are available, the terminal will be located in the intersection of the lines defined by the angles of arrival. Moreover, in AOA, accuracy can be improved by more than two measurements where Non-Line-of-Sight, reflection, diffraction and cost are obstacles to the development of this approach.
	Multipath Fingerprint	Terminal location is discovered by matching the multipath-produced "fingerprint" of the signal received by one or more base stations with location/fingerprint database. This technique requires continuous database management and updating.
	Timing Advance (TA)	During link establishment terminal aligns its frame/slot times with the serving base station, and uses this as a measure of its distance to base station. So, using network-enforced handoff, at least three measurements with different base stations are made and location is determined via triangulation. Moreover, sequential measurements make the method unreliable when terminal is moving. However, no modifications to handsets and minor changes in base station software are needed.
Network / Mobile station based positioning	Enhanced Forward Link Triangulation (E-FLT)	Solution unique to CDMA, primarily based on TDOA using forward-link signals received by terminal. Performance can be enhanced by complementary methods, including pattern matching of RF characteristics, statistical modeling, round trip delay measurements, and AOA.
Mobile Station based positioning	GPS	A GPS receiver is built-in terminal and works as a standalone device.
	Assisted GPS (A-GPS)	A partial receiver, built in the terminal, is assisted in its function by core network.
	Enhanced Observed Time Diference (E-OTD)	Uses a mathematical algorithm to identify the location of the user based on the time the signal from different base station takes to reach the mobile set. Gathered time signals are then used in a triangulation scheme to determine the approximate area where the caller might be. Requires firmware upgrade in MS.
Composite positioning	TDOA & Received Signal Strength (RSS)	Highly accurate and highly robust methods are combined, and several inputs are used to increase robustness and coverage. A-FLT (Advanced Forward Link Trilateration) and E-FLT are basically the same algorithm. In fact, the main variation is that the former uses the IS-801 standardized message to carry the measurements at the software-upgraded mobile station, and the latter uses the Pilot Strength Measurement Message from TIA/EIA-95 (which was not designed for location but for hand-off purpose) and therefore covers the legacy handsets.
	TDOA & AOA	
	A-FLT & A-GPS	
	E-OTD & A-GPS	
	Reference Node Based (RNBP) Positioning	In RNBP a reference node (movable or fixed) is chosen to provide auxiliary positioning measurements of terminal. Reference node can be a positioning service device, a GPS receiver or any device with known position, which can be used as a reference point when determining terminals position. RNBP can be used with any positioning method. Enhancements by using RBNP came from utilizing additional reference devices in the network.

Table 3-2 - Positioning methods

3.6. Ultrasound-based sensing

Acoustic systems use the transmission and sensing of high-frequency sound, emitted around 40 KHz, to sense range. The basis for distance estimation to the target in an acoustic system is the usage of a transmitter/receiver pair, given a known fixed point. To find a 3D point, triangulation can be performed, either from three emitters and one receiver or three receivers and one transmitter.

Indeed, at least three transmitters or three receivers are needed to gather position and orientation. Mainly, two techniques can be used to determine position and orientation:

- Time of Flight (TOF); and
- Phase Coherence.

Both methods use the velocity of sound to convert time into distance measurements. Whether using TOF or Phase Coherence, the inherent delay in waiting for the signal to travel between emitter and receiver is always a drawback, aggravated by the slow speed of sound. At 0° C, the speed of sound in air is 331 m/s. However, sound speed is influenced by temperature and pressure, requiring a new estimation of the relation between time and distance.

The theoretical model for the speed of sound in a gas can be expressed as:

$$speed = \sqrt{\frac{\gamma RT}{M}}$$

γ is the thermodynamic constant of air, R is the ideal gas constant, T is the absolute temperature, and M is the molecular weight. Moreover, acoustic energy diminishes with the square of the distance between the transmitter and the receiver.

In 1968, Sutherland developed a phase coherence ultrasound tracking system. The system used three transmitters, attached to the head of the user, and four receivers, in a grid attached to the ceiling, to track user's head. A continuous wave source was then transmitted, and a computer count major changes in phase to keep track of motions of more than one wavelength [39].

However, phase coherence methods suffer from multipath, similar to radio systems, introducing errors in the system. Walls and objects in a building reflect acoustic signal varying phase and amplitude of the signal, with implications in the user's position calculation. TOF methods overcome the multipath effect, sending signals in intervals and waiting for the first signal to arrive. Since, the speed of sound is slower than radio it is possible to detect the first signal arrived from a direct line of sight (DLOS) and signals resulting from multipath.

Namely, acoustic tracking system can suffer from the following additional problems:

- Omnidirectional receivers are required in 3D tracking,
- Efficiency of an acoustic receiver is proportional to the active surface;
- Highly resonant receivers affect tracking cycles;
- Ambient noises affect performance;
- The size of the receiver and frequency dependent attenuation of sound in air reduces range;
- Reverberation affects tracking cycles;

Indeed, unconstrained 3D tracking requires omnidirectional receivers, so that the signal can be detected no matter how the emitter is positioned or oriented in the reference space. Thus, to achieve a wide coverage, small speakers and microphones, with active surfaces a few millimetres in diameter, can be deployed in the surrounding space, attached to objects or persons to track. However, the efficiency of an acoustic receiver is proportional to the active surface diameter. A smaller active surface reduces the tracking range.

To overcome the tracking range problem, highly resonant receivers can be used. Nevertheless, usage of such receivers also raises a new problem affecting tracking cycles, due to the shape of the receiving wave. Indeed, the solution to a previously found problem in an acoustic tracking system can raise a new problem requiring a solution.

Namely, acoustic systems can be affected by ambient noises. Thus, higher frequencies can be used; since most ambient noises diminish their impact with increasing frequencies. Moreover, higher frequencies can avoid interference and shorter wavelengths offer higher resolution. However, the size of the receiver and the frequency dependent attenuation of sound in air can also reduce system range [47].

Reverberation is also an important issue. In some environments, tracking cycles have to be delayed due to environment conditions. In conclusion, ultrasound systems performance and accuracy suffer from several restrictions leading to the development of hybrid systems to overcome all mentioned problems. Consequently, Priyantha et al. [35], in the Cricket Location-Support System, combines RF signals and ultrasound hardware.

3.7. Inertial sensing

Inertia is the tendency of a body to maintain its state of uniform motion unless acted on by an external unbalanced force. Therefore, the inertial reference frame is a coordinate system where no unbalanced force is applied to a body. This physical phenomenon is explored in inertial sensors to measure acceleration and rotation relative to the inertial reference frame of the earth.

Indeed, the coordinate system of inertial sensors is not inertial, since the earth suffers from changes in acceleration, whether linear or centripetal. However, inertial sensing can be used to estimate absolute position and orientation of an object.

3.7.a) Mechanical Gyroscope

Inertial gyroscope is a device for measuring or maintaining orientation, based on the principle of conservation of angular momentum. The device has a spinning wheel on an axle that tends to resist to changes in orientation. The axle of the spinning wheel is defined as the spin axis.

The wheel responds to a force applied about the input axis by a reaction force about the output axis. The 3 axes are perpendicular, and this cross-axis response is the simple essence of the gyroscopic effect, see figure 6 [22].

3.7.b) Accelerometers

An accelerometer measures its own linear acceleration. The main specifications for an accelerometer are: single degree of freedom, with some kind of mass; spring-like supporting system; and a frame structure with damping properties. Several technologies are used to implement accelerometers, namely:

- Capacitive
- Piezoelectric
- Piezoresitive

- Hall Effect
- Magnetoresitive
- Heat transfer

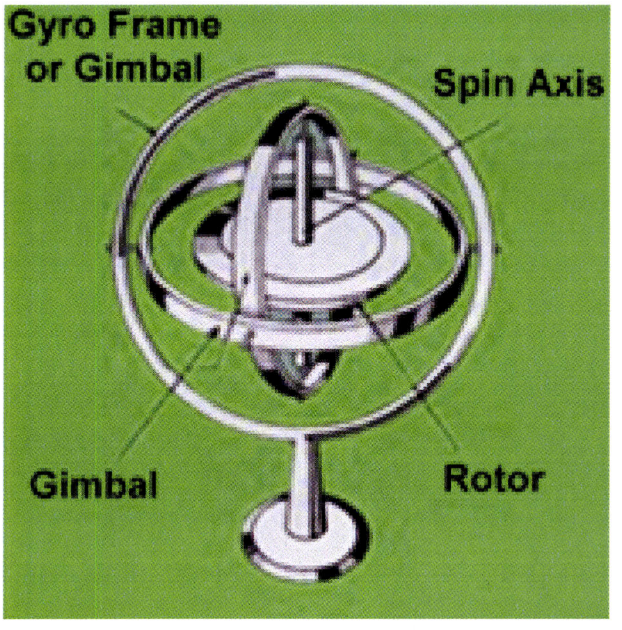

Figure 3-6 - Gyroscope schema

Capacitive and piezoelectric accelerometers are the most used type of accelerometers. Capacitive accelerometers sense a change in electrical capacitance when acceleration is provided to the system, changing the output of an energized circuit. The sensing elements are two parallel capacitor plates acting in a differential mode. These capacitors operate in a bridge circuit, along with two fixed capacitors, and alter the peak voltage generated by an oscillator when the structure undergoes acceleration. Detection circuits capture the peak voltage, which is then fed to a summing amplifier that processes the final output signal.

Piezoelectric accelerometers take advantage of the piezoelectric effect. The piezoelectric effect is the ability of certain crystals to generate a voltage in response to applied mechanical stress. A piezoelectric crystal has two dipoles where positive and negative charges are symmetrically distributed. When stress is applied to the crystal this symmetry is disturbed and a voltage is generated across the material.

Piezoelectric accelerometers contain a mass between two piezoelectric crystals. When acceleration is provoked in the system the symmetry in the crystals are disturbed, proportionally to the induced acceleration. Thus, it is possible to measure the acceleration knowing the amount of voltage generated in the crystal.

3.8. Mechanical sensing

Mechanical sensing involves a direct link between the reference and the target object being tracked. These systems involve a set of articulated linkages interconnected with electromechanical transducers, such as potentiometers or shaft encoders. When some movement is performed the transducers' output reflects the amount of movement performed.

A priori knowledge of the mechanical pieces and associated movement of the mechanical pieces allow the estimation of target object's orientation and position. YDreams developed a Virtual Sightseeing system that employs AR techniques to add virtual information to what the user is seeing. Orientation tracking is performed by mechanical sensing, providing good accuracy results for the AR system [49].

Another project developed by YDreams employing mechanical sensing tracks motion of a fire-fighter, iGarment. In this project, variable resistors are used to measure the angle of body joints of the fire-fighter. Thus, wearable conductive yarns and variable resistors are embedded into the garments. When the shape of a wearable variable resistor changes its resistance also changes. Consequently, by using a direct relation between resistance and the angle of the resistor it is possible to measure the angle of body joints unobtrusively. [48]

3.9. Direct-field sensing

Direct-field sensing involves tracking a target through the use of a magnetic-field, magnetic field sensing, or recurring to the inertial reference frame of the earth to track the same object. Direct-field sensing is mainly used for orientation.

3.9.a) Magnetic field sensing

Magnetism is one of the phenomena by which materials exert an attractive or repulsive force on other materials. When an electric current is induced in a coil then a magnetic field is generated. If a magnetic field sensor is placed in the vicinity, the magnetic field induces a magnetic flux in the magnetic field sensor, so called magnetic coupling. Afterwards, the magnetic flux can be measured, resulting in a direct relation with the distance of the magnetic field sensor, and its orientation relative to the coil.

Three coils with orthogonal magnetic fields can be used to estimate the position and orientation of a target object. These coils define a spatial reference to be used to track the target object. Afterwards, other three magnetic field sensors are used to measure the components of the magnetic field in the target object position.

Magnetic trackers are inexpensive, lightweight, and compact making them suitable to be used in a wide range of tracking scenarios. However, magnetic trackers have the disadvantage of introducing lag into the system, and can be limited by the attenuation of the signal with distance.

Three types of magnetic trackers can be used for tracking, namely sinusoidal alternating current (AC), pulsed direct current (DC), and Magnetometer/Compass. Sinusoidal alternating current trackers are based on alternating the current feeding the emitting coils. Sinusoidal AC trackers create Eddy currents in the vicinity of metallic objects, distorting the emitted magnetic field, consequently distorting measurements.

Pulsed direct current (DC) use a pulsed constant flux to excite the sensors, in contrast to the alternating current feed of sinusoidal alternating current. However, pulsed DC suffer from the same problem as sinusoidal AC. Nevertheless, it is possible to wait until Eddy currents vanish, introducing a lag. This may be inadequate for some applications.

Finally, the magnetometer/compass measures the magnetic field of the earth to gather the orientation of the target object. Magnetometers include fluxgate, Hall effect, magneto-resistive, and magneto-inductive sensors [18]. With three sensors, the orientation of an object with respect to the magnetic field can be determined. The compass can supply pitch, and the other angular degrees of freedom are measured by other means, for instance by inclinometers. As with other magnetic field sensors there are associated problems with the usage of this technology. Namely, due to the inhomogeneous characteristic of the Earth's electromagnetic field, feeding angular errors in the orientation measurements. Furthermore, such technology is sensitive to disturbances in the ambient magnetic field.

3.10. Hybrid Sensing

Individually, each sensing technology has problems, whether its costs to deploy in larger areas, computational power to allow its usage, accuracy, delay in sensor's measurements, and so many other problems previously mentioned. Thus, to improve measurements and system performance, different technologies and different methods can be combined to improve the overall system performance. Hybrid sensing combines several sensing technologies to empower the overall tracking system and reduce weaknesses suffered by each technology.

Moreover, as stated by Rolland et al. [38], the definition needs to be extended to also include systems that use different principles of operation, possibly using the same technology, such as TOF versus Phase Coherence in acoustic systems. It is a fact that hybrid sensing increase the complexity of the sensing system (and possibly its costs); however both technologies can complement themselves, providing access to a wider number of variables that only one technology cannot offer, or provide more exhaustive measurements.

Thus, sensor fusion procedures, involving filtering and predictive techniques, can be use to take advantage of incomplete data sets from sensors. As mentioned previously, tracking systems such as [6][7][9][35][50][51], employ sensor fusion techniques to track the target object surpassing the problems of each single technology.

3.10.a) Fusion of tracking sensors information

For location-based services, knowledge of user position is crucial, in order to supply her or him suitable information related to the contextual information [12]. Therefore, factors like user physical position or specific tracking technology variables influence location and orientation estimation, since accuracy of location information can vary dynamically. So, each tracking system reveals problems related to the technology they use: vision-based trackers are computationally intensive, magnetic trackers have low-accuracy and mechanical trackers are cumbersome.

Hence, a combination of several tracking systems, simultaneously or alternatively, will be ideal to exploit strengths and reduce weaknesses of each system. Combining all of them must account for delay, inner and outer interference, and precision of each device. Thus, to combine tracking measurements, polynomial-based predictors, Kalman filters, Particle Filters, and Single-Constraint-At-A-Time (SCAAT) are some of the techniques used to predict and smooth measurements. To summarize, each technique is described in the table below:

Technique	Description
Polynomial-based predictors	Provide estimates of future values of polynomial-like signals [40]. Thus, if tracking measurements are according to some polynomial expression than future values can be predicted by evaluation of that expression.
Kalman filter	An algorithm that estimates the non-measured states from the other measurements and smoothes measured inputs [4]. Therefore, when a measured state has values very different from previous ones, these values are smoothed, and, in non-measured states, values are predicted from previous states.
Particle Filters	A technique where weights are dynamically attributed to each measured state. The set of states and weights is named a Belief, where weights are attributed based on a location model and measured locations. Thus, the location prediction is biased by the location model and the number of measurements [17]
SCAAT	A technique based in the premise that single observations provide useful information about the user's state, and thus can be used to incrementally improve a previous estimate [45].

Table 3-3 - Fusion algorithms

For example, Azuma et al., [5] developed a motion-stabilized AR display for outdoors based in a compass and tilt sensor, a differential GPS receiver and three rate gyroscopes that works both in hand-held and head-worn modes. In this project, sensor fusion is influenced by a SCAAT algorithm [45].

Hightower and Borriello [25] surveyed and categorized tracking systems for ubiquitous computing. They believed that future research should be directed towards goals like: lowering costs, reducing the amount of infrastructure, improving scalability, and creating systems that are more flexible within the taxonomy.

In addition, independent location sensors must be used to effectively combine increasing accuracy and precision of individual techniques. Hightower and Borriello also alleged that ad hoc location sensing could be used to estimate locations, allowing neighboring objects to cooperate with each other by sharing sensor data to factor out overall measurement error. Moreover, in a cluster, ad hoc objects can be located in twofold: located relatively to one another; or absolutely, if at least an object has a known position.

Finally, latency is another crucial issue in location-based services with high update rates. Several systems use different devices for input and output, although all systems want to diminish relative latency between streams. So, an ideal end-to-end system does not have latency, although it is very difficult to achieve. Consequently, several techniques can be used to reduce latency. Jacobs et al. [27], describes latency in augmented reality systems.

3.11. Location sensing properties

Location sensing technologies can use additional metrics to classify a location sensing system. Thus, to determine how well a location sensing system works three metrics can be used, as seen in the following table [29]:

Metric	Definition
Precision	Determined by how well the mobile terminal and/or listener can detect the boundary between two spaces.
Granularity	The smallest possible size for a spatial location such that boundaries can be detected with a high precision degree.
Accuracy	Used to calibrate individual base stations and/or beacons and mobile terminals and/or listeners; it is the degree to which the distance from a beacon, estimated by a listener, matches the true distance.

Table 3-4 - Location sensing metrics

Precision is the degree to which further measurements or calculations will show the same or similar results. In other words, precision is the ability of a measurement to be consistently reproduced. Figure 7 illustrates a high level of precision comparing to a low level of accuracy.

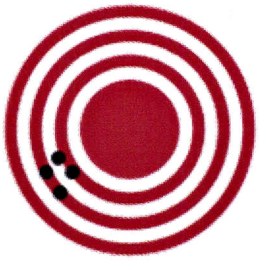

Figure 3-7 – High precision and low accuracy

Granularity is related to the precision of the location sensing system. It quantifies the noise associated with each sensing location system. All trackers are limited in granularity by a quantification unit. Mainly, all technologies are limited by the size of measured technology, namely a quantum of light, or the wavelength of ultrasound wave. However, at the application level the granularity considered is much larger than the limiting quantification considered.

Accuracy is a measure of the absolute error of either position or orientation in the reference system used. Additionally, accuracy provides estimations of position and orientation using noise measurements and averaging them. To calculate accuracy, a large number of measurements should have been gathered to yield unbiased estimates of the mean values of the associated distribution for position and orientation. Opposed to the previous figure, figure 8 illustrates a high level of accuracy opposed.

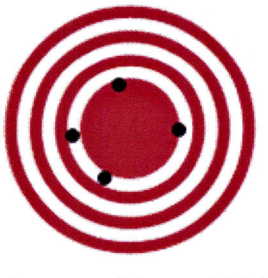

Figure 3-8 - Low precision and high accuracy

Latency, as previously mentioned, is an issue of critical importance. In some systems, virtual information is only generated after proper reception of the signal measurements.

This introduces a lag between the moment that an action takes place and the moment that virtual information is shown to the user. This lag involves the establishment of measurements conditions, such as time to complete the measure before data is available, filtering, signal propagation and transmission times, and synchronization between the tracking system, the computer and the display.

To solve latency, fusion algorithms, as stated before, are used to estimate where the target object will be based in previous measurements. Moreover, scalability is also an important issue when choosing the sensing technology. Indoor environments require improved accuracy, in comparison with outdoor environments. Indeed, several sensing technologies are suitable for indoor usage but aren't extendable, or can't even be used while outdoors. Scalability is mainly biased by costs in deploying the technology over a larger area.

Therefore, complex algorithms, allowing a seamless transition between technologies used outdoor and indoor, require further research and development, as systems are being scaled and hybrid technologies are being used to surpass the weaknesses of each single technology.

3.12. How to sense location

Location sensing can be achieved using three major techniques [26]:

Technique	Description
Triangulation	Uses specific measurements from sensors in range to estimate locations. Can be performed using lateration where multiple distances to known points are estimated, or using angulation where angles between known points are used to estimate location;
Proximity	Measures nearness to a point of interest. Can be achieved through physical contact, monitoring, or observation;
Scene analysis	Examines features of interest in the environment.

Table 3-5 - Locasion sensing techniques

Location sensing can be biased by the sensing technology in use, or by the requirements of a specific application. To illustrate the previous sentence, imagine that a location system intends to use radio sensors scenario installed indoor near doorways, then the proximity technique is the technique to use, since neither triangulation nor scene analysis are practical approaches for this problem.

Triangulation uses triangle's geometry to calculate the target object position. Triangulation can be further sub-classified into lateration and angulation. The lateration term is used to mean that distances are being measured. Basically, in 2D three non collinear points and its distances to an unknown point are required to uniquely determine the unknown point. Moreover, in 3D, four non coplanar points and its distances to an unknown point are required to uniquely identify that point. However, previous knowledge of the environment where location sensing is taking place can reduce these requirements.

Distance measurements can be performed using three distinct methods:

Direct	Involves the usage of physical action to measure distance whether using a rule or, by means of an automatic probe, in a robot context, used by the robot near an obstacle.
TOF	Uses time measurements to determine the travelled distance from the target object to a reference, at known velocity. Several sensing technologies, such as ultrasound, radio or optical systems, take advantage of this method to measure distances. However, optical and radio location sensing systems may require higher time resolution to provide better accuracy, since light and radio travel at higher velocities than sound. Sound waves travel approximately at 344 meters per second in 21°C air, whether light travels at 299,792,458 meters per second. TOF location sensing also requires methods to synchronize time between the emitter and the receiver. Clocks between all parts involved must be accurately synchronized to allow a greater degree of accuracy. Thus, the receiver and the emitter need some "agreement" methods to synchronize clocks. However, when a round-trip solution is used, only the clock of emitter is used not requiring further improvements in the receiver's clock.
Attenuation	The intensity of emitted signal decreases in the inverse ratio as distance from the emission source increases. This phenomenon is known has attenuation. Given a correct relation between distance and attenuation, for a determined type of emission and emitted signal strength, then it is possible to estimate distance from the emitter and the receiver measuring the received signal strength (RSS). Indoor, attenuation methods may reveal themselves inaccurate, due to multipath factors.

Table 3-6 - Distance measurements methods

Angulation measures angles to estimate distances, instead of time as in lateration. Angulation requires knowledge of the distance between two reference points and the measurements of the angles between the vectors defined by known points and an unknown point. Afterwards, the law of sines can be used to find the distance from the unknown point to the vector formed by the two known vectors. Finally, the Pythagorean Theorem can be used to determine the remaining distances.

In three dimensions, one length measurement, one azimuth measurement, and two angle measurements are required to calculate the location of the unknown point. The magnetic north is often used as a reference frame. A practical scenario where angulation can be used requires phased antenna arrays. Multiple antennas with known separations measure the time of arrival of the signal. Afterwards, given the TOA of the signal and the geometry of the receiving array, it is possible to calculate the angle where the emission was originated.

Proximity determines the "nearness" of the target object related to the reference. Three methods are used to sense proximity:

Detecting physical contact	It's a basic approach to sense proximity. Between the technologies used to sense physical contact are pressure sensors, touch sensors, and capacitive field detectors.
Monitoring wireless cellular access points	This method is also named, cell ID, and determines when a target object is in the range of the reference, namely when a mobile device is in the range of one or more base stations.
Observing automatic ID systems	This method involves the usage of an automatic identification system such as credit card point-of-sale terminals, computer login histories, land-line phone records, electronic card locks log, and identification tags.

Table 3-7 - Methods to sense proximity

Furthermore, proximity sensing systems may be combined with identification systems to uniquely identify the target object.

Finally, scene analysis uses features from the scene to determine the location of the observer or the observed objects. Tracked features are chosen so that they can be easily identified. Scene analysis can be further classified in static, or differential.

Static scene analysis matches observed features against a feature database to estimate position. Differential scene analysis tracks differences between different successive scenes to estimate position, or use the tracking of known feature's location to estimate location relative to their position.

Location sensing can be achieved using one or more of these techniques to estimate locations for people, objects, or both. The choice to use each technique is mainly dependent on the sensors being used, and the accuracy needed for a specific application.

Scene analysis or triangulation can supply better accuracy than proximity. However, given the complexity to perform calculations in triangulation or scene analysis, proximity can be a better option making the system simpler and faster.

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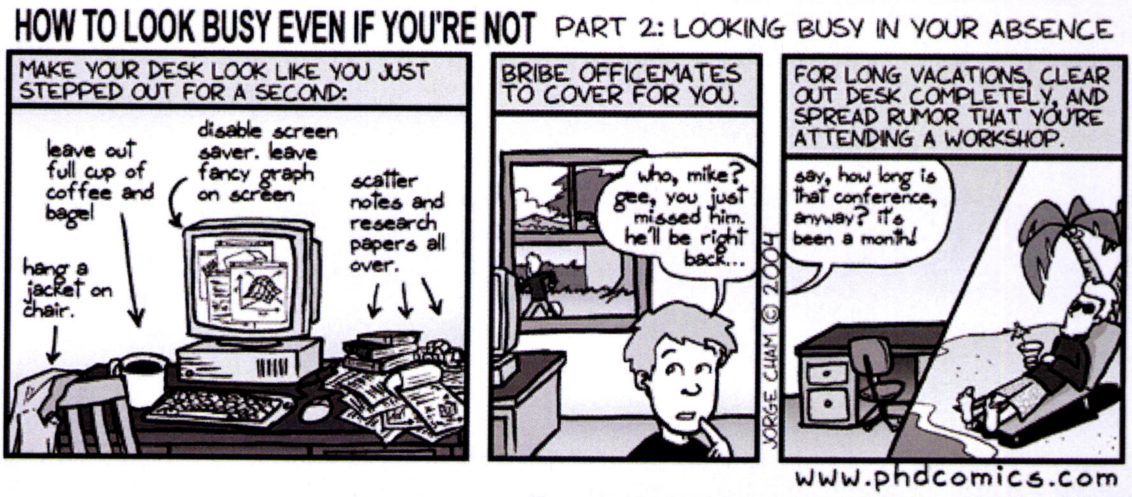

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4. Augmented Reality

Abstract

Augmented Reality is a concept dealing with various inter-complementary disciplines. From sociologists to engineers, everyone has a part in the path to AR acceptance and widespread of the technology. Furthermore, several technological aspects need further improvement, namely tracking accuracy, registration methods, or even context capture.

In this chapter, major concepts related to AR are presented as well as some interfaces that have inspired developments in this area of research.

4.1. Introduction

Augmented reality is a technology in which the user's view of the real world is enhanced with virtual objects that appear to coexist in the same space as real objects. Azuma et al. [1] define an augmented reality system to have three properties:

- Combines real and virtual objects in a real environment;

- Runs interactively, and in real time; and
- Register real and virtual objects with each other.

More recently, Milgram and Kishino [2], focusing in the vision sense, defined the concept of a "virtuality continuum" where classes of objects are mixed in any particular display situation, see figure 4-1. At one end of the continuum are real environments and at the other end there are virtual environments. In the first case, solely real objects are included, like real video, and in the later case, only virtual objects are represented, resembling a graphic simulation. So, anywhere between the extreme of the "virtuality continuum", real and virtual objects are presented together within a single display revealing Mixed Reality (MR).

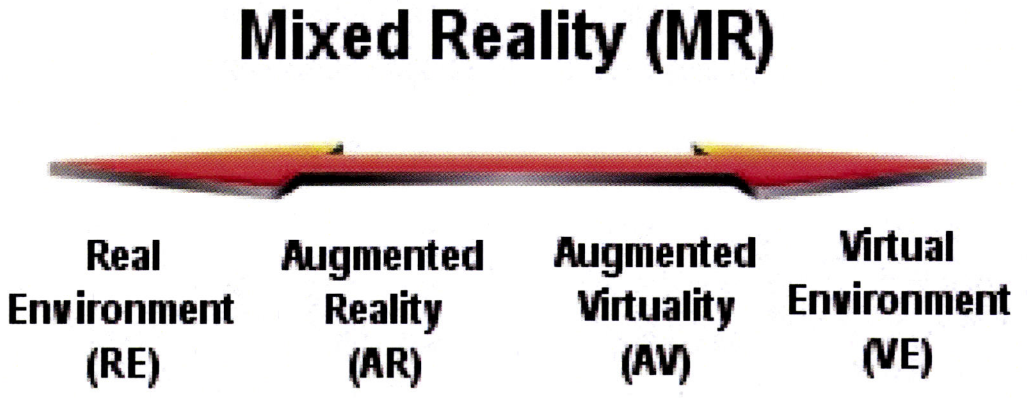

Figure 4-1 - Virtuality continuum

Augmented Reality is a slice of the Mixed Reality concept defined by Milgram and Kishino, where the real environment is "augmented" by means of virtual objects. Another part of Mixed Reality is Augmented Virtuality defined by any case where virtual environment is "augmented" by means of real objects.

Based in this definition, AR is a powerful concept that allows a user to examine and work with the physical world, while receiving additional information about the objects in it. It can be applied to target application areas such as environmental management, computer-aided surgery, repair and maintenance of complex engines, facilities modification, and interior design.

Indeed, enhancements are not limited to our sense of vision. All senses, like touch, hearing and smell can also be enhanced in an augmented reality system. Furthermore, AR is not limited to adding virtual objects to the scene; real objects can be removed, also called mediated or diminished reality by some researchers. In the next section, a brief description of some AR systems that marked the evolution of the technology is presented.

4.2. Interfaces

In the following sections several AR systems are presented, as well as different interfaces, methods and techniques to improve augmented reality experiences.

4.2.a) General Interfaces

Registration of virtual objects in real scenes is a main point of concern, but researchers should also care about how users will interact with AR systems. Azuma et al. [1] points two main trends in AR interaction research:

- The use of heterogeneous devices to leverage the advantages of different displays, and
- Integration of the virtual and real world through the use of tangible interfaces.

Furthermore, Greenhalgh et al. [3] developed seven different interfaces that illustrate several approaches to augmented reality interfaces:

- Use of telephones, fixed and public, to create audio tunnels between physical and virtual worlds, see figure 4-2;
- Same as previous, using mobile phones;
- Combine PDA, GPS device and wireless networks to create a digital activity meter, an interface for locating hotspots of activity in a parallel virtual world and displaying these on a radar display;
- Another digital activity meter using sonification instead of visual display;
- A portable tripod-mounted display called an augurscope through which users may view virtual activity when outdoors;
- The projection of a virtual world into public space as virtual shadows, where a shadow projection can be perceived as a viewpoint. That viewpoint allows a particular location within a virtual world to be projected into the correspondent public place, see figure 4-3;
- A second projection of a virtual world as an ambient sound field.

Figure 4-2 - Augmenting Reality Through Coordinated Use of Diverse Interfaces "Image courtesy The Mixed Reality Laboratory - The University of Nottingam, (c) 2003, used with permission"

In this project, real and virtual world are apart and information is exchanged between them, over an abstract channel that carries all information between worlds, to provide an augmented reality experience. Each different interface has its particular advantages:

- The usage of mobile and fixed telephones to support the engagement of several users at low cost. Since telephones are common technology nowadays, they are a good technology to give potential users a first contact with a particular augmented reality experience.
- Simple hand-held devices supporting abstract displays (ex. radar) to deal with small tracking accuracy and bandwidth adequately. Indeed, hand-held devices may also help in the process of involving new users.
- Medium scale devices (ex: Augurscope), to support small groups better than hand-helds. Since Augurscope is a device that is not fixed, but it is not really mobile either, it can support mixed patterns.
- Embedded devices approach, such as environment sound fields or virtual shadows. This approach helps users to bind technology more with locations then with persons. Per se, devices embedded in the evironment avoid problems in mobile technology such as: tracking (there's no need of a tracking device), trust of users carrying devices and need for wireless networking. Indeed, these devices can also improve experiences of people not involved in the augmented experience.

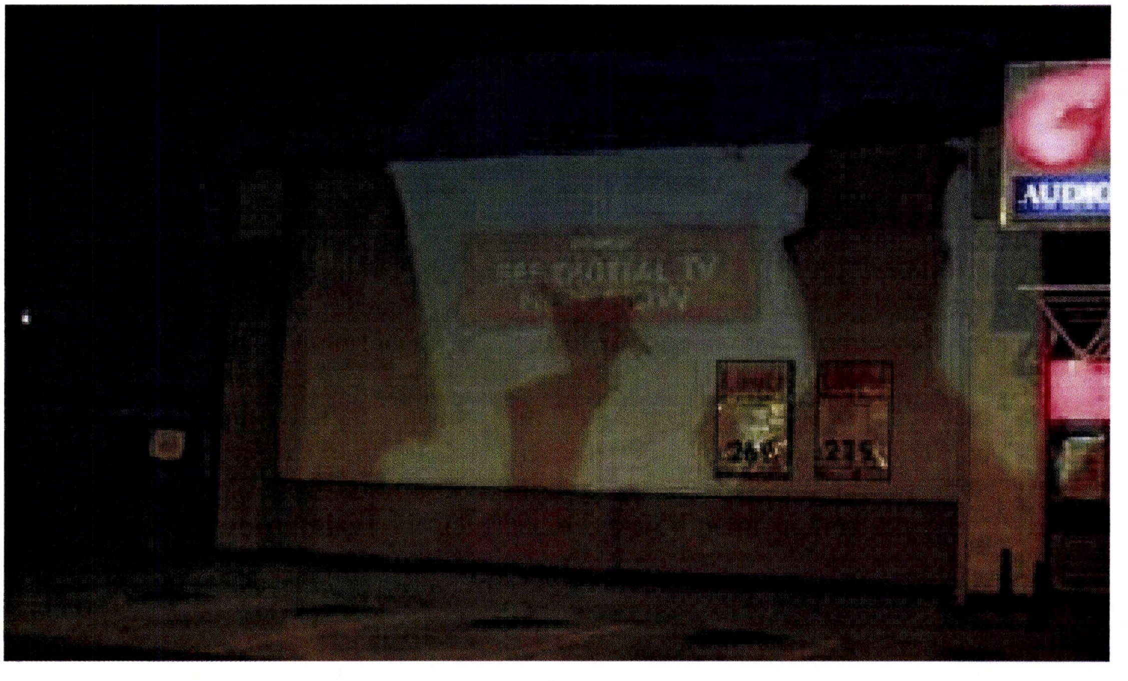

Figure 4-3 - Augmenting Reality Through Coordinated Use of Diverse Interfaces "Image courtesy The Mixed Reality Laboratory - The University of Nottingam, (c) 2003, used with permission"

Nevertheless, all these interfaces may be fitted together to produce a larger picture. When different activities are performed, when the user's interest change or even when current user's needs change, the user may be required to move between different interfaces. Indeed, a user in an augmented experience may select the interface that best fits the related space. In addition, it should be stated that a user moving from an augmented space to another (virtual shadows or ambient audio) expects a coherent experience between them.

In Mobile Augmented Reality System (MARS) [4] different indoor and outdoor interfaces are shown allowing users to manipulate information that is spatially registered within the real world, as described bellow:

- Outdoor users can experience augmented world by multimedia material on a see-through and hear-through display. They are tracked using a real-time-kinematic GPS and an inertial/magnetometer orientation sensor equipped with a backpack computer system;
- A hand-held device can also be used outside, providing a map based UI with a backpack system or standalone;
- Indoor, a desktop or projector display UI allows the creation and highlight of virtual objects, and annotation of real objects for outdoor users. In addition, outdoor users can point objects and events for indoor users to see. Moreover, outdoor user's activity is also registered;
- An immersive indoor UI allows users to manipulate virtual information on and over a physical desk, using see-through head-worn displays, 6DOF head and hand trackers, and 3DOF object trackers.

So, these UI allow indoor and outdoor users to interact, but does not allow indoor and outdoor seamless usage.

Claymore, developed by Mitsunobu et al. [5], showed a method to manipulate a three dimensional object without considering three independent orthogonal views. Claymore uses "augmented manipulation" which is a direct manipulation technique via the use of additional information in the screen. Therefore, with this technique Claymore emphasizes:

- Augmented manipulation - users can operate a three dimensional object directly through the usage of additional information.
- Intuitive operation - the object represented by the surface models are composed by a group of polygons, being empty in the inside while users see them as if they where not empty.

In Claymore, the 3D position is specified by: mouse position and shape of the object.

4.2.b) Tangible Interfaces

Tangible interfaces are important to integrate augmented reality systems with the physical world. Brereton et al. [6] based their research on the premise that if we could understand how humans interpret and use objects in their activities, we will be better positioned to design devices and tangible interfaces to support human activities. Moreover, this research illustrate the role that physical objects play in supporting thinking and develops a basis for a discussion of the roles that physical objects can play in augmented reality systems. Consequently, from this research Brereton found that:

- Thinking of objects to design is heavily dependent upon references to physical objects and gesturing with physical objects. In addition, designers are active and opportunistic in seeking out physical props to help them think through design problems and communicate design ideas,
- The interpretation and use of an object depends heavily on the context in which it is placed,

- Quick rough prototypes that model key attributes of designed objects are often preferable to time-consuming accurate prototypes,
- Tangible interfaces need to make a trade off between exploiting the ambiguity and varied affordances of specific physical objects and exploiting the power of general representations.

Ishii et al. [7], in Tangible Bits, showed another vision of HCI. Ishii et al. introduced three design projects: metaDESK, transBOARD and ambientROOM. These projects attempt to turn digital information from cyberspace into tangible media in physical world, and is based in three concepts:

- Interactive surfaces: Physical surfaces can be changed into active interfaces between the cyberspace and the physical world;
- Coupling of bits with graspable physical objects: Digital information is associated with everyday graspable objects;
- Ambient media for background awareness: Ambient media can be used in background to interface with cyberspace at the periphery of human perception.

metaDESK is an attempt to embody popular GUI into real objects, and the richness of various instruments and devices is also used to improve interaction. ambientROOM complements metaDESK using ambient media to communicate information at the periphery of human perception.

For that matter, ambientROOM tries to make seamless transition between foreground and background perception. transBOARD explores the concept of interactive surfaces. transBOARD absorbs information from the physical world, transforming this data into bits and distributing it into cyberspace. In order to distribute the information, transBOARD uses a networked and digitally-enhanced physical whiteboard to achieve its intents.

4.2.c) Mixed Reality Interfaces

In addition, Dias et al. [8] developed a tangible Mixed Reality system, named MixDesign, aimed for Architectural Design. This tangible system can be used for Conceptual Design, Client Brief or Architectural Design education. MixDesign benefits from the usage of intuitive tangible interfaces, namely a paddle, to perform different actions. Those actions can be: selecting a option in a menu, select a 3D virtual object, transport a virtual object within the scale model surroundings, or geometrically transform an object using operations like rotation or scaling.

In resume, MixDesign allows an architect to intuitively interact with a real scale architectural model of the design. He or she can observe an enhanced version of the scale model, with 3D virtual objects registered to the real ones. In addition, the architect is able to switch between augmented reality and full virtual reality, in the virtuality continuum of mixed reality, and vice-versa.

4.2.d) Interface models

The widespread of mobile devices brought distinguish interfaces with different interaction techniques. Therefore, a general human-computer interaction technique is not enough to get all the potential from each device.

Consequently, all services must adapt themselves to the device in use, namely the input and output interfaces supplied by that specific device. Mobile computing interfaces should put up with with:

- Different screen resolution,
- Different screen sizes,
- Limited interaction capabilities, requiring a big number of steps to reach a result,
- Limited processing power, and
- Different protocols and OS: Java, Symbian, CE Phone Edition, ...

Vanderdonckt et al. [9] described several techniques to handle these restrictions, where each technique envelops creation of several relations between model components. These relations will then be interpreted in a way to produce a UI that is specifically adapted to the device and context of use. So, three parameters are evaluated as contributing to the required display size in UI design:

- Individual interactors size;
- Interactors layout within a window; and
- Interactors' location among several windows.

In this evaluation, interactors are defined as any element of the interface with whom the user can interact. The last two items can be grouped in the concept of a presentation structure. So, given a screen-resolution, afforded by the platform, a suitable presentation structure must be selected. Hence, accommodating screen resolution constraints can be achieved with two methods, adjusting size of individual interactors:

- Shrink the interactors; and
- Replace the interactors by a smaller alternative.

Since, different platforms have different constraints; Vanderdonckt et al. developed an intelligent mediator agent. The intelligent mediator is able to determine the maximum usable screen resolution for each device, and evaluate the amount of screen resolution required by each alternative presentation structure.

Afterwards, the intelligent mediator selects the nearest alternative to the maximum screen resolution. This approach also allows for changes in devices and is suitable for new devices. Regarding that, a set of abstractions is structured into a hierarchy. These abstractions are then used to construct an automated design tool that generates several platform-optimized presentation models from a starting presentation model that is platform independent.

Furthermore, when the context of use changes, a task model must take advantage of this knowledge and optimize UI for each device. Therefore, the task model creates mappings between the platform and the task to show appropriate UI.

Furthermore, to leverage the users' learning process of a new UI, UI should also allow users to enter and extract information in their own language. Cultural background of a user or group of users can play a key role in the users' cognitive model or even in the adoption of new devices [10].

Currently, mobile devices are customized with user's preferences, and the functionality is increasing, evolving from classic mobile terminals to mobile terminals with functionalities like PIM, fax, and web browsing, so called communicators. So, with all this roles, users develop a mental model of the system functionality through a metaphorical understanding of the user interface elements and behaviour. Accordingly, UI metaphors are rooted both in experiences common to all humans (e.g., bodily experience) and experiences or contexts that are culturally determined (e.g., colors are metaphorical and have culturally varied meanings) [11], [12].

So, while developing UI, designers must check context of use and specified user target group. In addition, physical context must deal with the different constraints in mobile environment: wireless use, noisy surroundings, unstable or varying usage positions, and environmental factors. Mobility implies variability of social context of use, and results in:

- need to collaborate and share information,
- need to keep interaction paths,
- need for privacy and discreteness,
- need to differentiate oneself from the other users.

In case of location based-applications, and mobile AR, the interface reacts to different levels of the tracking position accuracy. Consequently, this should be done in a way that allows users to understand when and how location information may change the functionality of the application. Moreover, there are tasks frequently used or time/context critical that should be kept short by:

- ordering/prioritizing menus,
- offering shortcuts,
- designing limited amount of dedicated buttons,
- or designing the task flow in a flexible way.

Indeed, indirect manipulation, small displays, miniaturized and monolithic form factor of the terminal, and lack of UI standards may increase complexity of UI developers tasks. Thus, studies should be performed in order to discover better and innovative interaction techniques able to hide and make technology more intuitive.

4.2.e) Mobile Phone Interfaces

Third generation of mobile terminals is expected to enhance interconnectivity between various devices, resulting in new techniques of interaction, where a mobile terminal will be a gateway to the outside world. Hence, Nokia said that third generation mobile terminals improve quality of use. Quality of use is defined as the "extend to which a product can be used by specified users to achieve precise goals with effectiveness, efficiency, and satisfaction in a specified context of use [13].

Additionally, multimedia capabilities will be introduced into services and terminals. Symbian is an open platform, founded by Nokia, Ericsson, Motorola, and Psion, allowing easy development of applications by third parties. Moreover, location-based services, may totally change the way people, communicate, plan, and carry out their tasks while moving around.

At this point, better interaction techniques need to be developed and a lot of research must be done to achieve better UIs for mobile terminals. Nevertheless, mobile AR systems can take advantage of mobile terminals. Indeed, the development of a good mobile augmented reality UI for mobile terminals could spread usage of augmented reality systems. However, the development of mobile AR in mobile terminals must be concerned with constraints applied to mobile terminals.

In some mobile ARs, the interface can be one or more objects on the scene. Thus, a user can take advantage of augmented information unobtrusively. Pulli et al. [14] developed MARISIL, which stands for Mobile Augmented Reality Interface Sign Interpretation Language. MARISIL is an interface for a mobile device that combines Augmented Reality, table-based interface and sign language. As a result, instead of having real input devices with form and shape, MARISIL is a Virtual or computer generated interface.

This interface can adapt itself to user habits and needs, and it can also expand or contract itself based on the users' level and desires. In addition, MARISIL interface allow users to see their hands has a panel, using augmented reality techniques to overlaying interface in their hands. So, the user hands are used as keyboard, panel, display and pointer, and hand language will be interpreted by device allowing users not to carry any special plate or pen to have the panel or pointer.

4.2.f) Collaborative Interfaces

Collaborative Supported Computer Work requires special interfaces, to accomplish a good collaboration between users. Butzs et al. [15] developed a prototype experimental user interface for a collaborative augmented environment, EMMIE (Environment Management for Multi-User Information Environments). EMMIE's main goal is to create an environment where information in 3D augmented reality and conventional 2D devices could be complemented and easily moved between devices, also called hybrid interaction.

Furthermore, EMMIE is able to handle user's privacy with privacy lamps and vampire mirrors.When used, privacy lamps can light objects the user allows others to see. Similarly, objects in front of a vampire mirror can be hidden or show to other users.

Fuhrmann et al. [16], proposed a system that allows multiple collaborating users to simultaneously study tree dimensional scientific visualizations in a "study room" - Studierstube. Studierstube is an augmented reality system that allows true stereoscopy, 3D-interaction, individual viewpoints and customized views for multiple users, free natural collaboration and low cost. Moreover, Studierstube is controlled with a Personal Interface Panel (PIP). Indeed, PIP allows intuitive 3D manipulation and input of numerical data and commands.

MAGIC (Mobile Augmented Group Interaction in Context) project was developed by Renevier et al. [17] and supports archaeologists while in the field. MAGIC allows archaeologists to: take notes, and perform object sketches and photograph local scenes, therefore enhancing available information about work field. The user interface is based in the Clover Model [18], which partitions the features of groupware applications into functions supporting: Coordination, Communication and Production.

First, coordination between users is based in an archaeology exploration map, displayed in a dedicated window. This map is the common interaction place, representing an archaeology field: local topology, found objects and archaeologist location. Magic lenses are used to obtain detailed information. Next, communication is done through three tools: a post-it application, a chat room and another tool to store pictures and adding notes to the pictures. Finally, production allows the description of objects, through a form, and their analysis, through a pen computer and HMD. Thus, information can be seen based on user location providing an augmented stroll.

4.2.g) Mobile adaptive Interfaces

Another system showed a tourist guide, named GUIDE [19], where a city visitor can have dynamic and context-sensitive multimedia information while walking around. GUIDE is based in a distributed cell architecture where each cell has the responsibility to broadcast information related to its region. In fact, a network based architecture, like GUIDE, permits flexibility, supplies context-sensitive information, supports dynamic information and interactive services; compared to a standalone system where content and related actions cannot change while in use.

GUIDE communications were developed accounting the following issues:

- flexibility,
- fast response times,
- services flexibility,
- support for unconnected operations, and
- minimum energy use.

This intelligent visitor guide allows a visitor to use it has he or she wishes. It can be used as a search engine, guided tour, or just giving guidelines about some spots. Moreover, visitor's personal and environment context are also accounted.

Höllerer et al. [20], describes an interface that adapts itself according to changes in tracking accuracy. The interface employs different technologies to locate users, resulting in various position accuracies. Namely:

- Indoor, a ceiling-mounted ultrasonic tracker covering a portion of indoor lab is used,
- Outdoors, a real-time kinematic GPS handles tracking, and
- In areas where neither of the previous systems work a dead-reckoning approach is used.

Indeed, dead reckoning combines a pedometer and an orientation tracker with environmental knowledge expressed in spatial maps and accessibility graphs. An adaptive interface is designed as a navigational assistant, helping users to familiarize themselves in unknown environments. In addition, inference and path-planning components use environment knowledge to guide users to chosen targets.

Furthermore, dead-reckoning approach uses the pedometer information from the dead-reckoning module to determine when a user walks. However, the system uses orientation information from a precise orientation tracker, instead of the built-in magnetometer from the dead-reckoning module. Afterwards, this information is used to verify, in the spatial map, if the user crossed an impenetrable frontier.

Depending on the tracking accuracy two user interfaces had been developed. So, when the user is accurately tracked, the system overlays a wire frame model consisting of lab's walls and ceiling, doors, static objects of interest, and rooms in the immediate neighbourhood. However, when a user can not be tracked another user interface is used, also leveraging a relatively superior orientation. Indeed, a World in Miniature (WIM), which is a scaled-down 3D model of the environment, hovers in front of the user, moving with him or her as he or she walks.

In another project, Rakkolainen et al. [21] developed a web-based 3D city info connected to a database. In this project, the results showed that search and visualization of location-based information of a city becomes more intuitive with 3D objects. Therefore, a 3D model of the environment is presented to the user guiding him or her through the space.

4.2.h) Audio Interfaces

Augmented reality can be done not just by adding visual information to environment but also by adding audio information. Bederson [22], developed an automated tour guide, superimposing audio on the world, based on visitor location. Thus, visitors can choose their own way, and, when passing near some pieces, visitors can ear its description; accordingly leaving a piece will shorten description. Friends can stay in sync just by viewing the same pieces at the same time. In addition, most seen pieces can be enriched with more information, based on visitors history.

In maintenance scenarios, augmented reality can be of great help. Behringer et al. [23] developed a system that overlay 3D objects, animations and text notes over a known object, where system main goal is to supply "x-ray vision" into real objects in the field of view. So, device components can be queried using a voice recognition system and an animation of the component and/or 3D spatialized audio cues will be overlaid. Indeed, spoken notes can be left in device components for other users to retrieve. Therefore, a vision tracking system is used to track user / camera position relative to device, using a distributed network of PC's with off-the-shelf components.

Table 4-1 performs an overview of all the projects reviewed in this chapter.

Table 4-1 - Overview of discussed interfaces

Augmented reality through coordinated use of diverse interfaces	Seven different interfaces, using fixed and mobile terminals, a combination of PDA and GPS device, a portable tripod-mounted display (Augurscope) and projection of virtual shadows and ambient sound to create an abstract channel between real and virtual worlds.
MARS (Mobile Augmented Reality System)	Interfaces allowing users to manipulate information that is registered in the real world, using: - See-through and hear-through display tracked with a real-time-kinematic GPS, an inertial/magnetometer orientation sensor and a backpack computer, while outdoors; - A hand-held device providing a map UI, also while outdoor; - A desktop or projector display UI that allow to create and highlight virtual objects and annotate real objects for outdoor users, while indoor; and - An indoor immersive UI that allow to manipulate information on and over a physical desk.
Claymore	Introduces a method to manipulate a three dimensional object without considering three independent orthogonal views using "augmented manipulation".
Tangible interfaces	Illustrate the role that physical objects play in supporting thinking and discusses the roles that physical objects can play in augmented reality systems
Tangible Bits	Attempts to turn digital information from cyberspace into tangible media in physical world. It also introduces three design projects: metaDESK, transBOARD and ambientROOM.

MixDesign	Allows an architect to intuitively interact with a real scale model of the design, in normal working settings, and using intuitive tangible interfaces, where he can observe an enhanced version of the scale model, with 3D virtual objects registered to the real ones.
Model-Based design of mobile user interfaces	Uses a presentation structure that can be selected to adjust interface to a particular device, with an intelligent mediator. It also uses a task model to optimize user interface when context of use changes.
MARISIL	An interface to mobile device that combines real input devices augmented reality, table-based interface and sign language.
EMMIE (Environment Management for Multi-User Information)	Create an environment where information in 3D augmented reality and conventional 2D devices could be complemented and easily moved between devices.
Collaborative visualization in augmented reality	Proposed a system that allows multiple users to simultaneously study tree dimensional scientific visualizations in a "study room" – Studierstube. Studierstube is controlled in a Personal Interface Panel (PIP)
MAGIC (Mobile Augmented Group Interaction in Context)	Supports work field by archaeologists: taking notes, object sketches and photography's from the local. Using the Clover Model, MAGIC has an archaeology exploration map, using magic lenses for detailed information, a post-it application, a chat room and another tool to store pictures and notes, and can describe objects through a form, and analyze them with an head-mounted display and pen computer.
GUIDE	Allows a city visitor to have dynamic and context sensitive multimedia information while walking.
Steps toward accommodating variable position tracking accuracy in a mobile AR	Describes an interface that adapts its user interface accordingly to changes in tracking accuracy. When user is accurately tracked a wire frame model consisting of lab's walls and ceiling, doors, static objects of interest, and rooms in the immediate neighborhood, otherwise a World in Miniature hovers in front of the user, moving with him as she or he walks.
3D city info for mobile users	A Web-based 3D city info connected to a database. Settle in the idea that location-based information can be easily understood while in 3D.
Audio augmented reality: a prototype augmented tour guide	An automated tour guided, superimposing audio on the world based on visitor's location.
A distributed device diagnostics system utilizing augmented reality and 3D audio	Developed a system that overlay 3D objects, animations and text notes over a known object. Additionally, It also queries device components using a voice recognition system, and an animation and/or 3D spatialized audio cues will be overlaid.

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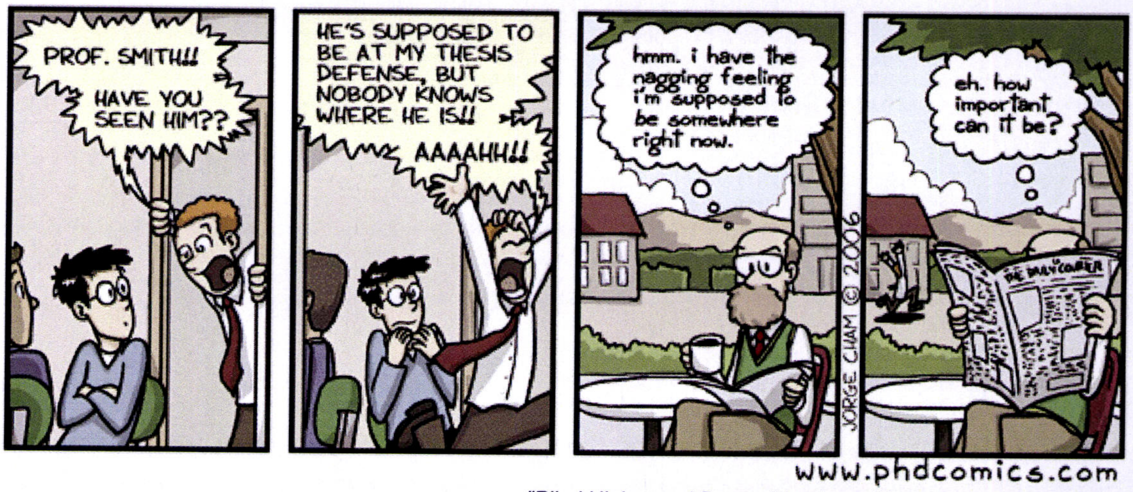


"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

5. Bluetooth Positioning

Abstract

This chapter presents an experimental evaluation of a server-side Bluetooth positioning system, named BPoSS. The system is able to track the user in three dimensions, (x, y, floor), and is independent of the Bluetooth access points being used. This ability allows for scalability and enables usage of any existing Bluetooth network topology. In areas with no Bluetooth coverage, BPoSS assumes the last known position is the location closer to the user's current position.

The distance of the user to an access point is calculated measuring the Received Signal Strength Indicator (RSSI) and using an estimate of related distance or, alternatively, using pre-calculated values. User's position is then determined using triangulation. Indeed, proximity or triangulation methods are used based in the user's request. That allows BPoSS to provide geometric and symbolic information.

5.1. Introduction

With the increasing popularity of mobile computing devices, position based services become more significant, raising the spectrum of new application possibilities able to take advantage of user's mobility. The Global Positioning system (GPS) and several methods in Cellular Networks, such as Cell-ID, and TDOA (see chapter three for details), are being used to track users. While these technologies can be suitable for some applications, indoor, the accuracy provided can be insufficient. Thus, wireless network technologies available worldwide, such as Bluetooth, can also be used to track users indoor with finer granularity.

Bluetooth has problems when used for tracking purposes, namely interferences and signal reflection, but its worldwide availability and low power consumption can be considered strengths in some tracking scenarios. Bluetooth was developed as a cable replacement technology, with promising features, such as: low power, short range, and the ability to be used in the creation of several wireless services. This technology operates in the 2.4 GHz-2.483 GHz band, known has the Industrial Scientific and Medical (ISM) band, available in the majority of countries, making Bluetooth available worldwide.

Bluetooth Core Specification v1.1 does not specify any positioning service [2]. Nonetheless, Bluetooth Local Positioning Work Group is developing a Local Positioning (LP) Profile Specification in order to define a mechanism and formats for the transfer of position-related data over Bluetooth. This profile will allow for interoperability between Bluetooth-enabled devices supporting the LP profile.

Generally, to connect two Bluetooth devices, the client should [3]:

- Perform device discovery to find devices in the area (Inquiry);
- Perform service discovery to get information on how to connect to services on each device discovered;
- Choose a service to use, and use information obtained during service discovery to connect to it.

First, to inquire devices in range, the inquiring device (IQD) sends a series of inquiry packets in different frequencies. Afterwards, the IQD changes frequency 3200 times per second, allowing it to cover a wide range of frequencies as rapidly as possible.

On the other end, the inquiry scanning device (IQSD) changes frequency every 1.28 seconds in order to minimize interference, and to have a good strategy to be found by inquiring devices. When the IQSD receives an inquiry it waits a random short period of time, then if it receives a second inquiry, it sends a Frequency Hop Synchronization (FHS) packet, which tells the IQD all relevant information needed to establish a connection. This scheme avoids a high-power coordinated pulse of radiation in the ISM band, if a synchronized answer occurred.

An average inquiry process can take 3-5 seconds average and can take up to 10.24-30.72 seconds. In addition, to connect devices, they must be in page and page scan mode, respectively. The paging device, in page mode, initiates the connection and the page scanning device, in page scan mode, responds. The described process takes 1.28 seconds in average and can take up to 2.56 seconds.

In total, a connection between two Bluetooth devices takes 4.28-6.28 seconds average and can take up to 12.8-33.28 seconds. The resulting connection times can be affected by other technologies also operating in the unlicensed ISM band. This fact results in interferences between them and inevitably decreased throughput, longer connection times, and less frequencies available. As an example, a list of some of the technologies that can interfere with Bluetooth is shown bellow:

- IEEE 802.11b and g,
- Home RF,
- some Digital Cordless Communications (DECT) variants, and
- some handheld short-range two-way radio sets.

Additionally, there are problems with signal fading due to distance and blockers. Blockage is due to the water content of each object, the more water an object has, the more blocking effect the object will have.

Unintentional interferences from other sources can also be found, such as:

- microwave ovens,
- high-power sodium lights,
- thunderstorms,
- overhead cables,
- communication channels in other bands – e.g. GSM, and
- spark generators such as poorly suppressed engines.

Despite all that, Bluetooth uses a frequency-hopping scheme, named Frequency Hopping Spread Spectrum (FHSS) to minimize interference. The FHSS is able to hop between 1 MHz channel spaces with a strong central peak. Using the range between 2.4 GHz and 2.83 GHz, Bluetooth uses 79 distinct channels to hop.

With technologies such as the family of IEEE 802.11 standards and the unintentional interferences named previously, the ISM band can be crowded in many situations. Even, when several near Bluetooth devices are performing an inquiry operation, interference between them increase the time needed for the operation to complete. Thus, the IQD is using the maximum possible range of frequencies in the Inquiry process to surpass the problem.

Bluetooth discovery can be used, to implement a location system. However, the process of discovering Bluetooth devices can flood the ISM band. When several neighbour devices try to discover others in a close range, interference can deteriorate results. If discovery could take place only in the infrastructure, problems with radio signals, namely interference and reflection, can be predicted and solutions can be found to overcome them.

Therefore, BPoSS is a Bluetooth positioning system developed server-side. The number of inquiring devices is known, minimizing radio usage. In addition, BPoSS can track any Bluetooth device, in discoverable mode; the BPoSS location Engine is independent of the Bluetooth AP being used and, BPoSS is able to track users with a geometric or symbolic model.

In the next section related work is presented and all aspects that encourage this project are pointed out. Afterwards, a new section gives an overview of the entire system and describes each component of the system. The following section describes measurements performed to describe radio behaviour. Finally, conclusions and future work are presented.

5.2. Related Work

Research on how to track users with Bluetooth technology is in its infancy. There are several research efforts using Bluetooth for positioning purposes with alternative conclusions.

Hallberg et al. [4] developed a positioning system where a client requests for a positioning service in all neighbouring devices, and then requests for their positions. Next, triangulation is performed using a defined cell size. In this work, Hallberg et al. assume an unreliable relation between signal strength and distance, and use a fixed value to perform triangulation.

Another work by Feldmann et al. [5], consists in the development of a Bluetooth positioning system based in the relation between RSSI and the associated distance between sender and receiver. The distance is modelled with an empirical model to overcome fading, shadowing, reflections and blocking problems of the radio signal. The client measures RSSI values between itself and three access points. Afterwards, triangulation is used to estimate the related position.

Similarly, Kotanen et al. [9] have developed a system that translates RSSI values into received (RX) power level, and models the correlation between distance and RX power level. Due to the noisy measurements of radio signals, Kotanen also uses an Extended Kalman Filter to reduce the median measurement errors.

A different approach can be found in Yoneyama et al. [6] work, where a symbolic model is used to track users at room level. The overall system relies in a database to track users and a Webserver to retrieve information related to a specific context.

Kindberg et al. [7], from the HP Cooltown project, developed the sense of Web presence. In this project, Bluetooth and IrDA is used to beam URLs to user's nearby, allowing them to retrieve additional information about their location. Thus, a bridge between the real world and World Wide Web is built. Commercial systems are also using Bluetooth to track users, namely Blis4Platform, a commercial server side-system [8].

5.3. System Description

BPoSS is a server-side Bluetooth positioning system with four independent but inter-dependent modules. These modules are:

- BPoSStub,
- BPoSSEngine,
- BPoSSClient and,
- BPoSSConfiguration3D.

Figure 5-1 describes the system architecture.

In a brief overview of each module function, we have the BPoSSEngine as the main module. BPoSSEngine is responsible for tracking Bluetooth devices and perform further calculations when required by location-aware applications. Next, BPoSStub is responsible for Bluetooth sensors specific details.

The BPoSStub module is platform and access point dependent. Thus, the development of different BPoSStubs for different Bluetooth networks allows the system to grow independently of the specific features in each one, and gives the chance to use already deployed Bluetooth networks. Accordingly, this module must be developed to manage all access points in the network.

The BPoSSConfiguration3D collects all information needed to start the system and stores it in a database. In addition, BPoSSConfiguration3D provides a friendly interface to calibrate the system and an overview of system coverage. Finally, the BPoSSClient describes the Bluetooth devices carried by each user to interact with the system.

In the next subsections, every BPoSS module is described in more detail.

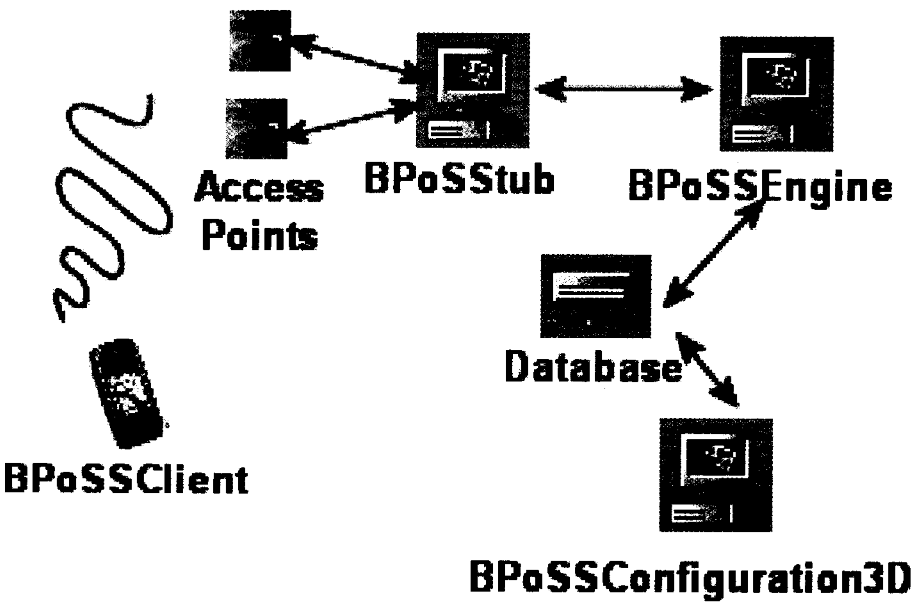


Figure 5-1 - System Architecture

5.3.a) BPoSStub

This module was developed to execute Bluetooth operations in each Bluetooth Access Point (BTAP) issued from the BPoSSEngine. Since there are different implementations of the Bluetooth Stack and different platforms where BTAPs can work, this approach gives a transparent interface to transfer data between BTAP and the BPoSSEngine module. Consequently, a different BPoSStub has to be developed for each platform used.

For that matter, a set of messages was specified, in order to allow the development of additional BPoSStubs. Moreover, all messages between each BPoSStub and the BPoSSEngine are exchanged using a TCP connection. Indeed, three different Bluetooth platforms were tested and surveyed for this system.

Firstly, Tadlys' Bluetooth Infrastructure was tested and surveyed. The tested system was an initial version of the Infrastructure. In this version, the Bluetooth Infrastructure was a self-contained platform accessed trough a TCP connection with a predefined set of messages. The tested API didn't allow for RSSI or RX power level measurements. Nevertheless, a predefined value was used for location estimation purposes.

Therefore, the cell size was estimated to have 10 meters radius, since the majority of everyday Bluetooth devices have class 2 antennas with 2.5 mW and an approximate range of 10 meters. The value was then used for triangulation purposes. Indeed, the system wasn't easily scalable since each server could only attach up to 16 Bluetooth nodes through a serial connection to a PC. Consequently, for larger areas, several PCs need to be used to enlarge coverage area. However, the Tadlys Bluetooth system was easily adapted to this architecture despite its limited accuracy.

Another disadvantage detected in Tadlys system was the usage of cumbersome serial cables. Afterwards, Tadlys created an indoor location solution, named TOPAZ. TOPAZ uses Bluetooth access points, enhanced by IR to track objects of interest. Moreover, in TOPAZ, each Bluetooth server can be extended up to 32 Bluetooth nodes. Nevertheless, the evolution wasn't tested.

Secondly, BPoSStub module was implemented using Bluetooth dongles and an ESDK from Open Interface to access all operations in the Bluetooth Stack. The ESDK from Open Interface is a C library that can be used in Linux or Windows environments. The library enabled us to measure RSSI values using USB/Bluetooth dongles. Indeed, a good set of operations is implemented in the library, resembling the Bluetooth Core Specification 1.1.

This makes comprehension of the library easy, given that, full comprehension of the Bluetooth Core Specification 1.1 is attained. However, the version tested used class 2 USB/Bluetooth dongles, thus it wasn't possible to control antennas' RX power level range. Furthermore, as well as Tadlys, Open Interface ESDK evolved and now also supports Bluetooth Core Specification 2.0.

In fact, usage of Bluetooth nodes supporting Bluetooth Core Specification 2.0 can further improve performance of the system. In version 2.0 of the core, it is possible to perform RSSI measurements during inquiry process, opposed to version 1.1 where it is necessary to perform inquiry and afterwards perform a connection to the device to be able to measure RSSI values. The new version wasn't tested. However, this new version requires usage of Bluetooth dongles supporting core 2.0 and the improvement will be in enhanced performance, less latency, rather then enhanced accuracy results.

The last Bluetooth Infrastructure used for test purposes was BlipNet from BlipSystems. The BlipNet architecture is based in three main components: BlipServer, BlipManager, and BlipNodes. The BlipServer configures, monitors and controls the BlipNodes in the BlipNet. It also provides a rich Java API which makes it possible for third party developers to interface with the BlipNet and create custom applications.

Next, the BlipManager allows administrators to configure and monitor the complete BlipNet. BlipManager is a graphical user interface for BlipNet and it can be applied on any java compatible platform. Finally, the BlipNode is a point-to-multipoint access point with full Bluetooth performance supporting a large number of profiles, allowing the development of different applications.

Scalability is another strong point in BlipNet. The system can be scaled through various forms. The basic form is to scale BlipNet through the connection of newer BlipNodes into the current Ethernet network. It is also possible to have a wireless network across BlipNodes, requiring a power cable, or use "power on LAN".

Custom applications within BlipNet System are developed through the BlipNet API, a Java library offering all the easiness of Java tools. The API hides all the complex tasks of Bluetooth Core Specification, not compromising functionality. Therefore, BlipNet API was the easiest API to use, also supplying the required functionality. Afterwards, an alpha version of BlipNet API, supporting Bluetooth Core Specification 2.0, was tested with a considerable increase in performance.

BlipNet API was the easiest API to use. However, only a full implementation for the Open Interface API supporting Bluetooth Core Specification 1.1 was performed. Consequently, the tests were performed with Open Interface API. However and also to reinforce independence of the BPoSStub from the other modules, any Bluetooth device and API could be used if a suitable stub was developed.

Following a general description of the functionality for BPoSStub is presented. The BPoSStub module receives requests from the BPoSSEngine to discover neighbour Bluetooth devices and reports the results to the BPoSSEngine. When possible, BPoSStub creates an L2CAP connection to each discovered device, using PSM 1, i.e. a connection to the SDP database, to measure connection time and RSSI. An L2CAP_Ping operation could be used instead, but the API from Open Interface ESDK did not allow us to measure RSSI within this operation.

For each Bluetooth device found, the stub sends its address, discovery time, time to connect, and RSSI. When a connection to the L2CAP layer is not possible the BPoSStub module sends default values. Namely, the usage of default values intend to inform the BPoSSEngine that pre-calculated position measurements can be used as probable location of the target object.

5.3.b) BPoSSEngine

This module was developed to track all Bluetooth devices reported by each BPoSStub. The module is also the core of the system collecting and estimating devices positions. Initially, BPoSSEngine module collects all information from BPoSStubs and related BTAP, kept in a database.

This module is able to communicate with all BPoSStubs modules. It starts sending inquiries, at defined intervals, to all BTAP reported by the BPoSS modules, and waits for the corresponding reports. Afterwards, the reported information is collected and stored in an object related to the found device. The information collected from each Bluetooth device discovered and used for location estimation is described in figure 5-2.

The Bluetooth Core Specification v1.1 does not provide a way to directly measure signal strength. Nevertheless, RSSI can be used to establish a relation between signal strength and distance. In addition, it should be noted that the equation for radio signal propagation in free-fields is not suited for indoor usage due to signal fading, shadowing and reflections, as proved by Feldmann et al. [5].

Hence, to estimate user's position an empirical formula was calculated for each tested scenario. RSSI measures and related distances were read from different points at different distances. Afterwards, a function that best describes those measures was also calculated to estimate the distance to the BTAP. This procedure was used to best build the radio signal's model for different devices and in different places, so called calibration process.

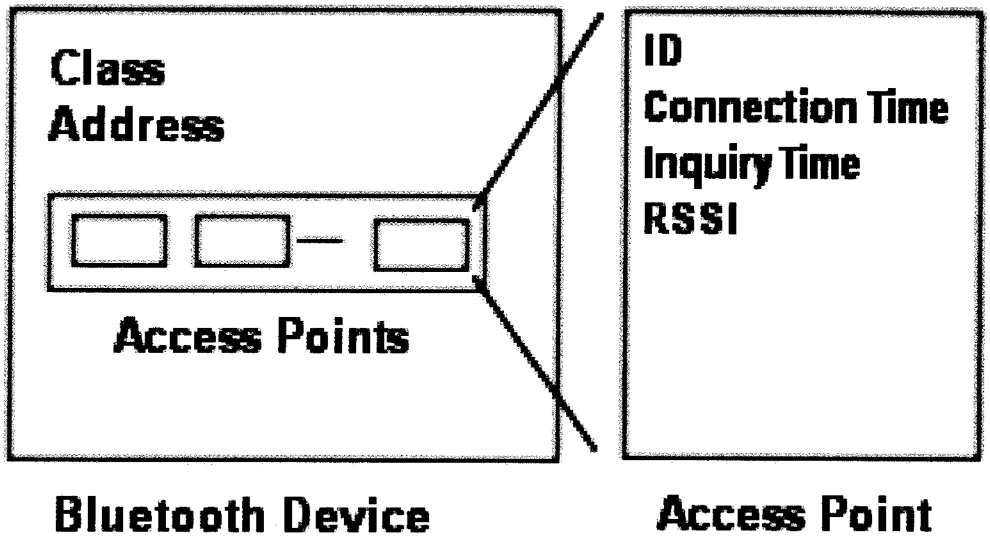


Figure 5-2 - Bluetooth Object Description

In this process, information from RSSI measurements for distinct sensors and at different distances was collected. Afterwards, a mix between pattern fingerprint and a global model was used since a different model is created for each sensor, best describing the radio signal propagation in the related location. Indeed, the collected information describes the sensor used, the environment and also the target device used in measurements.

From the values calculated in the measurements section, it was found that different devices have different radio signal propagation models, in different environments. However, a global model is used for simplicity. At the moment, no UI is available for calibration purposes. Nevertheless, in the future it is unveiled that a UI will be developed, allowing for location selection while in the calibration process.

Such interface can be used for device addition and selection, as well as location selection while in the calibration process. Afterwards, measurements are analysed and a polynomial equation with up to the six degrees is generated that best fits the measurements between BTAP and BPoSS clients. The polynomial equation is stored in the database for future use by the BPoSSEngine.

The time taken to discover a BPoSS client is also considered as a distance estimate. Thus, to estimate the Bluetooth device location, the BTAP that discovered the device at less time is chosen, and marked as the reference BTAP in the current calculation step. Afterwards, the BPoSSEngine checks if the range of all BTAP that discovered the device overlaps the range of the reference BTAP, discarding the BTAPs that do not overlap.

This is important, because a moving Bluetooth device can be discovered by several non-overlapped BTAP. In this case, there is not a common area where all BTAP range overlaps and, only the last overlapped area is chosen. Moreover, it allows the system to estimate the location of a Bluetooth device in movement.

Afterwards, RSSI values are considered and triangulation is performed using the empirical function to estimate distance to the related access point, and the triangulation method described in the Geometrical Algorithm of Bluetooth Local Positioning Profile [1] to estimate a position.

For floor estimation, the system assumes that the user is in the same floor as the BTAP with the strongest RSSI value. When the BPoSStub doesn't perform RSSI measurements, pre-calculated values are returned as the probable location of the target object. These values are calculated using the triangulation method with the cell size of each BTAP, entered in the database, by the BPoSSConfiguration3D module.

Besides the geometric model, it is possible to use symbolic location information in BPoSSEngine (Chapter 6 has further details about location models). The symbolic model is better suited for regular LBS where accuracy is not the main issue. In the database, all BTAP are identified with the corresponding ID, and additional information about a specific location can be delivered to the user, based in the ID.

Overlapping areas are returned as an ordered string with all found BTAP ID, thus they can be seen as distinct areas. Finally, all queries to the BPoSSEngine can be performed using a Web Service.

5.3.c) BPoSSClient

Any Bluetooth enabled device can be used as a client of BPoSS. This was one of the main goals while developing this architecture: the ability to track any mobile phone, PDA or other gadget with a Bluetooth antenna, therefore increasing possible usages.

To minimize interference, a GPRS connection can be used from the client to access the Web Service in BPoSSEngine module and retrieve its position. The usage of IEEE 802.11b or additional BTAP can also be an option when the number of devices to track is reduced and the interference level does not affect the expected results.

In the evaluated test scenarios, two cell phones were used, a SonyEricsson P800 and a Nokia 6310i. These devices were used to better exemplify the differences in Bluetooth devices. Both devices have a class 2 antenna, but their radio coverage range is different.

5.3.d) BPoSSConfiguration3D

This module was developed to allow an easy configuration of the BPoSS system. BPoSSConfiguration3D module is accessed using a regular Web Browser, therefore supplying a familiar interface to all users. Any user can easily manage the BPoSS system as seen in figure 5-3.

ASP.Net was the development tool used to create BPoSSConfiguration3D. This tool supplied a set of additional tools that fasten development and make interaction with the system easy, mainly resembling the interaction supplied by dedicated form applications. In addition, SQL Server was also used to store all information related to the information collected through BPoSSConfiguration3D.

BPoSSConfiguration3D requires the insertion of all BPoSStubs, registered with IP address, used port, and all BTAP working in the specified BPoSStubs, as well as cell radius. This step is performed in the Config System Page where all details can be inserted, as seen in figure 5-4.

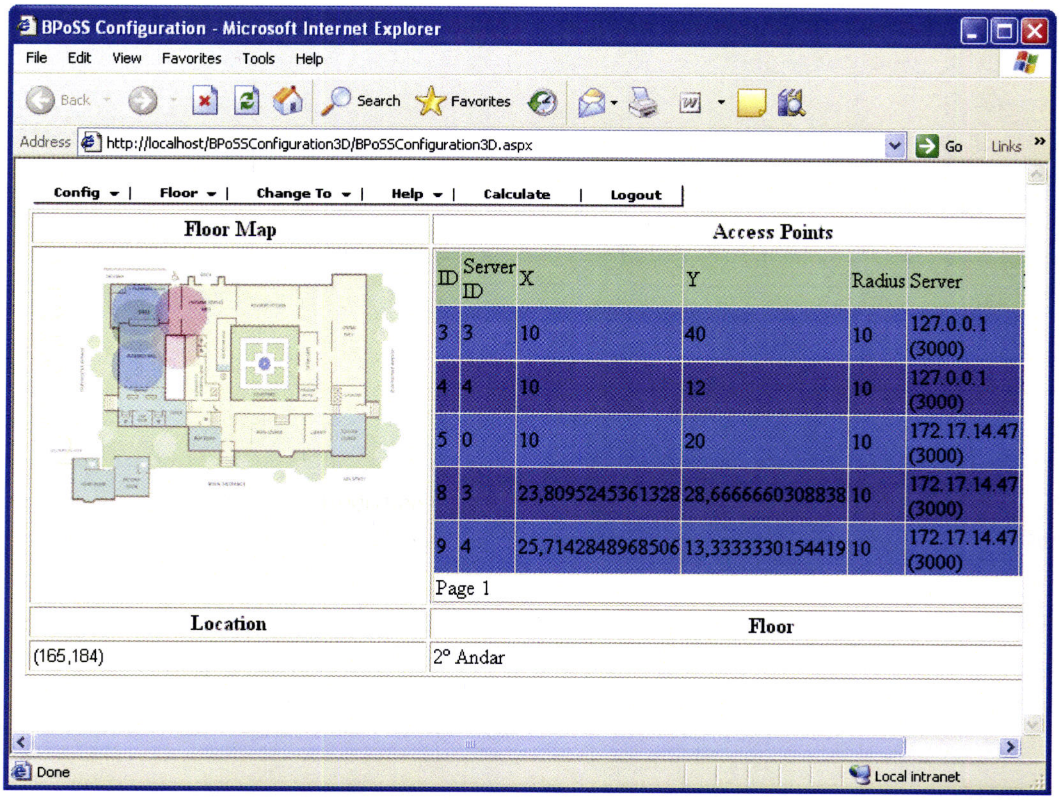


Figure 5-3 – BPoSSCofiguration 3D main control page

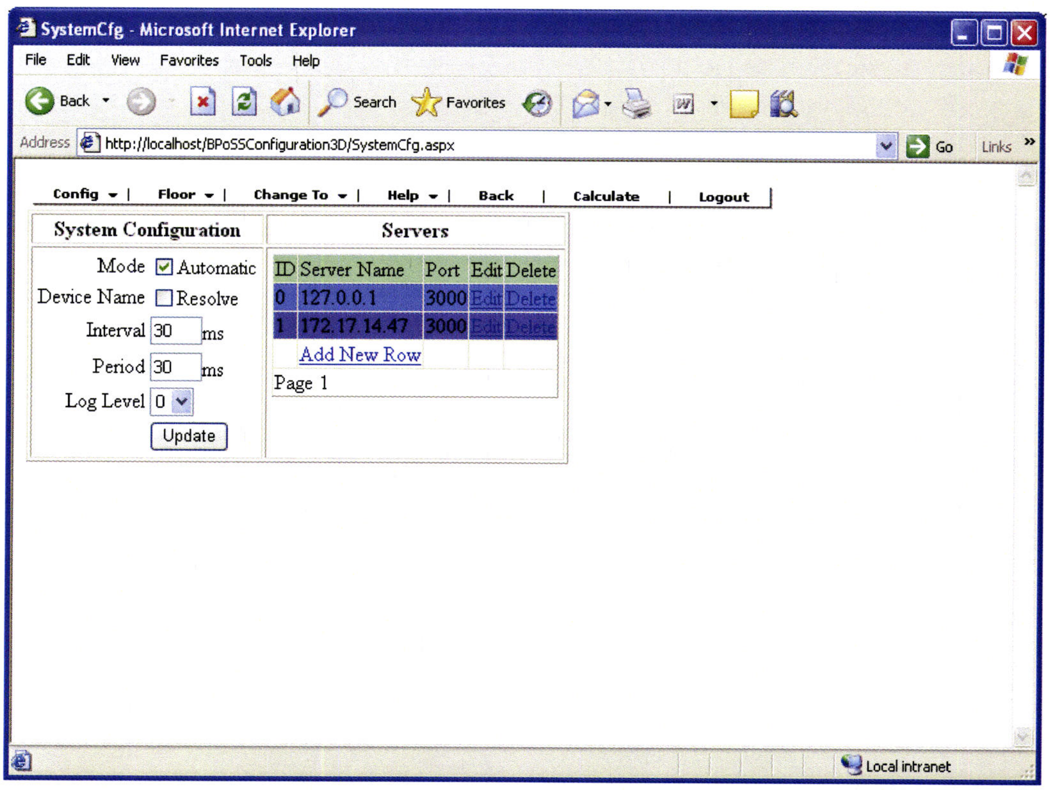


Figure 5-4 - Config System Page

The Config System Page allows the configuration of Interval and Period time. These global variables are valid across the entire system and relate to the synchronization of location data. Interval is the time for each search operation, while period is the time between subsequent inquiry requests.

In addition, only server name or IP address, and port number is needed to add a BPoSStub. It is then necessary to define a coordinate system for each floor, just by inserting two known points in the floor fingerprint. In addition, the floor fingerprint also needs to be uploaded to the BPoSSConfiguration3D. A sample image of the Floor Calibration Page is shown bellow in figure 5-5.

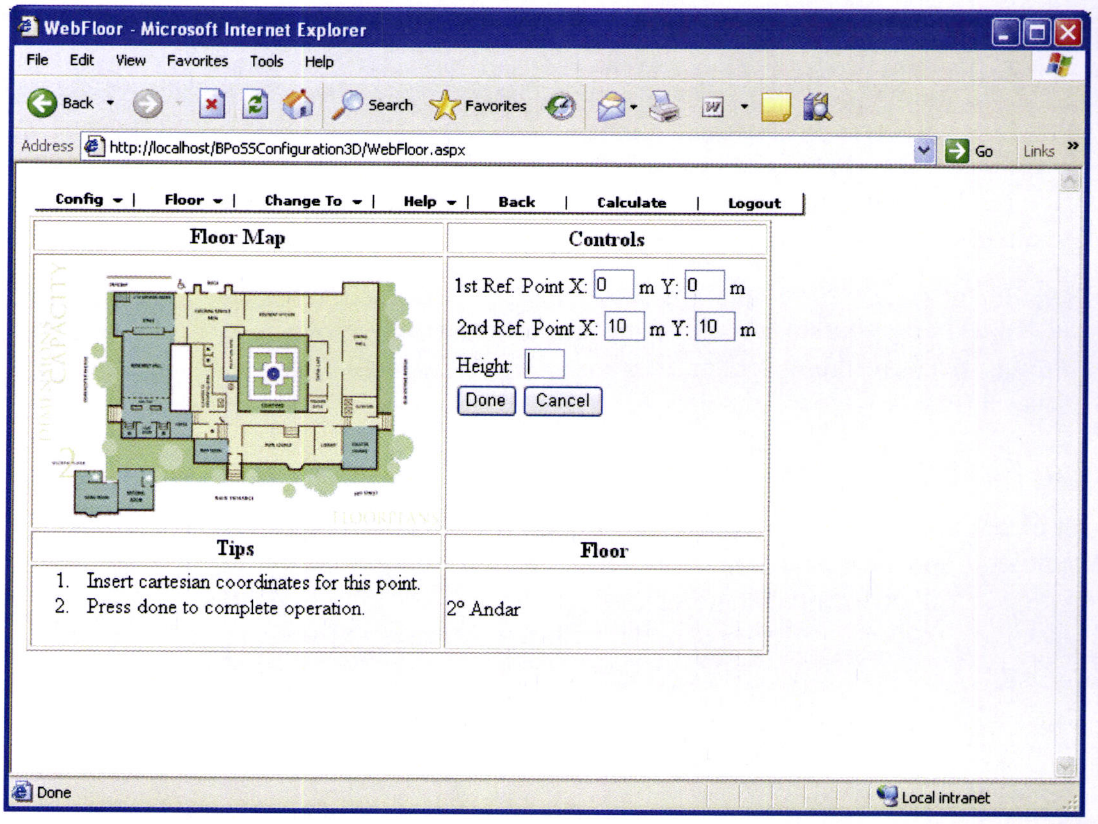


Figure 5-5 - Floor Calibration Page

Afterwards, the BPoSS administrator has to click on the floor fingerprint and add the associated BTAP. Automatically, its location is inserted in the database, and an overview of BTAP radio coverage is shown to the user. Later, the information related to each BTAP can be updated.

After collecting all information, BPoSSEngine creates a rough version of the location model. Without information from signal model propagation, knowing the position of all BTAP and calculating all mid points of overlapping areas, it is possible to provide better accuracy than just proximity. These calculations will then be used to speed up the process of position estimation when no RSSI measurements can be performed.

Therefore, when RSSI measurements are retrieved from the BPoSStub, BPoSSEngine module has to directly map the symbol calculated to the location of the target device. It is also up to the BPoSSConfiguration3D to build all possible symbols used by the BPoSSEngine for the symbolic model.

5.4. Measurements

BPoSS system was evaluated in two different scenarios. One scenario was a long corridor and the other was a room with 8,8m x 6,4m. In each scenario, several positions where chosen to retrieve radio signal measurements and related distances to each access point. The access points used were Class 2 Bluetooth dongles from Open Interface, each running in a different computer.

The clients were two cell phones, a Nokia 6310i and a SonyEricsson P800. These cell phones can be easily tracked since they can be inquired as long as the user is willing to be tracked by the system. Nonetheless, there are cell phones with Bluetooth capabilities that are difficult to track, such as Ericsson T68i, since they can only be discoverable in a limited range of time.

Furthermore, a good set of parameters to estimate distance was studied, namely RSSI, Bit error and L2CAP connection time to the SDP database. The parameter evaluated was the L2CAP_Ping operation. During this operation, it is possible to send a set of data to the client device and check for the number of errors.

However, the API used simply discarded the sent data. Therefore, this parameter was discarded. Afterwards, an L2CAP connection to the SDP database was performed and the time to perform the operation was measured. With both client devices, the L2CAP connection time to the SDP database did not reflect a relation with the related distance.

5.4.a) First Scenario

A set of tests was performed between 10 centimeters to 150 centimeters with steps of 10 centimeters, and between 2 meters and 18 meters with steps of 1 meter, in the first scenario. In all different distances, the values ranged from milliseconds, mainly 360 milliseconds, to almost 2 seconds in the majority of cases. Thus, this parameter was also discarded.

The bit error parameter wasn't tested since the API used did not support the operation. Therefore only the RSSI parameter was considered. Nonetheless, RSSI are not possible in some Bluetooth networks. Moreover, signal propagation can change with different weather conditions as well as with furniture changes in the environment.

Hence, due to fading, shadowing, reflections and blocking problems of the radio signal, for each test scenario, different signal propagation models should be evaluated to best fit the environment conditions. Moreover, tests shown that different Bluetooth devices returned different RSSI values, even at the same distance to the access point. It should also be stated that, for each new location in the grid defined for the related scenario, tests were ran for 5 minutes and measurements with no RSSI values were discarded.

Using the same grid distance and scenario as described for L2CAP connection time measurements, the RSSI values where collected and a model was generated based on all observations of both client devices. This approach is simpler, but a more accurate approach can be achieved using different models for each client device.

Indeed, with SonyEricsson P800 the RSSI measurements were best modelled with a polynomial function of order 6 with R^2 = 0,7744 and in the Nokia 6310i the RSSI measurements were best modelled with a polynomial function of order 6 with R^2 = 0,8106. When a global model is used with the values collected from both devices, a polynomial function of order 6 and R^2=6424 is the best function to model signal propagation, as seen on figure 5-6.

When there is a direct LOS from the BTAP until the target object, a good relation exists between RSSI measurements and related distance. In addition, the corridor where the tests were performed had reduced Wifi coverage, reducing interference, and only one sensor was used to model the environment. In this scenario, it was also possible to estimate distance of each device up to 18 meters.

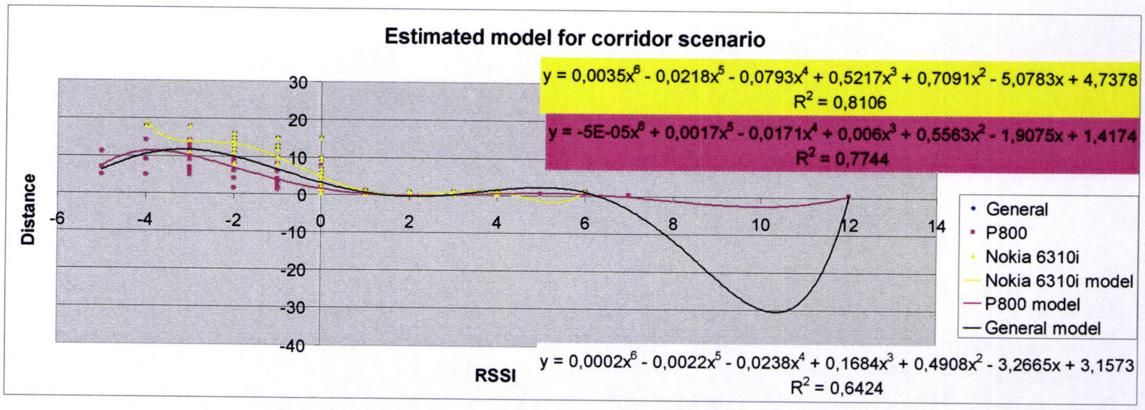
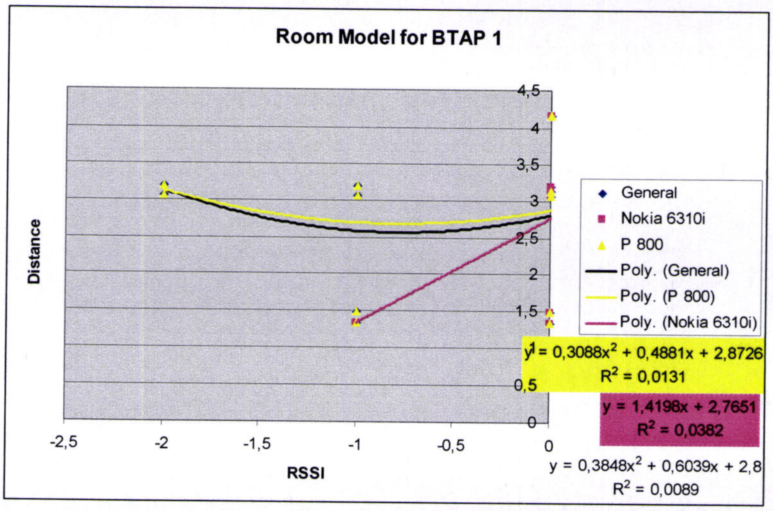


Figure 5-6 - Model used to estimate distance in the first test scenario

5.4.b) Second Scenario

The same test was performed in a second scenario with several devices using the ISM band, namely a WiFi wireless network, and furniture blocking the Bluetooth signal. Radio range was up to 18 meters, therefore all BTAP were flooding the radio spectrum during the inquiry process. The results were severally decreased as seen in figure 5-7.



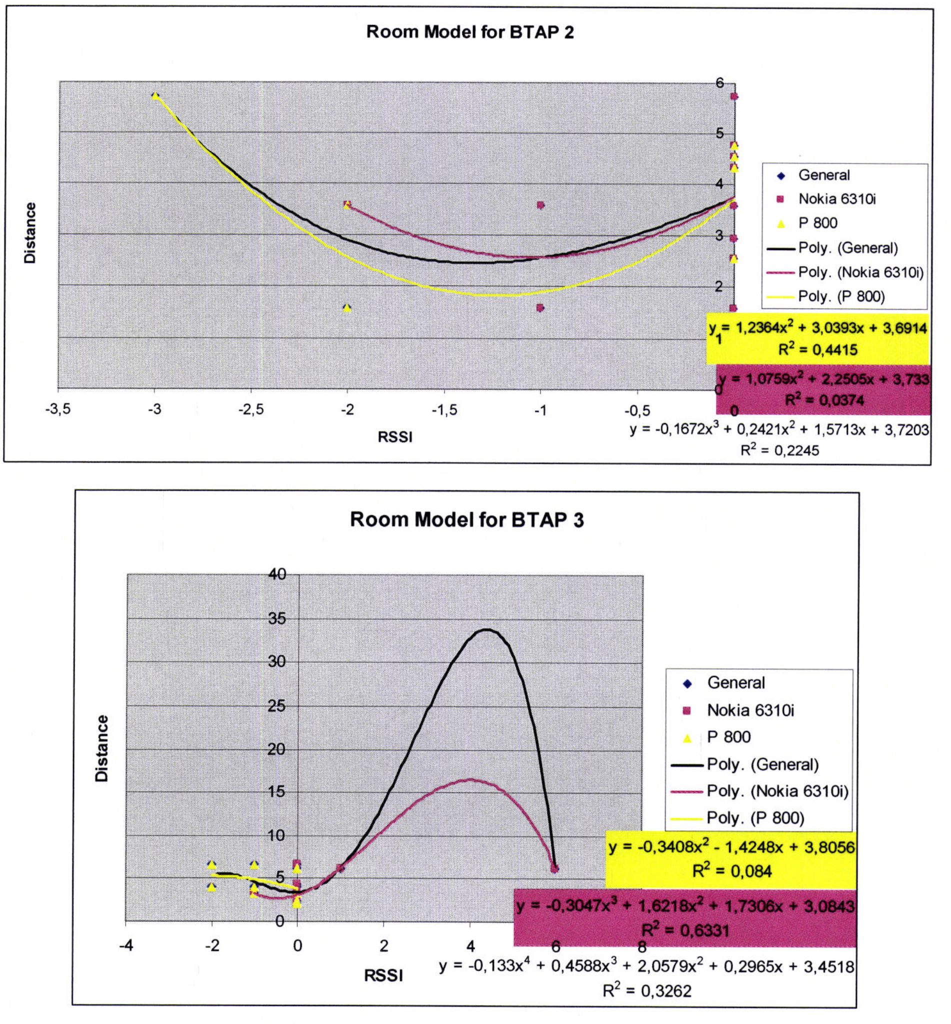


Figure 5-7 - Model used to estimate position in the second test scenario

In the second scenario, a symbolic model is a better option since the accuracy is reduced, due to interference and signal fading, shadowing and blockage. In the worst-case scenario, accuracy is up to cell size, in these tests up to 18 meters. Another problem in the second scenario was that BT devices may need more time to be discovered by all BTAP in range, or may not be discovered at all reducing accuracy.

The positioning error will reflect the topology of the network and the level of interference. Overlapped cells will improve accuracy; as long as neighbour BTAP cannot discover each other. However, interference level reduces efficiency of the system when several BTAP overlap. So a good compromise should be taken.

5.5. Conclusions

In this chapter, a server-side Bluetooth Positioning System was described and evaluated. This system allows the user to navigate with 3 degrees of freedom (3DOF), namely x, y and floor coordinates. Several parameters and problems of a Bluetooth positioning system were considered and compared. Thus, this work improves the process of building a Bluetooth positioning system, allowing the designer to use and consider the appropriate approach.

In performed tests, L2CAP connection time to a Bluetooth device has not supplied a good relation with the distance and bit error could not be used. However, RSSI measurements were evaluated showing that RSSI can be used to provide a distance estimation of the Bluetooth device to the BTAP. To improve accuracy different models for each Bluetooth device should be used and considered. The usage of a general model can also be a solution, although accuracy will decrease.

Apart from the geometric model, symbolic information can also be provided by BPoSS. Indeed, when just the symbolic model is used the effort needed to develop new LBS is reduced. BPoSS can also grow has needed and can use already deployed Bluetooth networks. In the future, work will be undertaken to improve accuracy and use different models for different devices.

5.6. References

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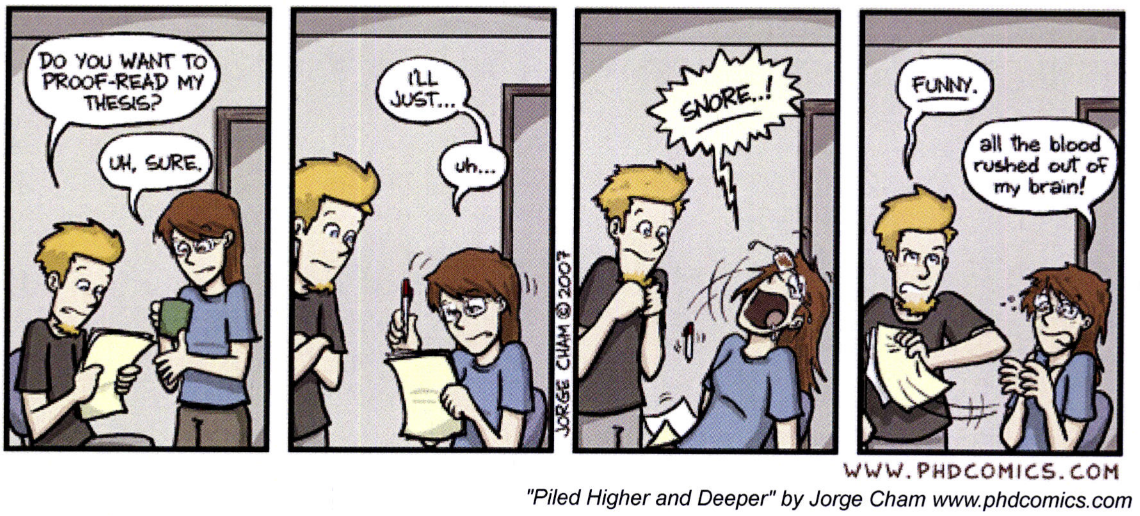


"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

6. Location Infrastructure

Abstract

A myriad of tracking sensors can be used in the environment to track persons and mobile devices. Further research is needed in how to combine all the information from different sensor types, in order to provide a more accurate and precise position of the element being tracked. Different tracking sensor types can supply different information about the elements being tracked, with different accuracy levels and at different time intervals. In addition, several applications can be developed to use location-aware information with specific needs. Applications can require different accuracy, different tracking information, whether symbolic or geometric information, in real-time or by request. This chapter explores and identifies the modules in a common framework able to seamlessly integrate additional sensor location technologies, location-aware services and applications. The framework should adapt itself to supply location information based in the requirements of each application using the system.

6.1. Introduction

Location data is becoming the propeller of new services and applications, but there is a lack for a common framework to build and develop new tracking systems and applications in order to independently use the myriad of existing technologies and location information formats. Therefore, several projects have been proposed and developed to overcome the lack of such framework.

In [8] a fusion algorithm, based on a formally defined location model, was purposed and implemented with performance limitations and problems dealing with asynchronous events generated by different sensors. In [10] an implementation of a Location Stack was also performed, resulting in a publicly available Java package containing a complete framework for operating with a multi-sensor location system in ubiquitous environments.

From the lack of a common framework, several efforts emerged to define a common format to express location information, as shown in [9]. However, these efforts were directed to more specific problems, often lacking a more conceptual and general way of expressing locations and limiting the usage of the same information by applications requesting for slightly different parameters. Indeed, location is an important source of context for context-aware or context-adaptive applications, as can be seen in [11], and [12].

Location information can be modelled, implicitly or explicitly, meaning that the location model can be stored in the application, or in a specific service, allowing the application to query the model data [13]. Implicit models can take advantage of the specific application knowledge and achieve better performances; however explicit models offer a more general approach enabling the model to be used by different applications.

Another interesting aspect in modelling location information is the ontology to be used. The decision on how to model location information is important. If possible, a common mean to represent location information between different models would be useful. However, this assumption can't always be possible and the system needs a way to convert between different location representations.

In order to provide applications with location information aimed for its specific functions, the location system may need to handle location data in geometric or symbolic form. Therefore, hybrid location models can handle queries such as "How far is the next bus station?", as well as queries like "Is there a printer in this room?". In the first query, geometric information is requested, and, in the second case, a query for containment can be issued to a symbolic model.

Moreover, privacy and security questions also need to be addressed. Location information is of great value and can be misused. When all the sensors used can be controlled in the client side, users can have a better control of privacy issues. However, given the myriad of sensors used it is difficult to control all in the client side. Thus, authentication procedures can be used in order to access and use location information retrieved from trusted third parties, resembling the X.509 certificates used in SSL connections.

A common framework should support sensor fusion from different sensor tracking technologies, also facilitating the development of new applications and services using location information. In addition, newly developed sensor technologies could easily be adapted to work with the framework, easily extending the location facilities of the framework. Since all applications have different requirements, the framework also needs a module to convert location information between its internal format and the format required by each application.

6.2. Roles and types of infrastructure

Location information is becoming more and more important in persons' life as devices and persons themselves increase their mobility. Thus, there is a common need for an infrastructure able to transparently give developers the tools to integrate new tracking sensors, services and applications. Several tracking technologies have been developed, mainly targeted for a special purpose, and limiting its use by other applications, see chapter three.

Moreover, there exists a common need to invest in new infrastructures, mainly indoor, to take advantage of the growing need for location information. Any service requiring location information requires the existence of four main components: Communication Infrastructure, Positioning Infrastructure, Mapping Infrastructure and, Services Infrastructure.

6.2.a) Communication Infrastructure

The Communication Infrastructure is required so that mobile devices can exchange location information between themselves or with related fixed devices. For a deep overview of communication technologies see chapter two.

6.2.b) Positioning Infrastructure

The positioning infrastructure is referred to as the set of all sensors and infrastructure required to track a person or an object. In the positioning infrastructure, possibly different sensors and a network infrastructure collaborate with each other to provide a large sensing network. Whether in the countryside, urban areas, indoor, or between each of these different sensing areas, sensors grab information from the environment to collaboratively track features of interest.

The positioning infrastructure is influenced by several restrictions, namely best features to track, privacy issues, size restrictions, limited resources, scalability, and network topology. In each scenario different features can be used to better track a person or object, thus a correct analysis of the best features to track can improve the overall performance of the positioning infrastructure.

Moreover, privacy is not widely considered in all sensing technologies. In some location systems, the fact that a person is using, or has used, the related location system is assumed to carry the desire for that person to be tracked. However, there are periods in time where an individual may which not to be tracked and these issues should be considered. Privacy issues can be considered in the services infrastructure, involving policies accepted by the tracking and tracked parties.

Sensors' size restrictions are also important in order to mingle the sensors in the environment. Consequently, small sensors blended in the environment may also have limited resources; where battery power, low CPU speeds, and small transmission ranges are considered constrains.

Scalability and network topology are also important issues to overcome noisy environments, enlarge transmission ranges, and, possibly, provide some redundancy. Both are considered and influenced by sensors' mobility, possible failures, sensors' inactivity periods, and environment topology.

Moreover, sensors data and features are modelled in the sensor's location model, or sensor's model for short, reflecting all considerations about the scenario where sensors were applied, and the sensors technology characteristics. Depending on each technology, physical or symbolic information is mapped in the model to represent geospatial data.

Physical geospatial data is related to the usage of a coordinate system, which can be a geocentric cartesian coordinate system, a polar geographic coordinate system (latitude, longitude, elevation) or a planar projection coordinate system. For example, 38° 35.700 N by 8° 1.430 W are the WGS84 coordinates for a location in the city of Évora. Figure 6-1 shows an example of physical geospatial data.

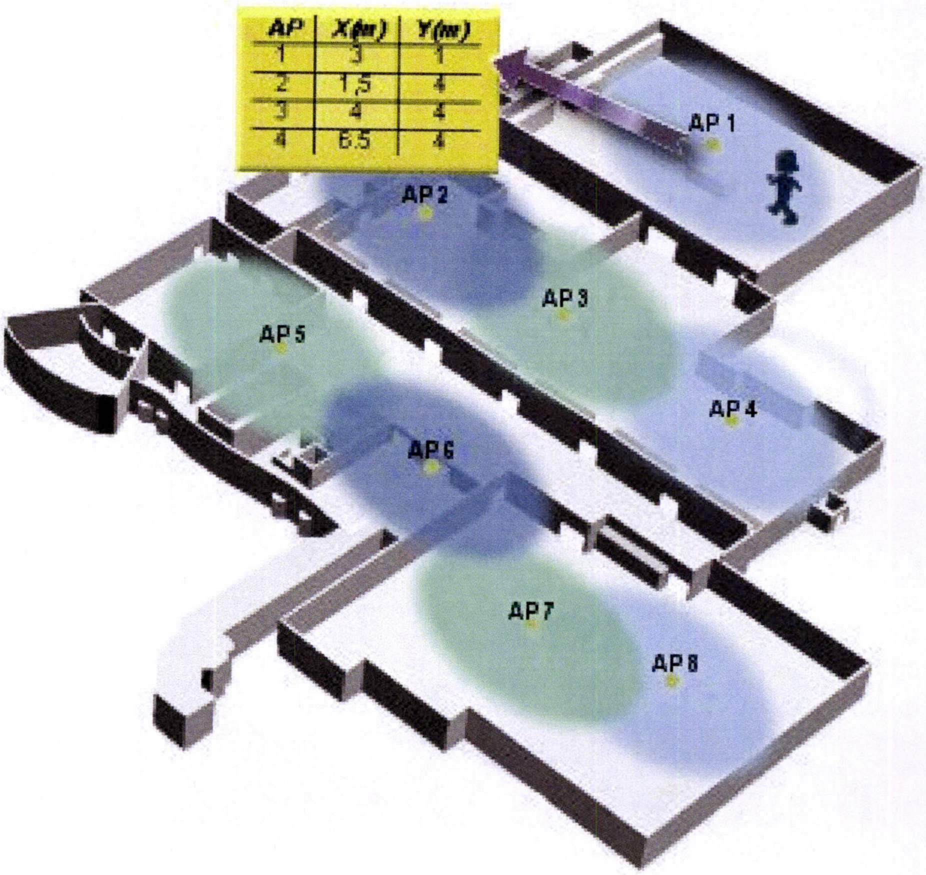


Figure 6-1 - Physical location

Symbolic geospatial data represents abstract ideas describing the space or relations between space entities, namely: in the Hall, near the portrait of Mona Lisa or, next to the entrance. Figure 6-2 shows an example of symbolic geospatial data.

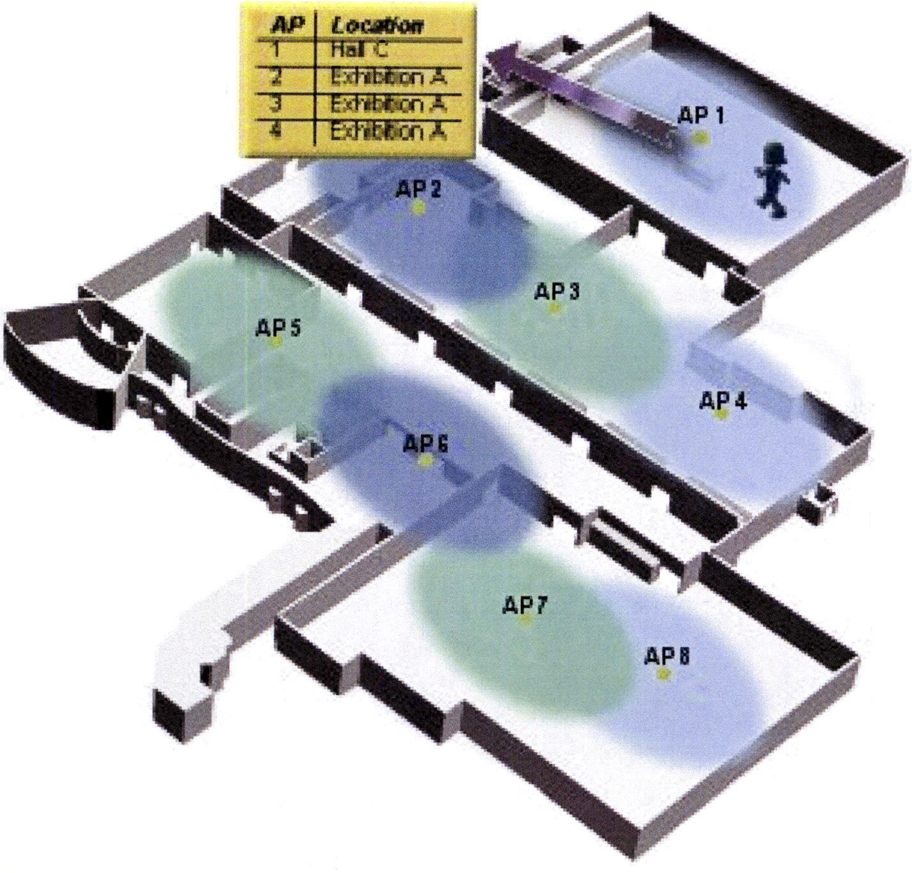


Figure 6-2 - Symbolic location

For example in a simple scenario, low cost RF sensors are well suited to supply symbolic geospatial data. In such scenario, each RF sensor broadcasts an ID. When a device is in the range of a sensor, it is able to read the ID associated with a specific location, using proximity methods, see chapter three. In addition, some RF range can be programmed enabling small or large areas to be defined by a symbol.

A major advantage of such structure is the allowed flexibility to change the environment with minimal adjustments, or even no modification in the system, if the remaining points of interest persist. When triangulation, or scene analysis, is used in RF or acoustic systems, it is often required to re-calibrate the system.

When accuracy is an important feature, the use of physical geospatial data is a better option. In order to achieve improved accuracy, previous calibration and model of selected sensors' parameters estimating the distance form a person or object to them is required. The first step is to define a coordinate system related to a known point (for example a planar coordinate system) and measure the location of each RF tag related to the previously defined coordinate system. Afterwards, persons, or objects can receive their position in a proximity basis, i.e. with their position being the position of the nearby RF tag, or in a triangulation basis, i.e. measuring RF parameters and using known position of RF tags to estimate their location.

6.2.c) Mapping Infrastructure

Different LBS applications deal with different scales. For example, both, the Buddy Finder and the Product Finder can operate on a building scale (i.e., "notify me when

Bob is in the shopping mall…" or "show me the location of the store that sells the product that I am looking for…"). Furthermore, both applications can be improved to require room-scale (i.e., "notify me when Bob is in the same room…" or "show me the corridor where I can find the product…").

As a result, it is important to make sure that the underlying location model is suitable for the aimed functions. Different types of location models exist that provide an abstraction between users/devices and the raw data provided by various location sensing technologies, see chapter three. Moreover, when the user moves between different spatial areas, using distinct sensing technologies, and consequently different location models, a seamless transaction is required to enable various location-aware applications to explore both areas.

Indeed, location-aware applications can take advantage of larger areas, using different sensors, required that a correct mapping between different locations models is performed. Sensor fusion is an important issue, as discussed in chapter three, however a common platform able to merge different formats from different sensors and also able to supply location data in the format required by an application is also important.

In [7], Korkea-aho and Tang surveys several location data formats used. In their work, they describe ideas and experiences in order to enable interoperability and reuse of location information from different applications.

Leonhardt et al., in [8], have purposed a formally defined algorithm to fuse the information retrieved from several sensor technologies. In this project, an acquisition stack was formally defined in a hierarchical location model, hiding the underlying information retrieved from sensors and giving a common framework for applications.

Inconsistencies, retrieved from sensors, can also be identified and dealt by the algorithm. However, the system doesn't store data concerning previous objects movements.

Hightower and Borriello [9] also have developed some work in this area with the Location Stack abstraction. This method integrates design abstractions and fusion techniques for location systems. Probabilistic techniques, such as particle filters, are used to fuse information from different sensor technologies. In addition, a uniform application interface was developed for applications.

Furthermore, Ranganathan et al. [10] developed a distributed framework that allows for the fusion of several sensor technologies and facilitates the integration of additional technologies as they become available. In [8] and in [10] hybrid models are used allowing the exploration of location data whether in a geometric or symbolic fashion. However, in the Ranganathan et al. work, there is a lack for a module that can convert location data between the internal infrastructure format and the format requested by the service or application.

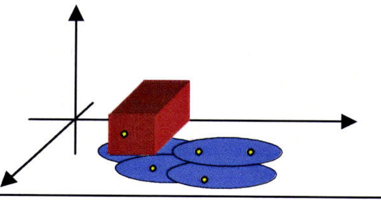
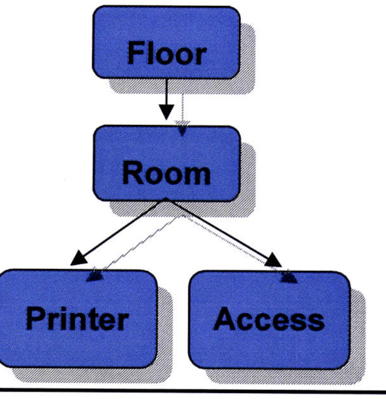
6.2.c.i) Location Models

Location models form the basis for location aware systems, providing an expressive, flexible, and efficient representation for the location of objects. Only the essential knowledge of spatial information should be modelled, focusing in independence of application domain and sensor technology in use. Indeed, a myriad of sensor technologies and algorithms urge to take advantage of all location aware applications in larger spaces. This also reinforces the need for location models independence from sensors and applications.

However, several location aware systems were developed merging positioning, mapping and services infrastructures, also lacking the independence that will allow location models usage for additional purposes. Namely, projects such as WebPark [12], CRUMPET [13], LoVEUS [14], or GUIDE [11] use location models aimed for the application domain and sensors used, mainly GPS. These location models take advantage of its simplicity and performance which is also important for some location aware systems.

Thus, several location models persist to represent spatial information depending on its particular requirements. Among the different spatial data formats used to represent location, common characteristics group them in major classes, depending on the type of location data used, namely geometric [15], symbolic [4], hybrid [5], non-deterministic [3], time-based [1], or semantic [2] spatial data. Domnitcheva [6] surveys different location models and their mean to represent spatial information.

Generally, four types of location models are considered: geometric, symbolic, semantic, and hybrid. However, as mentioned before, probabilistic and time-based models are gaining importance and are able to surpass some problems encountered in other models. A brief description of location model types is provided bellow, in table 6-1:

Type	**Description**	**Overview**
Geometric	Stores points, areas, and volumes in a predefined unit. The resolution of the model is limited by the measurement unit used. Lacks relations between points and the objects they point to.	
Symbolic	Locations are described in terms of names and abstractions (i.e. hierarquies). There is a strong link between objects in the real environment and symbols in the model. However, it lacks the precision of geometric models.	

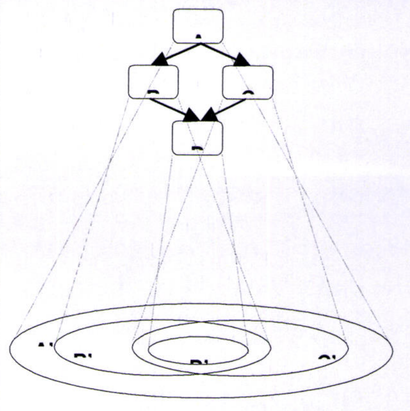
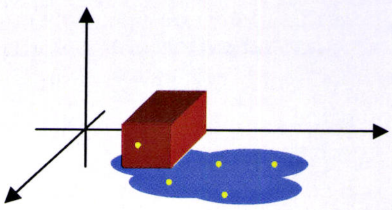
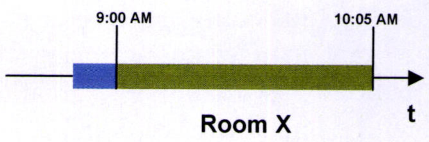
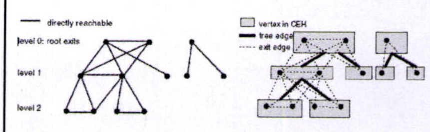
Hybrid	Represents a logical step forward in combining the advantages of the geometric, and symbolic model types in order to overcome their respective disadvantages. As a consequence, the hybrid model is more complex, requiring greater amounts of data.	
Non-Deterministic/Probabilistic	Probabilistic location problems deal with the stochastic nature of real-world systems. In these systems some parameters, such as for example travel times, the location of users, demand and the availability of servers are treated as random variables. The objective is to determine robust server/facility locations that optimize a given utility function, for a range of values of the parameters under consideration.	
Time-based	The environment and surrounding locations can change as time passes. Time-based location models deal with the dynamic changes in target objects locations along time.	
Semantic	Rather than focusing purely on position, this model type is concerned with relationships of entities in space and between the spaces themselves.	

Table 6-1 - Overview of location models

Ground basis for location models are provided from geometric and symbolic models. Thus, a brief description is presented in the following sections.

01.Brief taxonomy of location models

Geometric Models

Geometric location maps are made up of features (i.e., points, lines, polygons) that have metric (and non-metric) attributes. The dots in figure from table 1 (geometric model) are geometric points representing physical objects or persons in space with an absolute position.

Geometric models define an n-dimensional space, and the locations are points in this space that can be uniquely specified and accurately represented by a tuple of numbers (x, y, z). However, there are sometimes mismatches in the meaningful precision of the coordinates in various locations. An example of a spatial (coordinate) reference system is the one utilized by MIT Cricket [27].

Various coordinate systems may be used, but they must have well-defined transformations between them. For example, each floor of a building typically acts as a separate spatial reference space – two points on different floors may have the same coordinates on their respective floors, but have an unknown relationship in the real 3D world. One way to solve this problem is to allow each space to have its own local coordinate system by specifying the origin point and three axes of "x", "y", and "z."

Geometric models can also deal with absolute or relative locations. Absolute location is the exact location on the earth where a person or object resides. A good example would be the longitude and latitude of a place. Relative location is the place where its location is relative to another location. An example of relative location can be a coordinate system developed in the scope of a building with coordinates related to a location in the building, or even a different coordinate system to map each floor of the building.

One problem of geometric models is that to compute spatial relations (i.e., containment and intersection) geometric attributes must be present in a well-defined spatial reference system, such as shapes, extensions, point coordinates, etc. Therefore, there is a request for some calculations to perform those operations, which can be seamlessly modelled in a symbolic model.

Symbolic Models

A location entity, such as a shopping mall or university campus is decomposed into several intersected subspaces: building 1, building 2, and building 3. Each of these buildings is divided into smaller composing subspaces (floor 1, floor 2, floor 3, etc.), until enough level-of-detail is reached to reference / map objects in the space, which in this case is a room, a store, or a shelf in a store.

In the figure from table 1 (symbolic models), the parent-child link implies super/sub space relationships between two spaces. These divisions could be used as location entities providing a spatial reference for users (or other objects). The users themselves can be defined by some supposedly well known characterization rather than their physical properties. The location service needs to maintain a hierarchical style data structure for the space tree and handle queries of spatial relationship (i.e., containment) based on this data structure.

A symbolic map, sometimes referred to as a spatial model graph or a spatial tree, represents these different levels of spaces by nodes. Information is considered to be affiliated with a location, hence linked to a node in the spatial model. Edges (or lines) between the nodes define how these places are connected.

For example, a shopping mall can be represented as a set of spatial model graphs, each graph representing a floor. Each node is a place of interest (i.e., store, restaurant, ATM). The edges (arcs) between stores are the shopping mall's hallways. Each store represented as a node may have associated secondary nodes representing shelves or products. Links between floors can be represented by special arcs (i.e., represented as dotted lines), which have specific properties indicating the type of connection (stair, elevator, escalator, ramp) and the floors they link to. In the parking lot floors, each node could represent one parking spot and the edges (arcs) are the paths to elevators and stairs. This model can also represent access privileges. For example, thin dotted lines between rooms and doors (both represented as nodes) can indicate that the door is open, or the user has permission to use it.

Since the locations of objects are correlated to actual physical spaces, the model is capable of answering containment queries (i.e., "contains," "within") or connectedness queries (i.e., "near," "next to") that exists between two physical spaces. Simple queries include, "Where am I," "Who/what is there?" and neighbourhood discovery.

In a symbolic model, nodes can vary with respect to size and colour, which would associate them to specific physical properties. Persons or objects can be represented as nodes similarly to structural physical objects in space, but unlike the geometric model, they are represented in terms of relative positions, such that object1 is "next to" or "adjacent to" Store ABC (as opposed to absolute positions of Cartesian coordinates in the geometric model).

Although, symbolic models lack precision and the decision to describe space is not simple (nor standardized), they are sufficient for LBS applications that only require relative positioning.

Hybrid Models

A mapping infrastructure combining both the geometric and symbolic location models makes it possible to support LBS services at all relevant scales, in all types of positioning type environments. Approaches build upon hybrid space models, federating various interpretations of location and location-sensing technologies can achieve these goals. Thus, to get the interconnections between places, it is necessary to have relations between the objects involved.

Some relations are modelled implicitly when the geometry is modelled, e.g. which rooms are next to each other (topology). However, this may not be sufficient, if the geometric model lacks information about doors between rooms. In this case, this relation has to be explicitly modelled.

The counterpart of hybrid models is that, they may have complex requirements to achieve a good relation between area coordinates, in the geometric model counterpart, and names with membership in one or more domains, symbolic counterpart.

6.2.d) Services Infrastructure

LBS are increasing their popularity with the increasing number of mobile devices. Thus, to take advantage of the user's mobility, location information is an important issue. To locate the user, several methods can be used. For a basic location service, methods such as asking the user to enter/select his/her position (hence, no need for a positioning system), can be used. However location can be captured automatically, by means of sensor technologies/positioning systems, such as the sensors used in MIT Cricket. Nevertheless, context-aware systems use location and other context information, namely time, age, preferences, weather, or mood. In such systems, it is possible to provide specific information tailored to each type of user and/or device.

Dey and Abowd [28] define context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." For discussion purposes, the Cyberguide [11] system supplies context-aware information to the visitors of a building using IrDA technology through the indoor navigational system, named IRREAL.

In IRREAL, information is sent in cycles, resembling the technology from teletext. Different nodes of information have different importance to the system and nodes with higher importance are sent at higher rates to the mobile devices. Therefore, information can be adapted to the user's walking speed. A user walking fast will retrieve only abstract information, sent at higher cycle rates and, a standing user will retrieve additional information, sent at lower rates.

6.3. Conclusions

Location and context awareness is more difficult to achieve given the lack of infrastructure for the aim of some applications. Thus, investments should be made to provide intelligent spaces with location infrastructure. Moreover, location modeling is a research area in its infancy.

Geometric models are tailored to accurately know persons and objects locations, symbolic models are able to know relations between objects, also allowing to query the location model based in objects symbols. Suitable representations of models, as well as their integration in location or context-aware systems, are open problems that will derive future developments. So, extensions and new paradigms to model location need to be developed to take advantage of the wide spread of small, mobile, ubiquitous devices.

Finally, privacy issues should be considered and integrated in these location models. Some users are not willing to keep their location information open, and it raises the privacy problem. Several aspects should be addressed then: whether to add privacy constraints to the representation model or, design the system to avoid that issue.

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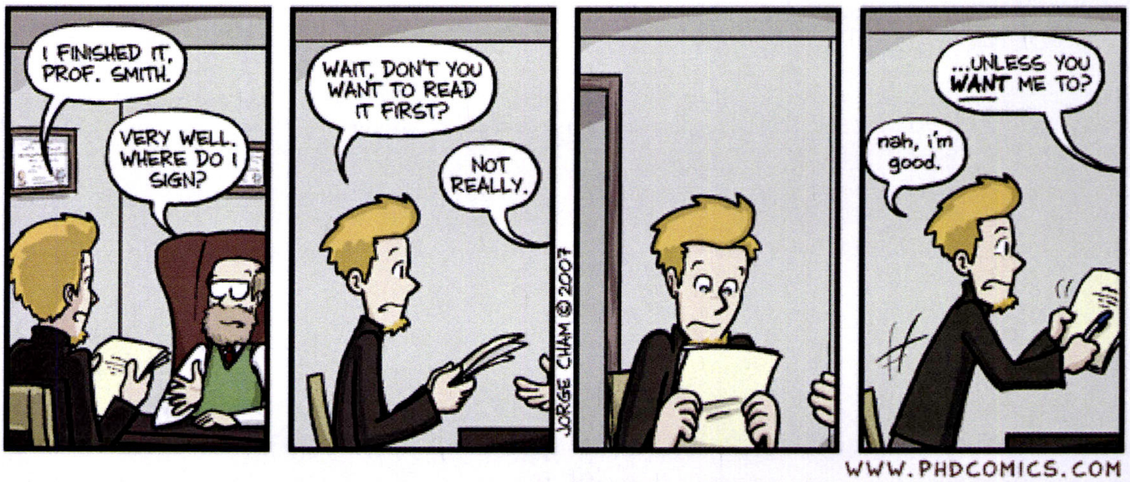

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

7. Low Cost Location-Based Services

Abstract

An extendable and low cost location based service to be applied in micro-geographical spaces – Location for You (Loc4U)

GPS is almost ubiquitous outdoors, but suffers from the need to have a clear line of sight to the sky. Several methods exist to overcome such difficulties, namely Assisted GPS (A-GPS), which is mainly controlled by mobile operators, or high sensibility GPS receivers, not commonly used. GSM cell ID can as well be used for location purposes; however some cells can have sizes of up to a few kilometres, making it also unsuitable for some context aware applications.

Indeed, commercial solutions can supply accuracies of up to the centimetre level, but the deployment costs are prohibitive in many cases. Furthermore, controlled environments have specific features that can be used to better supply location information to users. In fact, geometric geospatial data isn't suitable to all applications. This chapter describes a low-cost radio frequency (RF) location system,

Loc4U, that can be easily deployed anywhere with minimal impact in the environment. The overall architecture can grow as needed to supply better accuracy, include additional points of interest, and also support more types of interaction devices. Hybrid and symbolic location models will be used to better model geospatial data to applications. Optionally, orientation information can be supplied to visitors. Furthermore, radio interferences are taken into account and their impact is reduced.

7.1. Introduction

As seen in previous chapters, location aware applications are increasing in its interest. Several sensor types are being used to allow retrieval of location information. Nevertheless, major focus is being set to radio technologies, mainly because of its simplicity, cost, and widespread usage. Wi-Fi and Bluetooth are technologies that have reached worldwide usage, thus research projects, and even commercial products, have naturally emerged to explore location through their usage.

However, the tools to develop new location systems and commercial solutions with both technologies still have known problems for a common usage, namely development costs and power usage. Consequently, there is a request for further research to lower the costs of such systems. Industry has launched a promise to develop low cost Bluetooth chips, namely at $5. However, the prices haven't yet reached that promise and developments kits for Bluetooth are also expensive nowadays.

In the chapter five, a brief survey was performed through some of the systems that can be used for such purpose. In addition, for mobile devices development High-Point [17] has an Evaluation Development Kit that can be used as a first start to develop Bluetooth enabled applications for Pocket PC mobile devices. Symbian enabled mobile devices can also take advantage of a common framework for Bluetooth development.

On the other hand, Wi-Fi for long lacks a common framework, for application development across all manufacturers in the market. Consequently, in some Operating Systems efforts are being undertaken to reach a common framework between all Wi-Fi manufactures. Therefore, applications can be developed and use information retrieved from the Wi-Fi radio card, even if the device is built-in.

One of the first efforts to develop a common framework to retrieve Wi-Fi radio signal data across several manufacturers was an open source project called Pocket Warrior [15], targeted for devices running Windows Pocket PC 2002. Its main goal was to be used for "wardriving" (see related work), however it can be adjusted for various purposes. Afterwards with Windows Pocket PC 2003 and furthermore with Windows Mobile 5.0, a common framework was created so that developers for those OS could develop new ideas and applications using data from the radio card.

For Windows Desktop platforms, NDIS drivers [18] have been used as a common platform for Wi-Fi application development. While using Linux, the NDISWrapper [16] is a good starting point to develop such kind of applications. Major drawbacks for Bluetooth are development costs, while WiFi has problems with power consumption requiring frequent battery recharge when there's an intensive usage.

Nevertheless, commercial spaces, expositions, museums, and related events can largely benefit from the usage of such sensors, and location information to better direct information to their visitors. Nowadays, regular audio guides are used, requesting users to follow a predefined path, or obligating users to search for cues that identify a particular point of interest. Indeed, audio guides lack all the richness of location and other context elements.

As an alternative, low cost RF sensors can be used for coarse-grain location purposes. Low cost RF sensors have the advantage of reducing the complexity of Wi-Fi or Bluetooth solutions, also supplying a fine control over the radio control hardware. Several sensors can be dispersed in the space marking points of interest and helping users to freely navigate across the environment.

This chapter describes the work in progress for the development of a low cost RF location solution, Loc4U. Costs can be perceived in two major ways:

- Time costs involve the time required to install and support the location system,
- Space costs involve the space and amount of infrastructure, namely hardware to support the proper operation of the location system.

In the next section, several research projects related to this project are presented. In the following section, an overview of major methods used to sense location is presented and the chosen methods are discussed. The next section discusses how sensors best perceive location followed by a description on how to model the geospatial information supplied by all sensors, since there can be many types of sensors supplying data for a location model. Afterwards, the sensors used in this project are presented and discussed, and the proposed architecture is explained. Next, two study case scenarios are discussed as a proof of concept of the presented project. The chapter ends with conclusions and future work.

7.2. Related Work

Several tracking technologies have been developed, mainly targeted for a special purpose, and limiting its use by other applications. Nevertheless, efforts are being undertaken to develop tracking systems for more general purposes, namely Ekahau and Ubisense [3]. A survey of several tracking sensor technologies can be found in [8] and in chapter three. Moreover, there exists a common need to invest in new infrastructures, mainly indoor, to take advantage of the growing need for location information.

The high cost of some location systems, related calibration procedures and the increasing importance of geospatial data have driven to the development of open-source projects, namely Place Lab [11]. Place Lab uses Wi-Fi Access Points (AP) Basic Service Set ID (BSSID) to locate users. Through the usage of a spotter application, users scan for Wi-Fi radio signals in the area, look for related AP BSSID, and search for AP locations in a database. Afterwards, Place Lab can make logical inferences about where they are and what is nearby.

The physical location of each AP is collected using a method named "wardriving". "Wardriving" is the action of searching for BSSIDs and associating that information with GPS coordinates collected on-site. AP physical coordinates are then estimated based in the GPS coordinates of the wardriving user and Received Signal Strength Indicator (RSSI) values. Applications that require a coarse-grained accuracy, in areas with good Wi-Fi coverage, can use Place Lab to track users and objects. However, it is known that radio signal strength can be affected by numerous factors, namely humidity or other radio signals.

The European Commission Information Society Technologies (IST) funded project, AmbieSense, is developing a context-sensitive technology based in the usage of context tags. Small tags are installed in buildings with storage and communications capabilities, so that users can access context-sensitive information when in the vicinity of these tags. Supplied information is then customized, based on each user's preferences. The drawbacks of such system are costs, infrastructure deployment, and management of the entire network.

Besides the referred technologies, in outdoor scenarios GPS is a well established location technology. Various projects are using GPS to supply users with context-sensitive data, through the usage of PDAs and mobile phones. The mobile devices are the preferred choices to operate such applications, given their wide spread usage and growing functionality. However, several challenges persist in order to: manage geospatial data and geospatial related information; best suit the interface for the task being performed by the user; and improve interactivity. Projects such as: WebPark [4], CRUMPET [14], LoVEUS [9], GUIDE [2] and, Deep Map [12] discussed these issues and developed prototypes to overcome problems in this type of systems.

7.3. Location sensing

As seen in chapter three, location can be sensed through triangulation, proximity, or scene analysis. This low cost location system uses triangulation and proximity to estimate location. The used RF sensors can sense the received (RX) power level and an ID, making them suitable for both triangulation, and proximity schemes. Triangulation can supply better accuracy than proximity. However, given the complexity to perform calculations in triangulation, proximity can be a better option making the system simpler and faster. Thus, the proximity technique will be used as a basic configuration of the system and triangulation will be used when better accuracy is needed.

7.4. Types of Geospatial Data supplied by sensors

Geospatial data can be better supplied in physical, symbolic, or both types depending on the sensors being used and application's purpose. RF sensors in a basic way are well suited to supply symbolic geospatial data. In this system, each RF sensor broadcasts an ID. Thus, when a device is in the range of a sensor, it is able to read the ID associated with a specific location. In addition, in this system, RF range can be programmed enabling small or large areas to be defined by a symbol.

A major advantage of such structure is the allowed flexibility to change the environment with minimal adjustments in the system, or even no modification. For example, if a museum decides to change the layout of an exposition while using Loc4U, it may only need to change the RF tags of this system and place them according to the new layout. However, when triangulation is used in RF systems, it is often required to re-calibrate the system.

Nevertheless, when accuracy is an important feature for the system, physical geospatial data can be provided to people. In order to achieve this, previous calibration and modelling of the environment must be performed. The first step is to define a coordinate system related to a known point (for example a planar coordinate system) and measure the location of each RF tag related to the previously defined coordinate system.

Afterwards, located persons, or objects can receive their position on a proximity basis, i.e. with their position being the position of the nearby RF tag. Alternatively, located persons, or objects, can receive their position in a triangulation basis, i.e. measuring RF features and using known position of RF tags to estimate their location.

7.5. How to model location information

Geospatial data can be modelled in different ways, depending on the aimed functions of the application. In chapter five a brief description of the advantages and disadvantages of each system are presented. In the system presented in this chapter two types of models are used; namely a purely symbolic or a hybrid model.

The symbolic model provides the simplicity and relations between the spaces required in the basic framework of the system, a location-based audio-guide. The hybrid model complements the information provided by the symbolic model with the physical location of spaces, also improving the accuracy. The hybrid model can only be used when the system is being manipulated through PDAs or mobile phones, given the increased complexity.

7.6. Sensors

Given the increasing importance of location-aware applications, several sensors have been used to track people, or objects locations. In the design stage, a low cost location system was the goal to reach, leading to the choice of using RF sensors. Other important goals of the system include: being able to locate a possibly vast number of objects or people; allowing the needed flexibility to change the environment layout with minimal changes in the system; and reducing the amount of infrastructure needed to support the system.

IEEE 802.11 family of protocols and Bluetooth have been considered to be used in the system. Indeed, a major advantage of using such technologies is their wide adoption. In store shelves, a considerable range of mobile devices can be found with support for these technologies. However, the large cell size in IEEE 802.11, power consumption, and lack of a common framework to access radio features discourage its usage for this system. Bluetooth power class 1 devices were also considered as a possibility since these devices allow for radio range control. However, to overcome interference problems arisen when several Bluetooth devices are searching for other devices in the same location, a significant infrastructure would be need. Therefore, Bluetooth was also discarded.

Compared with the other alternatives simple RF sensors are simpler and less expensive. Moreover, selected RF sensors operate in a different frequency than common wireless technologies, such as Bluetooth and IEEE 802.11 b/g, thus interference is reduced. Deployment of the system involves spreading transceivers in the environment, implemented using Integration IA4220/21 Universal ISM Band Transceiver [19]. On the other side of the communication channel, receivers are placed in client devices, using the Integration IA 4320 Universal ISM Band FSK receiver [19].

This simple solution allows for full control of radio coverage and access to RX power level values, consequently providing a better control over radio interference.

Transceivers are the active part of this type of sensors, and the main focus for radio interference within the system, thus the decision was to have them within control of the infrastructure. On the other side of the communication channel, users carry radio receivers able to listen for radio beacons, the passive part of this type of sensors, also reducing interference. As a result, interference levels are within system control allowing the system to scale as needed.

This scheme to locate persons, or objects, also targets another important goal of location systems: privacy. With a major focus in privacy issues, it is up to the user to supply information related to his or her location to the system. However, it is possible to supply users with location based driven services, after acceptance to supply their location to the infrastructure.

Indeed, location improves user experience because applications can gather important hints about available operations in a specific spot. Additionally, user experience can be further improved with the usage of orientation, thus enhancing context-awareness. Orientation data allow applications to supply information regarding the direction the user is looking at. Given that, orientation information can be optionally added to the system in a compromise between costs and improved context-awareness. The sensor used to supply orientation to this system is a digital compass, namely the CMPS03S320160 [20].

7.7. System Architecture

The main components of Loc4U are: tags, spread in the environment and broadcasting an ID; and clients, translating IDs into locations, see figure 7-1. Tags are used to specify points of interest (POI) or navigation aids. Each transceiver broadcasts an ID that is associated with a specific location. These transceivers have a programmable output power level, enabling them to be adjusted to various scenarios, where smaller-scale POI can be defined.

When several transceivers are deployed in the environment with a reduced power level, it is easy to mark different and smaller spots with different IDs, allowing the definition of diverse POIs within a small area and reducing radio interference, see figure 7-1. Nevertheless, some interference may persist. Thus, each tag broadcasts its ID in random intervals, reducing collisions, and, with each ID broadcast, a checksum is sent to validate the related ID.

In the basic framework, each client device is a low cost audio guide, able to reproduce digital audio related to each visited location. All data is supplied to users based on their location, calculated from the relationship between tag ID and tag location. Thus, the client device comprises an OEM digital audio Player, a micro controller, a RF receiver, an EPROM, and optionally an OEM digital compass to provide the user's orientation.

In more detail, the receiver is able to read nearby tag IDs. These IDs are then supplied to the micro controller, a Microchip PIC 18F2520, so that the user's location can be estimated. Optionally, user's orientation can be received using an OEM digital compass. Based on the estimated user's location, and optional orientation, the micro controller will start the correspondent audio data item from the digital audio player, namely, the Ogg Vorbis player from FineArch [21].

Uploading the contents to the audio digital player is as easy as storing audio data on a regular SD card. However, a new challenge came up: how to upload new locations and tag IDs into the client EPROM, so that the micro controller can start the audio tracks related to a new specific location? For this purpose, a new application is being developed in order to upload the referred data into the client device, making it easy to change the museum layout and also change the client data related to the new layout.

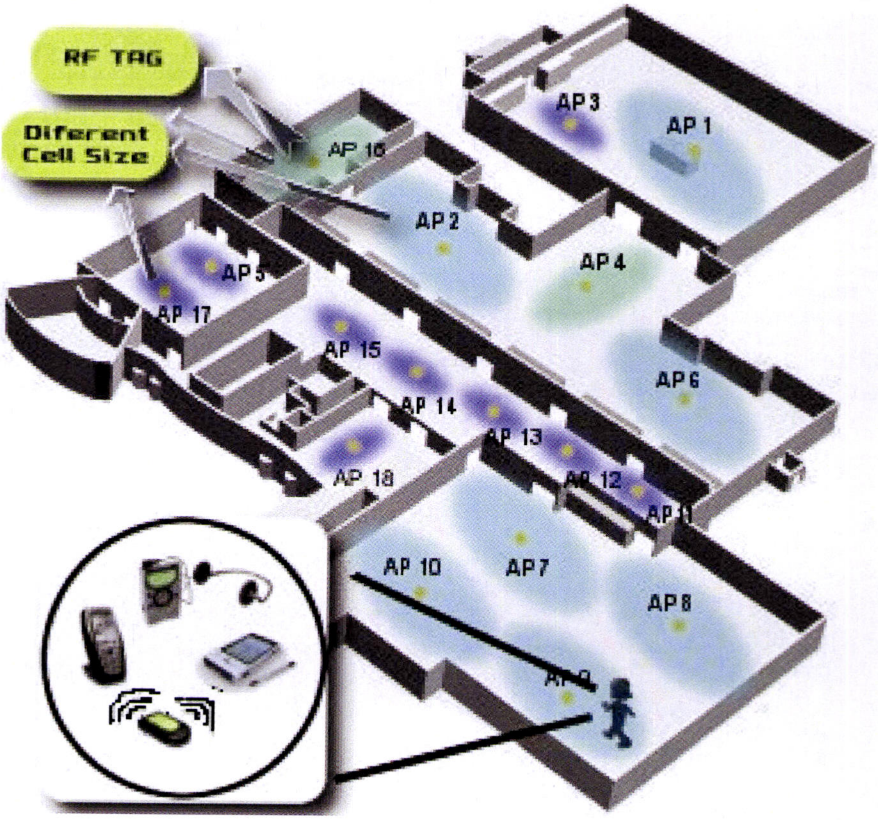

Figure 7-1 - Framework overview

Furthermore, the complete framework is being designed to extend its usage for PDAs, mobile phones, or any device with a Bluetooth connection. When using such appliances, users have to carry an additional small device, which receives tag IDs and sends the information to the PDA or mobile phone over Bluetooth. This small device contains a micro controller, a RF receiver, a Bluetooth antenna and, optionally, an OEM digital compass. The usage of Bluetooth in such cases isn't a major problem, since tags and Bluetooth are using different radio frequencies (tags are emitting in the 868 MHz frequency and Bluetooth is emitting in the 2.4 GHz frequency).

Moreover, an application, or library, has to be developed for each type of device to interpret the values sent over Bluetooth to the visitor's mobile unit, be it a PDA or a mobile phone. Afterwards, the application/library has to supply location-based information to visitors. RF tag IDs and the optional orientation information are supplied to the PDA or mobile phone through the Bluetooth connection, using the Serial Port Profile (SPP). The costs to extend the framework to be used in PDAs and mobile phones are reduced, since the system basis is the same as in the proposed audio guide.

Indeed, the proposed framework provides an easy and affordable way to extend itself to the most common devices used by visitors in a museum, also taking advantage of the wireless technology already available. In future, the described system can be further extended with the usage of a location engine to improve accuracy. Two metrics are being tested within the system to estimate the distance between the client and a known ID tag, as described in [1]: response rate and signal strength.

Addionally, positioning algorithms such as centroid, fingerprinting or particle filters can be used to improve accuracy. Namely, the centroid positioning algorithm can be used since it is easier to implement, easier to calculate, faster, and can supply good accuracies in areas with dense distribution of RF ID tags [1]. In such cases, the location engine can also be implemented in the client device, improving visitor's privacy and system performance.

7.8. Case Study Scenarios

The project described in this paper is mainly targeted for indoor spaces, namely museums and exhibition centres. Taking advantage of the RF technology, the user is able to know his or her location and take advantage of the knowledge of this important context feature. When nearby a POI the user will receive information related to that POI, as seen in figure 7-2. This project's main goal consists of reducing the costs of using and deploying location, also supplying a rich context feature to applications, namely location and identity.

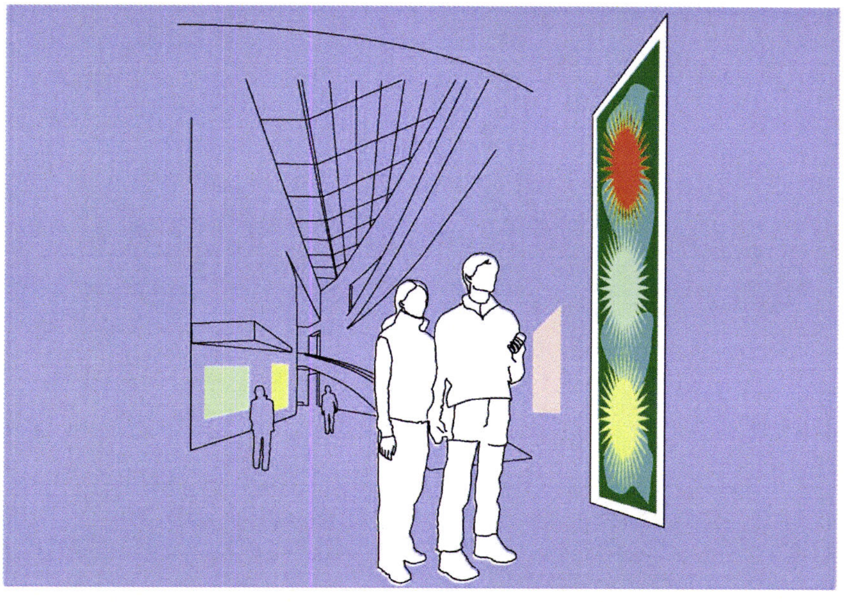

Figure 7-2 - Location aware information

As a proof of concept, the system will be deployed in two museums in the city of Lisbon. Text and audio information will be used to supply information to visitors of both museums, related to their location. Targeting all types of users, the system will support handicapped visitors, namely with vision and audition handicaps. In many cases, culture events are left out of handicap visitors reach. Thus, this system will be able to achieve a wider audience, offering a richer museum tour to each visitor.

Visual handicap visitors will have access to contextual information related to each POI through audio tips intended to guide them across the museum area. Auditive handicap visitors will have access to visual tips guiding them across the museum area through additional visual information related to each POI presented on a PDA. Visitors with no handicap will be able to use the same devices to access location related information.

7.9. Conclusions

With this framework, we believe that location-based applications can easily and affordably be deployed in several locations, improving the users' experience when exploring these physical spaces. As shown, the system can be extended according to the demands and costs supported by each institution. The audio guide is an entry solution that can be extended afterwards to also allow PDAs and mobile phones usage. Moreover, orientation information can be supplied to applications, narrowing the amount of information provided to users, from the user's vicinity to the POI in front of him or her. The system works indoor and outdoor making it suitable for a wide range of scenarios.

With the storage capabilities of actual mobile devices, augmented information can be supplied and stored within the client application. Basically, that's what happens with the audio guide, making the system suitable for places with poor wireless coverage. However, it can be extended to fetch real time content using the wireless capabilities of PDAs and mobile phones. Compared with other solutions, such as Placelab [11], this framework can supply better accuracy, since radio beacons size can be controlled. However, it lacks the ubiquity supplied in the former one, since GSM cells are widely deployed in urban areas.

Commercial solutions, such as Ekahau, may guarantee superior accuracies, but also represent less flexible solutions, involving larger configuration and maintenance efforts, as well as higher costs. In the basic approach proposed here, there is no need to tell the system the exact physical location of a POI or object. The administrator only has to bond the tags with the related data content to be supplied to visitors. Moreover, the relation between each tag ID helps to navigate within the visited location, thus resembling a symbolic location model approach.

In resume, this chapter proposes an extendable location infrastructure appropriate for navigation and exploration of micro-geographical spaces. A major goal is to develop a low cost system that encourages the usage of location aware applications by wider audiences, namely museum visitors even with visual or audition handicaps. The proposed system is easy to maintain, configure and deploy.

As a proof of concept, a location-based audio guide is being developed and the mechanisms to support the system usage through other mobile devices, such as PDAs and mobile phones, are being designed. Finally, these audio guides can be used to supply audio information and PDAs can be used when visual information is of greater importance.

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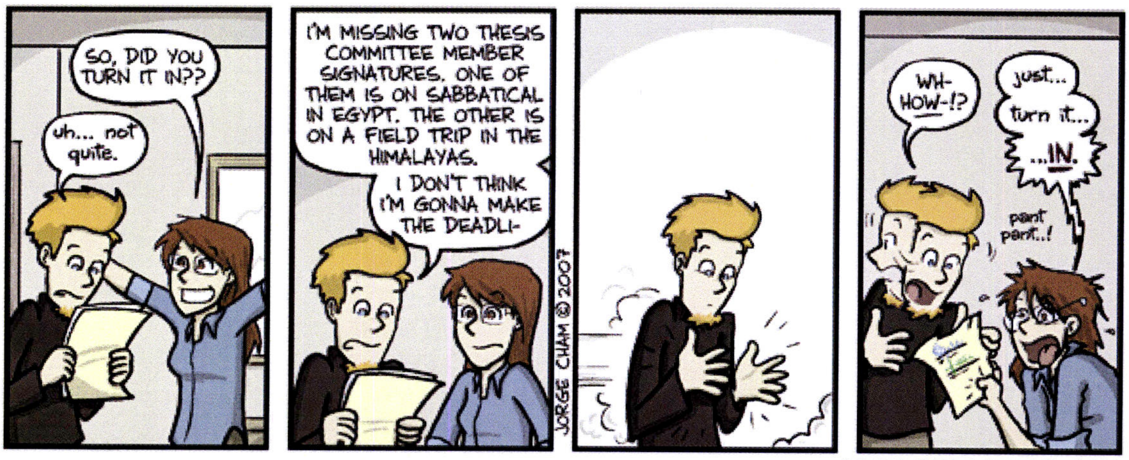

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

8. Buildings and Subsoil Augmentation

Abstract

Access to real-time data while in field observations is often a requested issue in environmental management. Additionally, it is easier to see that information spatially distributed where it makes sense, leveraging users of the task of searching for the context where the retrieved information can be applied. Augmented Reality (AR) is a technology that allows the superimposition of synthetic images over real images, providing augmented knowledge about the environment in the user's vicinity. In some situations, AR will also make the task more pleasant and effective for the user, since the required information is spatially superimposed over real information related to it. This chapter is part of ANTS (Augmented Environments), an AR project for environmental management providing geo-referenced information to the user. The system's architecture has a flexible design based on a client/server model, where several independent, but functionally interdependent modules are articulated. Therefore, modules can be moved from the server side to the client side or vice-

versa, according to the client processing capacity. The system was deployed in laptop computers and Personal Digital Assistant (PDA) devices. The purposed architecture is composed with three components: a 3D model and a geo-referenced database, used in the server for user positioning and content; and presentation components, used in the client to superimpose synthetic information over real images.

8.1. Introduction

Relevant information about the surrounding real world, whether it is natural or urban, is often needed in real time. However this information is not always easily accessible through our senses. Augmented Reality (AR) is a technology where the view of the real world is superimposed, in real time, with virtual objects, augmenting the information available to the user about the surrounding real environment. AR technologies allow users to receive additional information about the objects in the environment, improving their perception of the real world and helping them to efficiently accomplish their tasks.

Through the use of a Head Mounted display (HMD), users are allowed to easily and seamlessly interact with real environments. Additional information is rendered in real time, and in a contextual way to augment user's experience. Moreover, mobile devices, like PDAs or mobile phones, can also be used to augment users' experience, given their wide availability and wireless capabilities.

Typical AR systems, for a user to undergo an augmented reality experience, he or she must wear a huge set of devices, such as: a notebook, a HMD, an orientation tracker, and a position tracker. There is a disadvantage in these setups since they are not as mobile as the user would like them to be. Therefore, displaying information using personal displays, and avoiding burdening the user with heavy and cumbersome devices is an important goal while using a PDA in AR systems.

The PDA can act as a virtual window to the augmented world displaying what the user is seeing superimposed with the additional virtual objects. Thus, virtual objects can be seen in the viewer's line of sight through the PDA screen.

In order to develop an AR system, several problems must be taken into account, namely:

- Registration of synthetic images on real images
- Position identification
- Information retrieval
- Presentation

Moreover, several technological limitations must be taken into account while developing AR applications for mobile devices: displays size and resolution, processing power, low data bit rates, out of coverage gaps in wireless networks or network latency. The user interface should give a pleasant experience overcoming these issues and providing users with relevant information.

This chapter describes two applications designed to test and exemplify the usage of the ANTS system. The applications comprise:

- Superimposition of synthetic objects on real images of either urban buildings and/or natural landscapes to visualize their characteristics and temporal evolution;
- Projection of synthetic images on the ground, which reveal the soil's composition at the user's current spatial location (for example, the location of underground water supply networks and subsoil structure).

Currently, the ANTS system can be deployed in two different configurations: one uses a video-see-through HMD and a laptop and the other uses a PDA. In the future, it can be further migrate to other devices, such as 3G phones, as reported in the section describing ANTS infrastructure.

The following section reviews related research approaches. Afterwards, a description of the project infrastructure and the PDA client being developed is performed. The next section presents the applications where the AR system is being applied. Finally, the chapter ends with conclusions and future work directions.

8.2. Related Work

Augmented reality is a technology in which the user's view of the real world is enhanced with virtual objects that appears to coexist in the same space as real objects.

Main problems associated with AR systems are [2,3]:

- Image registration, which refers to the accurate alignment of real and virtual objects;
- Camera field vision should correspond exactly to the field of vision in order to avoid changes in the dimensions (amplification or reduction) of the real world;
- Technological limitations: displays, trackers and AR systems in general need to become more accurate, lighter, cheaper and less power consuming.

Accurately tracking user's position and viewing orientation is vital to minimize AR registration errors. However, available technologies and limitations from the environment narrow the possible types of interfaces and types of tracking sensors to use. A recent overview of tracking systems can be found in chapter three, which is a good start in the process of choosing the tracking technologies to use.

In prepared and controlled laboratory scenarios, registration errors are reduced when compared with outdoor uncontrolled scenarios. Consequently, for indoor accurate registration methods have been demonstrated [16], while, in unprepared environments, tracking still is an enormous challenge [3, 4], particularly concerning outdoor and mobile AR applications, increasing registration errors. In [13], a method for estimating registration errors is used to generate probabilistic error estimates for points, in either 3D world coordinates or 2D screen coordinates.

Indeed, each tracking system reveals different problems related to the technology they use: vision-based trackers are computationally intensive, magnetic trackers have low-accuracy and mechanical trackers are cumbersome. Hybrid technologies are then used to exploit strengths and compensate weaknesses of individual tracking technologies [4, 16]. It should be also noticed that accuracy, in mobile AR systems, changes over time and interface should adapt itself adjusting to changes in tracking accuracy [11].

The first outdoor AR system was the Touring Machine [8]. This system assists users interested in visiting the Columbia's University campus, overlaying information about points of interest in their neighborhood. It combines a video-see-through display with a handheld display using different interaction technologies to take advantage of their complementary capabilities.

A more recent version of the system rather than linking individual labels or web pages to locations, supports context-dependent, narrated multimedia presentations that combine audio, images, video, and omni directional camera imagery. Additionally, 3D graphics are overlaid in the user interface and presentation content, showing models of buildings that no longer exist and views of visually obstructed infrastructures. When selecting points of interest the user is also guided to them [10,12].

Available computational power is also rising, enabling a growing number of mobile devices to perform tasks that previously could only be done in desktop computers. With this in mind, in Vienna University of Technology, the Handheld AR project has developed a PDA-based AR system to be used in the SignPost project. In this project, a vision-based AR toolkit, named ARToolkit [1], was migrated from desktop to fit the limitations of PDAs. This system allows a user to stroll over an unknown building showing him or her several navigational hints [15].

In environmental management field, other applications were already developed. In the University of Michigan, an application was developed to allow humans to detect potentially hazard conditions, combining the collected data in a three geometric database. Human senses are unable to detect several dangerous conditions, namely harmful radiation or toxic gases. Therefore, the application uses augmented reality to present related information to the users [9].

In New University of Lisbon, BITS (Browsing in Time and Space), was developed for the exploration of virtual ecosystems. BITS allows users to navigate and explore a complex virtual world, interacting with surrounding objects and make annotations indexed in time and space [7].

The Archeoguide project developed a wearable AR system that will give visitors a feeling of how a historical site, as Olympia in Greece, was during previous periods of time [14]. Despite all research efforts, AR systems are still in their infancy with a few commercial systems in use, mainly for augmentation of broadcast video to enhance sports events and to insert or replace advertisements in a scene [6]. Displays, trackers, and AR systems, in general, need to become more accurate, lighter, cheaper and less power consuming. Indeed, only a few have evolved beyond lab-based prototypes [3,6].

8.3. ANTS Infrastructure

ANTS is an AR system designed to assist persons in the study of the surrounding environment. Over the real image, users are able to visualize contextual information superimposed over the real image. Information can be visualized through different setups, namely a HMD or a use a PDA. This approach allows users to select the setup that best fit the requirements for the task in hands, and is mainly targeted for environmental management.

The system tries to overcome the problems stated in the previous sections. With a flexible design, the ANTS's architecture is composed by a set of modules distributed between the client and server entities (Fig. 8-1). Some modules can be moved from or to the client entity according to its available processing capacities and the applications requirements.

On the PDA, a proxy database will be used to speed up the process of querying the database (Fig. 8-2).

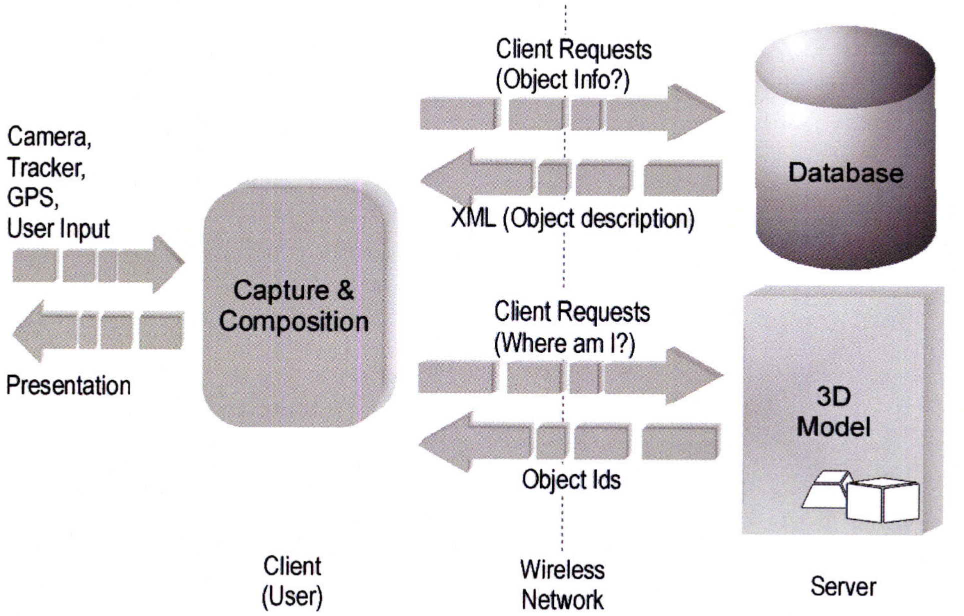

Figure 8-1 - ANTS Architecture and Information Flow

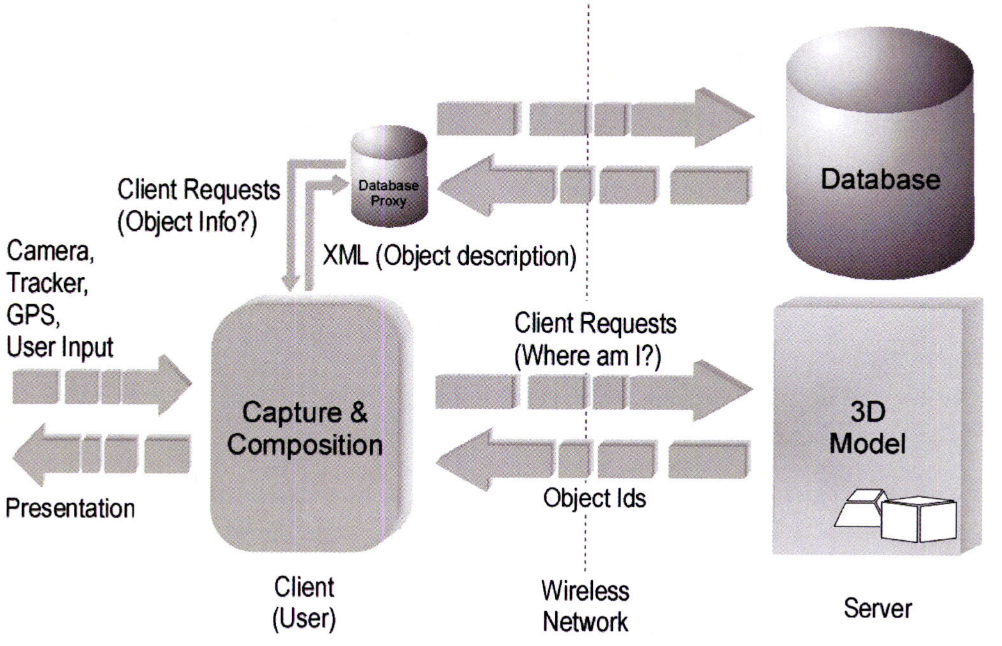

Figure 8-2 - ANTS Architecture and Information Flow (PDA)

8.3.a) System Architecture

In order to be able to provide contextual information, the system must know the user's position and orientation. Therefore, at the bootstrap, the system identifies the user position and orientation, by explicit interaction and manual calibration. After that, the system is able to track the user position and orientation combining several methods:

- GPS: The absolute position of the user is indicated by a GPS system. This type of system is used in combination with the other techniques below, in order to overcome the limitations and lack of precision associated with it.
- User tracking using appropriate devices: A tracker is used in order to obtain the current orientation of the user's head.
- Environment mapping: knowledge of the physical form and position of the entities on the environment that is being augmented.

All the additional information that serves to augment the real world is stored in a geo-referenced database kept in the server. To retrieve the information related to a particular location, the system uses the data obtained from the GPS and the orientation tracker to query the 3D model for a list of objects in the user's field of view. Afterwards, for any object in the list, several basic properties are specified including name, type and a unique object identifier (UOI) that can later be used to query the multimedia geo-referenced database.

The information returned from the 3D model server is the first layer of information used in the AR composition module. For more information, the multimedia geo-referenced database is queried using the UOIs returned from the 3D model. Next, the retrieved multimedia objects' data are superimposed over the real image, in the AR composition module.

The additional information, from the server components, are accessible through HTTP, a common standard, allowing different devices to perform requests. The main modules composing ANTS's architecture can be seen in figure 8-1 and are described in the following subsections.

8.3.a.i) 3D Model Server

The 3D Model Server works as a bridge between the virtual and real worlds, establishing a relationship between the physical space and the corresponding virtual representation. With this server it is possible to locate and depict the user and its surroundings, for a correct mapping of the contextual information. The 3D Model Server stores and edits the 3D model of the environment, which keeps information about the position, orientation and dimensions of the physical structures in the environment. It uses that information to determine which objects are in the user's field of view at any moment.

The 3D Model Server is an HTTP server, receiving queries from the client applications. Each query must have a set of specified parameters, including the user's position and orientation in order to process and retrieve the list of objects in the user's vicinity. Based on this data, the server identifies the relevant objects and relates them with the user. All the relevant objects (with corresponding description) are returned as an XML file. Indeed, XML is used to help the parsing process and provide standard access interfaces.

Models, used in the server, can be defined with commonly available tools, such as 3D Studio. However, to quickly obtain a representation of an urban landscape regarding its volumetric objects and their relative representation, without having to use a complex, all-purpose tool, we have developed a simple editor for 3D environments (Fig. 8-3). This tool uses maps or blueprints of the real environment as the basis for edition. While editing the model, the user only has to input the height of the each object in it.

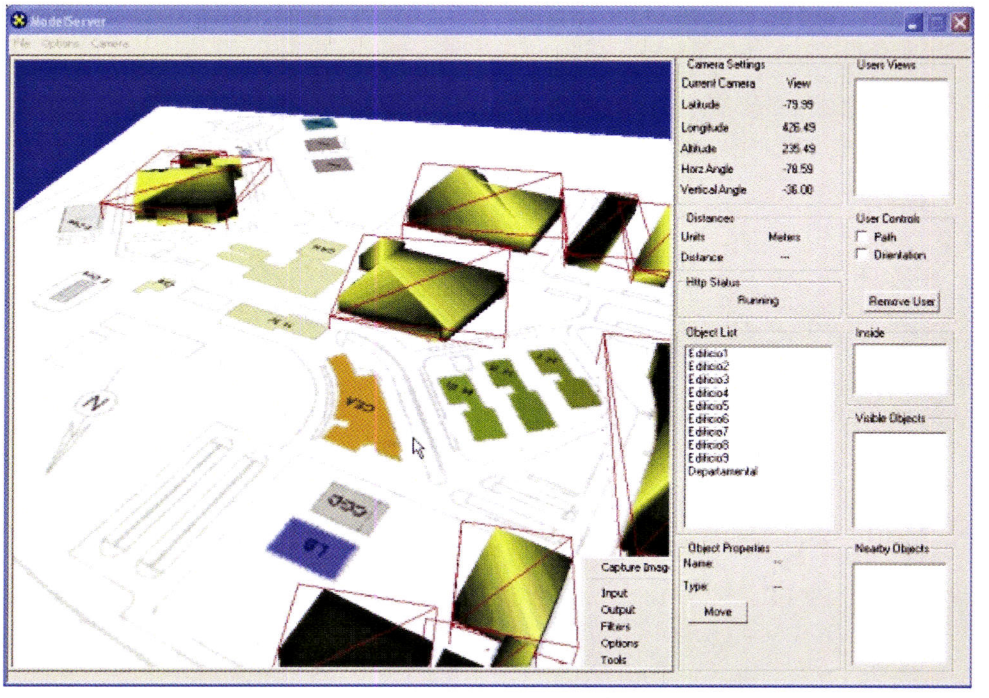

Figure 8-3 - 3D model editor

Every element in the 3D model has an identifier that will be used in search operations, to identify the objects in the geo-referenced database. When a request is made to the 3D model the server returns a list of all relevant objects in user's vicinity. These objects are classified in three main categories, accordingly to its spatial relation with the current user position and orientation (Fig. 8-4):

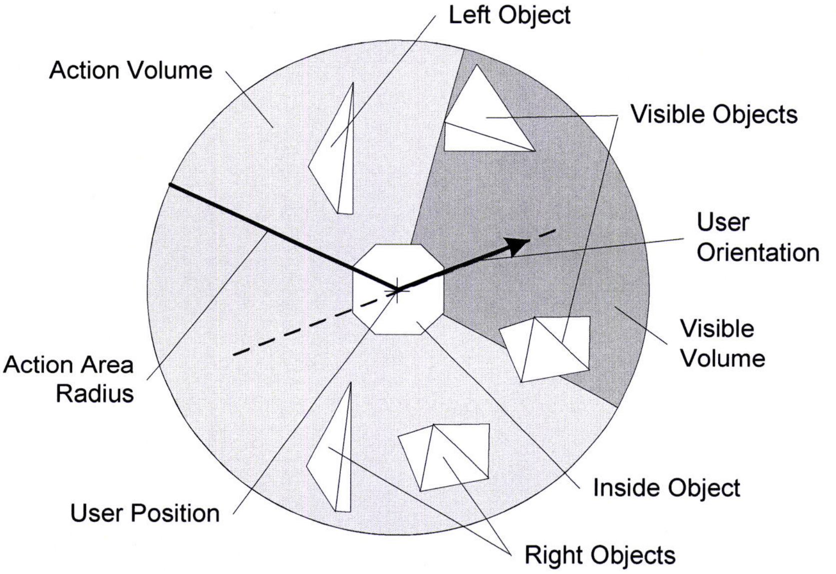

Figure 8-4 - Object classification

- Inside objects: all objects where the user is inside. There can be more than one as there is no requirement that the model is restricted to physical non-overlapping entities.
- Visible objects: all objects in front of the user and inside of a view volume, defined by an angle much in the same way as the field of view of a camera.
- Surrounding objects: all the other objects that are not visible objects or inside objects, and that are inside the action volume. These objects are further classified in "Left" and "Right" to enable user orientation when displaying information.
- Developed with Microsoft Direct 3D, this tool allows for a rapid production of a first approximate 3D model of the real world, often sufficient for augmented reality applications.

8.3.a.ii) Geo-referenced Database

All information related to the various elements filling the space under analysis is stored in a geo-referenced database. Object identifiers, contained in the list of objects returned by the 3D model enable the system to query the geo-referenced database and retrieve the related contextual information. Afterwards, a list of multimedia elements; whether text, graphics, images, audio or video, can be obtained. The resulting list of multimedia elements is returned in an XML file for future visualization purposes.

8.3.a.iii) AR Composition Model

The main goal of this module is to superimpose the data elements retrieved from the geo-referenced database over the real world image, captured by a camera, and display the composed image in the HMD or PDA screen.

This module has two functional components that can be seen as a set of filters (implemented using Microsoft DirectShow): InfoComposer and ObjectComposer (fig. 8-5). The InfoComposer shows all the information that surrounds the user, and the ObjectComposer show all the information related to a specific object.

InfoComposer receives a XML file from the 3D model and composes the embedded information with the image received from the video camera (fig. 8-6). For visible objects, the UOI, name, type and screen position are returned. The screen position is independent of the device being used in the AR composition module. Therefore, the AR composition module can adjust the values to its own screen values.

Figure 8-7 illustrates the results of composing the captured image with the data about the surrounding environment, using the InfoComposer. At the top, there is a list representing the objects on each side of the user field of view, the surrounding objects. The information about the surrounding objects, allows the user to change his or her orientation in order to place them in the field of view.

The PDA version of the AR Composition module only shows the objects seen by the user at any instant (fig. 8-8). Notwithstanding, the arrows are shown without labeling and the users are able to select them, sending a request for that information. This procedure saves computational power, which is important in a mobile device like the PDA. Thus, a more smooth visualization of the environment can be supplied to the user. When the user needs additional information, he or she will request it and it will be rendered over the real image for a while. This technique also avoids cluttering the scene with unnecessary information, given the small size of the display.

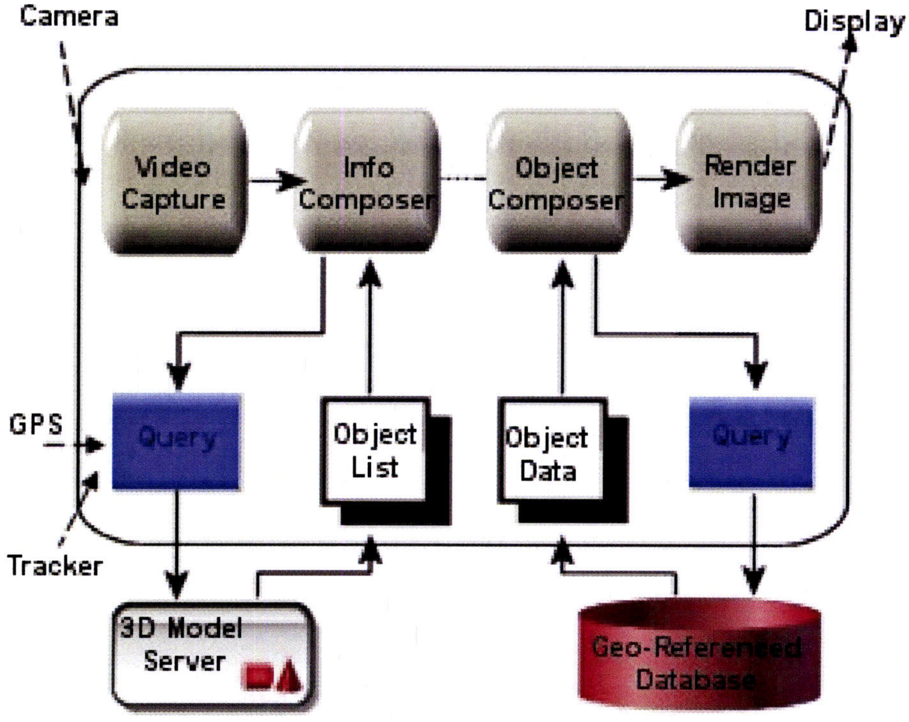

Figure 8-5 - AR User Module Architecture

```
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- <QUERY_RESULT>
    <INSIDE_OBJECTS />
  - <VIEW_OBJECTS>
    - <OBJECT>
        <ID>59</ID>
        <TYPE>Edificio</TYPE>
        <NAME>Oceanario</NAME>
        <SCREEN_POS_X>0.829000</SCREEN_POS_X>
        <SCREEN_POS_Y>0.515000</SCREEN_POS_Y>
      </OBJECT>
    - <OBJECT>
        <ID>69</ID>
        <TYPE>Transporte</TYPE>
        <NAME>Teleférico</NAME>
        <SCREEN_POS_X>0.609000</SCREEN_POS_X>
        <SCREEN_POS_Y>0.516000</SCREEN_POS_Y>
      </OBJECT>
    </VIEW_OBJECTS>
    <SIDE_OBJECTS />
    <ANGLE>-88.621620</ANGLE>
  </QUERY_RESULT>
```

Figure 8-6 - 3D Model Server Response

Attached to each visible object there is an icon and a label. If the user selects one of these icons, the object composer, using the UOI of the corresponding object, will query the geo-referenced database to obtain more detailed information. The returned data elements are then composed with the real image. The ObjectComposer accepts data elements of several types including images, video or text. Afterwards, the resulting composed image is displayed avoiding flickering.

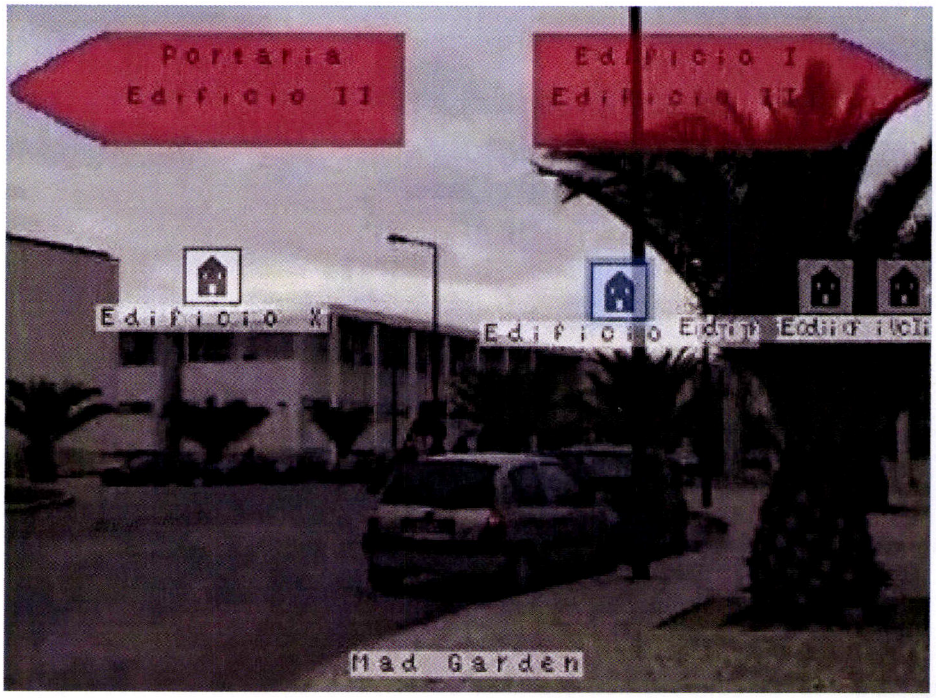

Figure 8-7 - Outdoor AR example

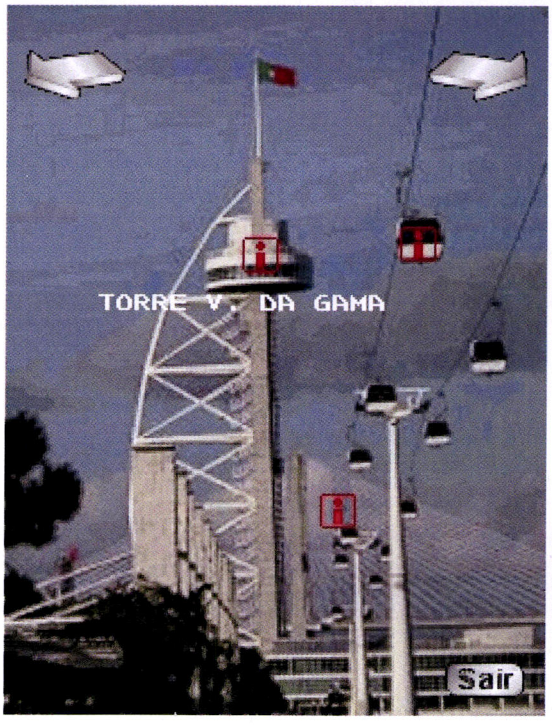

Figure 8-8 - PDA AR example

8.4. Applications

Although ANTS' infrastructure and image registration methods could be applied in the development of other AR systems, we focused on environmental management, for which geo-referenced and GIS functionalities are fundamental. Two main applications were developed and partly deployed in the Parque das Nações, in Lisbon:

- Superimposition of synthetic objects on real images of either urban buildings and/or natural landscapes to visualize their characteristics and temporal evolution;
- Projection of synthetic images on the ground, which reveal the soil's composition at the user's current spatial location (for example, the location of underground water supply networks and subsoil structure).

The presented applications enable access to contextual geo-referenced information. Therefore, the real environment is augmented with real time access to information not available through conventional observation methods. The user is then able to explore and analyze a spatial location, and access data about the elements that compose the area where he or she is located at: water, soil and physical elements.

8.4.a) Visualization of characteristics and temporal evolution of superficial solid structures

The main goal for this application is to allow users to stroll through a certain spatial area, while accessing information in real time. Accessed information is related to the objects in the surrounding area. These objects can be natural elements or man-made structures.

This application was developed for Parque das Nações in Lisbon (former area of the Expo 1998). It allows users to walk through the park and have access to contextual information about the different buildings and natural elements surrounding them. This information comprises data about the characteristics and functionalities of the different objects in the real world, as well as images showing former objects that have been replaced by them, see figure 8-9.

8.4.b) Visualization of subsoil structure

The main goal for this application is to locate infrastructures for public supply networks (water, sewage, telephone) in order to avoid damage when intervention to the subsoil is necessary. While using this application the user is able to look at the soil and see synthetic images revealing its interior (subsoil) constitution at that point. Other possible usages for this application are the exploration and analysis of the subsoil composition in geological terms, locating watersheds or locate subsoil infrastructures.

This application is also being deployed for the Parque das Nações in Lisbon, see figure 8-10.

8.5. Conclusions and future developments

ANTS project is an AR infrastructure developed for environmental management, supporting in loco observations and providing the user with additional knowledge about the surrounding environment. This infrastructure should be effectively used to visualize and manage information, as well as to locate and identify objects within the user's field of view. This project also supplies an infrastructure that can easily be used to develop other environmental management applications, by facilitating the perception and interaction with the involving spatial area and its natural and artificial components.

Figure 8-9 - Building Visualization

Figure 8-10 - Visualization of Subsoil Infrastructure

Additionally, the user is able to choose between two different clients of the system. While using a laptop-based client, the user is given an immersive experience using the

HMD. Alternatively, the user can handle a PDA, allowing him or her to directly observe the environment, and watch the PDA for additional information.

Based on the ANTS infrastructure, two different applications were developed enabling the visualization of: information related to superficial solid structures, and the structure of the subsoil. Future developments include improvement of the referred prototypes and applications, as well as the development of the system's remaining components, namely the integration of an image tracking module. Additional developments for supporting mobile phones are also planned.

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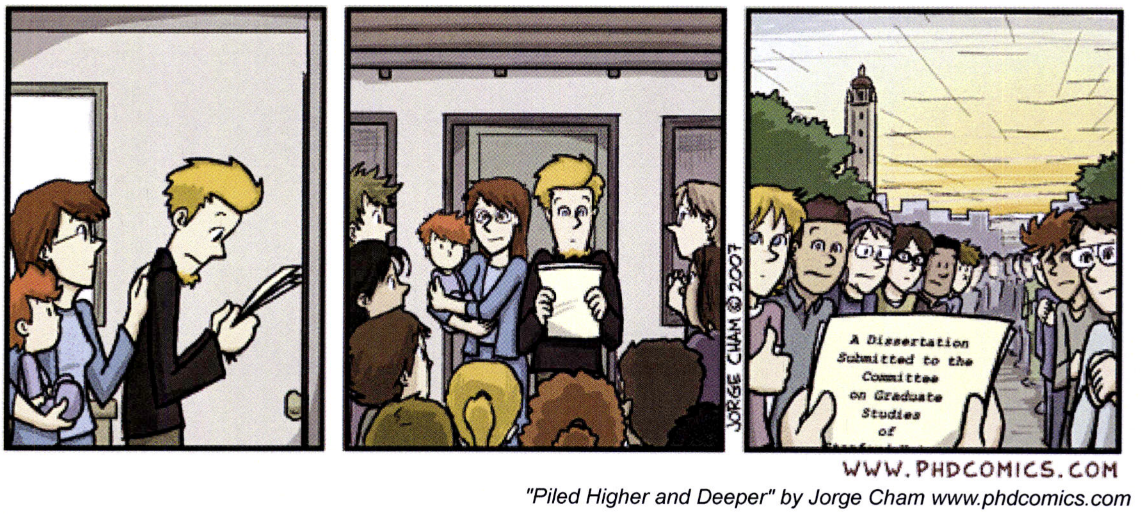

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

9. Mobile Environmental Visualization

Abstract

Environmental processes are a major point of concern for researchers, environmental engineers, and general public. This chapter presents a multi-user mobile system to visualize environmental processes. The proposed system enables multiple users to simulate and visualize environmental processes, and also retrieve additional information in real time, while roaming through the environmental area under analysis. Each user is able to contribute to the simulation and assess the impact of adding or removing agents to or from the model, respectively.

This system uses a modular approach, allowing its deployment over different platforms. Two main modules compose the system under development: a geo-referenced model and an Augmented Reality (AR) composition module. The geo-referenced model describes the environmental processes being modelled and tracks all users. The AR composition module allows users to visualize the geo-referenced

model evolution and to interact with the model through two different views, namely animated map view and AR view.

9.1. Introduction

Environmental changes may influence everyone's lives, being a major point of concern for researchers, managers, and general public. Environmental processes are complex and influenced by numerous natural factors and by the human activities. Tools and methods of analysis that help users to collaboratively gather, analyse, model and monitor diverse environmental data in a rapid and flexible manner are required to manage, assess and reduce the impact of natural phenomena or human activities on the environment.

These tools should allow users to visualize, analyse and evaluate environmental scenarios, by modelling and simulating environmental processes. Users with little experience in environmental issues should also be able to use these tools to query, display and produce maps and reports from environmental data sets held in a common source, namely in a GIS.

Geo-referenced models can be useful in "what if" scenarios to simulate the effects of adopting different policy options, where each stakeholder can give his or her opinion reflecting the overall choices in the simulation. Based on the interests of all, a more balanced choice could be made. Air and water dispersion pollution models are some examples of models that can be used to simulate "what if" scenarios, such as evaluating the impact of building a factory on a particular region.

Hence, GIS and geo-referenced models can become more responsive in dealing with environmental issues such as environmental contingency planning or disaster management. Geo-referenced models are tools that can be used by all users to aid in balancing the complex interacting factors that should be taken into account when studying environmental changes. Users can be any member of a community interested in assessing and visualizing the impact of a defined environmental change.

Often an extensive list of parameters, mainly spatial and temporal, should be supplied to the simulation to accurately characterize an environmental process. However, some details of the processes, which are not relevant for the tasks at hand, can be ignored, therefore, simplifying the model used to simulate the observed changes in the modelled environment.

By reproducing and simplifying real complex systems or processes, models are essential to understand and predict their behaviour. Several techniques can then be used to visualize model simulation, namely 2D Computer Animations, Virtual Reality (VR) and Augmented Reality (AR).

2D Computer Animations can be used as support tools to help designers to outline the basic features of the environment and give all users a way to move through different levels of detail in the visualized environment.

VR can be described as a computer system used to create an artificial world in which the user has the impression of being immersed, and has the ability to navigate through it and manipulate existing objects [7]. Visualization and interaction with the virtual world is accomplished through the usage of a Head-Mounted Display (HMD) and position trackers, enabling the VR system to tailor the output according to the user's position and line of sight.

A major disadvantage of traditional VR systems is perception blockage of the real world. Contrasting VR, AR superimposes virtual objects over real objects instead of replacing the real environment. Virtual objects, superimposed in the real environment, supply additional information to users, which is not easily detected with their own senses.

This AR property helps users to perceive and interact with the real world, freeing them from the task of searching for cues in the scene, and making it also more effective and pleasant. The desktop metaphor is nowadays limited due to the growing rise of mobile devices, increasing the need to access information anywhere and at any moment, and to better manage information. These goals have driven the design of AR systems [2].

In environmental management, access to real-time data, in the field of observations is an important issue making AR suitable for this purpose. Moreover, it is easier to see additional information superimposed in the field of observation rather than in a computer desktop, apart from the context. Indeed, for most AR systems, the area of interaction is limited to the user's field of view.

An animated map view can supply a more general view, but lacks realism, and VR blocks perception of the real world. Thus, a combination of different view modes can be used to overcome the problems presented by each view mode and enhance the best in each of them.

Environmental management, in several cases, requires the system to be mobile and friendly, so that the user can have a pleasant experience using it across a considerable spatial area. Traditional AR and VR systems require the use of several specific devices to support the experience, namely HMDs, orientation and position trackers, and laptops. However, these systems are too cumbersome and intrusive for a roaming user.

Personal Digital Assistants (PDAs) can be used to avoid burdening the user with all these devices and provide a visualization system more suitable for roaming users. Some users may not have the required technical experience to use a complex system, therefore requiring it to be easy to use and to provide an interface that offers a pleasant experience. Moreover, interaction between each user is also an interesting aspect, in order to provide them an opportunity for actively and collaboratively managing common interests.

Mobile Augmented Reality System (MARE) was designed to provide users with geo-referenced information required to accomplish their environmental management tasks. It is deployed in laptop computers and PDAs, and has its foundations in the Augmented Environments (ANTS) project [9]. The main goal of the system is to allow a group of users to interact during the simulation of an environmental process, providing them access to contextual geo-referenced information, and giving them the possibility to move freely across the area under analysis.

In the next section, an overview of several projects that inspired the ANTS project is presented. Next, a system overview is presented, followed by a presentation of the view modes used to display information to the several users, also detailing animated map view and AR composition view. Afterwards, the client and server modules architecture is described. Finally, the conclusions and future work are discussed to drive future research.

9.2. Related Work

Map-based visualization, VR and AR have been used for many purposes. Among these purposes are: specialized professionals training, entertainment industry, architecture and urban planning and, more recently, environmental visualization. These tools allow the simulation of different scenarios and the monitoring of people's responses and behaviour in real world situations.

Each visualization system has its potentialities, which leads research to the usage of hybrid interfaces, taking advantage of the characteristics of each different visualization method. Hedley et al. [6] explored the use of hybrid user interfaces for collaborative geographic data visualization with two interfaces. The first interface combines AR, immersive VR and computer vision based on hand and object tracking.

Users wear a lightweight camera and display, so that they can look at a real map and see three-dimensional virtual terrain models overlaid in the map. In this case, users can fly and experience the model immersively, or use free hand gestures or physical markers to change the data representation. The second interface allows users to zoom in/out of the image, paddle interactions and pen annotations.

Ghadirian and Bishop [5] introduced a project to combine GIS-based environmental processes modelling with the use of AR technology to illustrate environmental changes in an immersive environment. The project is applied to weed modelling and simulation. A GPS and a camera are used to track users.

Although research in mobile augmented reality systems is increasing, there still are technical challenges to develop these systems: extremely high update rates, network communication gaps, low processing resources in the client side, image registration, match between camera field vision and model, and technological limitations in the different sensors, namely GPS and magnetic trackers. Moreover, accurately tracking users' positions and viewpoint orientation is important to minimize image registration errors. An overview of tracking systems can be found in chapter three.

Pasman et al. [8] have described a mobile AR system. The system uses GPS and image capture to track users' position. Orientation tracking is retrieved from object recognition and direct feedback from inertial tracker. Outdoor AR systems, cover a wider area increasing the problems related with each tracking sensor.

The work developed in chapter eight is also developed for ANTS, therefore see chapter eight for additional informarion. Moreover, further research is needed to create more accurate, lighter, cheaper and less power consuming mobile devices. Furthermore, image registration errors should be reduced to maintain proper alignment of virtual information related to objects in the real scene.

9.3. System Overview

Agents are described as the elements in the environment, whether natural or human-made, that can cause environmental changes. For example, natural agents can be wind or fire, and human-made agents can be swine farms, factories or waste water treatment plants. Each agent has a set of related parameters that can be grouped to describe its behaviour in the scope of the model. Indeed, environmental processes are complex systems, involving several stakeholders in their study.

Thus, a modular architecture was developed, in order to provide users with a mobile system able to model, simulate and visualize environmental processes, and supply additional contextual information in real time. Two main modules are the basis for this client-server architecture, namely a geo-referenced model and an AR composition module as shown in figure 9-1.

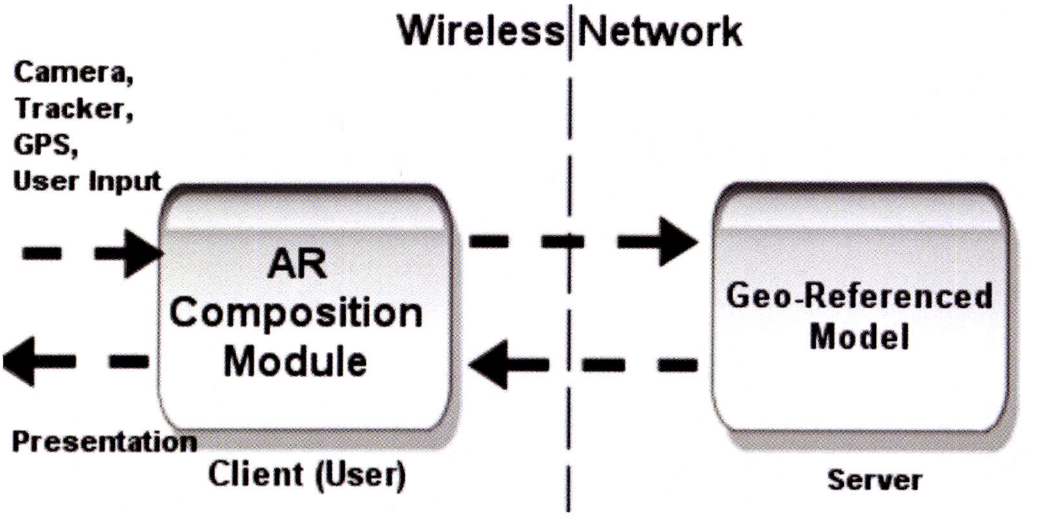

Figure 9-1 - Architecture Overview

The geo-referenced model is the main module, representing the real physical environment under analysis. This module uses the data gathered by the AR composition module, in the client side, to track users and evaluate the geo-reference model results, which are sent back to the AR composition module for visualization. The AR composition module is used to collect input from several users and visualize the geo-referenced model evolution, through two main views: animated map view and AR composition view.

The communication between these two modules is performed using the HTTP protocol. Given the wide support for this protocol in different client devices, HTTP also enables a common communication platform between them. As a case study, MARE system is being used to build an application for the visualization of water quality in artificial lakes and natural water streams.

9.4. Simulation Views

In the majority of cases, environmental management requires visualization of a wide area, also involving the simulation of several different scenarios to assess impact of each simulated scenario in the environment. The agents involved in the simulation can be apart from the user's position, although they can have a big impact in the environment near the user. Thus, for this mobile AR system, two views are being developed to allow the interaction with the simulation model and the visualization of the simulation progress.

The first view is an animated map view allowing the user to have a map view of the environment. In this view mode, the user is allowed to observe the simulation, add and remove agents to control the simulation evolution.

Alternatively, the user can see the simulation results superimposed in his or her view of the real environment. In this view, the user can easily assess the impact of environmental changes in the area in his or her vicinity. Given that the system is to be deployed in laptops and PDAs, the result will be tailored according to the display characteristics of the device, independently of the view mode being used.

9.4.a) Animated Map View

When analysing complex environments, combining overview and details, can give users the possibility to choose between a general outlook of the contextual situation and a detailed view of a restricted area of particular interest. MARE is able to supply an animated map view of an area, evolving over time according to a simulation in progress in the geo-referenced model. In this view mode, a zoom facility is provided allowing users to achieve the desired level of detail.

In addition, a user's physical location is represented through a yellow arrow in the animated map view. To keep focus on the user, the simulation result is returned with the related user's icon in the centre of the view. Hence, it is easier for the user to search for familiar cues representing points of interest in the environment. Moreover, to represent the limits of the model, when the user surpasses its physical limits, the user icon is placed in the nearest edge of the model representation.

User's orientation is another important cue for users. Thus, an arrow represents the user actual position and orientation enabling users, unfamiliar with the environment, to easily travel in the real environment. Since the model gives users real-time feedback from the geo-referenced model simulation, position and orientation of all users' movements in the real environment are reflected in the interface. All requests to the geo-referenced model are performed through HTTP requests.

Thus, the rate at which clients will receive new data from the simulation depends on the clients processing power and wireless network protocol being used. In a test scenario with the geo-referenced model and an application measuring the time for the request to arrive, the system was able to deliver responses in 256 milliseconds, in average. The geo-referenced model uses a distributed architecture, allowing the system to grow and handle huge amounts of data.

In the simulation, each agent is represented through the use of templates that describe all parameters needed to add or remove the related agent within the geo-referenced model. New templates can also be added to represent additional agents. Visually, each agent is represented as an icon in the user's view of the simulation.

In fact, by tapping on the screen or clicking in a location in the animated map view, the user can see a menu presenting the agents that can be added to the simulation in progress (see Fig. 9-2). When an agent is selected, a request is sent to the server to add the related agent to the simulation. In this request, the screen coordinates where the agent should be added, and the user position and orientation are sent to the server.

All data will then be used to perform a translation to model coordinates and add the correspondent agent to the simulation. When an agent is removed, user absolute position and orientation information is sent with information about agent relative positioning. In the server, the agent is searched within the geo-referenced model and removed. The resulting simulation will then be updated in each user's display.

Figure 9-2 - 2D Computer Animation View

9.4.b) AR Composition View

The AR composition view has been designed but requires future developments. The AR composition view should be able to provide a more realistic image of the impacts resulting from the current defined scenario. In this view mode, users should be able to visualize the real world image, according to their position and orientation. Virtual information is then superimposed with the environmental changes evaluated by the geo-referenced model.

In the water quality application, a pollution dispersion map should be superimposed over the river surface depicting the pollution dispersion retrieved from the geo-referenced model tailored to the position and perspective of the users. The main difference related to the animated map view is that the image returned from the server should be translated to the position and orientation of the user, allowing superimposition of that image over the real image.

In addition, the image returned from the server, while in animated map view, has information about the surrounding environments, as shown in figure 9-2, and in the AR composition view, the image is transparent, only having the pollution dispersion map. AR composition view does not have significant visual cues, diminishing the effect of superimposed virtual objects "floating" over the real image. Thus, some accuracy errors in image superimposition over water surface can be tolerated by the users. Moreover, each user is tracked within each request, enabling the resulting image to be tailored to each of them.

Currently, interaction with the geo-referenced model is not possible while in AR composition view. Environmental models cover a wide spatial area and activities taken place in one location may have relevant side effects in distant locations. Hence, to modify the current scenario, by adding or removing environmental agents to the geo-referenced model, and to perform new simulations, users must switch to the animated map view, in order to have a wider view of the surrounding environment.

9.5. Architecture

An important request of the ANTS project was to achieve a system architecture that gives users both mobility, and the ability to visualize geo-referenced models. In an effective mobile augmented reality system, adjustment to available resources, such as low processing power, screen size, different protocols and operating systems, is an important issue. Thus, in this system architecture the maximum operations needed to supply additional information to users are performed server-side, freeing clients to perform other tasks, namely to collect user input and retrieve information from several sensors.

9.5.a) Server

Resembling the web services architecture, the geo-referenced model is an HTTP server returning an XML file as an answer to queries from clients. This architecture allows several clients to interact with the geo-referenced model sending it queries as a set of parameters in the URL. In order to maintain consistency in the geo-referenced model, all requests from clients to add or remove an agent from the simulation are handled in a fist-in first-out (FIFO) method.

All users interact with the same simulation supporting different scenarios that could affect their interests. This approach enables a group of users to discuss issues more related to their interests, also enabling them to see the impact on the other users' choices. Currently, all users are able to add and remove agents from the simulation without restrictions.

In order to restrict user's permissions to perform specific tasks, a schema resembling the ones used in the file systems management could be implemented. Groups of users could be defined allowing them to perform defined operations. To improve this schema, a mutual exclusion object (mutex) could be used within a group of users allowing only one of them to perform an operation within the geo-referenced model. Thus, the user will be able to request ownership of the mutex to perform the operation and release ownership after performing the operation.

Apart from that, the simulation model being used in the development of MARE system is the Dispar pollutant transport model, but the system can be adjusted to accommodate other spatial dynamic simulation models. Dispar is a mathematical formulation to solve advection-diffusion problems in aquatic systems. The Dispar transport model is a 2D model able to simulate several pollutant scenarios (Ferreira and Costa, 2002).

In our application, Dispar is applied to the Tejo estuary (Lisbon). A previous calibration of the system is performed, mapping latitude and longitude values, gathered from the GPS, to model coordinates. In addition, users' orientation values are also mapped against geo-referenced model's orientation, in order to correctly show users' orientation or superimpose the related model evolution, whether in animated map view or AR view respectively.

Tracking information related to each user is kept in the server for visualization purposes. In the animated map view, it is possible to see the evolution of the geo-referenced model simulation and the position of all users in the view range. Thus, to track users, each user has to perform a registration step before being able to perform queries to the geo-referenced model.

In the registration step, a unique identifier (ID) is generated for the related user and sent back to the client. This unique identifier will later be attached to the information related to its corresponding user, namely tracking sensors information, client display size, and view mode. The first client interacting with the geo-referenced model also has to send a request to the server to perform a new simulation, which is carried by the interface and hidden from the user.

Afterwards, each registered client can request the model to add or remove agents acting in the simulation process (see figure 3). In each request, the server updates the geo-referenced model and sends an XML with the response. In the registration process, an ID is returned and in all other queries an image is returned with the current status of the geo-referenced model simulation.

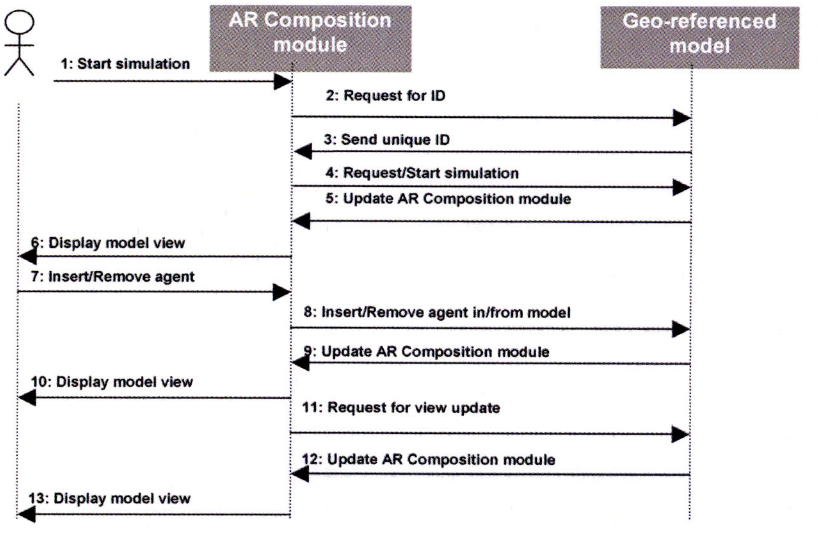

Figure 9-3 - Sample interaction with the geo-referenced model

Agents involved in this application can be pollutant sources, namely factories, swine farms, or water waste treatment plants. Moreover, the agents can be placed near a water stream or artificial lakes to assess the impact in water quality. Afterwards, a virtual sewage pipe is created to connect environmental agents at the nearest point in the water body describing the point where the environmental agents will affect the current region under analysis. If a pollutant agent is released within the range of a waste water treatment plant, the wastes are conducted to it and pollutant discharge is reduced.

9.5.b) Client

Despite the great evolution of mobile devices, namely increased battery lifetime, increased processing power, and decreased size of devices, some limitations persist, restricting user's experience while in a completely mobile environment. Since, simulations demand for processing power, the operations in the client are reduced to a possible minimum. The operations performed in the client side involve collecting the user position and orientation, superimposing additional information over the real images, and dealing with interactions from the user.

Each user is tracked via a GPS, to grab absolute user's position, and an orientation tracker, to obtain current user's head orientation. The orientation tracker used, an Intersense Intertrax 2, is sensible to disturbances in the ambient magnetic field causing superimposed information to float over the real image. In the future, it is planned to use position captured from GPS to reduce drift. Velocity vectors can be calculated based on user's movement, so this data can be used to correct information from the orientation sensor improving registration accuracy.

For this project, two versions of the client are in development: one for PDA and another for laptop computer client devices. For the PDA client device version the setup is formed by the following devices: HP iPAQ 5450 with Pocket PC 2002, Pretec CompactGPS, Lifeview FlyJacket i3800, Lifeview FlyJacket iCAM, Intersense Intertrax 2, Compaq iPAQ Serial Adapter Cable (3800/3900/5400 Series). In figure 9-4, a picture of the PDA setup is shown.

The laptop computer client device version setup is as follows: Laptop computer, Pretec CompactGPS, Phillips ToUcam Pro, Intersense Intertrax 2, and Cy-visor DH-4400VP. In addition, to provide the necessary mobility to the roaming users, a wireless network is used to connect the client and server module. Figure 9-5 shows the laptop setup.

Figure 9-4 - PDA Setup

Figure 9-5 - Laptop Setup

As described before, in each request the client sends all parameters in the URL to the server. All unknown requests received in the server are ignored, giving some robustness to the server. In table 10-1, all possible operations are described, starting with a base URL, namely: http://server.ip/request.xml?.

OPERATION TYPE (op=type)	OPERATION PARAMETERS	EXAMPLE
1 - Request ID	scr=x,y pos=lat,log,alt Ori=roll,yaw,pitch	http://server.ip/request.xml?op=1&scr=240,320&pos=0,0,0&ori=0,0,0
2 - Insert agent	id=user id type=agent type *agent type:* 1. Factory, 2. Suine farm, 3. Waste water treatment. scr=X offset,Y offset pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=2&id=0&type=1&scr=30,30&pos=0,0,0&ori=0,0,0&zoom=1
3 - Remove agent	id=user id scr=X offset,Y offset pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=3&id=0&scr=30,30&pos=0,0,0&ori=0,0,0&zoom=1
4 - New simulation	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=4&id=0&pos=0,0,0&ori=0,0,0&zoom=1
5 - Start	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=5&id=0&pos=0,0,0&ori=0,0,0&zoom=1

6 - Stop	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=6&id=0&pos=0,0,0&ori=0,0,0&zoom=1
7 - Update	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=7&id=0&pos=0,0,0&ori=0,0,0&zoom=1

Table 9-1 - Operation Description

In the registration step, when the client requests an identifier, a unique identifier is returned, stored in the client and sent to the server in all subsequent requests. This operation enables the server to uniquely track all users. All other requests return, to the client, an updated image of the geo-referenced model evolution, tailored to the user position, orientation, view mode, and screen size using base64.

Base64 encoding enables the server to send images in an XML file. By using HTTP and XML protocols, a wider number of client devices and programming languages can be used to develop new client devices for the system, also enhancing the modularity of the system. Figure 10-6, overviews the process of receiving the result from the geo-referenced model in the client device and displaying it on the screen.

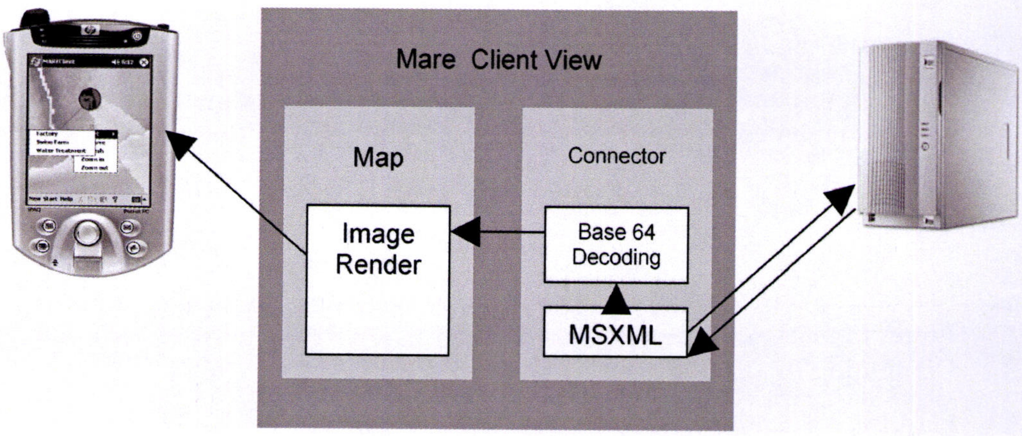

Figure 9-6 - Update Procedure

9.6. Conclusions and Future Work

For visualization and management of environmental changes, a client-server architecture is being developed to allow several users to work together in real time contextual simulations. Out of the labs, in the real environmental area under analysis users can have a more realistic view of the consequences of their different actions over the environment. A geo-referenced model and an AR composition module are the main modules of the system, enabling several users to interact and share experiences while using the system. Moreover, a demonstration of the system for the visualization of pollution dispersion in water streams and artificial lakes is under development.

Spatial superimposition of virtual objects where it makes sense leverages the users from the task of searching for the context to apply the retrieved information. However, it can be applied in other domains changing the geo-referenced model for the required purpose. In the future, a common environmental data source, namely a GIS, can be used to provide the geo-referenced model with additional data about the environment.

Indeed, the modular architecture facilitates the development of new modules for additional client devices or different geo-referenced models.

In addition, different clients with different screen sizes can also be easily used with the geo-referenced model. With the goal of providing a tool for the visualization of environmental changes to all users, interaction with the geo-referenced model is improved with the usage of templates representing pollutant agents or waste water treatment plants. Two interfaces are also in development to overcome the problems of each one.

Model simulation can be observed through two different views, also enabling users to view and interact with the system. In the first view, an animated map is used to interact with the model and provide a global analysis of the environment. The second view supplies an additional degree of realism with pollution dispersion in the user's vicinity superimposed over the real image. In the future, improvements in current modules should be made, namely the AR modules, either for PDA and laptop computer versions.

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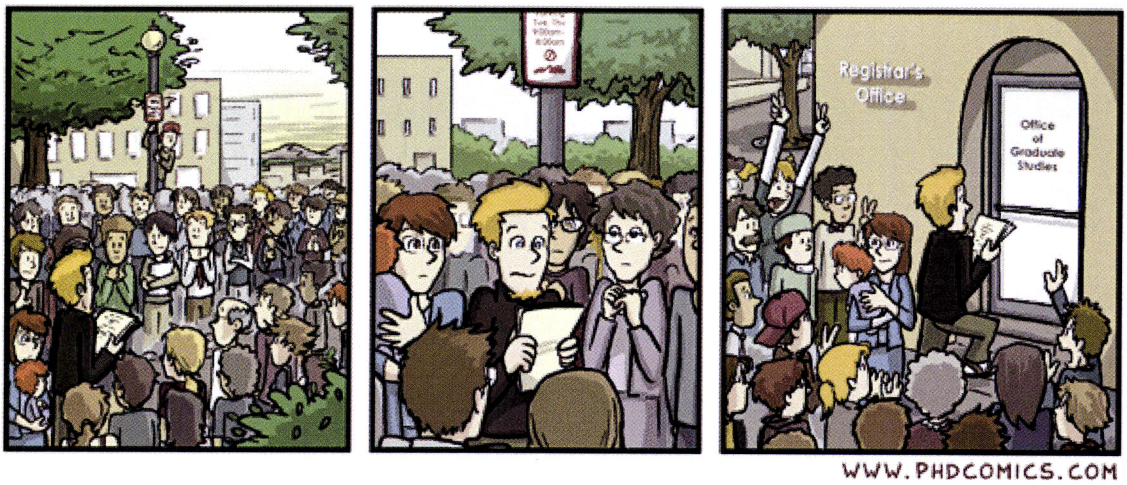

"Piled Higher and Deeper" by Jorge Cham www.phdcomics.com

10. AllienSpy – An Entertaining Augmented Reality

Abstract

This chapter presents a wireless augmented reality (AR) system for mobile phones and an innovative AR entertainment architecture. AR raised the expectations on the way superimposed information would enhance several activities, such as: tourism, medical procedures, environmental management, or entertainment. Until now, such expectations have failed to succeed.

The search for perfection, instead of usefulness, has lead research into bulky systems that retract any person to use it in their daily lives. AR can benefit from the recent developments in wireless technologies and contribute to develop systems with fewer or even no wires, also smaller and less bulky than actual systems.

The mobile AR system presented in this chapter is based in a modular approach applied to everyday mobile devices. The system transmits information wirelessly and tracks user's position and orientation. As a proof of concept an augmented reality game is in development. The

game is applied to the faculty campus and encourages the user to search for an alien mothership.

10.1. Introduction

Expectations were raised on how easy it will be to reach additional information related to the surrounding context, using augmented reality systems. In AR systems, virtual information appears combined with real objects improving users' perception of the real world and helping them to efficiently accomplish the task being performed. Applications dealing with medical visualization, specialized professionals training, entertainment, architecture and urban planning, environmental visualization, maintenance and repair, and annotation could benefit from this technology.

Nevertheless, some problems persist resulting in registration errors. Registration errors occur when virtual information is misaligned with related real objects. Misalignments can have a huge impact in the effectiveness of an AR system.

For instance, medical visualization applications can't accept misalignments in the registration of virtual information over real objects. However, for a large number of applications registration errors can be tolerated, not compromising the application.

Indeed, as stated by Coelho and MacIntyre [2] the assumption should be that registration errors are inevitable, instead of assuming that registration errors are due to tracking technologies and should be solved in the future. Therefore, AR systems should be developed targeting its usefulness instead of its perfection.

Typically, an AR system requires: a head-mounted display (HMD), a wearable computer, an accurate orientation tracker, and an accurate position tracker. The presented setup is cumbersome and reduces the mobility of the user, which is a requirement for some applications. Nevertheless, a good balance can be achieved, allowing some errors to occur within the system and also enhancing mobility and usability of the system.

To avoid burdening the user with heavy and cumbersome devices, there is the possibility to explore the usage of mobile devices in AR that, nowadays, a large number of users already carry, such as mobile phones or PDAs. Mobile devices can be a virtual window to the augmented world, displaying virtual information superimposed over the real image captured by the device. Indeed, it is common to find built-in cameras in mobile phones and PDAs.

In addition, mobile devices support some of the most used wireless technologies. Consequently, a special focus should be addressed to wireless technologies given that they can increase usability. One of the things that make current AR setups cumbersome is the large number of wires required to make the system work.

A common user would have problems to connect all the cables correctly. Possibly, a common user would give up before setting up the entire system. Nevertheless, wireless technologies can be used to search for neighbour devices and perform system setup. Thus, AR systems can be as easy to setup as a click in a program. In this chapter, a modular AR system based in a smartphone is presented, taking advantage of wireless sensors and built-in camera.

The AR system presented is suited for outdoor scenarios, where the environment can't be controlled. In such scenarios, tracking sensors reflect less accuracy, resulting in errors that can't always be predicted. Focus of the system is on usability rather then accuracy, thus registration errors can be tolerated not compromising the usefulness of the system.

In the next section, an overview of several projects, that inspired the current project, are discussed. Next, a system overview is presented, followed by a detailed description of the server, client, gameplay and game elements. Finally, conclusions about the work performed are presented.

10.2. Related Work

Mobile AR is a topic of growing interest, mainly influenced by a variety of highly portable devices with versatile computing capabilities. Until a few years ago, AR systems included a notebook computer, a camera, a head mounted display (HMD) and additional supporting hardware.

Usefulness was compromised, also requiring a high level of expertise from its users. The first mobile AR system, the Touring Machine, acted as a campus information machine. Users could query points of interest, such as buildings or statues, and could also request guidance to reach a location in the Colombia University campus [6,7].

Also focusing accuracy, AR Quake is an AR version of the Quake game. The AR version brought the game to the campus of the School of Computer and Information Science at the University of South Australia. However, the usefulness of the game is compromised by the large number of peripheral devices, sensors, and cables used [18].

The AR-PDA project is a marker-less AR system using handheld devices. The thin client uses a streaming mechanism to capture the user's field of view, sends it to the server, the server recognizes objects of interest in the image and sends the image back with augmented information rendered in the image. Nevertheless, vision based algorithms can be heavy when the system is deployed in larger areas.

ANTS is an AR project for environmental management providing geo-referenced information to the user. The system's architecture has a flexible design based on a client/server model, where several independent, but functionally interdependent modules are articulated. Therefore, modules can be moved from the server side to the client side or vice-versa, according to the client processing capacity.

The system is being deployed in laptop computers and Personal Digital Assistant (PDA) devices. A 3D model and a geo-referenced database are used in the server for user positioning, and presentation components are used in the client to superimpose synthetic information over real images. However, the system isn't tailored for entertainment lacking a game engine and a mobile client suitable for a gaming experience [14].

The Handheld AR project [17] developed an interactive, infrastructure independent, and, multi-user system architecture for AR applications. The system runs in off the shelf PDAs and uses vision-based tracking fiducials to calculate the position and orientation of the user. The system was demoed in several applications, namely Kanji Teaching, SignPost, The Invisible Train and Virtuoso.

However, only the last two applications emphasize the multi-user ability of the framework. The project enables users to have a complete mobile AR system in a handheld device, which was a large step in mobile AR research. For tracking purposes, Handheld AR uses fiducial markers to track object's position and orientation.

Tracking is based in the premise that fiducial markers can uniquely identify an object or location. Given the limitations of mobile devices, the system cannot easily be deployed in large areas and fiducials are harder to track at long distances. However, fiducial tracking is an important area of research and several projects are using them for mobile phone applications.

The Visual Code Recognition for Camera-Equipped Mobile Phones project is using off-the-shelf mobile phones to track fiducial markers, also exploring new interfaces using fiducial markers [13]. Marker-less applications like the classical game Pong, or Camera Controlled 3-D Wireframe were also developed, taking advantage of the mobile built-in camera and avoiding harming the environment with artificial fiducial markers [12].

Video see-through AR and optical tracking with consumer cell phones [8,9] is a challenging task, considering the processing power of mobile phones. Moehring et al. developed a prototype able to perform optical tracking and correctly integrate 2D/3D graphics into the video-stream captured by the phone's camera. In addition, in the PhoneGuide project, a lightweight object-recognition approach is used in the mobile phone to identify different objects. Therefore, the system is able to enhance objects in a museum with augmented information using little or no network connectivity [5].

The Siemens Virtual Mosquito hunt is another example of a marker-less game. In the game, user position doesn't enhance the gameplay, therefore optical flow techniques are used to track the phone motion. Afterwards, virtual mosquitoes are superimposed over the real image captured by the mobile phone camera.

As the user moves the camera, he or she can position a virtual crosshair over a mosquito and shoot it [16]. Consequently, mosquitoes don't have a relation to the real world and, the AR experience is compromised. Nevertheless, the game reached everyday users through their mobile phones exploring a new way of interacting with a game.

Nokia Research, through the Mobile Augmented Reality Applications project explores the use of camera equipped mobile devices and additional sensors, namely accelerometers, compasses and GPS to determine orientation and location of the user. The current prototype is explored through the Friend Finder application and the Location Finder application. The prototype supports a map based view and a video see-through AR view, enabling users to switch between them [10]. Therefore, by exploring mobile phones, GPS and a digital compass, the system has some similarities with the system presented in this chapter.

10.3. System Architecture

GPS sensors are an example of sensors that are already being developed with wireless facilities. Consequently, the cumbersome effect of carrying various cables to connect devices can be surpassed. This solution also requires the usage of a battery for each device and more power consumption for each device, due to the wireless consumption.

Nevertheless, that will enhance the information appliances concept, where small and simpler devices can connect and share information, taking advantage of each other features and being specially suited for the task they are designed for. Thus, in this AR system, there is a request for simpler devices that can efficiently perform their tasks and are easy to use. This can be an advantage for AR systems. If they are simple, easy to use, and less cumbersome, then more users will try to use them as an additional interface.

When combining all discussed concepts, such as less cumbersome outdoor AR systems, simpler devices, and wireless technologies widely adopted, than a mobile outdoor AR system using sensors connected through a wireless network is a concept requiring to be explored. Accordingly, this chapter presents an AR platform that explores the usage of mobile phones and wireless sensors for the navigation, management and study of outdoor environments. Additional goals are the usage of a new AR interface for mobile gaming, and a platform that can easily be adapted for different kinds of AR contents, namely games.

Mobile phones processing power is rapidly increasing, however their limitations for AR applications persist. Additionally, registration errors are the major problem in mobile AR systems requiring precise superimposition of virtual objects over real images. Some of the major problems identified are:

- Image registration, which refers to the accurate alignment of real and virtual objects;
- Camera field of vision should correspond exactly to the field of vision, in order to avoid changes in the dimensions (amplification or reduction) of the real world;
- Technological limitations: displays, trackers and AR systems in general need to become more accurate, lighter, cheaper, less power consuming, and increase processing power;
- Delays in the reception of wireless sensors values, and in communications with additional servers;
- Amount of data to transfer between wireless devices and wireless transfer rates of each technology.

With current mobile devices, and in outdoors scenarios, it is difficult to have a system that copes with all these issues. Indeed, a compromise can be achieved, in order to give an AR experience coping with some registration errors, less accurate sensor measurements, and delays due to technological limitations. The selected compromise should also consider the system usability, therefore leading to an easy and less cumbersome AR system.

The platform presented in this chapter, for outdoors scenarios, is based in a client – server architecture relaying to the server all main calculations, being the client mainly an AR viewer and sensor's reader. This approach allows the application of the system to operate in wider spaces, where the augmented world runs in the server-side, also diminishing the processing power required in the client. The presented AR client device comprises a mobile phone with Bluetooth facilities connected to a Game Server.

This approach intends to validate the mobile phone and its communication facilities as part of an AR architecture were minimal changes need to be perform in the client to cope with newer and different AR applications. In addition, the presented AR architecture improves usability by using wireless technologies to setup the system without major requirements from the user.

Therefore, the mobile phone will use its Bluetooth services to connect to two wireless sensors that will provide the 6 DOF required for this outdoor AR system. Namely, a Bluetooth GPS and a custom build orientation sensor with a digital compass, two inclinometers and a Bluetooth antenna are the selected sensors for the system. Nevertheless, errors persist in the sensors used.

GPS measurements can be affected by the number of satellites used to perform calculations, or by weather conditions. Indeed, the number of satellites used has a major impact in measurements accuracy. To overcome GPS errors, a GPS has been installed in a known location in the faculty campus.

The latitude and longitude related to that location is taken during an initial calibration of the system. Through this calibration step an average is taken to define the latitude and longitude of that location. Consequently, during the execution of the game this value is used as a reference point.

Afterwards, periodically GPS values, measured in that location, are used to evaluate the current GPS error. The error measured is than used to correct clients GPS measurements, sent to the server. This architecture mimics Differential GPS. However, it doesn't require the usage of such devices making it simpler. Thus, GPS errors are reduced, not compromising usability of the system and reducing registration errors. Nevertheless, additional sensors would be required to overcome additional limitations provided by the selected sensors.

Alternatively, the usage of fusion tracking algorithms to combine measurements and reduce predicted errors could be used, such as Bayesian filters (i.e., Kalman filters or particle filters [3]). To achieve a simplified solution these requirements were discarded, however, they can be implemented in future versions of the system, improving registration accuracy.

GPS devices, despite the associated errors, can offer 3-DOF. The remaining 3-DOF, needed for AR applications, ought to be supplied by other sensors. Thus, in the context of the project, a digital compass and two inclinometers were assembled in a single module to supply information about the missing 3 axis. Moreover, a Bluetooth antenna was also added to enable a wireless connection between the module and a Bluetooth enabled mobile phone. Consequently, a setup for mobile AR can be built avoiding cumbersome and difficult cable connections found in other AR systems.

For this setup, the following components were selected, as seen in figure 10-1:

- Nokia 6680 mobile phone
- Nokia Wireless GPS module LD-1W
- Digital Compass
- Two inclinometers
- Bluetooth Antenna.

Nevertheless, a big technological barrier in the development of such system is the ability to perform different Bluetooth connections with several client devices from the mobile phone model. Only recently mobile phones, such as the Nokia 6680, were launched with the ability to perform several Bluetooth connections. Therefore, to read data from sensors in two distinct devices, the mobile phone had to switch the single available connection between devices.

The process to connect two Bluetooth devices takes 1.28 seconds in average and can take up to 2.56 seconds [4]. So, this is a major drawback solved with the selected mobile phone. Another workaround to the problem is to develop a device with all sensors connected to the same Bluetooth antenna.

A first approach was developed with all sensors connected to a single Bluetooth antenna. However, this approach lacks the simplicity of information appliances where specialized, easy to use and low cost devices are developed to perform a task [11]. Consequently, a digital compass with two inclinometers connected to a Bluetooth antenna and a Bluetooth GPS was the preferred choice.

Figure 10-1: Client Overview

A description of the client device can be seen in figure 10-2. The constraints with processing power in the mobile phone lead to the development of a thin client. Therefore, data from the sensors is received in the mobile phone and uploaded to the server where the virtual world is running. This overcomes the limitations in the client's device computational power, allowing to enhance the game and to extend it to a larger spatial area.

Figure 10-2: Client Architecture

The server handles the gameplay and stores the information from every user playing the game. After an update of the user's position and orientation, the new status of the game is calculated. Therefore, the virtual world is updated and relevant information is retrieved and sent to the user. Afterwards, the information is superimposed over the view of the real world captured by the mobile's phone camera. Indeed, the mobile phone is committed to presentation purposes and user's interaction.

In the server side, a 3D model of the environment was built to model the environment and supply geo-referenced information (see figure 10-3). As a proof of concept for this project, a game is used to demonstrate the capacities of the system. The goal of the game is to search for an alien mothership.

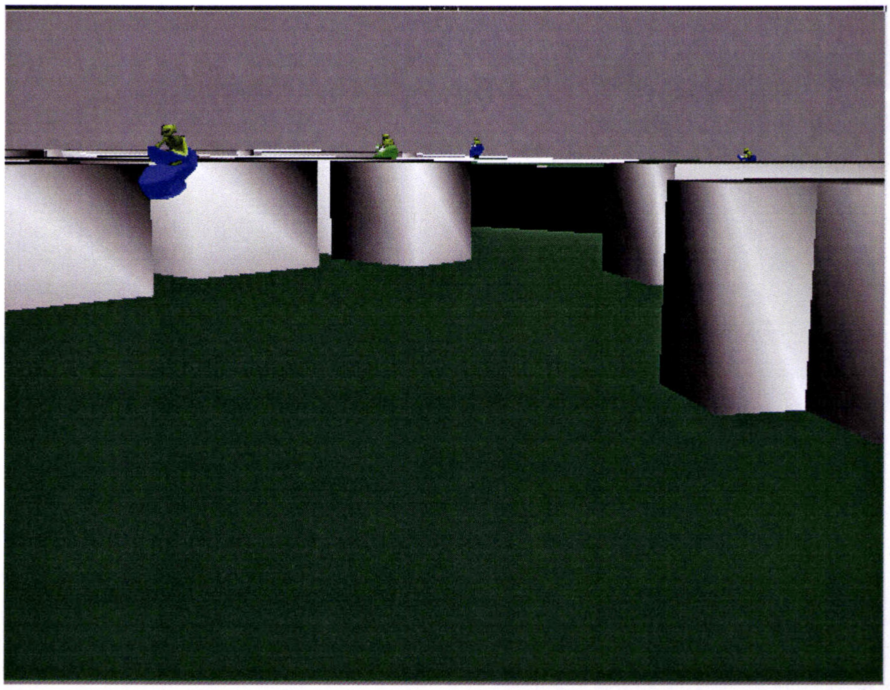

Figure 10-3: 3D Model

10.3.a) Server

The server was developed with Virtools Dev 2.5 [15]. This tool allows for fast development of 3D scenarios, since its main purpose is to develop 3D games and Virtual Reality systems. Virtools is a high-level visual programming language that can easily be used to develop 3D interactive applications.

In this programming language, blocks with specific functionalities can be connected by messages implementing the game functionality. Moreover, different graphs can be defined with inner blocks and messages implementing specific features. In addition, the 3D model used can easily be imported into the application through the tools supplied by this programming language.

In this prototype, the server has information about the gameplay and the 3D terrain model where the game takes place. In this case, the 3D model has information about the campus of the faculty. The building information was extruded from a 2D blueprint of the campus and used within the prototype without information about their precise height.

The 3D model of the environment performs a bridge between the real world and the virtual world. That relation is performed in a simple mapping between NMEA data, sent from the GPS device and correspondent locations with Cartesian coordinates, used by the 3D virtual world.

Since the space used for this project is reduced, a linear correspondence between NMEA coordinates and Cartesian coordinates, used within the 3D model, suffice. Moreover, an additional match is performed between the real world and the virtual world. When a user connects to the server, a virtual camera is used to simulate his or her view of the virtual scenario. Therefore, this virtual camera is set to describe the correct view of the correspondent user in the virtual world.

The match between values of sensors corresponding to the real world and the values of the virtual world, is performed through a custom matching performed in an initial calibration step. This calibration step was performed only once, in an ad-hoc fashion, and used across the project for the selected mobile phone. Nevertheless, the parameters of the virtual camera were also customized to match the parameters of the real camera used in the mobile phone. In a simpler approach for this prototype, the parameter used was the field of view (FOV).

Therefore, in the calibration process, an image is captured by the mobile phone camera and the FOV of the virtual camera is adjusted to match the FOV of the real camera. This simple approach is possible, because the nature of the application allows for some image registration errors.

During initialization, a 3G connection is performed taking about 30 seconds in average to perform. The interval varied, however, since that procedure was performed only in the beginning of the application, that restriction was considered as a loading task. Therefore, the connection time was not considered a major restriction.

After a successful connection to the server, users can interact with the virtual world through a set of messages corresponding to the possible actions in the gameplay. Users have to master their skills to look for the mothership and intervene with the game through different actions.

Therefore, to start the gameplay a startup message was set. Basically, this message is used to initialize all values within the virtual world. Afterwards, several agents, namely aliens, start moving across the virtual world.

The virtual world is a representation of the real world. Thus, all movements respect the allowed paths within the real world. Hence, aliens don't cross buildings and users can look at them studying the environment. Similarly, the user's position and orientation is updated with messages from the client's sensors and updated in the virtual camera set to the correspondent user.

This allows the user to visualize the virtual world as if he or she was really seeing it with his or her own eyes. Afterwards, that information is collected and an updated view of the virtual world is sent to the user. The previous set of messages only updates the current view of the user to the virtual world.

Indeed, the client can also send different actions to the server. In response, the server also sends an updated view of the game reflecting the actions performed by the user. Table 10-1 performs a summary of the set of messages defined for this prototype.

Updating the user's view is also a critical issue for the presented architecture. Consequently, two different scenarios are discussed and presented in this chapter:

- Send back an image of the virtual scenario to superimpose over the real camera's view in the client's view;
- Send a set of points describing the virtual agents and the movements performed by them.

Table 10-1 – Set of messages

Client	Server
Initialize – Asks the server to add the user	Initialize acknowledge – Acknowledge the successful addition of the user to the game, or an error otherwise

Info – Sends Information about sensors readings: GPS, compass and inclinometers	Game State – Update the orientation of the user within the virtual world and sends the current state of the game to the client
Action – Sends information about an action perform by the client	Game action state – Executes the action performed by the client within the virtual world and sends the current state of the game to the client

The first scenario is the simple one. The client sends updated information about its sensors or actions to be performed and, in response, the server sends an image with the current state of the game. However, the image update times were of up to 4 seconds in average. This update time is not enough for an augmented reality application, also leading to registration errors.

To cope with that, the client keeps refreshing the image captured from the real camera and sensors readings. Indeed, that information is the one used to reduce registration errors. Therefore, the virtual image stored in memory moves in the screen according to the updated sensors readings, and also gives the user a sense of real-time response from the game.

Changes in depth and position aren't considered, also simplifying the system. Nevertheless, when the image is panned in the screen, the user is presented with a view of the last updated state of the game, stored in the server, while continuing to read sensors. Therefore, giving the user the sense that the system is responding in real-time. Afterwards, when a new view is received the game state is updated.

In alternative, the client view can be updated with a set of 3D points, sent by the server, containing information relative to the state of the game in the vicinity of the user. Therefore, every alien is mapped to a 3D point, corresponding to its centre and sent to the user.

For this view, a 3D model of the world in the user's vicinity has to be developed, in the mobile phone. The 3D model has information about the position of each element within the virtual world, namely aliens and mothership. Afterwards, a 2D image is rendered over the real image based on the information contained in this 3D model.

In this model, x,y and depth are considered to correctly render a 2D image in each point. This approach is more versatile and allows for less information transferred between the server and the client. Therefore, faster updates are possible in the client and a more consistent approach is also possible, since more information about the virtual objects in the vicinity of the user can be used. Moreover, this approach also copes with larger periods of time without a good connection between the client and the server.

A major advantage of the first exposed scenario is that allows several augmented reality applications to be easily developed, only by changing the server. Minor changes would be needed to adapt the client for each new application. Although, the second scenario can supply faster responses in the client and a better experience, it would require major changes in the client since some of the game processing is also performed in the client. Figure 10-4 describes the architecture of this prototype.

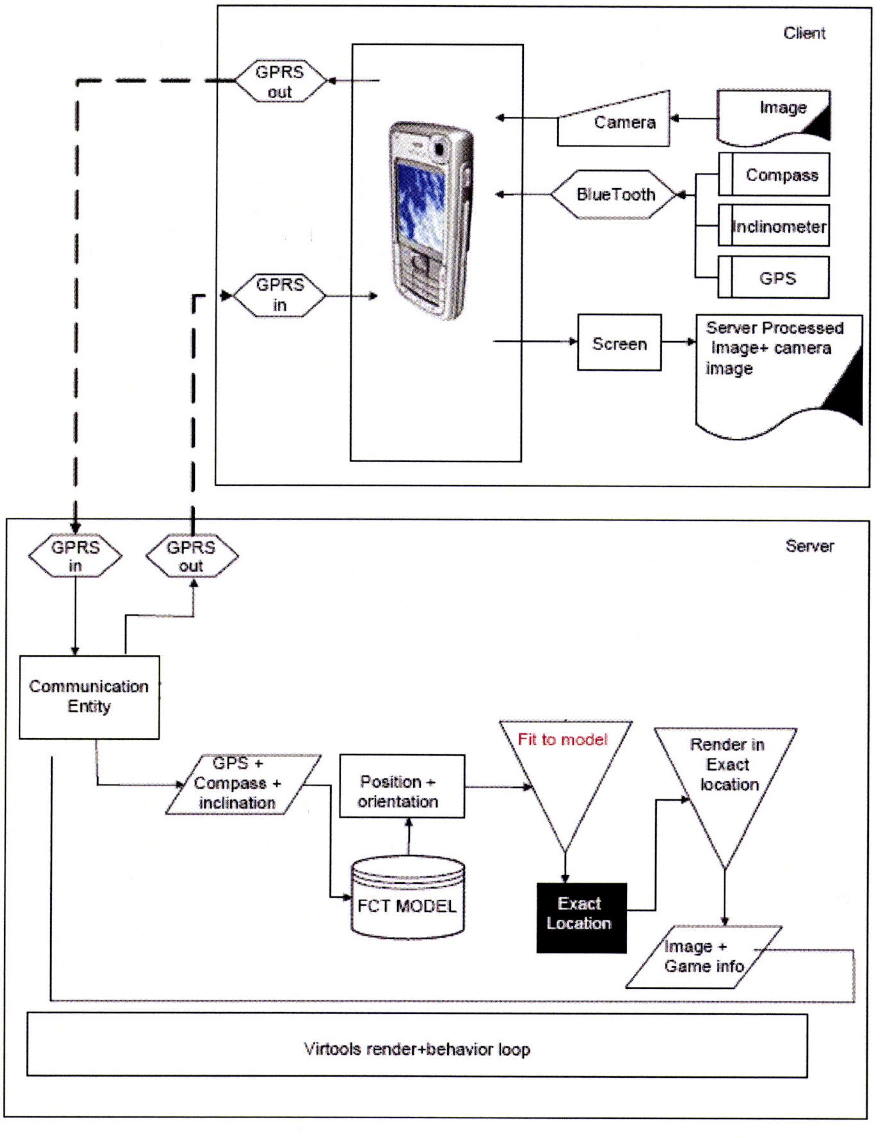

Figure 10-4 - System Architecture

10.3.b) Client

The client intends to be as thin as possible, leaving major calculations to the server. Nevertheless, the client should cope with network delays, sensor delays and image capture delays. In addition, the client should also supply an enjoyable experience to the user.

To cope with the described limitations, the client is always refreshing itself with the newest data available. Since the client was developed in Symbian OS (C++), several active objects were developed to:

- Read the compass and inclinometers values from a Bluetooth connection;
- Read NMEA data and parse it from a Bluetooth GPS;
- Update the image captured from the camera;
- Superimpose virtual information over the real image;
- Send data from the GPS, compass and inclinometers to the server;
- Receive information about the current state of the game.

This approach has lead to 6 modules performing the previously described functionalities, see figure 10-5. This modular approach allows for the replacement of these modules in the future, namely to include an indoor location system. Therefore, allowing this prototype to be used indoor.

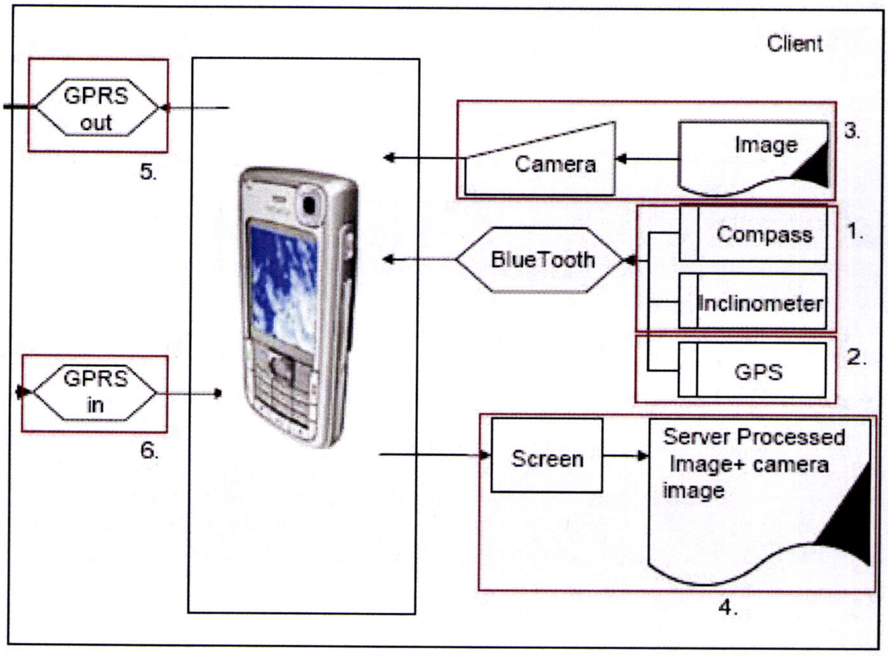

Figure 10-5 - Client modules

Another advantage of having a modular client is the possibility to integrate the system in a shape that enhances its functionalities and develop the system to afford its usage. This modular setup in the client allows for several interfaces to best fit the affordance of the system. If the interface can lead the user to the task it is designed to, than the system will be easier to use.

Therefore, the mobile phone, the GPS, the digital compass and the inclinometers can be included in a case that enhances the game features.

10.3.c) Gameplay

The main goal of the game is to discover the location of an alien mothership that has landed in the campus and established contact. Since, aliens have incorporeal bodies there is a request to use this prototype to detect their presence and movements.

Aliens have invaded our campus and are gathering information about humans. Scientist aliens are not hostile, but there is a request to find their space ship, in order to try to communicate with them. They float around gathering information about humans and users need a way to discover where they're stationed.

The system detects their presence and redraws the real image with an ectoplasm enhancement. Afterwards, the user could try to follow the aliens and figure out where the mothership is hidden. Nevertheless, aliens fly too fast. Thus, the user can try to target one and have their path recorded for a minute.

Some aliens pass by in their way to the mothership, but others don't. Thus, if the user marks too many creatures the paths will get confusing and the user will get lost. Aliens will only be outside the mothership for 10/15 minutes and afterwards the mothership changes its location.

Another thing to keep in mind is that, when an alien knows it's being followed it doesn't open the door of the mothership. Therefore, the alien does not expose its location. However, the user can keep an eye on stressed aliens.

To improve the game, another type of aliens was also added to the game. As soon as users start to track aliens, the ship starts to deploy another type of brainless warrior that track the ectoplasm detector and attacks the user. Warrior aliens don't kill, but temporarily interfere with the user's communications, making him or her blind.

Therefore, the user's ability to track aliens and find the mothership can be compromised. Several tricks can be used to discover the mothership and try to figure out their path across time.

10.3.d) Game Elements

Game consists in tracking the scientist aliens back to the mothership and establish contact. Below, there's a list of the behaviors implemented within the game for each of the characters involved.

Scientist aliens

- They appear everywhere in the University campus and go around gathering Information. They move around buildings and take notes.
- They will have a storage space for notes that will be Colour Keyed indicating if they are ready to go back to the ship [white Starting, Blue ¼, Green ½, Yellow 2/3, Red Ready to go home].
- The player is not informed about these colour keys, so they have to figure it out.
- They travel in short bursts of speed, making them impossible to track in real time.
- If tagged they leave a trace for 10 seconds and it will fade after 20 seconds.
- If a Player gets near than 15/20 meters of a scientist alien, it flees searching other source of studies.

Warrior aliens

- They are scattered around the university campus.
- They will never move directly to a place, they will always contour building trying to confuse the user.
- If a scientist alien is tagged the two nearest warrior aliens will converge to the trace as long as it exists.
- If they detect a user in a 50 meter range they approach and try to disable its equipment.
- They move in continues motion with 5 meters per second.
- The maximum distance for the alien to attack is 20 meters.
- Disabled equipment will take around 30 seconds to recover.
- Aliens cannot see the user when the equipment is disabled.
- It can be attacked by tagging him. A single tag will freeze it for 30 seconds. If tagged twice in less than 15 seconds it will be dissolved.

MotherShip

- The mothership is invisible.
- It changes position every time cycle (10 to 20 minutes).

- The ship is only visible when it accepts a scientist alien.
- If a scientist alien detects anyone in a range of 25 meters it will wait a few seconds (5 to 10)… if that detection is maintained it will go away to a place were it can gather resources and try to come back to the ship later.

Player

- The player needs to decode the color keys so it knows which aliens to follow.
- The player must tag the aliens and try to keep up with their trace.
- The maximum distance for the user to tag the alien is 30 meters.
- Must understand that if a scientist alien stops a few seconds somewhere means the spaceship is near.
- Must understand if an alien is aware he or she is tracking it.
- Must not tag to many targets, not causing confusion.
- Must dodge and run away from warrior aliens.
- If disabled or have a blocked path he must disable the warrior aliens.

10.4. Conclusions and Future Work

This chapter describes work in progress regarding a wireless augmented reality system for mobile phones. Indeed, advances in wireless technologies, built-in cameras, GPS, and orientation sensors were taken into consideration and explored, also enhancing the notion of information appliances.

The client hardware is built over simple modules, specialized in performing specific tasks. Therefore, the system is simpler and each device can be easily adjusted for additional usages. The presented architecture also explores the usefulness and usability of the system, coping with errors and delays from sensors or networks, and supplying the benefits of augmented reality technology.

The possibility to adjust client devices within a specific case is also explored to enhance system affordances, as well as the replacement of each system module to cope with the characteristics of the scenario were the system will be used.

Globally, the architecture involves a client-server architecture, where the server will take all major calculations and mobility is enhanced through the usage of thin clients. Nevertheless, two different approaches to update the client's view are explained, as well as the benefits of each approach.

As a proof of concept, a game was developed to explore the concepts presented in this architecture. The goal of the game is to find an alien mothership landed in the faculty campus, in order to establish contact with this alien specie. Aliens are incorporeal and roam across campus studying buildings and humans.

In future, thin client development will be finished and analysis will be performed for both methods proposed to update client's view. Moreover, usability tests will be performed to measure efficiency of the purposed architecture. Finally, the GPS error correction method will be measured to demonstrate its usefulness.

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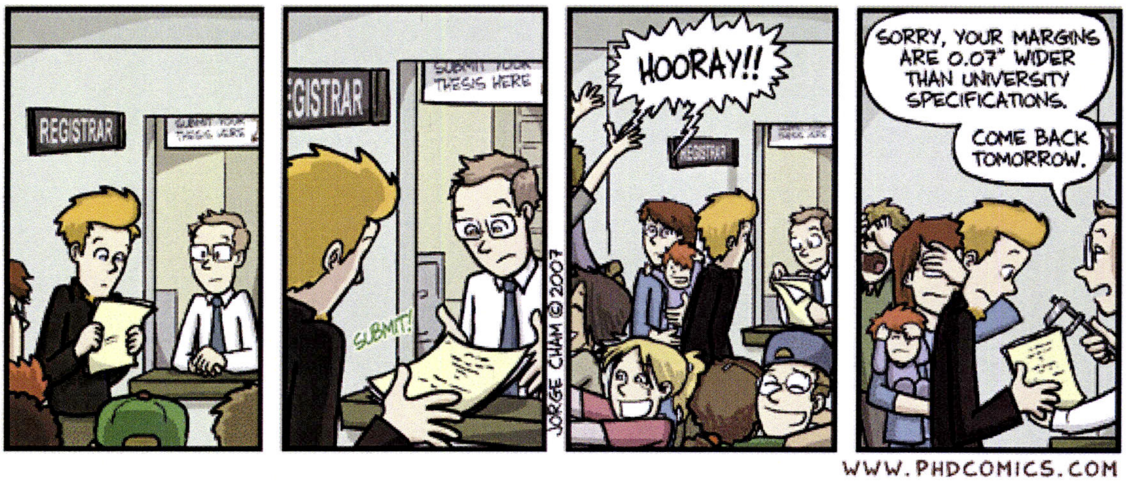

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11. Conclusions

Abstract

This chapter performs an overview of the contributions presented throughout this dissertation. The work reaches research areas such as ubiquitous, computing, augmented reality and location infrastructures. Future work is also outlined, allowing researchers to continue the work presented herein.

11.1. Introduction

This dissertation makes a number of original contributions in the area of mobile augmented reality, ubiquitous computing systems and location systems. The contributions described in this dissertation can be summarised as the development of augmented reality systems that can be applied in environmental management, integration of environmental models with augmented reality systems to access the impact of environmental changes, user interfaces for environmental management, architecture and variables to use in Bluetooth location systems, low cost location systems, location infrastructure for indoor location systems and mobile augmented reality systems for mobile gaming. These contributions have either been demonstrated with real world examples or are part of work in progress and constitute great value for future work. The contributions explained so far, open a wide range of future possibilities for new research and applications that may be used in scientific and commercial settings.

These unique contributions to the area of computer science are described in the following sections. These contributions form a solution to the problems associated with the three areas researched in this thesis. The introduction to this dissertation contained a set of eight research questions and five research goals. The contributions in the thesis constitute research towards the answers to these questions, providing a practical and demonstrated solution. Each of the goals outlined were used as principles during the development of these contributions and guided their development.

11.2. Bluetooth Positioning

Several Bluetooth location systems have been developed during the development of this thesis. However, this contribution shows the benefits of a server-side architecture and how Bluetooth location systems can be developed to take maximum advantage of an already deployed technology.

Therefore, several parameters and problems of a Bluetooth location system were considered and compared. The evaluation of these parameters, namely RSSI, bit error and connection time, intend to guide developers and designers to select the best solution for each problem.

In the tests performed, the connection time to a Bluetooth device has not supplied a relation with the distance, and bit error could not be used. However, RSSI measurements were evaluated showing that RSSI can be used to provide a distance estimation of the Bluetooth device to the BTAP. Indeed, to improve accuracy different models for each Bluetooth device should be used and considered. The usage of a general model can also be a solution, although accuracy will decrease.

The solution explored in this thesis, allows navigation with 3 degrees of freedom (3DOF), namely x, y and floor coordinates. However, BPoSS does not limit the user and developers of location systems to geometrical coordinates. BPoSS can also be used with symbolic information. Symbolic models can handle easier operation with sets, namely containment, union, interception, also making them more intuitive in the development and usage of location based services.

Indeed, when just the symbolic model is used the effort needed to develop new LBS is reduced. The proposed architecture also allows the system to grow easily and use already deployed Bluetooth networks.

11.3. Location Infrastructure

Location and context awareness lack a common infrastructure that eases development of applications exploring such features. Outdoors, GPS is almost ubiquitous, therefore used as a standard infrastructure for outdoor location-based applications. Indoor and in mixed scenarios there is a lack of a widespread infrastructure that can serve as a basis for such applications.

Given that, this dissertation identifies a common infrastructure and explains how it can be developed. Moreover, research location modelling is still in its infancy. So, extensions and new paradigms to model location need to be developed to take advantage of the widespread use of small, mobile, and ubiquitous computing devices.

Geometric models are often explored in location-based systems. However, symbolic models can easily provide relations between objects, enabling developers to easily query the location model based in objects symbols and their relations. Thus, suitable representations of models, as well as their integration in location or context-aware systems, are open problems that will derive future developments.

Finally, user's privacy is an issue of major importance. Several aspects should be addressed then: whether to add privacy constraints to the representation model or, design the system to avoid that issue.

11.4. Low Cost Location-Based Services

Location-based applications are already deployed for consumers to use. However, indoor location-based applications have its success compromised by the costs of deployment and usage. This thesis makes a contribution towards the development of an infrastructure that can be easy to deploy and use, and also bringing together low costs of deployment and management.

The low cost location system proposed in this thesis can easily and affordably be deployed in several locations, improving the users' experience when exploring these physical spaces. Scalability of the system was another issue explored in this solution to augment the coverage of the system and even include newer devices. The solution also integrates a compass, supplying orientation and allowing for the automatic selection of the most relevant information to the user.

Therefore, the amount of information supplied to the user is reduced from the information about the user's vicinity to the information about the specific POI in front of the user. Another advantage of the solution presented in this thesis is that it works indoors and outdoors making it suitable for a wide range of scenarios.

Accuracy and suitability of the system is also explored in parallel. The solution can be as easy to use and manage as well as accurate. In the basic approach proposed, there is no need to tell the system the exact physical location of a POI or object. The administrator only has to bond the tags with the related data content to be supplied to visitors. Moreover, the relation between each tag ID helps to navigate within the visited location, thus resembling a symbolic location model approach. For more accurate scenarios, triangulation can be used as well as geometric or hybrid location models.

11.5. Buildings and Subsoil Augmentation

In this dissertation there is also a major interest in developing systems and interfaces that can be applied in environmental management. Augmented reality systems where explored and developed to support in loco observations and provide the user with additional knowledge about the surrounding environment. The proposed infrastructure should be effectively used to visualize and manage information, as well as to locate and identify objects within the user's field of view. Therefore, it eases and enhances interaction with the involving spatial area and its natural and artificial components.

Two interfaces where explored, one for a laptop computer and another for a PDA. The laptop-based interface can provide the user with an immersive experience. However, the system lacks some usefulness given the calibration steps and infrastructure needed to make it work.

Alternatively, the user can handle a PDA, allowing him or her to directly observe the environment, and watch the PDA for additional information. These tools are evaluated in two different applications: information related to superficial solid structures, and the structure of the subsoil.

11.6. Mobile Environmental Visualization

Environmental management includes the forecast of environmental changes and how to assess their impact in the life of citizens. Therefore, it is often needed to assess and visualize simulations of environmental changes, namely pollution dispersion, to prepare and train resources to reduce negative impacts of such changes. Moreover, it is often required that team members contribute with ideas in real time for such simulations.

Indeed, working in the real environment under analysis, outside of a research lab, users can have a more realistic view of their actions' consequences in the environment. A geo-referenced model and an AR composition module are the main modules of the proposed system, enabling several users to interact and share experiences while using the system. A demonstration of the system for the visualization of pollution dispersion in water streams and artificial lakes is under development.

Virtual objects are superimposed over real images where it makes sense, leveraging users from the task of searching for the related context and retrieving information. This metaphor can be explored by adjusting different geo-referenced models regarding the domain of the problem. Therefore, it is easier for users to assess the impact of their actions.

A modular architecture for the system is proposed easing the development of new modules for additional client devices or different geo-referenced models. Different geo-referenced models can be used to assess the impact of different environmental changes, or possibly a combination of different geo-referenced models to assess different scenarios. However, users can also assess the evolution of environmental models through different devices, mainly with different screen sizes.

Therefore, the server allows clients to select the screen size and zoom level to best fit their specifications and required level of detail. Moreover, a template system was developed to represent different agents within the geo-referenced model and provide a standard way to visualize agents, namely pollutant agents or waste water treatment plants, between different platforms. In this system, it is also possible to use two different views to observe the model simulation.

In the first view, an animated map is used to interact with the model and provide a global analysis of the environment. The second view supplies an additional degree of realism with pollution dispersion in the user's vicinity superimposed over the real image.

11.7. AlienSpy – An Entertaining Augmented Reality

AR allows users to access information that isn't directly accessed by human senses. However, AR is still in its infancy and rarely gets out of research labs, barely reaching the final consumer. The registration problem, resulting namely from sensor errors, sensor delays and different interferences, is far from being solved. Therefore, augmented reality systems are distant from final consumers.

However, some applications can tolerate errors also supplying a thrilling experience to users. This thesis contributes with a work in progress regarding a wireless augmented reality (AR) system for mobile phones. Advances in wireless technologies, built-in cameras, GPS, and orientation sensors are taken into consideration and explored, also enhancing the notion of mobile appliances.

The architecture of this contribution involves a client-server setup, where the server will perform all major calculations, taking advantage of the mobility of thin clients. In addition, this architecture also explores the usefulness of the system, coping with errors and delays from sensors and networks, but at the same time providing the benefits of augmented reality.

This contribution also explores a modular approach allowing modules improvement in an independent way, explores two different paths to update information within mobile clients, and suggests the exploration of systems affordances to enhance user's experience.

11.8. Future work

All contributions performed throughout this thesis form the basis for additional and future work. It started with the work in project ANTS, exploring AR systems for environmental management. The work performed in this phase easily jumped into further problems, also explored herein.

When considering Bluetooth as the technology to use to track persons or objects, work can be undertaken to improve accuracy and use different models for different Bluetooth devices. Moreover, case studies to evaluate the usage of Bluetooth in real scenarios are required.

In addition, how location is modelled is also another interesting research field, how to better retrieve information related to the objects or persons being tracked in a location system and the possible relations between them. An engine within the infrastructure, possibly with a defined language, able to answer about the possible relations would also be an interesting point of research. Given that relations across time change, a system that can compute relation among persons and objects in real-time is also another interesting field of research for the future.

Location systems are a required infrastructure but if the costs of deployment and management are too high? Then decision makers will drop their acquisition, also making users apart from such solutions and their advantages. Therefore, newer solutions should be searched to lower the costs of such systems as well as solutions to ease their deployment and maintenance.

Chapters eight and nine explores augmented reality applied to environmental management. Future developments include improvement of the referred prototypes and applications, as well as the development of the system's remaining components, namely the integration of an image tracking module. Additional developments for supporting mobile phones are also planned. For the PDA, future improvements in modules should be made, namely the AR modules. The presented system can also be studied to integrate common environmental data sources, namely a GIS, to provide the geo-referenced model with additional data about the environment.

Chapter ten presents a lighter and wireless augmented reality system. This work constitutes work in progress. Therefore, the client requires improvements, namely in the update frame ratio, superimposition method and exploration of affordances. An important goal is to release users from having to connect an enormous amount of cables to operate the system. Moreover usability issues as well as social acceptance are also considered issues by using common and everyday devices to supply an augmented experience.

Anex i presents topics of research for the future, namely privacy, social and context issues. In fact, location is an important variable to consider in context, but other variables such as time, temperature and user preferences can be further studied to provide a base for better and well tailored applications as well as services to be provided for users. Social and privacy issues should also be further studied and developed in the future to better drive future research. Moreover, the development of a compelling and easy to use interface will be a major point of interest to define rules used in conflict resolution between user's preferences and will improve the success of such systems.

11.9. Final remarks

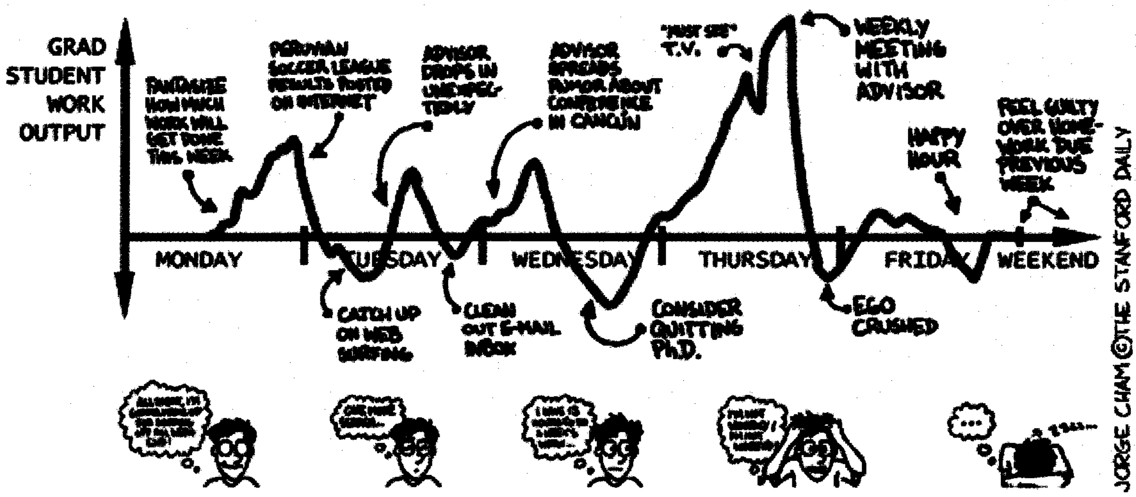
Despite significant work has been done AR, location systems and ubiquitous systems are still research areas with a large margin for evolution. Throughout this thesis, a number of contributions to these fields of research are presented but further research needs to be performed to enhance users' experience while using different devices.

The limitations found in actual systems where also presented throughout the thesis, in order to derive solutions to shorten the path to develop systems anyone can use. It was stated that some limitations can be accepted, allowing for the development of new solutions. Thus, users' experiences can be enhanced and their feedback can be used to drive future research.

In addition, spaces that can react to user's presence, supplying information presented in a more intuitive way and explore the different problems of everyone's life are just examples of further research. The usefulness of each system as well as privacy issues should also be considered to increase the acceptance of newer technologies among users.

Concluding, recent achievements, in the discussed areas of research, and the increasing requirements of users, have drawn a good path for research. Thus, context awareness, location systems, ubiquitous systems and augmented reality are fields of research that can enhance users' everyday life.

Anex 1



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1. What about context

Abstract

Location is an important facet when you want to add context to applications. Indeed, mainstream technologies, such as mobile telephony, or GPS, are using location information to target information to users. However a question is raised: Is it enough? Obviously, there's always the need to further improve applications and the way context is sensed.

Dey and Abowd define context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." Consequently, location, and further elements can be used to improve context. However, it is commonly accepted that computers cannot make use of context information (e.g. location, time, temperature, and other persons nearby) as easily as humans, and, consequently, adapt to new situations.

Nevertheless, a learning period for several context-aware applications can greatly enhance the possible services offered to users. An application that knows its user preferences' can accurately target information related to a specific context. The opportunities for context-aware applications are here, only stopped by privacy issues that need to be handled, so that a further step can be done for this type of applications. Brown et al. advocates that a killer application is

required to achieve credibility in the market place and surpass the "prototype" and "pilot" label. Furthermore, a killer app in the context-awareness field may set the right path to a compromise between privacy of its users' and functionality.

1.1. Introduction

In the majority of cases, mobile devices provide access to information processing and communication capabilities, but lack any awareness of the context in which they operate. "Context-aware" computing describes the special capability of an information infrastructure to recognize and react to the real world context in which it operates [4]. Location and identity, as well as time and activity, are primary aspects to describe the context that a user or device is in.

Context awareness can then be achieved in two ways:

- in real time, having the system constantly tracking the environment, or
- by request, asking the system to retrieve the context.

Richer location-aware applications require real-time tracking of context, while others may be based in a by request approach.

Until some degree, context aware systems are systems with the ability to react based in the user's current context. When a change occurs, the application reacts accordingly. For that matter, an infrastructure is needed to capture the current context and context memory [1]. In Brown et al, current context is captured in a network of sensors, each one capturing different elements of the environment. Nevertheless, it is also important to perform further judgements, or interpretations based in past actions performed in the environment. Thus, context memory needs to be stored in the infrastructure to allow future inferences, namely infer about a person's preferences.

In Dey and Abowd [5], their work about a context-based infrastructure for smart environments, specified a module to capture current context and context memory. The infrastructure is based in sensors, widgets, servers, interpreters and, finally, applications. Widgets are modules responsible to capture context and also store past readings of sensors. In resume, sensors are responsible to capture events in the environment that are kept in widgets to supply a transparent approach for sensor details. Servers kept a record of a person or object details, namely preferences, as well as a list of widgets to connect to capture required details. Finally, interpreters used widgets to infer about future context based in past actions.

Communication between modules requires a subscription and notification scheme that fulfils some requirements of context-aware applications, also using HTTP and XML protocols but simpler and lighter applications are often required, even in a "home" scenario where details can be controlled. For that matter, a description of a simple lightweight infrastructure for proximity-based services in a home environment is provided in this chapter.

The main goal for the system is it simplicity and functionality. While in the proximity of an action space, the space should react accordingly. Moreover, the system can be further extended to address issues such as learning based in past experiences. Nevertheles, privacy issues and social acceptance are presented to serve as guidelines for context-aware systems to be accepted.

In the following section, social issues are addressed discussing issues that may lead to the success or failure of some applications. Afterwards, related work is presented. Following, the project is presented, and finnaly conclusions and future work.

1.2. Social Issues

Social acceptance is the final challenge, as mentioned by Azuma et al., in [6]. Thus, the question is: Once ideal hardware and acceptable interfaces are found how will context-aware systems enter people's everyday life? Indeed, fashion and privacy issues may restrict usage of such devices.

Feiner [7] describes some social consequences of wearable computing systems, namely social influences in tracking accuracy, the importance of appearance and comfort, increase of collaborative applications, integration with other devices, and implications with personal privacy.

Location information as well as the entities allowed to access that information have raised numerous questions related to privacy. The technology is already in the field, used when functionality surpasses privacy issues, but what about everyday usage?

Social protocols may restrict what kind of location information is shown, and to which peers it is conveyed. As stated before, high accuracy tracking may be seen as a technical issue more important than social protocols, given the practical development of more accurate location systems.

Furthermore, with the increasing number of sensors, hybrid tracking systems are required for seamless indoor and outdoor usage. Those systems should incorporate vision, inertial, magnetic, radio-based, or other technologies, directing each to the environment that best fits its characteristics. Indeed, the ability to seamlessly go indoor and outdoor seamlessly allows users to be mobile and leave behind their desktops, improving collaborative work: mobile computing can be present in every activity and needed information will be easily accessible everywhere.

Certainly, the future will raise new paradigms of human interaction, where location information may be used to improve remote conversation and be a better approach to face-to-face conversation. For example, tracking information about a user's hand, head, or other things may be used to improve interaction. It is commonly accepted that face-to-face conversation has several advantages in collaborative work applications; so context-aware applications should also account for this issue.

Another interesting aspect is the number of specialized devices used by each person, and in different scenarios, namely mobile phones, PDAs, game consoles or multimedia devices. These devices are already accepted in our society, and can be enhanced with context information. Such devices are able to exchange private information between them and the infrastructure.

In fact, information exchange is already performed but more powerful and simpler protocols need to be used to attract its usage by everyone. Furthermore, how is this information exchanged? What rules and protocols should be used to invite people, and their devices, into a mobile collaborative group? Interfaces must change so that inviting another participant to a mobile collaborative group is as easy as it is in an unaugmented conversation. Voice, face, hand and body language must used in the same sense as in a normal conversation.

In the end, users will end up devices able to record everyday information, valuable to others than just themselves: images, sounds, locations, ... Thus, a set of rules are needed so that users can be comfortable with the usage of all these technology.

1.3. An intelligent home

Let's face the fact, intelligent systems are becoming more appealing nowadays. Projects such as: Aware Home [2] and "A Casa do Futuro Inclusiva" [3] are real showcases of technology that can be applied to an intelligent home. Furthermore, the X10 protocol has improved interconnection between devices in such scenarios, using the existing electrical wiring for device-to-device communication.

An intelligent home may focus on a variety of aspects: reuse of natural resources, security, and energy efficiency, to name a few. In this chapter, the project focuses in device automation and context capture.

For that matter, humans, for long, dream with an intelligent house that captures its inhabitant's presence and reacts according to their unique preferences. This house is a shared space between its inhabitants with different preferences, where each one has distinct ideas on how the house should best fit his or her requirements.

Thus, this project suggests that an intelligent home should supply an enjoyable experience to their inhabitants, creating profiles and priorities able to solve conflicts in a shared space between its inhabitants. To achieve these goals, "action spaces" were defined where house appliances have the possibility to adapt themselves and react to the proximity of each inhabitant.

For each "action space", a person's profile and priority are identified in real time, and, without direct intervention from the inhabitant, the space reacts according to this previous knowledge. Therefore, each inhabitant will be able to travel across the house, throughout the different spaces, always having his or her preferences set for each space. Nowadays, spaces detect presence instead of identity, thus to take advantage of improved context, further and newer sensors are needed for the next step of context-aware systems evolution.

Bluetooth and Zigbee are technologies that fit into fast and accurate identification of people and devices. However, Bluetooth is embedded in various devices that already take part in our every day life, which makes this the best choice for this purpose. Moreover, by choosing Bluetooth, and taking advantage of already deployed devices with this technology, social acceptance issues are already surpassed.

1.4. Project description

This project is a future work project, no development has been performed. The goal is to retrieve the identity of a person achieving a particular "action space" through the usage of a device that is unique and personal. When an individual proximityis discovered an action starts. Therefore, mobile phones are the best candidates for this purpose.

Almost everyone carries mobile phones in pockets or bags, thus in close proximity to the body. Therefore, a relation can be inferred between device's location and person's location. Even indoor, the relation is maintained.

This project presents a base system that can be used in smart houses to enhance context and take advantage of the concept of "action spaces". Moreover, the concept can be further extended or even used in different scenarios. However, developers should be aware of the Bluetooth limitations, presented in the chapter four. Additionally, this concept can serve as a base for different applications in an intelligent home dealing with context issues.

Proximity, identity and automatic conflict resolution can be important in shared spaces, such as an intelligent house. As a concept scenario, let us imagine a living room scenario. The living room is a space shared by all members of a family, however at specific moments in a day different settings can be defined to best fit family members' preferences and priorities.

For example, on a weekly day afternoon, children like watching cartoons. Therefore, during these periods, when children approach the TV, it starts playing cartoons even if the parents are present. Similarly, on a Sunday afternoon when the father is in the living room, the TV would switch automatically to a sports channel, despite the presence of other family members. Further different settings and priorities can be set to best fit each family member's preferences and solve conflicts in an automatic way.

To set up such settings and priorities in the system for specific action spaces, there is a request for an application to input that information. Therefore, an intranet web site can be developed with possible actions, spaces and profiles to delineate all rules. Even while setting preferences, conflicts can appear, thus a similar scheme resembling the priorities in an operating system can be defined. In-house parents define rules, thus they can set all possible rules for their children. In the operating system metaphor, they are seen as administrators.

According to the defined rules, each action space will identify all family members in it, use the preferences and priorities engine to solve conflicts, and start a predefined action. As a case study, this project intends to develop a simple version of the system with three boards where information is displayed according to the preferences of each family member. The boards can be configured to show a to-do list, news related to the family members preferences, or even pictures according to their preferences. Each board will have an action space and will react according to nearby family member's preferences, automatically solving conflict situations.

With this project we intend to promote the idea of a house constantly changing to best fit their inhabitant preferences. Bellow, in figure i-1 it is possible to see a description of the purposed application.

The proposed infrastructure can serve as a proof of concept of the idea. In addition, different scenarios, namely museums, can take advantage of the concept to target special information to people or improve the environment for their preferences.

1.5. Conclusion and Future Work

This proposed project intends to enhance a human machine interface, where the presence and identity of the user is important since it triggers actions in the system when in the presence of an action space. The space can be configured to dynamically change to best fit the user's preferences, also enabling the system to solve possible conflict situations. The proposed first step of the project will serve as a base and proof-of-concept which will be further improved to show the potentialities of the system. The development of a compelling and easy to use interface will also be a major part of the project since it can compromise the success of the system.

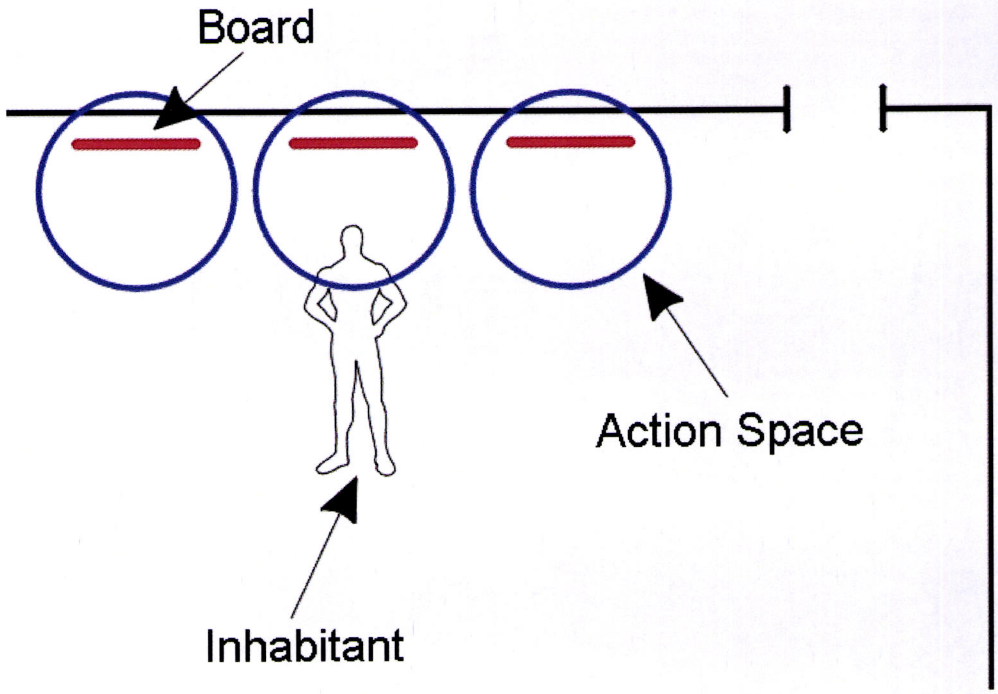

Figure i-1 - Application description

1.6. References

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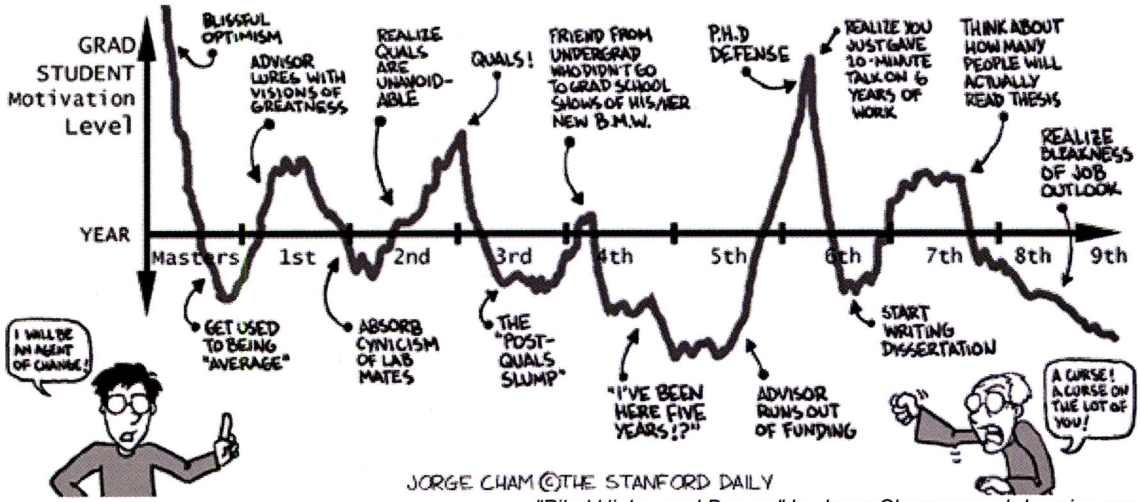
Anex 2



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2. Main Published Articles

BPoSS – A Bluetooth Positioning System

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ABSTRACT

This paper presents an experimental evaluation of a server-side Bluetooth positioning system, named BPoSS. The system is able to track the user in three dimensions, (x, y, floor), and is independent of the Bluetooth access points being used. This ability allows the system to grow when needed and gives the opportunity to use the existent network topology, if available. Moreover, several distinct areas with Bluetooth coverage can exist and the system is able to track the users seamlessly.

The distance of the user to an access point is performed measuring the Received Signal Strength Indicator (RSSI) and using an estimate to the related distance, or using pre-calculated values when measuring RSSI is not possible. User's position is determined afterwards using the triangulation method described in [1].

To improve radio usage, BPoSS is a server side system able to provide geometric and symbolic information. Thus, the process of developing LBS applications is quicker, where geometric information is not an important issue and symbols can identify all points of interest.

I. INTRODUCTION

With the increasing popularity of mobile computing devices, position based services become more significant. New application possibilities can then be developed to take advantage of mobility. The Global Positioning system (GPS) and several methods in Cellular Networks, such as Cell-ID, and TDOA, are being used to track users. Although these methods are not suitable for indoor applications, wireless network technologies available worldwide, such as Bluetooth, can be used to track users indoor.

Bluetooth was developed as a cable replacement technology, with promising features, such as: low power, short range, and the ability to be used in the creation of several wireless services. This technology operates in the 2.4 -2.483 GHz band, known has the Industrial Scientific and Medical (ISM) band, which is available unlicensed in the majority of countries, making Bluetooth available worldwide.

Bluetooth Core Specification v1.1 does not specify any positioning service [2]. Nonetheless, Bluetooth local positioning workgroup is developing a Local Positioning (LP) Profile Specification in order to define a mechanism and formats for the transfer of position-related data over Bluetooth. This profile will allow for interoperability between Bluetooth-enabled devices supporting the LP profile.

Generally, to connect to a specific service in another device, the client should [3]:

- Perform device discovery to find devices in the area (Inquiry);
- Perform service discovery to get information on how to connect to services on each device discovered;
- Choose a service to use, and use information obtained during service discovery to connect [illegible]

To inquiry devices in range, the inquiring device (IQD) sends a series of inquiry packets in different frequencies. The IQD changes frequency 3200 times per second, allowing it to cover a range of frequencies as rapidly as possible.

The inquiry scanning device (IQSD) changes frequency every 1.28 seconds in order to minimize interference and to have a good strategy to be found by inquiring devices. When the IQSD receives an inquiry it waits a random [illegible] period of time, then if it receives a second inquiry, it sends a Frequency Hop Synchronization (FHS) packet, which tells the IQD all relevant information needed to establish a connection. This scheme avoids a high-power [illegible] pulse of radiation in the ISM band, if a synchronous answer occurred.

An average inquiry process can take 3-5 seconds and can take up to 10.24-30.72 seconds. In addition, to connect devices, they must be in page and page scan mode, respectively; the paging device initiates the connection and the page scanning device responds. This process takes [illegible] seconds in average and can take up to 2.56 seconds.

In total, a connection between two Bluetooth devices takes 4.28-6.28 seconds average and can take up to [illegible] seconds. Many technologies also operate in the unlicensed ISM band, which results in interferences between them and consequentially decreased throughput, longer connection times, and less frequencies available. Namely, these technologies are: IEEE 802.11b and g, Home RF, [illegible] Digital Cordless Communications (DECT) variants and some handheld short-range two-way radio sets.

Additionally, there are problems with signal [illegible] distance and blockers. Blockage is due to the [illegible]

of each object, the more water an object has, more blocking effect the object will have.
Unintentional interferences from other sources can also be found, such as: microwave ovens, high-power sodium lights, thunderstorms, overhead cables, communication channels in other bands – e.g. GSM and, spark generators such as poorly suppressed engines.
This scenario gives an idea of how crowded the ISM band can be. Furthermore, when several near Bluetooth devices are performing an inquiry operation, interference between them will increase the time needed for the operation to complete, also decreasing the expected results. Thus, the [illegible] is using the maximum possible range of frequencies in the Inquiry process to surpass the problem.
This is the main reason why this Bluetooth positioning system is developed server-side. The number of inquiring devices is known, minimizing radio usage. Other main characteristics are: any Bluetooth device, in discoverable mode, can be tracked with no modification; location Engine is independent from the Bluetooth AP being used and ability to track users in a geometric model or in a symbolic model.
In the next section related work is presented and all aspects that encourage this project are pointed out. Section III gives an overview of the entire system and describes each component of the system. Next, section IV describes measurements performed to describe radio behaviour. Conclusions and future work are presented in section V.

II. RELATED WORK

Research on how to track users with Bluetooth technology is in its infancy. Indeed, there are several research efforts using Bluetooth for positioning purposes with alternating conclusions.
Hallberg et al. [4] developed a positioning system where a user requests for a positioning service in all neighbouring devices, and then requests for their positions. Next, triangulation is performed using a defined cell size. In this work, Hallberg et al. assume an unreliable relation between signal strength and distance, and use a fixed value to perform triangulation.
Another work by Feldmann et al. [5] consists in the development of a Bluetooth positioning system based in the relation between RSSI and the associated distance between sender and receiver. Distance is modelled with an empirical model to overcome fading, shadowing, reflections and blocking problems of the radio signal. The client measures RSSI value between itself and three access points. Afterwards, triangulation is used to estimate the estimated position.
[illegible] et al. [6] have another work with Bluetooth using a symbolic model to track users at room level. A database is used to track users and a Webserver can be used to retrieve that information.
Kindberg et al. [7], from the HP Cooltown project, developed the sense of Web presence. In this project, web servers are placed into objects and information about objects is placed in web servers. Thus, a bridge between real world and World Wide Web is built. Indeed, URLs are beamed to user's wireless devices, allowing them to retrieve additional information about their current location. Thus, Bluetooth and IrDA can be used to beam URLs to users.
Additionally, there are commercial systems using Bluetooth to track user's. Blis4Platform is a commercial server side-system [8].

III. SYSTEM DESCRIPTION

BPoSS is a server-side Bluetooth positioning system with four independent but functionally inter-dependent modules. These modules are: *BpoSStub, BPoSSEngine, BPoSSClient and, BPoSSConfiguration3D*.
Figure 1 describes system architecture.

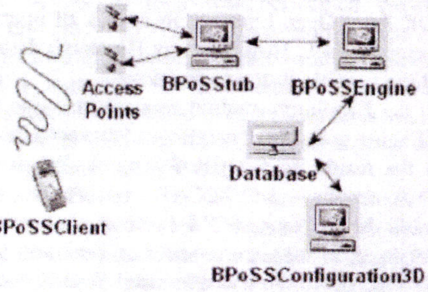

Figure 1 - System Architecture

The main module is the BPoSSEngine, where all Bluetooth devices are tracked and calculations are performed. All information needed to track devices is collected from the BPoSStub. The BPoSSConfiguration3D collects all information needed to start the system and stores it in a database. In addition, BPoSSConfiguration3D provides a friendly interface to calibrate the system and an overview of system coverage.
The BPoSStub module is platform and access point dependent. Thus, the development of different BPoSStubs for different Bluetooth networks allows the system to grow independently of the specific features in each one, and gives the chance to use already deployed Bluetooth networks. Accordingly, this module must be developed to manage all access points in the network.
In several use cases, position information requests for additional information, possibly supplied by a web server. Thus, when the system is to be deployed in crowded areas other communication infrastructure, such as GPRS, may be used to retrieve additional information and minimize interference in the ISM band used by Bluetooth.
Despite all that, Bluetooth uses a frequency-hopping scheme, named Frequency Hopping Spread Spectrum (FHSS) to minimize interference. The FHSS is able to hop with 1 MHz channel spacing with a strong central peak, resulting in 79 distinct channels to hop. Inevitably, the number of devices in range of each other reflects the interference level and, consequentially affects results.

In the next subsections, every BPoSS module is described in more detail.

A. BPoSStub

This module was developed to execute Bluetooth operations in each Bluetooth Access Point (BTAP) issued from the BPoSSEngine. Since there are different implementations of the Bluetooth Stack and different platforms where BTAPs can work, this approach gives a transparent interface to transfer data between BTAP and BPoSSEngine module.

A set of messages was specified so that additional BPoSStubs can be developed for different BTAP and platforms. All messages between each BPoSStub and the BPoSSEngine are exchanged using a TCP connection. Currently, BPoSStub module uses Bluetooth dongles and an ESDK from Open Interface to access all operations in the Bluetooth Stack. However, any Bluetooth device could be used if a suitable stub was developed.

Mostly, the BPoSStub module receives requests from the BPoSSEngine to discover neighbour Bluetooth devices and reports the results to the BPoSSEngine. When possible, BPoSStub creates an L2CAP connection to each discovered device, using PSM 1, i.e. a connection to the SDP database, to measure connection time and RSSI. An L2CAP_Ping operation could be used instead, but the API from Open Interface ESDK did not allow us to measure RSSI within this operation.

For each found Bluetooth device, the stub sends its address, discovery time, time to connect, and RSSI. When a connection to the L2CAP layer is not possible the BPoSStub module sends default values.

B. BPoSSEngine

This module was developed to track all Bluetooth devices reported by each BPoSStub. The module is also the core of the system collecting and estimating devices positions.

Initially, BPoSSEngine module collects all information from servers and related BTAP, kept in a database. Afterwards, the module is able to connect to all BpoSStubs and, starts sending inquiries, at defined intervals, to all BTAP, waiting for reports. Later, reported information is collected and stored in an object related to the found device. Figure 2 shows how collected information about each Bluetooth device is stored. Finally, this information is used to estimate Bluetooth device position.

Bluetooth Specification v1.1 does not provide a way to directly measure signal strength. Nonetheless, RSSI can be used to establish a relation between signal strength and distance. Moreover, Feldmann et al. [5] shown that the equation for signal propagation in free-fields is not suited to be used indoor due to signal fading, shadowing and reflections.

Hence, to estimate user's position an empirical formula was used. RSSI measures and related distances were read from different points at different distances an... that best describes these measures were chose... the distance to the BTAP.

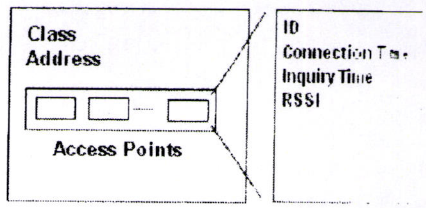

Figure 2 - Bluetooth Object Descripti...

Furthermore, to estimate Bluetooth device ... BTAP that discovered that device at less tim... named the reference BTAP in this time ste... BPoSSEngine checks if the range of all ... discovered the device overlaps the range of th... BTAP, discarding the BTAP that do not over... important, because a Bluetooth device in move... discovered by several non-overlapped BTAP. I... there is not a common area where all BTAP ran... and, with this alternative, only the last overlap... chosen. Moreover, it should be possible to es... position of a Bluetooth device in movement.

Afterwards, if it was possible to measure any R... triangulation is performed using the empirical ... estimate distance to the related access poi... triangulation method described in the C... Algorithm of Bluetooth Local Positioning Pr... estimate a position. To estimate the floor where ... the system assumes that the user is in the same ... BTAP with the biggest RSSI value. If ... measurement is performed when a user requests ... her position, a pre-calculated position is retu... value is calculated in the BPoSSConfiguration3D ... BPoSS can use a geometric model to track ... devices, as described above, but can also use a ... model. The symbolic model is better suited f... LBS where accuracy is not the main issue. Thus, ... are identified with the corresponding BTAP ... additional information about a specific spo... delivered to the user. In addition, overlapped ... determined in the same sense as in the geometr... without triangulation, returning an ordered string ... BTAP ID joined. All requests to the BPoSSEn... performed using a Web Service.

C. BPoSSClient

Any device can be used as a client of BPoSS. This ... of the main goals while developing this architect... possibility to track any mobile phone, PDA or other ... with a Bluetooth antenna increases the possibilitie... such system can be used.

...imize interference, a GPRS connection can be used ...e client to access the Web Service in BPoSSEngine ... and retrieve its position. The usage of IEEE ... or additional BTAP can also be an option when ...mber of devices to track is reduced and the ...ence level does not affect the expected results.

...aluated test scenarios, two cell phones were used, ...Ericsson P800 and a Nokia 6310i. These devices ...d to better exemplify the differences in Bluetooth ... Both devices have a class 2 antenna, but their ...erage range is different.

...Configuration3D

...ule was developed to allow an easy configuration ...PoSS system. Indeed, BPoSSConfiguration3D ...s accessed using a regular Web Browser, ... a familiar interface to all users. Thus, any user ... manage the BPoSS system.

...onfigure the BPoSS system all BPoSStub must ... to the database specifying their IP address and ... For each floor, a coordinate system must be ... To perform that operation the user only has to ... points on a floor fingerprint and the floor is ...

..., and with all this information collected into the ... the BPoSS administrator only has to click on the ...ngerprint and add the associated BTAP. ...lly, their location are inserted in the database, ...view of BTAP radio coverage is shown to the ... the information related to each BTAP can be ...ted.

...nformation will then be used to initialize the ...ine module. When all BTAP are inserted in the ... mid points in overlapping areas can be ...nd used by the BPoSSEngine module. These ... will be used to speed up the process of ...mation when no RSSI measurements can be ... Afterwards, the BPoSSEngine module only has ... all BTAP that have discovered a particular ... return the related value calculated by the ...guration3D module. Furthermore, the ...guration3D is responsible to build all possible ...d by the BPoSSEngine for the symbolic

IV. MEASUREMENTS

... was evaluated in different scenarios. One ... long corridor, with 3 m width, and the other ...with 8,8m x 6,4m. In each scenario, several ...were chosen to retrieve radio signal ... and related distances to each access point. ...ints used were Class 2 Bluetooth dongles ...erface, each running in a different computer. ...ed were two cell phones, a Nokia 6310i and a ... P800. This cell phones can be easily tracked ... be inquired as long as the user wants the system to track him. Nonetheless, there are cell phones with Bluetooth capabilities that are difficult to track, such as Sony Ericsson T68i, since they can only be discoverable in a limited range of time.

To find a good set of parameters to estimate distance from the Bluetooth device to the access point, RSSI, Bit error and L2CAP connection time to the SDP database of each client device were evaluated. While performing a L2CAP_Ping operation, it is possible to send a set of data to the client device and check for the number of errors. However, the access points used simply discarded the data sent. Therefore, this parameter was discarded. Furthermore, an L2CAP connection to the SDP database was performed and the time to perform the operation was measured.

With both client devices, the L2CAP connection time to the SDP database did not reflect a relation with the related distance. A set of tests was performed between 10 centimeters to 150 centimeters with steps of 10 centimeters, and between 2 meters and 18 meters with steps of 1 meter, in the first scenario. In all different distances, the values ranged from milliseconds, mainly 360 milliseconds, to almost 2 seconds in the majority of cases. Thus, this parameter was also discarded.

Nonetheless, BPoSS uses RSSI measurements, when possible, to estimate Bluetooth device position. Hence, due to fading, shadowing, reflections and blocking problems of the radio signal, for each test scenario a new model of the relation between radio signals (RSSI) and distance should be evaluated to best fit the environment conditions. Moreover, different Bluetooth devices return different RSSI values at the same distance to the access point.

As described in the measurements of the L2CAP connection time, the RSSI values where collected and a model was generated based on all observations of both client devices. This approach is simpler, but a more accurate approach can be achieved using a different model based on each client device. Indeed, with Sony Ericsson P800 the RSSI measurements were best modeled with a polynomial function of order 6 with $R^2 = 0,7744$ and in the Nokia 6310i the RSSI measurements were best modelled with a polynomial function of order 6 with $R^2 = 0,8106$. In the first test scenario, RSSI measurements with both clients were best fitted with an exponential function, as seen on figure 3.

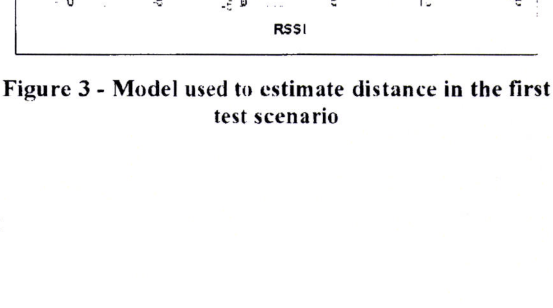

Figure 3 - Model used to estimate distance in the first test scenario

As seen in figure 3, all RSSI values were used in our test scenario. In this scenario, it is possible to estimate distance of each device up to 18 meters, each access point coverage range. The same test was performed in a second scenario with several devices using ISM band, namely a WiFi wireless network, and furniture, blocking the Bluetooth signal. The results were severally decreased as seen in figure 4.

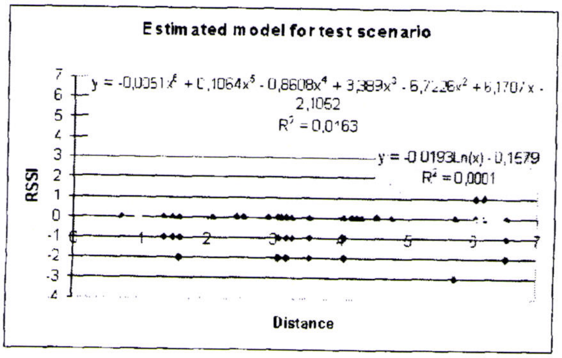

Figure 4 - Model used to estimate position in the second test scenario

In the last scenario, a symbolic model is a better option since the accuracy is reduced, due to interference and signal fading, shadowing and blockage. In the worst-case scenario, accuracy is up to cell size, in these tests up to 18 meters. Another problem that was discovered in the last scenario is that BT devices may need more time to be discovered by all BTAP in range, or may not be discovered at all reducing accuracy.

The positioning error will reflect the topology of the network and the level of interference. The number of overlapped cells will improve accuracy. Nonetheless, interference level reduces efficiency of the system when several BTAP overlap. So a good compromise should be taken.

V. CONCLUSIONS

In this paper, a server-side Bluetooth Positioning System was developed and evaluated. This system allows the user to navigate with 3 degrees of freedom (3DOF), namely x, y and floor coordinates. Several parameters and problems of a Bluetooth positioning system were considered and compared. This work aims at improving the process of building a Bluetooth positioning system, allowing the designer to use and consider the appropriate approach.

In our tests, L2CAP connection time to a Bluetooth device does not have a direct relationship with the distance and bit error could not be used. However, RSSI measurements were evaluated showing that RSSI can be used to provide a distance estimation of the Bluetooth device to the BTAP. Indeed, to improve accuracy, different models for each Bluetooth device should be used and considered. The usage of a general model can also be a solution, although accuracy will decrease.

BPoSS can either be used to supply ge... information or symbolic information. In the las... location system can easily be deployed. BPoSS ... grow has needed and can use already deployed ... networks.

In the future, work will be undertaken to improve ... and use different models for different devices. S... system can track several distinct areas, differen... need also to be added to accurately track device... area.

VI. ACKNOWLEDGMENTS

This project was developed within the ANTS ... founded by the Fundação para a Ciência e a Te... (FCT, Portugal) (project nº MGS/34376/99-00). W... like to thank YDreams (www.ydreams.com) for s... the work described in this paper.

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Mobile Augmented Reality for Environmental Management (MARE)

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Abstract

Access to real-time data while in field observations is often a requested issue in environmental management. Additionally, it is easier to see that information spatially distributed where it makes sense, leveraging users of the task of searching for the context where the retrieved information can be applied. Augmented Reality (AR) is a technology that allows the superimposition of synthetic images over real images, providing augmented knowledge about the environment in the user's vicinity. AR will also make the task more pleasant and effective for the user, since the required information is spatially superimposed over real information related to it. This short paper describes ANTS (Augmented Environments), an AR project for environmental management providing geo-referenced information to the user. The system's architecture has a flexible design based on a client/server model, where several independent, but functionally interdependent modules are articulated. Therefore, modules can be moved from the server side to the client side or vice-versa, according to the client processing capacity. The system is being deployed in laptop computers and work is in progress to deploy the system using Personal Digital Assistant (PDA) devices. A 3D model and a geo-referenced database are used in the server for user positioning, and presentation components are used in the client to superimpose synthetic information over real images. Several applications for the system are being developed and will also be discussed in this short paper.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems – Artificial, augmented, and virtual realities. H.2.8 [Database Management]: Database Applications – Spatial databases and GIS. I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction techniques.I.6.3 [Simulation and Modeling]: Applications.

Keywords: Augmented/Virtual Reality, Modelling/Animating Nature, Interaction/Multimedia-Techniques, Data Visualization.

1. Introduction

Relevant information about the surrounding real world, whether it is natural or urban, is often needed in real time. However this information is not always easily accessible through our senses. Augmented Reality (AR) is a technology where the view of the real world is superimposed, in real time, with virtual objects, augmenting the information available to the user about his or her surrounding real environment. AR technologies allow users to receive additional information about the objects in the environment, improving their perception of the real world and helping them to efficiently accomplish their tasks.

Through the use of a Head Mounted display (HMD) users are allowed to easily and seamlessly interact with real environments. Therefore, additional information is rendered in real time, and in a contextual way to augment user's experience. Moreover, mobile devices, like PDAs or mobile phones, can also be used to augment users experience, given their wide availability and wireless capabilities.

In regular AR systems, for a user to undergo an augmented reality experience, he or she must wear a huge set of devices, such as: a notebook, HMD, orientation tracker, and position tracker. There is a disadvantage in these setups since they are not as mobile as the user would like them to be. Therefore, displaying information using personal displays, and avoiding burdening the user with heavy and cumbersome devices is an important goal while using a PDA in AR systems.

Furthermore, the PDA can be a virtual window to the augmented world displaying what the user is seeing superimposed with the additional virtual objects. Thus, virtual objects can be seen in the viewer's line of sight through the PDA screen.

In order to develop an AR system, several problems must be taken into account, namely:

- The register of synthetic images on real images
- Position identification
- Information retrieval
- Presentation

Moreover, technological limitations are a significant issue while developing AR applications for mobile devices. Small displays, small screen resolution, limited processing power, low data bit rates, out of coverage gaps in wireless networks or network latency are examples of the problems that need to be addressed while developing AR systems. The user interface should give a pleasant experience overcoming these issues and giving users just the relevant information.

This paper describes ANTS, an AR system for environmental management that contributes towards the solution of these problems, and presents the applications that are being developed to test and exemplify its usage. These applications comprise:

- Monitoring water quality, in artificial lakes and natural water streams, using pollutant transport simulation models;
- Superimposition of synthetic objects on real images of either urban buildings and/or natural landscapes to visualize their characteristics and temporal evolution;
- Projection of synthetic images on the ground, which reveal the soil's composition at the user's current spatial location (for example, the location of underground water supply networks and subsoil structure).

The system currently uses a video see-through HMD. Work in progress aims its migration to PDA and similar devices, such as 3G phones, as reported in section 3.

The following section reviews related research approaches. Section 3 describes the project infrastructure and the PDA client being developed. Section 4 presents the applications where the AR system is being applied. The paper ends with conclusions and future work directions.

2. Related Work

Augmented reality is a technology in which the user's view of the real world is enhanced with virtual objects that appears to coexist in the same space as real objects.

Main problems associated with AR systems are [1, 17]:

- Image registration, which refers to the accurate alignment of real and virtual objects;
- Camera field vision should correspond exactly to the field of vision in order to avoid changes in the dimensions (amplification or reduction) of the real world;
- Technological limitations: displays, trackers and AR systems in general need to become more accurate, lighter, cheaper and less power consuming.

Accurately tracking user's position and viewing orientation is vital to minimize AR registration errors. A recent overview of tracking systems can be found in [5]. In prepared and controlled laboratory experiments, accurate registration methods have been demonstrated [2]. However, tracking in unprepared environments is still an enormous challenge [1, 3], particularly concerning outdoor and mobile AR applications. In [4] a method for estimating registration errors is used to generate probabilistic error estimates for points, in either 3D world coordinates or 2D screen coordinates.

Each tracking system reveals different problems related to the technology they use: vision-based trackers are computationally intensive, magnetic trackers have low-accuracy and mechanical trackers are cumbersome. Hybrid technologies are then used to exploit strengths and compensate weaknesses of individual tracking technologies [2, 3]. Accuracy in mobile AR systems changes over time and interface should adapt itself adjusting to changes in tracking accuracy [6]. In [7] authors developed a method to build a computer augmented environment using a portable device, called NaviCam, that has the ability to recognize the user's situation by detecting color-code IDs, in real environment. Additional information is then superimposed in the video-see-through display.

The first outdoor system was the Touring Machine [8]. This system assists users interested in visiting the Columbia's University campus, overlaying information about points of interest in their neighborhood. It combines a video-see-through display with an handheld display using different interaction technologies to take advantage of their complementary capabilities. A more recent version of the system rather than linking individual labels or web pages to locations, supports context-dependent, narrated multimedia presentations that combine audio, images, video, and omni directional camera imagery. Additionally, 3D graphics are overlaid in the user interface and presentation content, showing models of buildings that no longer exist and views of visually obstructed infrastructures. When selecting points of interest the user is also guided to them [9, 10].

In [16] seven different interfaces illustrate several approaches to AR interfaces. In this project, virtual and real worlds are apart and information is exchanged between them over an abstract channel that carries all information, to provide an augmented reality experience. Mobile devices are improving their computational power. Indeed, in the Vienna University of Technology, the Handheld AR project is developing a PDA-based AR system to be used in the SignPost project. This system allows a user to stroll over an unknown building showing him or her several navigational hints. (**http://www.ims.tuwien.ac.at/research/handheld_ar**).

Human senses are unable to detect several dangerous conditions, namely harmful radiation or toxic gases. In the University of Michigan, an application is being developed to allow humans to detect potentially hazard conditions, combining the collected data in a three geometric database, and using augmented reality to present this information to the users (**http://www-vrl.umich.edu/sel_prj/ar/hazard/**). BITS (Browsing in Time and Space) interface was developed for the exploration of virtual ecosystems. It allows users to navigate and explore a complex virtual world, interact with surrounding objects and make annotations indexed in time and space [11].

The Archeoguide project is developing a wearable AR system that will give visitors a feeling of how a historical site, as Olympia in Greece, was during previous periods of time [12]. AR systems are still in their infancy with a few commercial systems in use, mainly for augmentation of broadcast video to enhance sports events and to insert or replace advertisements in a scene [14]. Displays, trackers, and AR systems in general need to become more accurate, lighter, cheaper and less power consuming. Only a few have evolved beyond lab-based prototypes [1, 13].

3. ANTS Infrastructure

ANTS project tries to overcome the problems stated in the previous sections and provides contextual information, using a HMD or a PDA for environmental management. With a flexible design, the ANTS's architecture is composed by a set of modules distributed between the client and server entities (Fig. 1). Some modules can be moved from or to the client entity according to its available processing capacities and the applications requirements.

On the PDA, a proxy database will be used to speed up the process of querying the database (Fig. 2).

3.1. System architecture

In order to be able to provide contextual information, the system must know the user's position and orientation. Therefore, at the bootstrap, the system identifies the user position and orientation, by explicit interaction and manual calibration. After that, the system is able to track the user position and orientation combining several methods:

- GPS data: The absolute position of the user is indicated by a GPS system. This type of system is used in combination with the other techniques below, in order to overcome the limitations and lack of precision associated with it.
- User tracking using appropriate devices: A tracker is used in order to obtain the current orientation of the user's head.
- Environment mapping: knowledge of the physical form and position of the entities on the environment that is being augmented.

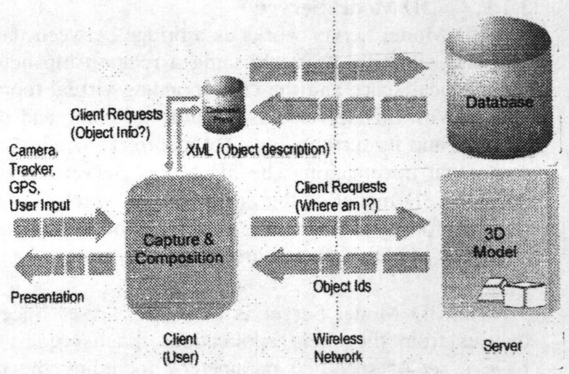

Figure 1: *ANTS Architecture and Information Flow (PDA)*

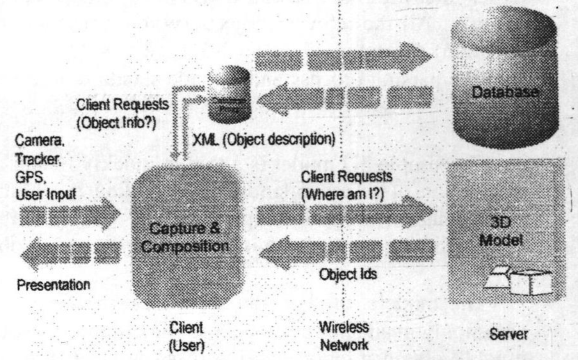

Figure 2: *ANTS Architecture and Information Flow (PDA)*

All the additional information that serves to augment the real world is stored in a geo-referenced database kept in the server entity. To retrieve the information related to a particular location, the system uses the data obtained from the GPS and the orientation tracker to query the 3D model for a list of objects in the user's field of view. For any object in the list, several basic properties are specified including name, type and a unique object identifier (UOI) that can later be used to query the multimedia geo-referenced database. This information, returned from the 3D model server, is the first layer of information used in the AR composition module.

For more information, the multimedia geo-referenced database is queried using the UOIs returned from the 3D model. The retrieved multimedia objects' data is then superimposed over the real image, in the AR composition module. The server components are accessible through HTTP, a common standard, allowing different devices to perform requests.

The main modules composing ANTS's architecture can be seen in figure 1 and are described in the following subsections.

3.1.1. 3D Model Server

The 3D Model Server works as a bridge between the virtual and real worlds, establishing a relationship between the physical space and the corresponding virtual representation. With this server it is possible to locate and depict the user and its surroundings, for a correct mapping of the contextual information. The 3D Model Server stores and edits the 3D model of the environment, which is used to return information about the position, orientation and dimensions of physical structures.

The 3D Model Server is an HTTP server, receiving queries from the client applications. Each request must have a set of specified parameters, including the user's position and orientation in order to process and retrieve the list of objects in the user's vicinity. Based on this data, the server identifies the relevant objects and relates them with the user. All the relevant objects (with corresponding description) are returned as an XML file. XML is used to help the parsing process and provide standard access interfaces.

The simple 3D model is a tool to quickly obtain a representation of an urban landscape regarding its volumetric objects and their relative representation. While editing the model, the user only has to input the height of each object.

The models, used in the server, can be defined with commonly available tools, such as 3D Studio. However, to quickly obtain a representation of an urban landscape regarding its volumetric objects and their relative representation, without having to use a complex, all-purpose tool, we have developed a simple editor for 3D environments (Fig. 3). This tool uses maps or blueprints of the real environment as the basis for edition. While editing the model, the user only has to input the height of the each object in it.

Every element in the 3D model has an identifier that will be used in search operations, to identify the objects in the geo-referenced database. When a request is made to the 3D model the server returns a list of all relevant objects in user's vicinity. These objects are classified in three main categories, accordingly to its spatial relation with the current user position (Fig. 4):

- Inside objects: all objects where the user is inside. It can be more than one as there is no requirement that the model is restricted to physical non-overlapping entities.
- Visible objects: all objects in front of the user and inside of a view volume, defined by an angle much in the same way as the field of view of a camera.
- Surrounding objects: all the other objects that are not visible objects or inside objects, and that are inside the action volume. These objects are further classified in "Left" and "Right" to enable user orientation when displaying information.

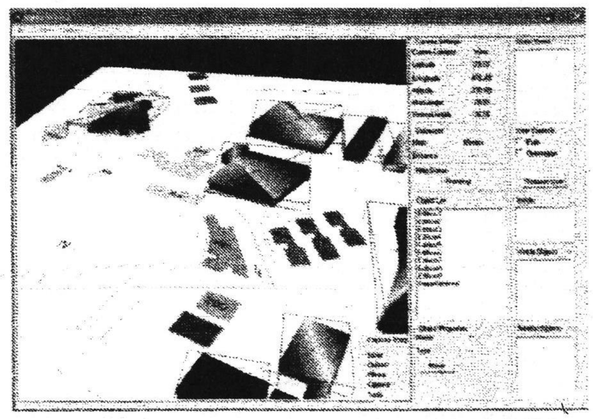

Figure 3: *3D model editor*

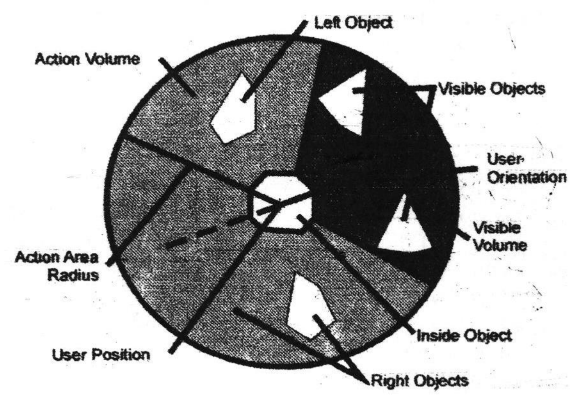

Figure 4: *Object classification*

Developed with Microsoft Direct 3D, this tool allows for a rapid production of a first approximate 3D model of the real world, often sufficient for augmented reality applications.

3.1.2. Geo-referenced database

All information related to the various elements filling the space under analysis is stored in a geo-referenced database. Using the object identifiers contained in the list of objects in the user's vicinity returned by the 3D model, the system is able to query the geo-referenced database and retrieve the related contextual information. A list of multimedia elements to be shown to the user, whether text, graphics, images, audio or video, can then be obtained. As a result a XML file is returned describing the multimedia elements to be delivered to the client for visualization purposes.

3.1.3. AR Composition Module

The main goal of this module is to superimpose the data elements retrieved from the geo-referenced database with the support of the 3D model over the image of the real world captured by the video camera, and display the composed image in the HMD or PDA screen.

This module has two functional components, that can be seen as a set of filters (implemented using Microsoft DirectShow): InfoComposer and ObjectComposer (fig. 5). The InfoComposer shows all the information that surrounds the user, and the ObjectComposer show all the information related to a specific object.

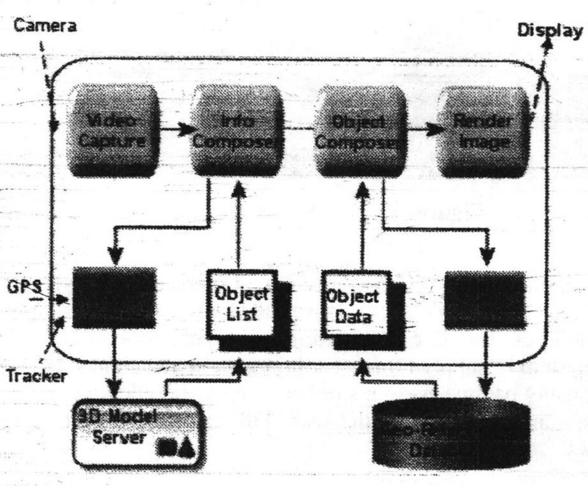

Figure 5: *AR User Module Architecture*

InfoComposer receives a XML file from the 3D model and composes the embedded information with the image received from the video camera (fig. 6). For visible objects, the UOI, name, type and screen position are returned. The screen position is independent of the device being used in the AR composition module. Therefore, the AR composition module can adjust the values to its own screen values.


```
- <OBJECTS>
  + <INSIDE_OBJECT>
  - <VIEW_OBJECT>
    - <OBJECT>
      - <ID>6</ID>
      - <TYPE>BUILDING</TYPE>
      - <NAME>Oceanario</NAME>
      - <SCREEN_POS>0.3223,0.273
        </SCREEN_POS>
      </OBJECT>
    </VIEW_OBJECT>
  - <SIDE_OBJECT>
    - <OBJECT>
      - <ID>12</ID>
      - <TYPE>TRANSPORT</TYPE>
      - <NAME>Teleferico</NAME>
      - <SIDE>1</SIDE>
      </OBJECT>
    + <OBJECT>
    </SIDE_OBJECT>
  - <DIRECTION_OUI>45.78095,8.22123
    </DIRECTION_OUI>
</OBJECTS>
```


Figure 6: *3D Model Response Example*

Figure 7 illustrate the results of composing the captured image with the data about the surrounding environment, using the InfoComposer. At the top, there is a list representing the objects on each side of the user field of view, the surrounding objects. The information about the surrounding objects, allows the user to change his or her orientation in order to place them in the field of view. Being currently developed, the PDA version of the AR Composition module only shows the objects seen by the user at any instant (fig. 8). Notwithstanding, the arrows are shown without labeling and the users are able to select them, sending a request for that information.

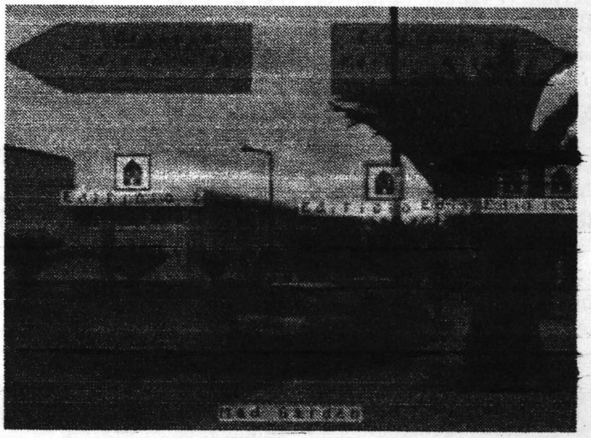

Figure 7: *Outdoor AR example*

Avoiding this step saves computational power, which is important in a mobile device like the PDA. Thus, a more smooth visualization of the environment can be supplied to the user. When the user needs additional information, he or she will request it and it will be rendered over the real image for a while. This technique also avoids cluttering the scene with unnecessary information, given the small size of the display.

Figure 8: *PDA AR example*

Attached to each visible object there is an icon and a label. If the user selects one of these icons, the object composer, using the UOI of the corresponding object, will query the geo-referenced database to obtain more detailed information. The returned data elements are then composed with the real image. As with the InfoComposer, ObjectComposer accepts data elements of several types including images, video or text. The resulting composed image is returned to user display fully finished, avoiding flickering. A version of this tool is already operating for a HMD and laptop interface. At the present time, a new version, using Pocket PC 2002 tools, is being developed for use with a PDA interface, since there is no support for DirectShow in this platform.

4. Applications

Although ANTS' infrastructure and image registration methods could be applied in the development of other AR systems, we focused on environmental management, for which geo-referenced and GIS functionalities are fundamental. At the moment three main applications are being developed to be deployed in the Parque das Nações and the Tagus Estuary (Lisbon):

- Visualization of water quality, in artificial lakes and natural water streams, using pollutant transport simulation models;
- Superimposition of synthetic objects on real images of either urban buildings and/or natural landscapes to visualize their characteristics and temporal evolution;
- Projection of synthetic images on the ground, which reveal the soil's composition at the user's current spatial location (for example, the location of underground water supply networks and subsoil structure).

Contextual geo-referenced information augments the real environment giving the user real time access to information not available through conventional observation methods. The user is then able to explore and analyze a spatial location, enabling him or her to see-through the elements that compose the area where he or she is located at: water, soil and physical elements.

4.1. Visualization of Water quality

While observing a water body, such as a river or a lake, the user may need to ascertain corresponding water quality data or simulate a pollutant to check its behavior in order to prevent future hazards. Interacting directly with a pollutant transport model and visualizing selected parameters generated by this model, allows the user to simulate several possible scenarios and use that information to prevent future environmental aggressions (Fig. 9). All additional information is generated dynamically, calculated in real time and can be seen and controlled by the user.

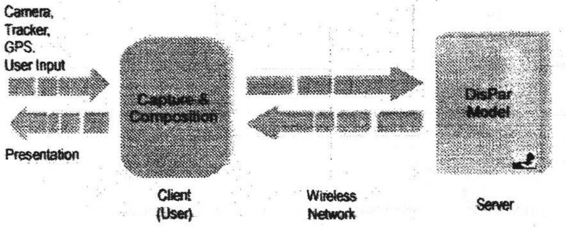

Figure 9: *Client-Server for water quality application*

This application is being deployed in a Compaq iPAQ with GPS, camera, orientation tracker and wireless network capabilities. The user is tracked in real time, which allows the system to supply him or her information about the water quality parameters in his or her vicinity. In order to see evolution of the model the user will have two distinct views.

In the first view, user position is marked with an icon in the map of the region where the model is evolving. This view is similar to the approach used in the PC view of the model and allows a more general view of the model. The user's position is always in the field of view, although users are allowed to zoom in or zoom out, to see a more detailed view of the region near them or to see a more general view of a wider region, respectively. In this view, the user is also able to adjust model parameters to simulate the desired situation. In figure 10, an image of a simulation, using DisPar transport model, is presented. The DisPar (Discrete Particle distribution model) model is a mathematical formulation to solve advection-diffusion problems in aquatic systems [15].

Figure 10: *DisPar "Image courtesy of FCT/UNL, (c) 2003, used with permission"*

Since Compaq iPAQ has a small screen, and the interaction with the model requires a huge number of parameters to be defined, templates are used to enhance interaction with the DisPar transport model. Template icons, representing pollutant agents, are embedded with predefined values and the user just has to choose between them and select the initial point in the map where the pollution will begin.

In the second view, the user is able to see the evolution of the DisPar transport model in his or her vicinity, superimposed in the view of the real environment. In this case, the water body will be replaced by the model evolution in the corresponding position.

4.2. Visualization of characteristics and temporal evolution of superficial solid structures

The main goal for this application is to allow users to stroll through a certain spatial area, while accessing information in real time. Accessed information will be related to the objects in the surrounding area. These objects may include additional information about the natural elements or man-made structures.

Currently, this application is being developed for Parque das Nações in Lisbon (former area of the Expo 1998). It allows users to walk through the park and have access to contextual information about the different buildings and natural elements surrounding them. This information comprises data about the characteristics and functionalities of the different objects in the real world, as well as images showing former objects that have been replaced by them.

This application is being targeted into two different devices, a laptop computer and a PDA. Therefore, the interface is adapted to adjust to the features and different interaction techniques of these devices. The content deployed in this application is used and adjusted, if necessary, by each platform.

4.3. Visualization of subsoil structure

The main goal for this application is to locate infrastructures for public supply networks (water, sewage, telephone) in order to avoid damage when intervention to the subsoil is necessary. While using this application the user will be able to look at the soil and see synthetic images revealing its interior (subsoil) constitution at that point. Other possible usages for this application are the exploration and analysis of the subsoil composition in geological terms or for locating watersheds.

This application is also being deployed for the Parque das Nações in Lisbon. Similarly, to the application seen above it is targeted into two different devices, a laptop and a PDA. While in a stroll, the user may wish not to be in an immersive environment, so the PDA may be a better interface, allowing the user to see the environment directly and look for additional information on the PDA. Depending on the task being performed, different interfaces may be more suitable to accomplish the goal.

5. Conclusions and future developments

ANTS project is an AR infrastructure developed for environmental management, supporting in loco observations and providing the user with additional knowledge about the surrounding environment. This infrastructure should be effectively used to visualize and manage information, as well as to locate and identify objects within the user's field of view. This project also supplies an infrastructure that can easily be used to develop other environmental management applications, by facilitating the perception and interaction with the involving spatial area and its natural and artificial components.

Additionally, the user is able to choose between two different clients of the system. While using a laptop-based client, the user is given an immersive experience using the HMD. Alternatively, the user can handle a PDA, allowing him or her to directly observe the environment, and watch the PDA looking for additional information.

These tools are evaluated in three different applications: water quality, information related to superficial solid structures, and the structure of the subsoil. Future developments include improvement of the referred prototypes and applications, as well as the development of the system's remaining components, namely the integration of an image tracking module. Additional developments for supporting mobile phones are also planned.

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A MULTI-USER MOBILE SYSTEM TO VISUALIZE ENVIRONMENTAL PROCESSES

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Abstract

This paper presents a multi-user mobile system to visualize environmental processes. Two main modules define the system's architecture, a geo-referenced model and an Augmented Reality (AR) composition module. The geo-referenced model is applied to the visualization of water quality, in rivers or lakes, but other models can be used allowing the visualization of different environmental processes. The AR composition module is the client side of this architecture, allowing users to visualize and interact with the geo-referenced model via two different views.

The first view, a 2D computer animation, enables the interaction with the geo-referenced model by adding or removing pollutant agents to the simulation. The second view, AR view, enables users to visualize the simulation over real images. Thus, it is possible to observe the evolution of the model in the vicinity of the users, superimposed over the view of the real environment.

Interacting with the model requires the knowledge of several distinct parameters. Therefore, several templates were defined to represent different agents. These templates are embedded with predefined values for an easier interaction with the model used in the simulation. In the client, these templates are viewed in the form of icons representing real agents. The model supports multiple users interacting with a unique simulation.

A GPS and an orientation tracker are used to track the users in the field of observation. The information obtained by these devices is sent to the server, so that the simulation model only sends data related to the environment in the vicinity of the user. Moreover, the information is sent to the client device tailored to its specifications, namely screen size.

INTRODUCTION

Environmental changes are a topic of interest for academics, managers and general public. Indeed, changes in the environment may affect everyone's lives, and be a great point of concern. Simulation and visualization systems should provide realistic reproductions of the changes in the environment, for purposes as diverse as description, explanation, forecasting or planning.

In this work, a simulation model, simplified by ignoring certain details, is used to simulate observed environmental changes. The model allows complex systems to be understood and their behavior to be predicted within the scope of the model. In environmental management, the systems to be modeled are environmental processes, inherently spatial and temporal. The visualization of the simulations outputs can be made using different techniques, namely 2D Computer Animations, Virtual Reality (VR) and Augmented Reality (AR).

Computer animations, in 2D, can be considered as a support system to help a designer to outline the basic features of the environment and give all users a more general view of the system. VR enables immersion in a synthetic, computer generated 3D environment. Immersion can be accomplished by wearing a Head Mounted Display (HMD) and position trackers, which allow the computer to modify the output according to the user's position and line of sight. However, most of the perception of the real world is blocked out when users are interacting with a traditional VR system.

AR generates a composite view for the user, combining both the real and virtual information generated by the computer, in real-time. AR enhances human perception supplying further information to the user not ordinarily detectable by human senses. Additionally, AR techniques improve efficiency, free the user from searching for additional cues in the scene and make the task more pleasant.

In fact, traditional AR systems are built with a huge set of devices, namely a Head-Mounted display (HMD), a laptop, and orientation and position trackers. These systems allow an easy and seamless interaction with real environments. Nonetheless, these setups are too cumbersome to provide a seamless and non-intrusive interaction for a roaming user.

Personal displays, namely personal digital assistants (PDAs), avoid burdening the user with heavy and cumbersome devices improving the AR experience. However, precisely due to its small size, a PDA-based AR system has technological limitations which can greatly degrade the user experience. Therefore the user interface is of extreme importance and should help to overcome these limitations, offering a pleasant experience. Furthermore, interaction between groups of people working on a project, often in different sites, is an important requirement in environmental management.

Considering these issues, the project Augmented Environments (ANTS) is developing a Mobile Augmented Reality System for environmental management providing geo-referenced information to the users, to be deployed in laptop computers and PDAs (Romão et al., 2002). This system allows a group of users to interact during the simulation of an environmental process, using geo-referenced information from each user.

In the next section, several projects that inspire our work will be discussed naming some of its potentialities. Subsequently, the system architecture of this mobile system is presented, firstly showing an overview of the complete system and finally discussing the server and client modules of the system. Lastly, project conclusions are shown and possible future work is presented.

RELATED WORK

Map-based visualization, VR and AR have been used for many purposes. Among these purposes are: specialized professionals training, entertainment industry, architecture and urban planning and, more recently, environmental visualization. These tools allow the simulation of different scenarios and the monitoring of people's responses and behavior in real world situations. Each visualization system has its potentialities, which leads research to the usage of hybrid interfaces, taking advantage of the potentialities of each different visualization method.

Hedley et al. (2002) explored the use of hybrid user interfaces for collaborative geographic data visualization with two interfaces. The first interface combines AR, immersive VR and computer vision based hand and object tracking. Users wear a lightweight camera and display, so that they can look at a real map and see three-dimensional virtual terrain models overlaid in the map. In this case, users can fly and experience the model immersively, or use free hand gestures or physical markers to change the data representation. The second interface allows zooming the image, paddle interactions and pen annotations.

BITS (Browsing in Time and Space) interface was developed for the exploration of virtual ecosystems. It allows users to navigate and explore a complex virtual world, interact with surrounding objects and make annotations indexed in both time and space (Dias et al. 1995). Ghadirian and Bishop (2002) introduced a project to combine GIS-based environmental processes modeling with the use of AR technology to illustrate environmental changes in an immersive environment. The project is applied to weed modeling and simulation. A GPS and a camera are used to track users.

Despite research in mobile augmented reality systems is increasing, the technical challenges to develop these systems are still enormous: extremely high update rates, network communication gaps, low processing resources in the client side, image registration, match between camera field vision and model, technological limitations in the different sensors, namely GPS, magnetic trackers.

Accurately tracking users' positions and viewpoint orientation is important to minimize image registration errors. An overview of tracking systems can be found in Rolland et al. (2001). Each tracking sensor has its advantages and disadvantages, namely vision-based trackers are computationally intensive, magnetic trackers have low accuracy and mechanical trackers are cumbersome.

Hybrid methods are then used to take advantage of each tracking method, also minimizing their problems (You et al., 1999; Azuma et al., 1999). Pasman et al. (1998) have described a mobile AR system. The system uses GPS and image capture to track users' position. Orientation tracking is retrieved from object recognition and direct feedback from inertial tracker. Further research is needed to empower mobile devices with more accurate, lighter, cheaper and less power consuming devices. Furthermore, image registration errors should be avoided to maintain proper alignment of virtual information related to objects in the real scene.

SYSTEM ARCHITECTURE

Two main modules are the basis for this client-server architecture, namely a geo-referenced model and an AR composition module, as presented in Figure 1. The geo-referenced model is a central model in the system architecture. It is used to represent the physical environment being explored and track the user's position.

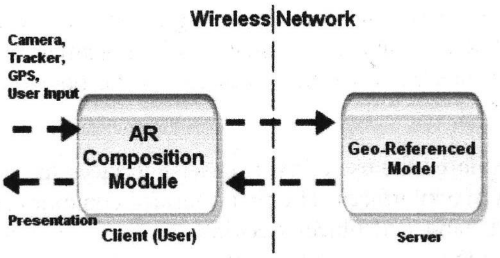

Figure 1: Architecture Overview.

The geo-referenced model is an HTTP server, receiving queries from the client applications. Each request must have a set of specified parameters, including the user's position and orientation, in order to process and retrieve the supplementary information. The AR composition module is used to retrieve additional information from the geo-referenced model. The visualized data is the result of the query to the geo-referenced model, used in the simulation, and can be viewed using a computer animation, in 2D, or through AR.

To exemplify the use of this system, the ANTS project introduces an application for visualization and auralization of water quality in artificial lakes and natural water streams. In the next subsections, a description of the server and client architecture is presented.

Server

Targeted to mobile devices, the system architecture was designed to perform, in the server-side, the maximum operations needed to supply additional information to clients. Thus, server runs the simulation model, tracks users and performs additional transformations in the information, so that the client only has to use the information as it is, without the need for local adjustments. Namely, the server is able to adjust the information to client specific screen size.

The geo-referenced model is an HTTP Server, allowing a different set of devices to interact with the model. Thus, to query the model the client only has to set the needed parameters in the URL. Each client will interact with the same simulation, which allows testing different scenarios.

The Dispar (Discrete Particle distribution model) transport model is used in the geo-referenced model module of this application. Dispar is a mathematical formulation to solve advection-diffusion problems in aquatic systems. The Dispar transport model is a 2D model able to simulate several pollutant scenarios (Ferreira and Costa, 2002).

In our application, Dispar is applied to the Tejo estuary (Lisbon). Thus, it is possible to perform a previous calibration of the system and map latitude and longitude values gathered from the GPS to model coordinates. In addition, client orientation values are also mapped against the orientation of the module to supply correct information to the clients.

To interact with the server and be correctly identified in the model, the server stores an identifier (ID) linked with the information about the screen size of the client device. Thus, at bootstrap the client sends a request to the server with information about its position and orientation, view mode and screen size. In the reply, server sends a unique ID to the client.

The first client interacting with the geo-referenced model also has to send a request to the server to perform a new simulation, which is carried by the interface and hidden from the user. Afterwards, each client can request the model to add or remove agents acting in the simulation process (see Figure 2). Agents involved in the simulation can be pollutant sources, namely factories and swine farms, or waste water treatment plants.

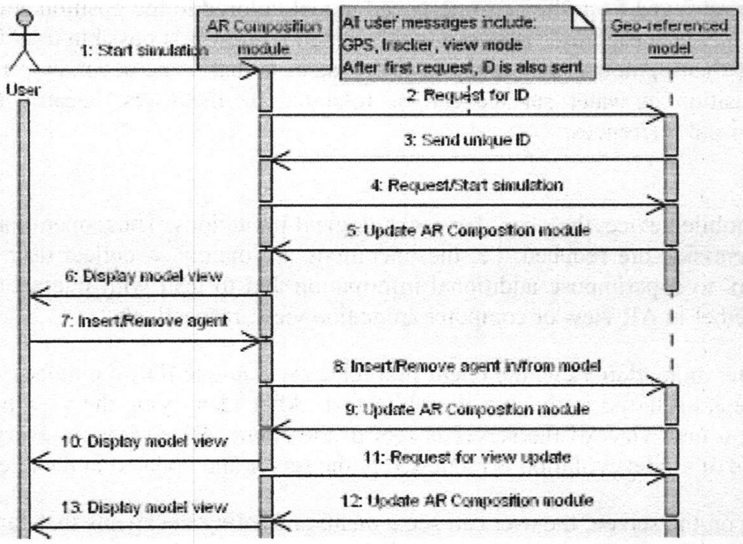

Figure 2: Sample interaction with the geo-referenced server.

Agents are templates embedded with predefined values, used to change parameters in the simulation and allowing for an easier interaction with the model. These templates allow common users to interact with the model and be able to visualize the impact in water quality when related agents are set near a water stream or artificial lake.

Environmental systems are spatial and temporal. Thus, all information retrieved from the geo-referenced model is generated dynamically, calculated in real time and controlled by the user. The user's position and orientation is updated in each request to improve simulation view in the client application. The result will also be tailored according to the view mode in the client, whether in either computer animation view or AR view.

When the client is in computer animation view the geo-referenced model returns a map view of the model evolution in the user vicinity with an icon representing the user's position and current orientation. Hence, the user can easily identify the environment in his or her vicinity. To allow users to control the view detail, a zoom facility was implemented enabling them to see a more detailed view of the nearby region or to see a more general view of a wider region.

When a position is selected in this view, agents can be linked to their related position in the geo-referenced model. Sewage pipes connect pollutant agents and a point in the water body to illustrate pollution release. If a pollutant agent is released within the range of a waste water treatment plant the wastes are conducted to it and pollutant discharge is reduced.

For visualization purposes, an AR view can also be selected. In this view the users cannot interact with the simulation. However, they are able to visualize the model evolution superimposed in the image of the real environment. In this view the degree of realism is increased, also improving environmental decision support.

A river surface is flat, so the image superimposed in the real environment is the pollution dispersion retrieved from the geo-referenced model tailored to the position and perspective of the users. Since each user is tracked within each request it is possible to tailor the image to each of them. Another advantage of this system is that some accuracy errors in image superimposition in water surface can be tolerated by the users, because there are no accurate visual references.

Client

Being a mobile device, the client has technological limitations. Thus, operations performed in the client-side are reduced, i.e. the operations are mainly to collect user position and orientation, to superimpose additional information and to deal with interactions from the users, whether in AR view or computer animation view, respectively.

In computer animation view, the client first requests a unique ID from the server sending it all parameters referred in the server architecture. After identifying the view mode used by the client, a map view of the server is sent to the client. Afterwards, in every time step a new image of model evolution is requested to the server and updated in the client.

By taping on the screen, the user can see a menu presenting the agents that can be added to the simulation in progress (see Figure 3). When an agent is selected, a request is sent to the server to add the related agent to the simulation. In that request, screen coordinates where the agent should be added, together with user position and orientation are sent to the server. With this information, a translation to model coordinates is performed in the server and the correspondent agent is added to the simulation. Removing an agent from the simulation is performed in the same way. After adding or removing an agent from the simulation, the changes will be reflected in all users.

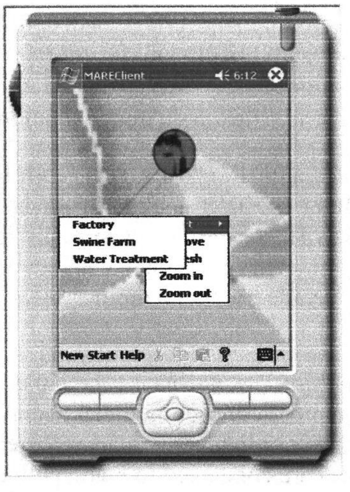

Figure 3: 2D Computer Animation.

In AR view, a unique ID is also requested as in the computer animation view. Afterwards, an image of the model evolution is superimposed over the real image of the environment captured by a camera installed in the client device. The retrieved image is previously adjusted to client position and orientation in the geo-referenced model saving resources in the mobile client. The users will then be able to visualize the model evolution in their vicinity, superimposed over the real image.

While in the field of observation, the users are tracked via: GPS data, to grab the absolute position of the user; orientation tracker, to obtain the current orientation of the user's head; and environment mapping, knowledge of the physical form and position of the entities on the environment that is being augmented.

For this project, two versions of the client are in development. First, a client is being developed for a PDA. The setup is formed with the following devices: HP iPAQ 5450 with Pocket PC 2002, Pretec CompactGPS, Lifeview FlyJacket i3800, Lifeview FlyJacket iCAM, Intersense Intertrax 2, Compaq iPAQ Serial Adapter Cable (3800/3900/5400 Series). In Figure 4, a picture of the PDA setup is shown without Pretec CompactGPS.

Figure 4: PDA setup (without GPS).

Finally, an additional client is in development for laptop computers. This setup is as follows: Laptop computer, Pretec CompactGPS, Phillips ToUcam Pro, Intersense Intertrax 2. In addition, to provide the necessary mobility to the roaming users, a wireless network is used to connect the client and server module. The described system doesn't take into account gaps in the connection. A reliable connection is needed to perform updates in the client view.

CONCLUSIONS AND FUTURE WORK

The presented architecture was studied and tailored for environmental management, namely visualization of pollution dispersion in water streams and artificial lakes. With this architecture multiple users can interact with the geo-referenced model, enabling common users to interact with a pollution transport model. However, it can be applied in other domains adjusting the geo-referenced model for each situation.

The modularity of the present architecture facilitates the development of new modules for additional devices or different geo-referenced models. Different clients with different screen sizes can also be easily used with the geo-referenced model. Moreover, interaction with the model is improved with the usage of templates, also enabling common users to interact with a pollutant transport model and assess environmental impact of pollutant agents or waste water treatment plants.

The AR composition module supplies two different views to observe the model simulation. The first view, a computer animation, is suitable to interact with the model. The second view, supplies an additional degree of realism with pollution dispersion in the user's vicinity superimposed over the real image. In the future, improvements in current modules should be made, namely the AR modules, either for PDA or laptop computers.

ACKNOWLEDGMENTS

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REFEREED PAPER

Mobile Environmental Visualization

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Environmental processes are a major point of concern for researchers, environmental engineers and the general public. This paper presents a multi-user mobile system to visualize environmental processes. This system enables multiple users to visualize and simulate environmental processes, and also retrieve additional information in real time, while moving through the environmental area under analysis. Each user is able to contribute to the simulation and assess the impact of adding or removing agents to or from the model, respectively.

This system uses a modular approach, allowing its deployment through different platforms. Two main modules compose the system under development: a geo-referenced model and an Augmented Reality (AR) composition module. The geo-referenced model describes the environmental processes being modelled and tracks all users. The AR composition module allows users to visualize the geo-referenced model evolution and to interact with the model through two different views, namely animated map view and AR view.

Keywords: Environmental Processes Visualization, Augmented Reality, animated maps, interactive maps, multi-user geovisualization

1. INTRODUCTION

Environmental changes may influence everyone's lives, being a major point of concern for researchers, managers and the general public. Environmental processes are complex and influenced by numerous natural factors and by the human activities. Tools and methods of analysis that help users to collaboratively gather, analyse, model and monitor diverse environmental data in a rapid and flexible manner are required to manage, assess and reduce the impact of natural phenomena or human activities on the environment. These tools should allow users to visualize, analyse and evaluate environmental scenarios, by modelling and simulating environmental processes. Users with little experience in environmental issues should also be able to use these tools to query, display and produce maps and reports from environmental data sets held in a common source, namely in a GIS.

Geo-referenced models can be useful in 'what if' scenarios to simulate the effects of adopting different policy options, where each stakeholder can give his or her opinion reflecting the overall choices in the simulation. Based on the interests of all, a more balanced choice could be made. Air and water dispersion pollution models are some examples of models that can be used to simulate 'what if' scenarios, such as evaluating the impact of building a factory in a particular region. Hence, GIS and geo-referenced models can become more responsive in dealing with environmental issues such as environmental contingency planning or disaster management. Geo-referenced models are tools that can be used by all users to aid in balancing the complex interacting factors that should be taken into account when studying environmental changes. Users can be any member of a community interested in assessing and visualize the impact of a defined environmental change.

Often an extensive list of parameters, mainly spatial and temporal, should be supplied to the simulation to accurately characterize an environmental process. However, some details of the processes, which are not relevant for the tasks at hand, can be ignored, simplifying the model used to simulate the observed changes in the modelled environment. By reproducing and simplifying real complex systems or processes, models are essential to understand and predict their behaviour. Several techniques can then be used to visualize model simulation, namely 2D

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Computer Animations, Virtual Reality (VR) and Augmented Reality (AR).

2D Computer Animations can be used as support tools to help designers to outline the basic features of the environment and give all users a way to move through different levels of detail in the visualized environment. VR is described as a computer system used to create an artificial world in which the user has the impression of being immersed, has the ability to navigate through it and manipulate the objects in it. Visualization and interaction with the virtual world is accomplished through the usage of a Head-Mounted Display (HMD) and position trackers, enabling the VR system to tailor the output according to the user's position and line of sight.

A major disadvantage of traditional VR systems is perception blockage of the real world. Contrasting VR, AR superimposes virtual objects over real objects instead of replacing the real environment. Virtual objects, superimposed in the real environment, supply additional information to users, which is not easily detected with their own senses. This AR property helps users to perceive and interact with the real world, freeing them from the task of searching for cues in the scene, and making it also more effective and pleasant.

The desktop metaphor is nowadays limited due to the growing rise of mobile devices, increasing the need to access information anywhere and at any moment, and to better manage information. These goals have driven the design of AR systems (Barfield and Caudell, 2001). In environmental management, access to real-time data, in the field of observations is also an important issue making AR suitable for this purpose. Moreover, it is easier to see additional information superimposed in the field of observation. In many AR systems, the area of interaction is limited to the user's field of view. An animated map view can supply a more general view, but lacks realism, and VR blocks perception of the real world. Thus, a combination of different view modes can be used to overcome the problems presented by each view mode and enhance the best in each of them.

Environmental management, in several cases, requires the system to be mobile and friendly, so that the user can have a pleasant experience using it across a considerable spatial area. Traditional AR and VR systems require the use of several specific devices to support the experience, namely HMD, orientation and position trackers, and laptops. However, these systems are too cumbersome and intrusive for a roaming user. Personal Digital Assistants (PDA) can be used to avoid burdening the user with all these devices and provide a visualization system more suitable for roaming users. Some users may not have the needed technical experience to use the system, requiring it to be easy to use and to provide an interface that offers a pleasant experience. Interaction between each user is also an interesting aspect, in order to provide them an opportunity for actively and collaboratively managing their futures.

Mobile Augmented Reality System (MARE) was designed to provide users with geo-referenced information required to accomplish their environmental management tasks. It is deployed in laptop computers and PDAs, and have its foundations in the project Augmented Environments (ANTS) (Romão *et. al.*, 2002). The main goal of the system is to allow a group of users to interact during the simulation of an environmental process, providing them access to contextual geo-referenced information, and giving them the possibility to move freely across the area under analysis.

In the next section, an overview of several projects that inspired the ANTS project is presented. Next, a system overview is presented, followed by a presentation of the view modes used to display information to the several users, also detailing animated map view and AR composition view. Afterwards, the client and server modules architecture will be described. Finally, the conclusions and future work will be shown to drive future research.

2. RELATED WORK

Map-based visualization, VR and AR have been used for many purposes. Among these purposes are: specialized professionals training, entertainment industry, architecture and urban planning and, more recently, environmental visualization. These tools allow the simulation of different scenarios and the monitoring of people's responses and behaviour in real world situations. Each visualization system has its potentialities, which leads research to the usage of hybrid interfaces, taking advantage of the characteristics of each different visualization method. Hedley *et al.* (2002) explored the use of hybrid user interfaces for collaborative geographic data visualization with two interfaces. The first interface combines AR, immersive VR and computer vision based on hand and object tracking. Users wear a lightweight camera and display, so that they can look at a real map and see three-dimensional virtual terrain models overlaid in the map. In this case, users can fly and experience the model immersively, or use free hand gestures or physical markers to change the data representation. The second interface allows users to zoom in/out of the image, paddle interactions and pen annotations.

BITS (Browsing in Time and Space) interface was developed for the exploration of virtual ecosystems. It allows users to navigate and explore a complex virtual world, interact with surrounding objects and make annotations indexed in both time and space (Dias *et al.*, 1995). Ghadirian and Bishop (2002) introduced a project to combine GIS-based environmental processes modelling with the use of AR technology to illustrate environmental changes in an immersive environment. The project is applied to weed modelling and simulation. A GPS and a camera are used to track users. Although research in mobile augmented reality systems is increasing, the technical challenges to develop these systems are still enormous: extremely high update rates, network communication gaps, low processing resources in the client side, image registration, match between camera field vision and model, technological limitations in the different sensors, namely GPS and magnetic trackers.

Accurately tracking users' positions and viewpoint orientation is important to minimize image registration errors. An overview of tracking systems can be found in Rolland *et al.* (2001). Each tracking sensor has its advantages and disadvantages, namely vision-based trackers are computationally intensive, magnetic trackers have low accuracy and mechanical trackers are cumbersome. Hybrid

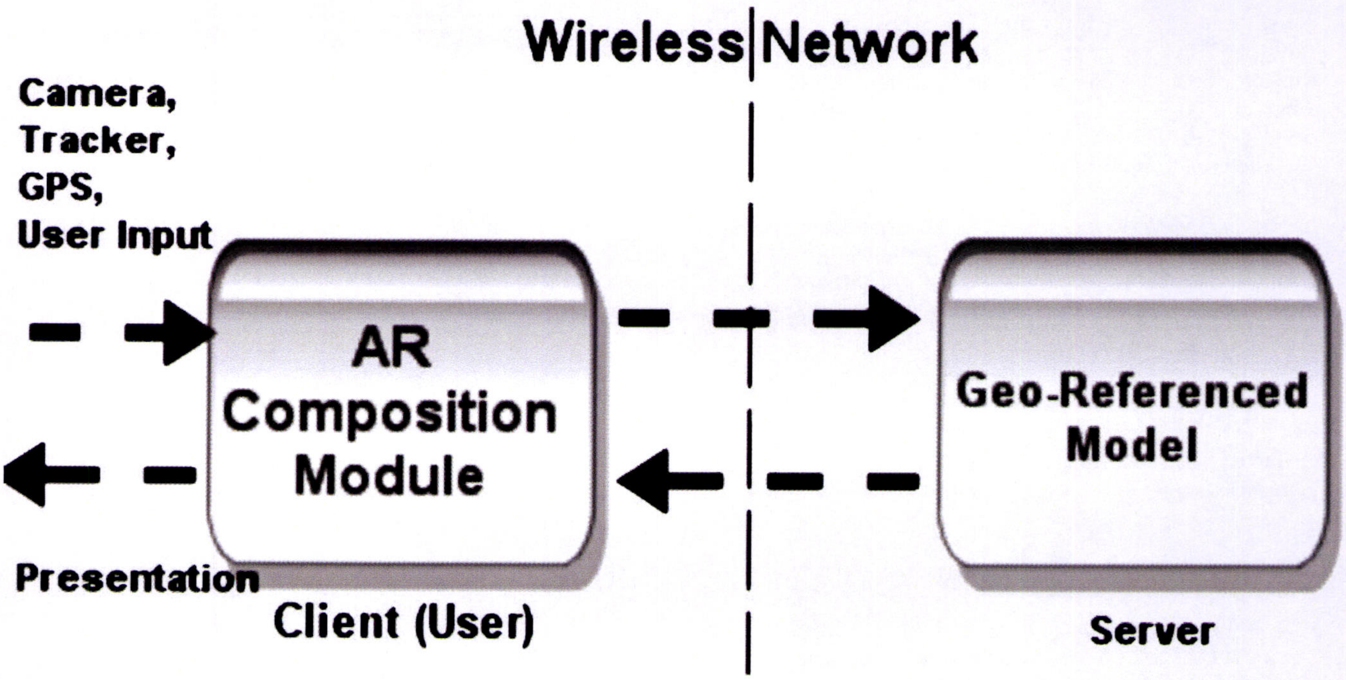

Figure 1. Architecture overview

methods are then used to take advantage of each tracking method, also minimizing their problems (Azuma *et al.*, 1999; You *et al.*, 1999). Pasman *et al.* (1998) have described a mobile AR system. The system uses GPS and image capture to track users' position. Orientation tracking is retrieved from object recognition and direct feedback from inertial tracker. Outdoor AR systems cover a wider area, increasing the problems related to each tracking sensor. Hence, challenges to develop an outdoor AR system are enormous.

The first AR outdoor system was the Touring Machine (Feiner *et al.*, 1997). This system assists users interested in visiting the Columbia's University campus, overlaying information about points of interest in their neighbourhood. It combines a video-see-through display with a handheld display using different interaction technologies to take advantage of their complementary capabilities. A more recent version of the system rather than linking individual labels or web pages to locations, supports context-dependent, narrated multimedia presentations that combine audio, images, video and omni directional camera imagery. Additionally, 3D graphics are overlaid in the user interface and presentation content, showing models of buildings that no longer exist and views of visually obstructed infrastructures. When selecting points of interest the user is also guided to them (Hollerer *et al.*, 1999a; Hollerer *et al.*, 1999b). Further research is needed to create more accurate, lighter, cheaper and less power consuming mobile devices. Furthermore, image registration errors should be avoided to maintain proper alignment of virtual information related to objects in the real scene.

3. SYSTEM OVERVIEW

Agents are described as the elements in the environment, whether natural or human-made, that can cause environmental changes. For example, natural agents can be wind or fire, and human-made agents can be swine farms, factories or waste water treatment plants. Each agent has a set of related parameters that can be grouped to describe its behaviour in the scope of the model. Environmental processes are complex systems, involving several stakeholders in their study. Thus, a modular architecture was developed, in order to provide users with a mobile system able to model, simulate and visualize environmental processes, and supply additional contextual information in real time. Two main modules are the basis for this client-server architecture, namely a geo-referenced model and an AR composition module as shown in Figure 1.

The geo-referenced model is the main module, representing the real physical environment under analysis. This module uses the data gathered by the AR composition module, in the client side, to track users and evaluate the geo-reference model results, which are sent back to the AR composition module for visualization. The AR composition module is used to collect input from several users and visualize the geo-referenced model evolution, through two main views: animated map view and AR composition view. The communication between these two modules is performed using the HTTP protocol, given the wide support for this protocol in different client devices also enabling a common communication platform between them. As a case study, MARE system is being used to build an application for the visualization of water quality in artificial lakes and natural water streams.

4. SIMULATION VIEWS

In the majority of cases, environmental management requires visualization of a wide area, also involving the simulation of several different scenarios to assess impact of each simulated scenario in the environment. The agents involved in the simulation can be apart from the user's position, although they can have a big impact in the environment near the user. Thus, for this mobile AR system two views are being developed to allow the interaction with the simulation model and the visualization of the simulation progress.

The first view is an animated map view allowing the user to have a map view of the environment. In this view mode, the user is allowed to observe the simulation, add and remove agents to control the simulation evolution. Alternatively, the user can see the simulation results superimposed in his or her view of the real environment. In this view, the user can easily assess the impact of environmental changes in the area in his or her vicinity. Given that the system is to be deployed in laptops and PDA, the result will be tailored according to the display characteristics of the device, independently of the view mode being used.

Animated Map View

When analysing complex environments, combining overview and details give users the possibility to choose between a general outlook of the contextual situation and a detailed view of a restricted area of particular interest. MARE is able to supply an animated map view of an area, evolving over time according to a simulation in progress by the geo-referenced model. In this view mode, a zoom facility is provided to allow users to achieve the desired level of detail. In addition, a user's physical location is represented through an icon in the animated map view. To keep focus on the user, the simulation result is returned with the related user's icon in the centre of the view. Hence, it is easier for the user to search for familiar cues representing points of interest in the environment. To represent the limits of the model, when the user surpasses the physical limits represented in the geo-reference model, the user icon is placed in a correspondent position. Namely, a user out of the limits of the geo-referenced model is placed in the nearest edge of the model representation.

User's orientation is another important cue for users. Thus, an arrow represents the user actual position and orientation enabling users, unfamiliar with the environment, to easily travel in the real environment. Since the model gives users a real-time feedback of the geo-referenced model simulation, position and orientation of all users' movements in the real environment are reflected in the interface. All requests to the geo-referenced model are performed through HTTP requests. Thus, the rate at which clients will receive new data from the simulation depends on the clients processing power and wireless network protocol being used. In a test scenario with the geo-referenced model and a client measuring the time for the request to arrive, the system was able to deliver responses in 256 milliseconds, on average. Nonetheless, the geo-referenced model uses a distributed architecture, allowing the system to grow and handle huge amounts of data.

In the simulation, each agent is represented through the use of templates that describe all parameters needed to add or remove the related agent within the geo-referenced model. New templates can also be added to represent additional agents. Icons are used to represent each agent in the user's view of the simulation. In fact, by tapping on the

Figure 2. 2D computer animation view

screen or clicking in a location in the animated map view, the user can see a menu presenting the agents that can be added to the simulation in progress (see Figure 2). When an agent is selected, a request is sent to the server to add the related agent to the simulation. In this request, the screen coordinates where the agent should be added, and the user position and orientation are sent to the server. All data will then be used to perform a translation to model coordinates and add the correspondent agent to the simulation. When an agent is removed, user absolute position and orientation information is sent with information about agent relative positioning. In the server, the agent is searched within the geo-referenced model and removed. The resulting simulation will then be updated in each user's display.

AR Composition View

AR composition view is able to provide a more realistic image of the impacts resulting from the current defined scenario. In this view mode, users are able to visualize the real world image, according to their position and orientation, superimposed with the environmental changes evaluated by the geo-referenced model. In the water quality application, a pollution dispersion map is superimposed over the river surface depicting the pollution dispersion retrieved from the geo-referenced model tailored to the position and perspective of the users. The main difference related to the animated map view is that the image returned from the server is translated to the position and orientation of the user, allowing superimposition of that image over the real image.

In addition, the image returned from the server, while in animated map view, has information about the surrounding environments, as shown in Figure 2, and in the AR composition view, the image is transparent, only having the pollution dispersion map. AR composition view does not have significant visual cues, diminishing the effect of superimposed virtual objects 'floating' over the real image. Thus, some accuracy errors in image superimposition over water surface can be tolerated by the users. Moreover, each user is tracked within each request, enabling the resulting image to be tailored to each of them.

Currently, interaction with the geo-referenced model is not possible while in AR composition view. Environmental models cover a wide spatial area and activities taken place in one location may have relevant side effects in distant locations. Hence, to modify the current scenario, by adding or removing environmental agents to the geo-referenced model, and to perform new simulations, users must switch to the animated map view, in order to have a wider view of the environment in their vicinity.

5. ARCHITECTURE

An important request of the ANTS project was to achieve a system architecture that gives users both mobility, and the ability to visualize geo-referenced models. In an effective mobile augmented reality system, adjustment to available resources, such as low processing power, screen size, different protocols and operating systems, is an important issue. Thus, in this system architecture the maximum operations needed to supply additional information to users are performed server-side, freeing clients to perform other tasks, namely to collect user input and retrieve information from several sensors.

Server

Resembling the web services architecture, the geo-referenced model is an HTTP server returning an XML file as an answer to queries from clients. This architecture allows several clients to interact with the geo-referenced model sending it queries as a set of parameters in the URL. In order to maintain consistency in the geo-referenced model, all requests from clients to add or remove an agent from the simulation are handled in a first-in first-out (FIFO) method. All users interact with the same simulation supporting different scenarios that could affect their interests. This approach enables a group of users to discuss issues more related to their interests, also enabling them to see the impact on the other users' choices. Currently, all users are able to add and remove agents from the simulation without restrictions.

In order to restrict user's permissions to perform specific tasks, a schema resembling the ones used in the file systems management could be implemented. Groups of users could be defined allowing them to perform defined operations. To improve this schema, a mutual exclusion object (mutex) could be used within a group of users allowing only one of them to perform an operation within the geo-referenced model. Thus, the user will be able to request ownership of the mutex to perform the operation and release ownership after performing the operation.

The simulation model being used in the development of MARE system is the Dispar pollutant transport model, but the system can be adjusted to accommodate other spatial dynamic simulation models. Dispar is a mathematical formulation to solve advection–diffusion problems in aquatic systems. The Dispar transport model is a 2D model able to simulate several pollutant scenarios (Ferreira and Costa, 2002). In our application, Dispar is applied to the Tejo estuary (Lisbon). A previous calibration of the system is performed, mapping latitude and longitude values, gathered from the GPS, to model coordinates. In addition, users' orientation values are also mapped against geo-referenced model's orientation, in order to correctly show users' orientation or superimpose the related model evolution, whether in animated map view or AR view respectively.

Tracking information related to each user is kept in the server for visualization purposes. In the animated map view, it is possible to see the evolution of the geo-referenced model simulation and the position of all users in the view range. Thus, to track users, each user has to perform a registration step before being able to perform queries to the geo-referenced model. In the registration step, a unique identifier (ID) is generated for the related user and sent back to the client. This unique identifier will later be attached to the information related to its corresponding user, namely tracking sensors information, client display size and view mode.

The first client interacting with the geo-referenced model also has to send a request to the server to perform a new simulation, which is carried by the interface and hidden from the user. Afterwards, each registered client can request the model to add or remove agents acting in the simulation process (see Figure 3). In each request, the server updates the geo-referenced model and sends an XML with the response. In the registration process, an ID is returned and in all other queries an image is returned with the current status of the geo-referenced model simulation.

Agents involved in this application can be pollutant sources, namely factories, swine farms or water waste treatment plants. Agents can be placed near a water stream or artificial lakes to assess the impact in water quality. Afterwards, a virtual sewage pipe is created to connect environmental agents and the nearest point in the water body describing the point where the environmental agents will affect the current region under analysis. If a pollutant agent is released within the range of a waste water treatment plant, the wastes are conducted to it and pollutant discharge is reduced.

Client

Despite the great evolution of mobile devices, namely increased battery lifetime, increased processing power, and decreased size of devices, some limitations persist restricting user's experience while in a completely mobile environment. Since, simulations demand for processing power, the operations in the client are reduced to a possible minimum. The operations performed in the client side involve collecting the user position and orientation, superimposing additional information over the real images, and dealing with interactions from the user. Each user is tracked via a

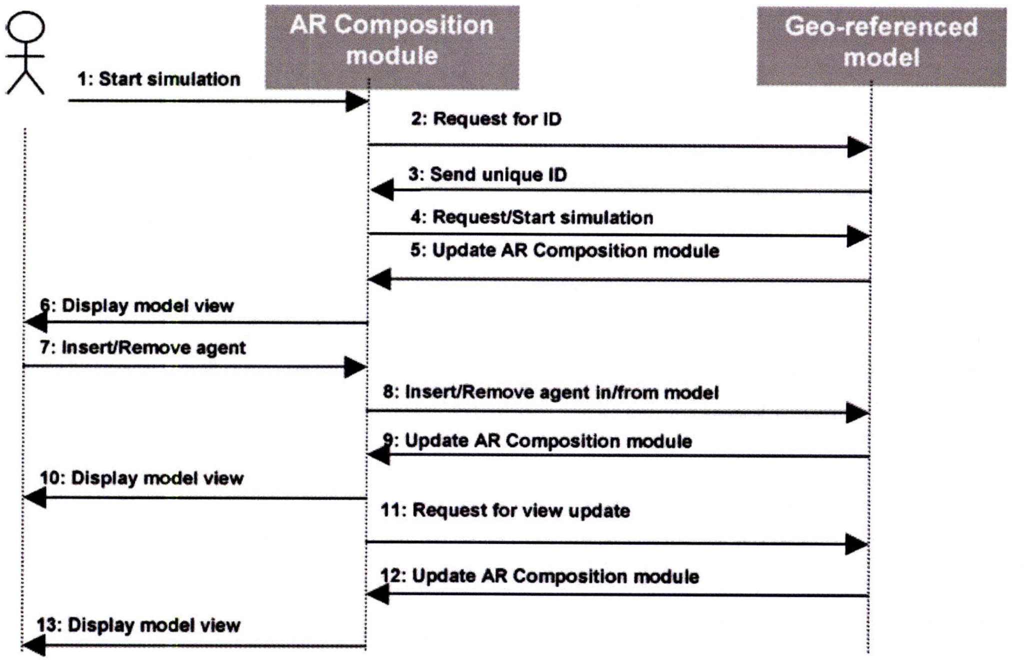

Figure 3. Sample interaction with the geo-referenced model

GPS, to grab absolute user's position, and an orientation tracker, to obtain current user's head orientation. The orientation tracker used, an Intersense Intertrax 2, is sensible to disturbances in the ambient magnetic field causing superimposed information to float over the real image. In the future, it is planned to use position captured from GPS to reduced drift. Velocity vectors can be calculated based on user's movement, so this data can be used to correct information from the orientation sensor improving registration accuracy.

For this project, two versions of the client are in development: one for PDA and another for laptop computer client devices. For the PDA client device version the setup is formed by the following devices: HP iPAQ 5450 with Pocket PC 2002, Pretec CompactGPS, Lifeview FlyJacket i3800, Lifeview FlyJacket iCAM, Intersense Intertrax 2, Compaq iPAQ Serial Adapter Cable (3800/3900/5400 Series). In Figure 4, a picture of the PDA setup is shown. The laptop computer client device version setup is as follows: Laptop computer, Pretec CompactGPS, Phillips ToUcam Pro, Intersense Intertrax 2, and Cy-visor DH-4400VP. In addition, to provide the necessary mobility to the roaming users, a wireless network is used

Figure 4. PDA setup

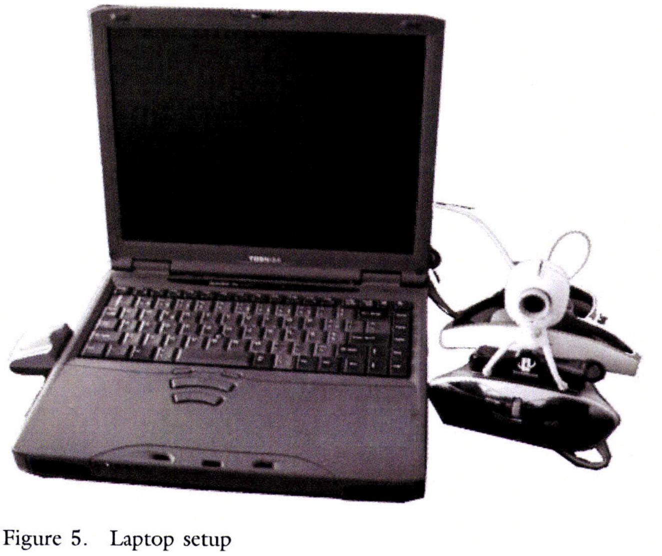

Figure 5. Laptop setup

to connect the client and server module. In Figure 5, a picture of the laptop setup is shown.

As described before, in each request the client sends all parameters in the URL to the server. All unknown requests received in the server are ignored, giving some robustness to the server. In Table 1, all possible operations are described, starting with a base URL, namely: http://server.ip/request.xml?

In the registration step, when the client requests an identifier, a unique identifier is returned, stored in the client and sent to the server in all subsequent requests. This operation enables the server to uniquely track all users. All other requests return, to the client, an updated image of the geo-referenced model evolution, tailored to the user position, orientation, view mode, and screen size using base64. Base64 encoding enables the server to send images in an XML file. By using HTTP and XML protocols, a wider number of client devices and programming languages can be used to develop new client devices for the system, also enhancing the modularity of the system. Figure 6, overviews the process of receiving the result from the geo-referenced model in the client device and displaying it on the screen.

6. CONCLUSIONS AND FUTURE WORK

For visualization and management of environmental changes, a client-server architecture is being developed to allow several users to work together in real time contextual simulations. Out of the labs, in the real environmental area under analysis users can have a more realistic view of the consequences of their different actions over the environment. A geo-referenced model and an AR composition module are the main modules of the system, enabling several users to interact and share experiences while using the system. A demonstration of the system for the visualization of pollution dispersion in water streams and artificial lakes is under development.

Spatial superimposition of virtual objects where it makes sense leverages the users from the task of searching for the context to apply the retrieved information. However, it can be applied in other domains by adjusting the geo-referenced model for each situation. In the future, a common environmental data source, namely a GIS, can be used to provide the geo-referenced model with additional data about the environment. Modular architecture facilitates the development of new modules for additional client devices or different geo-referenced models.

Table 1. Operations description

OPERATION TYPE (op=type)	OPERATION PARAMETERS	EXAMPLE
1 - Request ID	scr=x,y pos=lat,log,alt Ori=roll,yaw,pitch	http://server.ip/request.xml?op=1&scr=240,320&pos=0,0,0&ori=0,0,0
2 - Insert agent	id=user id type=agent type *agent type:* 1. Factory, 2. Suine farm, 3. Waste water treatment. scr=X offset,Y offset pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=2&id=0&type=1&scr=30,30&pos=0,0,0&ori=0,0,0&zoom=1
3 - Remove agent	id=user id scr=X offset,Y offset pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=3&id=0&scr=30,30&pos=0,0,0&ori=0,0,0&zoom=1
4 - New simulation	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=4&id=0&pos=0,0,0&ori=0,0,0&zoom=1
5 - Start	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=5&id=0&pos=0,0,0&ori=0,0,0&zoom=1
6 - Stop	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=6&id=0&pos=0,0,0&ori=0,0,0&zoom=1
7 - Update	id=user id pos=lat,log,alt ori=roll,yaw,pitch zoom=zoom level	http://server.ip/request.xml?op=7&id=0&pos=0,0,0&ori=0,0,0&zoom=1

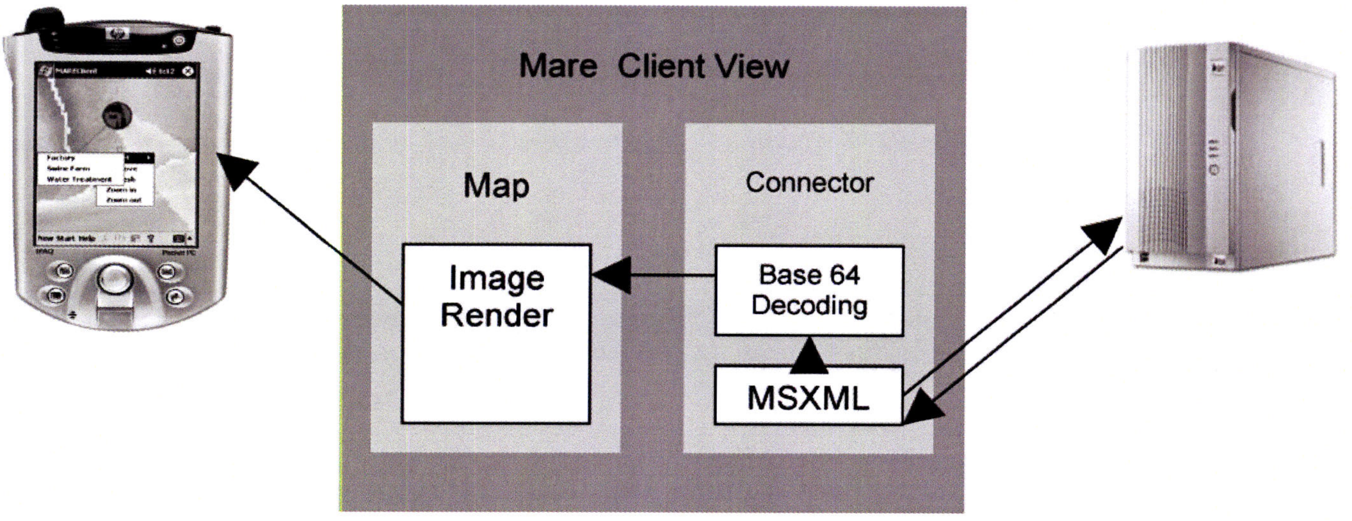

Figure 6. Update procedure

Different clients with different screen sizes can also be easily used with the geo-referenced model. With the goal of providing a tool for the visualization of environmental changes to all users, interaction with the geo-referenced model is improved with the usage of templates representing pollutant agents or waste water treatment plants. Hybrid interfaces are also in development to overcome the problems of each one. Two different views to observe the model simulation enable users to view and interact with the system. In the first view, an animated map is used to interact with the model and provide a global analysis of the environment. The second view supplies an additional degree of realism with pollution dispersion in the user's vicinity superimposed over the real image. In the future, improvements in current modules should be made, namely the AR modules, either for PDA and laptop computer versions.

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In-Building Positioning: Modeling Location for Indoor W[illegible]

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Abstract

The combination of location positioning technologies such as GPS and initiatives like the US Federal Communications Commission's E911 telecommunication has generated a lot of interest in applications and services that are a function of a user's location, referred to as location-based services (LBS). A multitude of applications and services would also benefit from indoor (in-building) positioning and navigation. However, despite GPS technology and the positioning capabilities of cellular networks such as GSM, millions of square meters of indoor space are out of reach of these systems.

Fortunately, over the past decade, advances in location positioning technology have made it possible to locate objects indoors. These alternative technologies are now being introduced to the market enabling many kinds of indoor LBS applications. The argument/exploration of this paper is that in order for indoor LBS to become widely used, there is a need for the infrastructure investment.

1. Introduction

Mobile devices are becoming ubiquitous in our daily life, giving users a huge sense of mobility. Accompanying this growth, mobile and mobile-aware software are more sophisticated, taking advantage of the knowledge of their and other object's physical location. Moreover, different sensor technologies can be used to position users and devices.

Indoor world's several constraints should be addressed given the issues related to these spaces. Thus, a question is raised: "What's different in the indoor world?" Both GPS and cellular network (i.e., GSM) based positioning are not appropriate for indoor use, due to lost of line of sight for GPS and signal blockage (i.e., by walls), fading and shadowing for GSM. Nonetheless, GSM can be [illegible] accuracy system, mainly using cell-ID.

In addition, the indoor world can [illegible] controlled environment and several [illegible] methods can be used, alone or combined, [illegible]

- Triangulation
  - lateration - Time of Flight (TOF), [illegible]
  - angulation - Angle of Arrival (AOA) [illegible] against some baseline can be measured [illegible] strength (SS) or time difference of [illegible] SS systems compare the received SS [illegible] with a spectrum of angles and return [illegible] maximum strength. Time based [illegible] arrangements of receivers to measure the [illegible] thus the difference in distance from each [illegible] the transmitter. Combined with [illegible] arrangements of the receiver array is [illegible] solve the AOA.
- Scene analysis
  - use of a feature as a reference [illegible] RADAR) [1]
- Proximity
  - physical contact through pressure [illegible] (SmartFloor) [2]
  - monitoring (Active Badge) [3]
  - observing (automatic ID systems)

Indoors location systems encompass [illegible] scales in a wide range of application settings [illegible] LBS, micro-geography. Additionally, [illegible] positioning (i.e., Cartesian coordinates) or [illegible] positioning ("in room 101") can be [illegible] accordingly, geometric location data models [illegible] vector features, metrics like distance) or [illegible] location data models (no metrics; symbols [illegible] represent a spatial meaning).

2. Roles and types of infrastructure

The infrastructure needed for a locat[illegible] service can be divided in four pieces: Comm[illegible]

Infrastructure, Positioning Infrastructure, Mapping Infrastructure and, Services Infrastructure.

2.1. Communication infrastructure

Indoor's several technologies can be used to exchange information between devices. When deciding what technology to use the system designer should choose between low power and low rate technologies, such as Bluetooth and, high power and higher rates, such as IEEE 802.11b or g. Nonetheless, the system designer may use already deployed and wider technologies, such as Universal Mobile Telecommunications System (UMTS).

2.2. Positioning infrastructure

Within the indoor world, different zones of positioning types can co-exist not only on different floors, but also on the same floor. Figure 1 shows a user in an indoor setting such as a floor of a shopping mall. In one part (zone) of the floor, relative positioning is provided, while in another part, absolute positioning is provided.

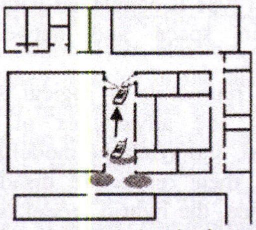

Figure 1. Absolute and relative positioning

For discussion purposes, MIT Cricket [4] is used for the absolute positioning. Active Badge [3] is used for relative positioning. There are two possibilities with this scenario: IEEE 802.11b cell-id based positioning where one can achieve absolute positioning (the IEEE 802.11b APs have absolute (fixed) coordinates), while the other, relative positioning (the system has symbolic locations, i.e., "room 2, floor 201" "sector 1, hallway Z").

2.2.1. Absolute Positioning. Absolute positioning using the IEEE 802.11b cell-id positioning method works as follows. IEEE 802.11b access points (APs) transmitting RF signal augmented with their physical (fixed) coordinates can be used to estimate the location of the mobile host by distance measurements. The strengths of the RF signals arriving from more APs can be related to the position of the mobile terminal and can be used to infer the location of the user. The accuracy of the system might be limited by the (possibly large) cell size. Handling off location to a room can be done with a tolerance level using such methods as location fingerprinting ("snapping"), as shown in Figure 2.

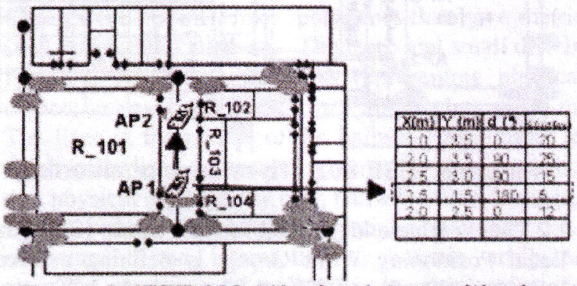

Figure 2. IEEE 802.11b absolute positioning

2.2.2. Relative Positioning. Similarly, relative positioning works by means of referencing the IEEE 802.11b AP that the user is accessing to its location, which in this case, is symbolic. IEEE 802.11b access points (APs) transmitting RF signal augmented with their relative position ("sector 1, hallway 101") can be used to estimate the location of the mobile user. The position is derived based on the IEEE 802.11b AP that the user accessed, of which the location (the room number) is known (i.e., AP#201_1 is "in room 201").

To locate a user then, the idea is that if '*User 1*' access '*AP #201_1,*' he/she is mapped/referenced to '*Room 201.*' Moreover, each AP has an access range/perimeter, which is represented (modeled in the symbolic database) so that a user accessing AP1 is "within" the range of that AP1. This range may or may not be defined to a specific metric distance (i.e., range of 10m). The point is that it does not need to be for such applications as the Buddy Finder because knowing that AP1 is "next to" AP2 will allow referencing (matching) that the user accessing AP1 is "next to" the user accessing AP2, without any use of metrics (i.e., distance), as shown in figure 3.

2.2.3. Relative Positioning to Absolute Positioning Seamless Handover. Designing a location system for a single environment presents difficulties when the system is applied to other environments. Depending on the aim of the positioning system, different environments may need to handle different sensor data, whether absolute or relative. This fact raises the need to have a positioning system that successfully bridges the differences between absolute and relative. For instance, without a tracking sensor technology, it is difficult for a person to go to a museum, given its destination position 38° 39' N, 8° 13' W. Accordingly, it will be difficult for a "driver" to know what is the distance to the gas station if the location model is only operating with symbolic names.

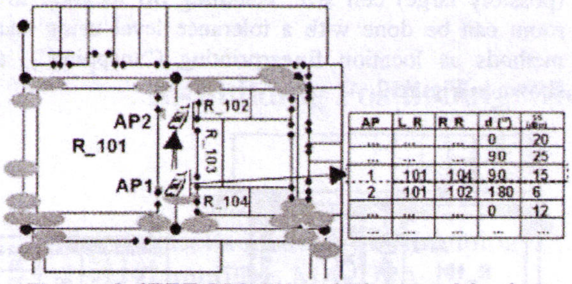

Figure 3. IEEE 802.11b relative positioning

Thus, a Bluetooth Special Interest Group (SIG), the Local Positioning Work Group, is defining a Local Positioning Profile (LPP) for Bluetooth. In LPP, a set of XML messages, the Local Positioning Messaging Protocol (LPMP), can be used to exchange location information between devices. The location can be latitude and longitude, or additionally a hierarchical message can be exchanged with information about the environment.

In the NEXUS Project, a query language and a modeling language, named Augmented World Query Language (AWQL) and Augmented World Modeling Language (AWML) respectively, were developed to describe the objects in the environment and query the augmented world model [5]. Both languages are defined using XML. In AWML, Objects geometry is described using Geographic Markup Language (GML).

AWML models geographic location, geometry of objects and symbolic descriptors of the objects, such as room numbers and relationships between objects. In addition, AWQL allows the querying of the world model for objects holding to certain restrictions. Given these restrictions it is possible to know spatial relationships to other objects, such as: includes, inside, closest, excludes, overlaps and inside. Moreover, these restrictions can be combined with Boolean operators. The querying language also supports generalization and aggregation rules allowing small details to be removed and small objects to be combined into larger objects.

2.3. The mapping infrastructure (mapping out the indoor world)

Different indoor LBS applications deal with different scales. For example, both, the Buddy Finder and the Product Finder can operate on a building scale (i.e., "notify me when Bob is in the shopping mall..." and "show me the location of the store that has the product that I am looking for..."). In addition, both applications could require room-scale location model (i.e., "notify me when Bob is in the same room..." and "show me the aisle where I can find the product...").

As a result, it is important to make sure that the underlying location model is suitable for the aimed functions.

Different types of location models exist that provide an abstraction between users/devices and the raw data provided by various location sensing technologies (previous section). Numerous location models have been defined in different applications domains.

In general, location models can be classified into four types:

1. *Geometric* - allows points, areas (2-D) and volumes (3-D) to be modeled; however a point in geometric space has no relationship to what it points to. The resolution of this model is as fine as the units of measurement used.
2. *Symbolic* - describes location and space in terms of names and abstractions (i.e., hierarchies). Unlike the geometric model, humans and computational devices can understand this model better. However, they lack the precision of geometric models in terms of metrics for location and distance. (Types: spatial model graph, topological.)
3. *Semantic* – rather than focusing purely on position, this model type is concerned with relationships of entities in space and between the spaces themselves.
4. *Hybrid* - represents a logical step forward in combining the advantages of the geometric, topological, and symbolic model types in order to overcome their respective disadvantages. As a consequence, the hybrid model is more complex, requiring greater amounts of data.

2.3.1. Symbolic Maps and Location Data Models

A location entity, such as a shopping mall or university campus is decomposed into several intersected sub-spaces: building 1, building 2, building 3, etc. Each of these buildings is divided into smaller composing sub-spaces (floor 1, floor 2, floor 3, etc.), until enough level-of-detail is reached to reference / map objects in space, which in this case is a room, a store, or a shelf in a store.

In figure 4, the parent-child link implies superior space relationships between two spaces. These divisions could be used as location entity providing a spatial reference for users (or other objects), which will themselves, be defined by some supposedly well-known characterization rather than their physical properties. The location service needs to maintain a hierarchical style data structure for the space tree and handle queries of spatial relationship (i.e., containment) based on this data structure.

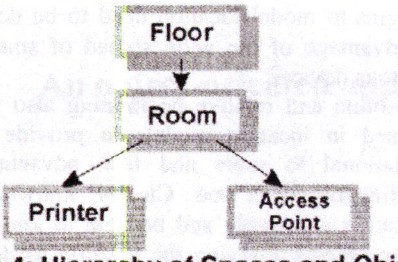

Figure 4: Hierarchy of Spaces and Objects within Them

A symbolic map, sometimes referred to as a spatial model graph or a spatial tree, represents these different levels of spaces by nodes. Information is considered to be affiliated with a location, hence linked to a node in the spatial model. Edges (or lines) between the nodes define how these places are connected.

For example, a shopping mall can be represented as a set of spatial model graphs, each graph representing a floor. Each node is a place of interest (i.e., store, restaurant, ATM). The edges (arcs) between stores are the shopping mall's hallways. Each store represented as a node may have associated secondary nodes representing shelves or products. Links between floors can be represented by special arcs (i.e., represented as dotted lines), which have specific properties indicating the type of connection (stair, elevator, escalator, ramp) and the floors they link to. In the parking lot floors, each node could represent one parking spot and the edges (arcs) are the paths to elevators and stairs. This model can also represent access privileges. For example, thin dotted lines between rooms and doors (both represented as nodes) can represent that the door is open.

Since the locations of objects are correlated to actual physical spaces, the model is capable of answering containment queries (i.e., "contains," "within") or connectedness queries (i.e., "near," "next to") that exists between two physical spaces. Simple queries include, "Where am I," "Who/what is there?" and neighborhood discovery.

In terms of mapping out the positioning infrastructure, specifically the location of APs, Figure 2 shows that they are represented as small points (which have xy coordinates) but could as well be represented by a node (nodes can vary with respect to size and color, which would associate them to specific physical properties). These APs represented as nodes are physical objects in space, but unlike the geometric model, they are represented in terms of relative positions, such that AP1 is "next to" or "adjacent to" Store ABC (as opposed to absolute positions of Cartesian coordinates in the geometric model).

Although, symbolic models lack precision and the decision to describe space is not simple (nor standardized), they are sufficient for LBS applications that only require relative positioning.

2.3.2. Geometric Maps and Location Data Models. Geometric location maps are made up of features (i.e., points, lines, polygons) that have metric (and non-metric) attributes. The large and small dots in Figure 2 are geometric points representing physical objects in space (i.e., APs) with an absolute position. The lines in the middle of the hallways are similar to street centerlines, resembling the metric characteristics of a physical object/entity (i.e., hallways) like distance.

In order to compute spatial relations (i.e., containment and intersection) geometric attributes must be present in a well-defined spatial reference system[1], such as shapes, extensions, point coordinates, etc. Geometric models define an n-dimensional space, and the locations are points in this space that can be uniquely specified and accurately represented by a tuple of numbers (x, y, z). However, there are sometimes mismatches in the meaningful precision of the coordinates in various locations. An example of a spatial (coordinate) reference system is the one utilized by MIT Cricket.

Various coordinate systems may be used, but they must have well-defined transformations between them. For example, each floor of a building typically acts as a separate spatial reference space – two points on different floors may have the same coordinates on their respective floors, but have an unknown relationship in the real 3D world. One way to solve this problem is to allow each space to have its own local coordinate system by specifying the origin point and three axes of "x", "y", and "z."

2.3.3. Hybrid Maps and Location Data Models. A mapping infrastructure combining both the geometric and symbolic location models makes it possible to support LBS services at all relevant scales, in all types of positioning type environments. Approaches build upon hybrid space models, federating various interpretations of location and location-sensing technologies can achieve these goals. Thus, to get the interconnections between places, it is necessary to have relations between the objects involved.

Some relations are modeled implicitly when the geometry is modeled, e.g. which rooms are next to each other (topology). However, this may not be

[1] Note, there is no such thing as a single absolute coordinate reference system; for the sake of our argument, it could be either geocentric cartesian coordinates, polar geographic coordinates (latitude, longitude, elevation) or planar projection coordinates, as defined under a "well-known" geodetic system.

sufficient, if the geometric model lacks information about doors between rooms. In this case, this relation has to be explicitly modeled.

The counterpart of hybrid models is that, they may have a complexity of requirements to achieve a good relation between area coordinates and a name with membership in one or more domains.

2.4. Services Infrastructure

LBS are increasing their popularity with the increasing number of mobile devices. Thus, to take advantage of the user's mobility, location information is an important issue. Indeed, to locate the user, several methods can be used.

First, basic methods, such as asking the user to enter/select his/her position (hence, no need for a positioning system), can be an option. Second, a location-aware method by means of sensor technologies/positioning systems, like the MIT Cricket that can be improved with Cricket Compass to determine the users' orientation. *Third*, context-aware systems, in addition to location, use other context information such as time, age, preferences, weather, mood, which can be supplied to the system in order to provide specific information tailored to each type of user and/or device.

Dey and Abowd [6] define context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." For discussion purposes, the Cyberguide [7] system supplies context-aware information to the visitors of a building using IrDA technology through the indoor navigational system, named IRREAL.

Information is sent in cycles, resembling the technology from teletext. Although, different nodes of information have different importance to the system and nodes with higher importance are sent at higher rates to the mobile devices. Therefore, information can adapt to the user's walking speed. A user walking fast will retrieve only abstract information, sent at higher cycle rates and, a standing user will retrieve additional information, sent at lower rates.

3. Conclusions

Indoor's location and context awareness is more difficult to achieve given the lack of infrastructure for the aim of some applications. Thus, investments should be made to provide buildings with location infrastructure. Moreover, indoor location modeling is a research area in its infancy. So, extensions and new paradigms to model location need to be developed to take advantage of the wide spread of small, mobile, ubiquitous devices.

Absolute and relative positioning also need to be addressed in location models to provide additional informational to users and take advantage of the capabilities in each one. Clearly, knowing position information accurately and be able to know relations between objects querying the location model based on objects symbols are main characteristics of absolute and relative modules, respectively. Thus, [illegible] representations of models, as well as their integration in location or context-aware systems, are open problems that will derive future developments.

Finally, if some users are not willing to keep their location information open, it raises the privacy problem. Several aspects should be addressed [illegible] whether to add privacy constraints to the representation model or, design the system to avoid that issue.

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Low Cost Location-Based Services

An extendable and low cost location based service to be applied in micro-geographical spaces - Location for You (Loc4U)

Jose DANADO, Eduardo DIAS, Teresa ROMÃO, Patricia VALINHO, Bruno SERRAS, Ivan FRANCO and David PALMA

GPS is almost ubiquitous outdoors, but suffers from the need to have a clear line of sight to the sky. Several methods exist to overcome such difficulties, namely Assisted GPS (A-GPS), which is mainly controlled by mobile operators, or high sensibility GPS receivers, not commonly used. GSM cell ID can as well be used for location purposes; however some cells can have sizes of up to a few kilometers, making it also unsuitable for some context aware applications.

Indeed, commercial solutions can supply accuracies of up to the centimeter level, but the deployment costs are prohibitive in many cases. Furthermore, controlled environments have specific features that can be used to better supply location information to users. In fact, geometric geospatial data isn't suitable to all applications. This paper describes a low-cost radio frequency (RF) location system, Loc4U, that can be easily deployed anywhere with minimal impact in the environment. The overall architecture can grow as needed to supply better accuracy, include additional points of interest, and also support more types of interaction devices. Hybrid and symbolic location models will be used to better model geospatial data to applications. Optionally, orientation information can be supplied to visitors. Furthermore, radio interferences are taken into account and their impact is reduced.

KEYWORDS

Microgeography, Mobility, Location Awareness, Low Cost Location Systems.

INTRODUCTION

An increase in mobile devices availability and mobility of users has raised the need for location-aware computing. Thus, there is an incremental importance in geospatial data to assist users to accomplish many every day tasks. Taking advantage of geospatial data, several applications have already been developed: office applications such as nearest printer services and mobile desktop control to increase workplace productivity; tour and museum guides to help people navigate in unfamiliar spaces; Friend Finder utilities that link with instant messaging for social or business purposes; conference aids to track presentation attendance and facilitate note taking and discussion; medical facilities to track staff and monitor patients for emergency response; and home applications to help with household management and home entertainment, as well as aid the aged and disabled in performing everyday tasks [7].

In the majority of cases, mobile devices provide access to information processing and communication capabilities, but lack any awareness of the context in which they operate. "Context-aware" computing describes the special capability of an information infrastructure to recognize and react to the real world context in which it operates [13]. Location and identity, as well as time and activity, are primary aspects to describe the context that a user or device is in. Context awareness can then be achieved in two ways: in real time, having the system constantly tracking the environment, or by request, asking the system to retrieve the context. Richer location-aware applications require real-time tracking of context, while others may be based in a by request approach.

GPS has been, for long, the widely used technology to retrieve user's location [5][6]. Outdoors, GPS is almost ubiquitous, mainly requiring line of sight to the sky. GPS can overcome such problems using methods such as A-GPS, controlled by mobile operators, or high sensibility GPS receivers, not commonly in use. Alternatively, some applications [11] are using GSM Cell ID and IEEE 802.11 Mac Address as beacons to locate people and objects indoor.

For most daily life applications, these technologies can be sufficient, supplying accuracies from tens of meters to a few kilometers. Undeniably, mobile phones are becoming ubiquitous in our daily lives and GSM cells are widely deployed in urban areas, where most of these applications can be used. Commercial location systems, such as Ekahau, are in use, supplying accuracies of up to a meter using IEEE 802.11 Access Points (AP). However, more accurate systems exist claiming accuracies of up to the centimeter level, namely Ubisense.

The high cost of these systems inhibits its usage in a more wide scale. Museums and historical places all around the world can benefit from location information to supply more detailed descriptions of their content to visitors, giving them the freedom to visit the space on their own while receiving contextual information related to what they are looking at. However, tight budgets and complex configuration procedures may move some of these institutions away from this kind of technologies.

Location technologies based in IEEE 802.11 family of protocols, or even Bluetooth, can be an option, but not all visitors carry devices supporting these technologies. Institutions could rent such devices to their visitors, providing them an augmented experience. However, it implies an initial investment, with the deployment of a basic infrastructure across the whole physical space to be visited, involving new maintenance costs and also raising security concerns. In addition, many of these institutions have limitations in the type and quantity of equipment to integrate in the original environment.

Moreover, in controlled environments, such as indoors, or even in controlled environments outdoors, different schemes to present geospatial data to users may be used, other than the geometric geospatial data that we are used to. In fact, several location scales and different sensors may be used, and a wide range of applications may have different specifications. Thus, geometric geospatial data, such as WGS84, may not be adequate in such spaces, raising the need to combine geometric models with others that may provide more suitable features to these kinds of environments. Symbolic, hybrid and semantic models are location models that may be more suitable for some applications. Consequently, applications can be more easily developed and deployed when such models are used.

Lacking all the richness of location and other context elements, systems based in audio guides, with predefined paths, and making users search for the related information, are commonly used. However, competitive solutions can be built using low-cost radio frequency systems. Several sensors can be dispersed in the space marking points of interest and helping users to freely navigate across the environment. This paper describes the work in progress for the development of a low cost RF location solution, Loc4U. Costs can be perceived in two major ways. Time costs involve the time required to install and support the location system. Space costs involve the space and amount of infrastructure, namely hardware to support the proper operation of the location system.

In the next section, several research projects related to this project are presented. In the following section, an overview of major methods used to sense location is presented and the chosen methods discussed. The next section discuss how sensors best perceive location and; afterward there is a description on how to model the geospatial information supplied by all sensors, since there can be many types of sensors supplying data for a location model. Afterwards, the sensors used in this project are presented and discussed. Then, the architecture used is explained. Next, two study case scenarios are discussed as a proof of concept of the presented project. Finally, we present some conclusions.

RELATED WORK

Several tracking technologies have been developed, mainly targeted for a special purpose, and limiting its use by other applications. Several efforts are being undertaken to develop tracking systems for more general purposes, such as Ekahau, Ubisense, [3]. A survey of several tracking sensor technologies can be found in [8]. Moreover, there exists a common need to invest in new infrastructures, mainly indoors, to take advantage of the growing need for location information.

The high cost of some location systems, related calibration procedures and the increasing importance of geospatial data have driven to the development of open-source projects, namely Place Lab [11]. Place Lab uses Wi-Fi Access Points (AP) Basic Service Set ID (BSSID) to locate users. Users scan for Wi-Fi radio signals in the area, look for related AP BSSID, and search for AP locations in a database. Afterwards, users can make logical inferences about where they are and what is nearby.

The physical location of each AP is collected using a method named "wardriving". "Wardriving" is the action of searching for BSSIDs and associate that information with GPS coordinates collected on-site. AP physical coordinates are then estimated based in the GPS coordinates of the wardriving user and Received Signal Strength Indicator (RSSI) values. Applications that require a coarse-grained accuracy, in areas with good Wi-Fi coverage, can use Place Lab to track users and objects. However, it is known that radio signal strength can be affect by numerous factors, namely humidity or other radio signals.

The European Commission Information Society Technologies (IST) funded project, AmbieSense, is developing a context-sensitive technology based in the usage of context tags. Small tags are installed in buildings with storage and communications capabilities and users can access context-sensitive information when in the vicinity of these tags. Information supplied to users is customized based in their preferences. Costs and infrastructure deployment can be a problem when installing this system.

Outdoors, mobile users elected GPS as a main device for location. Thus, several projects are using GPS to supply users with context-sensitive data. PDAs and mobile phones are also the preferred devices to operate such applications, given their wide spread and potentialities. However, several challenges persist in order to: manage geospatial data and geospatial related information, best suit the interface for the task being performed by the user, and improve interactivity. Projects such as: WebPark [4], CRUMPET [14], LoVEUS [9], GUIDE [2] and, Deep Map [12] discussed these issues and developed prototypes to overcome problems in this type of systems.

HOW TO SENSE LOCATION

Location sensing can be achieved using three major techniques:

- Triangulation - uses specific measurements from sensors in range to estimate locations. Can be performed using lateration where multiple distances to known points are estimated, or using angulation where angles between known points are used to estimate location;
- Proximity - measures nearness to a point of interest. Can be achieved through physical contact, monitoring, or observation;
- Scene analysis - examines features of interest in the environment.

Location sensing can be achieved using one or more of these techniques to estimate locations for people, objects, or both. The choice to use each technique is mainly dependent of the sensors being used, and the accuracy needed for a specific application. Our low cost location based system uses triangulation and proximity to estimate location. This system uses RF sensors, which are able to sense specific radio features making them suitable for the triangulation, or proximity schemes.

Triangulation can supply better accuracy than proximity. However, given the complexity to perform calculations in triangulation, proximity can be a better option making the system simpler and faster. Thus, the proximity technique will be used as a basic configuration of the system and triangulation will be used when better accuracy is needed.

TYPES OF GEOSPATIAL DATA SUPPLIED BY SENSORS

Sensors can supply geospatial data of two types: physical and symbolic. Physical geospatial data is related to the usage of a coordinate system, which can be a geocentric cartesian coordinate system, a polar geographic coordinate system (latitude, longitude, elevation) or a planar projection coordinate system. For example, 38° 35.700 N by 8° 1.430 W are the WGS84 coordinates for a location in the city of Évora. Figure 1 shows an example of physical geospatial data. Symbolic geospatial data represents abstract ideas describing the space or relations between space entities, namely: in the Hall, near the portrait of Mona Lisa or, next to the entrance. Figure 2 shows an example of symbolic geospatial data.

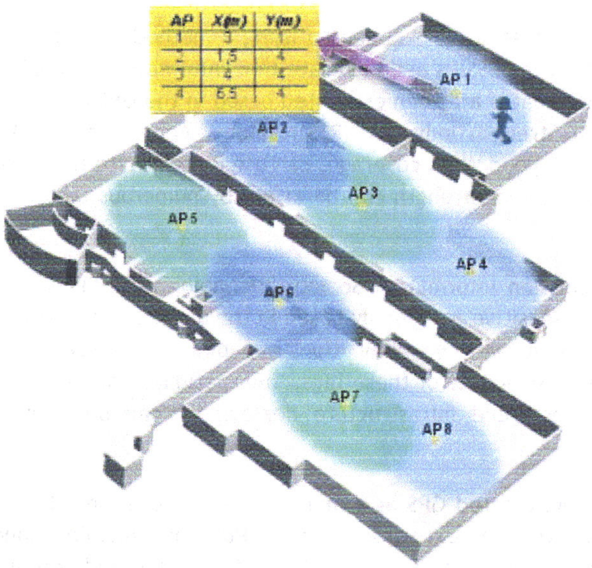

Figure 1: Physical location.

Geospatial data can be better supplied in physical, symbolic, or both types depending on the sensors being used and application's purpose. RF sensors in a basic way are well suited to supply symbolic geospatial data. In this system, each RF sensor broadcasts an ID. Thus, when a device is in the range of a sensor, it is able to read the ID associated with a specific location. In addition, in this system, RF range can be programmed enabling small or large areas defined by a symbol.

A major advantage of such structure is the allowed flexibility to change the environment with minimal adjustments in the system, or even no modification, if the remaining points of interest persist. For example, if a museum decides to change the layout of an exposition while using Loc4U, it may only need to change the RF tags of this system and place them according to the new layout. When triangulation is used in RF system, it is often required to re-calibrate the system.

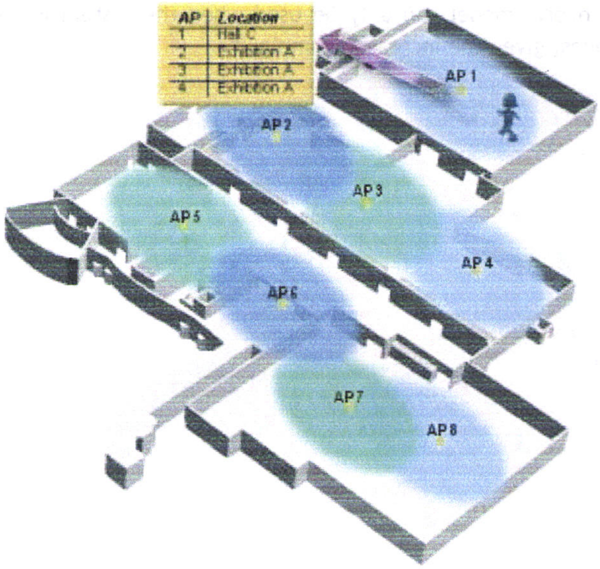

Figure 2: Symbolic location.

When accuracy is an importance feature for the system, physical geospatial data can be provided to people. In order to achieve this, previous calibration and model of the environment must be performed. The first step is to define a coordinate system related to a known point (for example a planar coordinate system) and measure the location of each RF tag related to the previously defined coordinate system. Afterwards, located persons, or objects can receive their position in a proximity basis, i.e. with their position being the position of the nearby RF tag, or receive their position in a triangulation basis, i.e. measuring RF features and using known position of RF tags to estimate their location.

HOW TO MODEL LOCATION INFORMATION

Location models provide an abstraction between users/devices and the raw data provided by various location sensing technologies. Four major categories were defined to classify location models (see Figure 3):

- Geometric - stores points, areas, and volumes in a predefined unit. The resolution of the model is limited by the measurement unit used. Lacks relations between points and the objects they point to.
- Symbolic - locations are described in terms of names and abstractions (i.e. hierarquies). There is a strong link between objects in the real environment and symbols in the model. However, it lacks the precision of geometric models.
- Semantic - rather than focusing purely on position, this model type is concerned with relationships of entities in space and between the spaces themselves.
- Hybrid - combines the advantages of geometric and symbolic models. However, this results in a more complex model with more data to represent locations.

Geospatial data can be modelled in different ways, depending on the aimed functions of the application. A description of the advantages and disadvantages of each system can be found in [3]. Consequently, this low cost location system aims to use purely symbolic and hybrid models.

The symbolic model provides the simplicity and relations between the spaces required in the basic framework of the system, a location-based audio-guide. Moreover, the hybrid model complements the information provided by the symbolic model with the physical location of spaces, also improving the accuracy. The hybrid model can only be used when the system is being manipulated through PDAs or mobile phones, given the increased complexity.

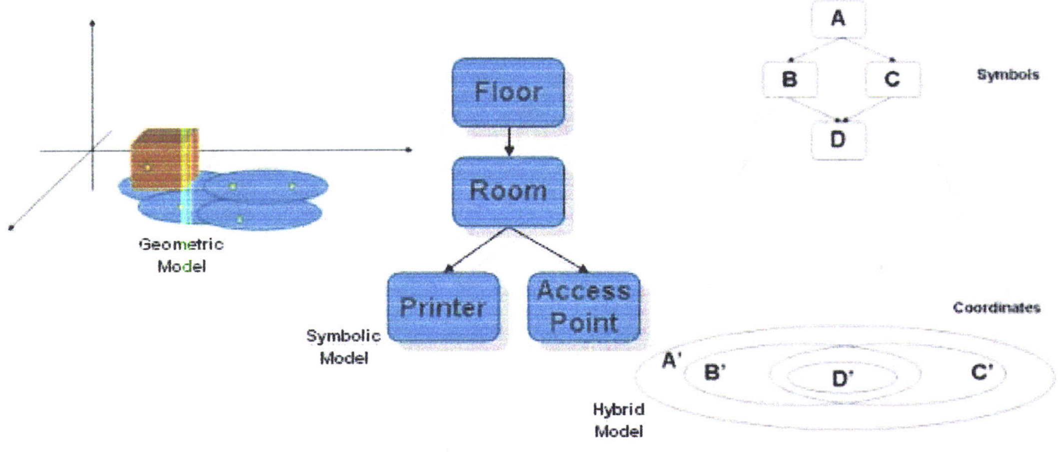

Figure 3: Location Models.

SENSORS

Given the increasing importance on location-aware applications, several sensors have been used to track people, or objects locations. With a major goal, cost, in mind, the option was to use RF sensors. Other important goals to the system include: being able to locate a possibly vast number of objects, or persons; allowing the needed flexibility to change the environment layout with minimal changes in the system; and reducing the amount of infrastructure needed to support the system.

IEEE 802.11 family of protocols and Bluetooth have been considered to be used in the system. A major advantage of using such technologies is their wide adoption. Nowadays, many mobile devices are deployed with support for these technologies. However, the large cell size in IEEE 802.11, power consumption, lack of control of radio features, and costs discourage its usage for this system. With Bluetooth power class 1 devices, it is possible to control radio range. However, to overcome interference problems arisen when several Bluetooth devices are searching for other devices in the same location, an infrastructure would be need. Therefore, Bluetooth was also discarded.

Compared with the other alternatives simple RF sensors are simpler and less expensive. Moreover, since the selected RF sensors operate in a different frequency than common wireless technologies, such as Bluetooth and IEEE 802.11 b/g, interference is reduced. In our system, transceivers are spread in the environment, based in the Integration IA4220/21 Universal ISM Band Transceiver. Receivers are then placed in the client devices and are based in the Integration IA 4320 Universal ISM Band FSK receiver.

The ability to control the radio signals used in the system allows a better control over radio interference. Since transceivers are the active part of this type of sensors, and the main focus for radio interference within the system, the decision was to have them within control of the infrastructure. Users carry radio receivers able to listen to radio beacons, the passive part of this type of sensors, also reducing interference. Consequently, the system can support as many users as needed.

This scheme to locate persons, or objects, also targets another important goal of location systems: privacy. With a major focus in privacy issues, it is up to the user to supply information related to his or her location to the system. However, it is possible to supply users with location based infrastructure driven services, when users accept to supply their location to the infrastructure.

Location improves user experience because applications can gather important hints about available operations in a specific spot. Additionally, user experience can be further improved with the usage of orientation, thus enhancing context-awareness. Orientation data allow applications to direct the supplied information related to the direction the user is looking at. Given that, orientation information can be optionally added to the system in a compromise between costs and improved context-awareness. The sensor used to supply orientation to this system is a digital compass, namely the CMPS03S320160.

SYSTEM ARCHITECTURE

The main components of Loc4U are: tags, spread in the environment broadcasting an ID; and clients, translating IDs into locations. Tags are used to specify points of interest (POI) or navigation aids. Each transceiver broadcasts an ID that is associated with a specific location. These transceivers have a programmable output power level, enabling them to be adjusted to various scenarios, where smaller-scale POI can be defined.

When several transceivers are deployed in the environment with a reduced power level, it is easy to mark different and smaller spots with different IDs, allowing the definition of several POI within a small area and reducing radio interference (figure 4). Nevertheless, some interference may persist. Thus, each tag broadcasts its ID in random intervals, reducing collisions, and, with each ID broadcast, a checksum is sent to validate the related ID.

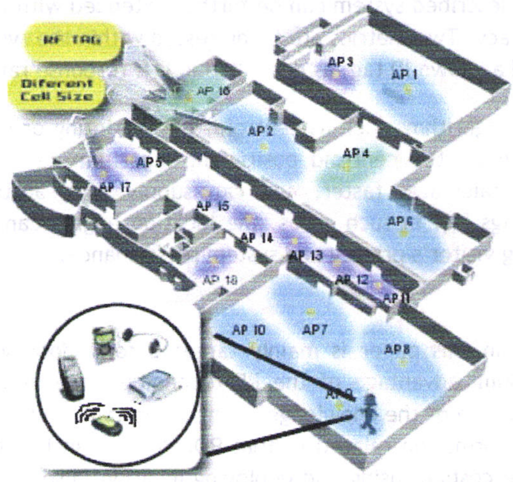

Figure 4: Framework overview.

In the basic framework, each client device is a low cost audio guide, able to reproduce digital audio related to each visited location. All data is supplied to users based on their location, calculated from the relationship between tag ID and tag location. Thus, the client device comprises an OEM digital audio Player, a micro controller, a RF receiver, an EPROM, and optionally an OEM digital compass to provide the user's orientation.

In more detail, the receiver is able to read nearby tag IDs. These IDs are then supplied to the micro controller, a Microchip PIC 18F2520, so that the user's location can be estimated. Optionally, user's orientation can be achieved using an OEM digital compass. Based in the estimated user's location, and optional orientation, the micro controller will start the correspondent audio data from the digital audio player, namely, the Org Vorbis player from FineArch.

Uploading the contents to the audio digital player is as easy as store audio data in a regular SD card. Nevertheless, a new challenge has arrived: how to upload new locations and tag IDs into the client EPROM, so that the micro controller can start the audio tracks related to a new specific location? For this purpose, a new application is being developed in order to upload the referred data into the client device, making it easy to change the museum layout and also change the client data related to the new layout.

Furthermore, the complete framework is being designed to extend its usage for PDAs, mobile phones, or any device with a Bluetooth connection. When using such appliances, users have to carry an additional small device, which receives tag IDs and sends the information to the PDA or mobile phone over Bluetooth. This small device contains a micro controller, a RF receiver, a Bluetooth antenna and, optionally, an OEM digital compass. The usage of Bluetooth in such cases isn't a major problem, since tags and Bluetooth are using different radio frequencies (tags are emitting in the 868 MHz frequency and Bluetooth is emitting in the 2.4 GHz frequency).

Moreover, an application, or library, has to be developed for each type of device to interpret the values sent over Bluetooth to the visitor's mobile unit, be it a PDA or a mobile phone. Afterwards, the application/library has to supply location-based information to visitors. RF tag IDs and the optional orientation information are supplied to the PDA or mobile phone through the Bluetooth connection, using the Serial Port Profile (SPP). The costs to extend the framework to be used in PDAs and mobile phones are reduced, since the system basis is the same as in the proposed audio guide.

Indeed, the proposed framework provides an easy and affordable way to extend itself to the most common devices used by visitors in a museum, also taking advantage of the wireless technology already available. The described system can be further extended with the usage of a location engine that can improve accuracy. Two metrics are being tested within the system to estimate the distance between the client and a known ID tag, as described in [1]: response rate and signal strength.

Addionally, positioning algorithms such as centroid, fingerprinting or particle filters can be used to improve accuracy. Namely, the centroid positioning algorithm can be used since it is easier to implement, easier to calculate, faster, and can supply good accuracies in areas with dense distribution of RF ID tags [1]. In such cases, the location engine can also be implemented in the client device, improving visitor's privacy and system performance.

CASE STUDY SCENARIOS

The project described in this paper is mainly targeted for indoor spaces, namely museums and exhibition centers. Taking advantage of the RF technology, the user is able to know his or her location and take advantage of the knowledge of this important context feature. When nearby a POI the user will receive information related to that POI, as seen in figure 5. This project's main goal consists of reducing the costs of using and deploying location, also supplying a rich context feature to applications, namely location and identity.

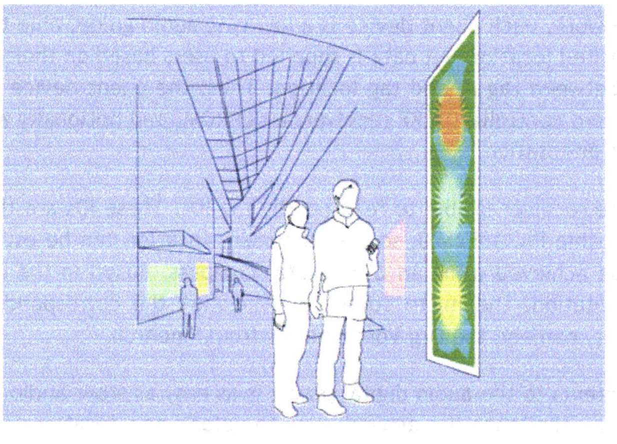

Figure 5: Location-aware Information

As a proof of concept, the system will be deployed in two museums in the city of Lisbon. Text and audio information will be used to supply information to visitors of both museums, related to their location. Targeting all types of users, the system will be able to be used by handicapped visitors, namely with vision and audition handicaps. In many cases, culture events are left out of handicap visitors reach. Thus, this system will be able to achieve a wider audience, offering a richer museum tour to each visitor.

Visual handicap visitors will have access to contextual information related to each POI and audio tips to guide them across the museum area. Sound handicap visitors will have access to visual tips to guide them across the museum area and additional visual information related to each POI will be presented. Visitors with no handicap will be able to use the same devices to access location related information.

CONCLUSIONS

With this framework, we believe that location-based applications can easily and affordably be deployed in several locations, improving the users' experience when exploring these physical spaces. As shown, the system can be extended according to the demands and costs supported by each institution. The audio guide is an entry solution that can be extended afterwards to also allow PDAs and mobile phones usage. Moreover, orientation information can be supplied to applications, narrowing the amount of information provided to users, from the user's vicinity to the POI in front of him or her. The system works indoor and outdoor making it suitable for a wide range of scenarios.

With the storage capabilities of nowadays' mobile devices, augmented information can be supplied and stored within the client application. Basically, that's what happens with the audio guide, making the system suitable for places with poor wireless coverage. However, it can be extended to fetch real time content using the wireless capabilities of PDAs and mobile phones. Compared with other solutions, such as Placelab [11], this framework can supply better accuracy, since radio beacons size can be controlled. However, it lacks the ubiquity supplied in the former one, since GSM cells are widely deployed in urban areas.

Commercial solutions, such as Ekahau, may guarantee superior accuracies, but also represent less flexible solutions, involving larger configuration and maintenance efforts, as well as higher costs. In the basic approach proposed, there is no need to tell the system the exact physical location of a POI or object. The administrator only has to bond the tags with the related data content to be supplied to visitors. Moreover, the relation between each tag ID helps to navigate within the visited location, thus resembling a symbolic location model approach.

In resume, this paper proposes an extendable location infrastructure appropriate for navigation and exploration of micro-geographical spaces. A major goal is to develop a low cost system that encourages the usage of location aware applications by wider audiences, namely museum visitors. The proposed system is easy to maintain, configure and deploy. A location-based audio guide is being developed and the mechanisms to support the system usage through other mobile devices, such as PDAs and mobile phones, are being designed. Audio guides can be used to supply audio information and PDAs can be used when visual information is of greater importance.

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