Augmented Reality Technology

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Summary:
Augmented reality (AR) is a relatively new technology that allows mixing virtual with real world in different proportions to achieve a level of immersion that no virtual equipment can provide. Recent advances of computer and vision technology make possible AR systems to go beyond indoor applications (e.g. surgery and inspection of hazardous environments) to support complex analysis, decision-making and governing processes.

This report investigates the current status of the AR systems, starting from available operational equipment and ending with the last achievements in the research field, in order to estimate the operational level and identify urgent topics for investigations. The overview concentrates on outdoor, wireless systems (approaches, devices, solutions) providing users with geo-data. The report is organised in seven chapters that supply definitions and important Internet links, discuss fundamental principles and equipment appropriate for outdoor AR systems, present current status of database management systems for real-time applications and review projects related to technology required in AR systems.

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Contents

Table of figures

0. Introduction

Augmented reality (AR) is one of the technologies gaining increasing interest. By mixing virtual with the real world in different proportions, augmented reality allows a level of immersion that no virtual equipment can provide. AR systems have been already used in many applications as surgery, inspection of hazardous environments, engineering. Most of those systems, however, only operate indoors and cover relatively small areas. The advances of the computer, vision and wireless technology make possible development of outdoor wireless systems to support complex analysis, decision-making and governing processes. The benefits of utilising such systems in these processes are twofold: 1) data supply on "the spot" (location-based services) and 2) provision of 2D, 3D geo-information.

In the last several years, both the government and private sector are recognising the considerable value of location information as a platform for improved services and business applications. Urban and landscape planning, traffic monitoring and navigation, road, railway and building construction, telecommunications, utility management, cadastre, real estate market, military applications and tourism are some of the most common examples. Very often in a day, individuals want to know the location of a shop, an office, a house, a petrol station or a hospital, the fastest way to home or another town and street, possibilities for travelling without waiting in traffic jams, etc. The technological progress appeared to have reached a level, at which a broader utilisation is made of existing "containers" (GIS, CAD, database) of geo-data and related to it attribute info (e.g. personal data, company data).

However, the development of a robust outdoor wireless AR system is a complex process that involves a large number different technologies and devices to assemble and tune. The goal of this report is to investigate the current status of the outdoor wireless systems, in order to estimate the operational level and identify urgent topics for investigation. It focuses on approaches, technologies, devices and systems that can be used to provide mobile users with advanced information (in the form of text, video, sound and graphics).

The report is organised into seven chapters. The first chapter provides definitions and classifications of AR systems, and discusses similarities and differences between AR, Virtual Reality (VR) and Augmented Virtuality (AV) systems as well as the link with location-based services (LBS). The second chapter concentrates on fundamental principles and components for realising AR system as more "traditional", indoor approaches are discussed. The third chapter highlights the new issues in AR systems with respect to outdoor, wireless application. The major wireless networks (global and local) are reviewed. The fourth chapter discusses current availability and functionality of commercial equipment (hardware and software). Special attention is paid on presently available displays and possibilities to track the user everywhere, indoors and outdoors. The accuracy of the GPS systems, telecommunication systems and hybrid systems is analysed. The fifth chapter concentrates on the present functionality of DBMS to support wireless and real-time applications. The sixth chapter reviews some research projects aimed at outdoor AR or similar applications. The last chapter summarises some visions related to future developments in wireless technology.

Surveys on AR systems available on the Web:

1. Azuma, R.T., Y. Baillot, R. Behringer, S. Feiner, S. Julier, B. MacIntyre 2001, Resent advances in Augmented reality, available at: http://www.cs.unc.edu/~azuma/cga2001.pdf
2. Azuma, R.T., 1997, Hughes Research Laboratories, A survey of Augmented reality, available at: http://www.hitl.washington.edu/projects/knowledge_base/ARfinal.pdf
3. Borenstein, J. H.R. Everett and L. Feng, 1996, Where I am? Sensors and methods for mobile robot positioning, University of Michigan, available at: http://www.eng.yale.edu/ee-labs/morse/other/intro.html
4. Bonsor, K., 1998, How Augmented reality will work, HowStuffWorks, available at: http://www.howstuffworks.com/augmented-reality.htm
5. Ditlea, S., 2002, Augmented reality, Popular science, available at: http://www.popsci.com/popsci/computers/article/0,12543,190327,00.html
6. Encarnação, M., 2002, Augmented reality and its application to medicine, Human Media Technologies, Fraunhofer Center for Research in Computer Graphics (CRCG), Inc., available at: http://www.dartmouth.edu/~engs13/syllabus/Miguel_dartmouth%208-02%20for%20print.pdf
7. Heltzel, P., 2002, Augmented reality technology can help make sense of unfamiliar battlegrounds, MIT enterprise technology review, available at: http://www.technologyreview.com/articles/wo_heltzel080602.asp

8. Montelius, J., 1997, Augmented reality Survey, SICS, Intelligent System Laboratory, available at: http://www.sics.se/isl/iar/survey.html

9. Valino, J., Augmented reality pages, available at: http://www.se.rit.edu/~jrv/research/ar

1. What is Augmented Reality?

This chapter is organised in four sections. The chapter gives a broad definition of AR systems, discusses AR problems with respect to similar techniques for representing, interacting with 3D worlds (VR and AV) and communicating with mobile users (LBS), and provides classifications of AR systems.

It is rather difficult to classify and name the applications and systems that provide such functionality. Some of them are related to the real physical world, others are closer to abstract, virtual, imagery worlds in which gravity, time, space obey different laws. Very often AR is defined as a type of “virtual reality where the Head Mounted Display (HMD) is transparent”. The goal of augmented reality systems is to combine the interactive real world with an interactive computer-generated world in such a way that they appear as one environment. As the user moves around the real object, the virtual (i.e. computer generated) one reacts as it is completely integrated with the real world. Furthermore, the virtual object may move but still the movements are registered with respect to the real world. Figure 1-1 shows three examples of AR views, a static view of a brain, a virtual car moving around the monument and a virtual Packman “jumping” in an office.

Figure 1-1: Examples of AR views: brain on a real human head, a virtual car in a real square (LORIA), Packman in the office (UbiCom)

Wireless AR systems face three fundamental problems. The first one is the manner of mixing real and computer-generated environments (i.e. *alignment* of virtual and real objects). An AR system should provide the user with a perception of an integrated working environment (Figure 1-2). Depending on the approach used, the AR systems can have several forms and can be classified into different groups. Another critical issue in AR systems is tracking (determining the position, direction and speed of movement) of the mobile user. The third problem is related to the wireless communication between users and backbone computers. While alignment of virtual and real objects is a specific AR issue, tracking of a mobile user and wireless communications are well know issues in VR systems and LBS. Therefore, the survey on wireless AR systems cannot be completed without referring to some topics more familiar for VR systems and LBS.

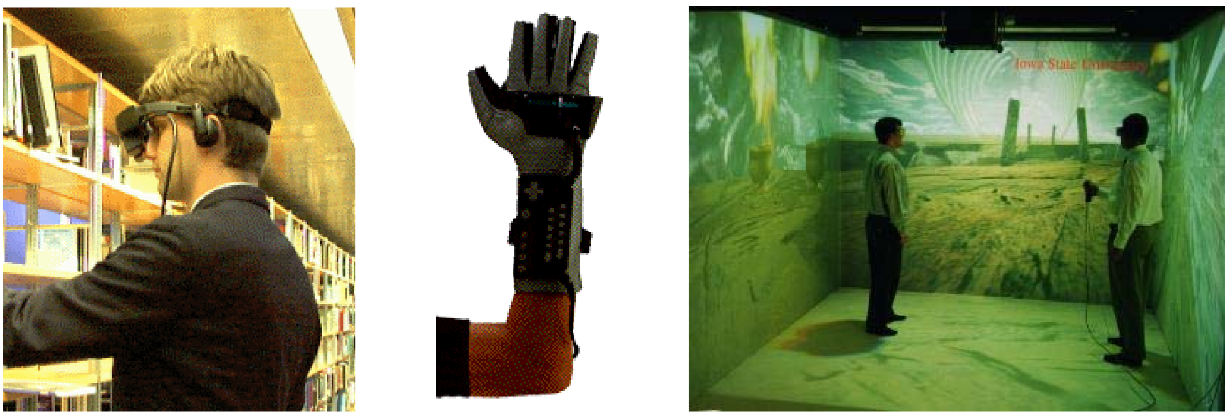


Figure 1-2: Head Mounded Display (HDM), Glove Input Device and CAVE

1.1. AR as a mixed environment

This section discusses the place of AR with respect to VR (being completely computer generated) and the real world. Firstly, a vision of Mixed Reality (*reality-virtuality continuum*) is used to clarify the link between AR, VR and the real world. Secondly, the understanding of VR is commented to provide a background for discussion on similarities and differences with AR. To complete all the possible “mixtures” between computer-generated and real objects (images), a brief overview of a few AV systems is given at the end.

1.1.1. Reality-virtuality continuum

Milgram et al 1994, introduce the reality-virtuality continuum that defines the term *mixed reality* and portrays the “link” between the real and the virtual world (Figure 1-3). If the real world is at one of the ends of the continuum and VR (i.e. computer-generated, artificial world) is at the other end, then the AR occupies the space closer to the real world. The closer a system is to the VR end, the more the real elements reduce. For example, the AR systems using Optical See-through Displays are placed closer to the real world compared to AR systems with Video-mixing (Figure 1-3). If the real world can be augmented with virtual objects, it is logical to expect that the virtual world can be is augmented with real scenes (views, objects). Such an environment is called *augmented virtuality*. On the reality-virtuality continuum, AV occupies the space closer to the VR environments.

Since this diagram provides a very good overview of all the systems that mix real and virtual worlds, it became a starting point for discussions, classifications and comparisons between different techniques. In the following text, we will shortly discuss the different techniques with respect to the link with AR.

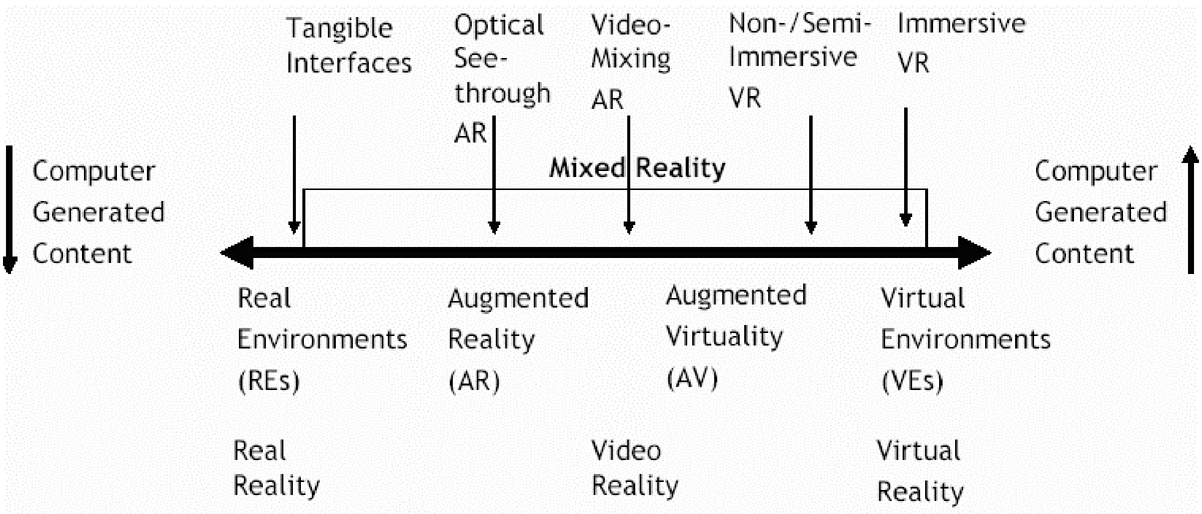


Figure 1-3: Reality-virtuality Continuum (Milgram and Kishino 1994)

1.1.2. Virtual Reality

The term *virtual reality* has a different meaning for different people. There are people to whom VR is a specific collection of technologies such as Head Mounted Display (HMD), Glove Input Device and Cave (Figure 1-2, see also Chapter 2). Some other people extend the term to include conventional books, movies or pure fantasy and imagination. The web site http://whatis.techtarget.com , (containing more than 10 000 IT terms) describes VR as:

“… simulation of a real or imagined environment that can be experienced visually in the three dimensions of width, height, and depth and that may additionally provide an interactive experience visually in full real-time motion with sound and possibly with tactile and other forms of feedback. The simplest form of virtual reality is a 3-D image that can be explored interactively at a personal computer, usually by manipulating keys or the mouse so that the content of the image moves in some direction or zooms in or out.”

Perhaps the best (and shortest) description of virtual reality as a “...way for humans to visualise, manipulate and interact with computers and extremely complex data” (Isdale, 2002). The visualisation is understood in a broad sense as some kind of sensual output. The manipulation and interaction comprise all facilities that supply users with tools to contact the objects from the model and directly manipulate and change them. There are two important issues in this definition to be considered:

- the world (usually 3D) is a sort of a model, and
- an appropriate level of interaction and realism is required.

It should be noted that the model may be an abstraction of the real physical world (3D model of a town, Figure 1-5), or a completely virtual imaginary object (a new model of car, fantasy object, etc.). When the models of the real world are considered, the minimum requirements for high level of visual realism are good illumination and shading models and/or texture mapping. The minimum interaction is usually real time navigation (i.e. fast reaction on human actions and movement inside the model).

Many attempts to systematise and classify the VR systems are made, i.e. on the basis of the used hardware (from desktop equipment to spatially immersive systems, e.g. CAVE), the display system (from observing the screen, to being inside the VR environment) or both. Yet another interesting classification is the Simulation-Presentation-Interaction (S-P-I) chart (Figure 1-4). It is one attempt to formulate the complex interrelation between data, their presentation and interaction with them. *Simulation* characterises the complexity of data. Three level of simulations are given: pure geometry (lines, points, geometric shapes) static semantics (realistic complex static objects) and dynamic semantics (dynamic objects). *Presentation* classifies the way data are displayed: single frames, sequence of frames (animation), or real-time work. *Interaction*, which ranges from none to full immersion, indicates the special high level hardware equipment used. For example, CAD and GIS systems fall inside the box on Figure 1-4, left, while virtual reality software falls inside the space between the two boxes on Figure 1-4, right.

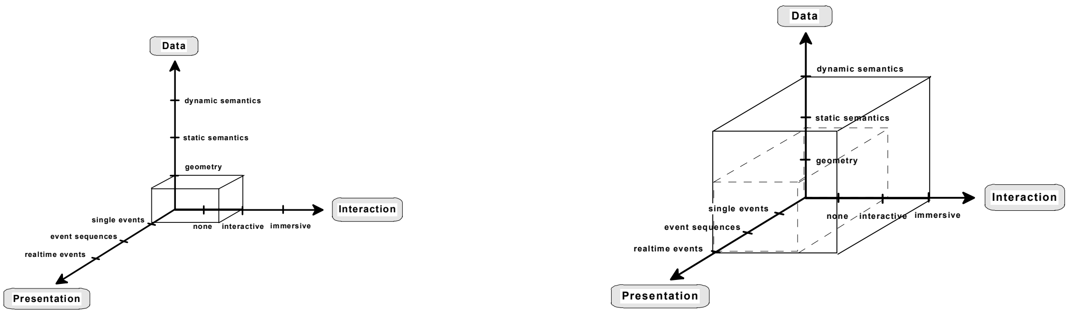


Figure 1-4: The I-S-P model

Clearly, VR comprises a broad spectrum of ideas and many of the technologies appear to be similar for AR and VR systems. For example, HMD may be used in both systems; fast real-time rendering processes are necessary to achieve sufficient performance; tracking of the user is required in both environments; both systems need immersive environments. However the differences are quite significant:

- The very visible difference between the two systems is the type of immersiveness. High-level VR systems require a totally immersive environment. The visual, and in some systems tactile senses, are under control of the computer. This is to say that the VR system models the artificial world completely and actually provides immersiveness with the virtual world. In contrast, an AR system augments the real world scene and attempts to maintain the user's sense of being in the real world. The rationale behind this is twofold. First, real environments contain much more information than is possible to model and simulate by computer. Secondly, knowing that the end goal is to enhance the real-world task, it would be better to keep the user's feeling of being in the real world as much as possible.

- Another difference is that an AR system merges the virtual images with a view of the real scene to create the augmented display. This merging requires a mechanism to combine the real and virtual that is not present in virtual reality work.

- The nature of the visual interface between computer and user is different. Both VR and AR systems give the user a sense of immersion ensuring that the user receives a consistent set of sensory inputs. However, because the user looks at the virtual world, there is no natural connection between the user's internal coordinate system and the virtual world coordinate system. This connection must be created. Thus any inconsistency the user perceives, are less visible and the user adapts to them. In contrast, in AR systems the misregistration results in inconsistency between the real-world coordinate system and the computer system. The registration requirements in AR systems are much higher. Practically, registration requires two problems to be solved. Firstly, the position and the orientation of the user in the real world have to be very accurately determined. Secondly, the delay in the AR system (i.e. *lag*) has to be eliminated or reduced to tolerable values. If the lag is large, the connection between two coordinates systems will be practically made for an old position of the user and therefore will not correspond to the present view. The result will be a shift in the position of the virtual object.

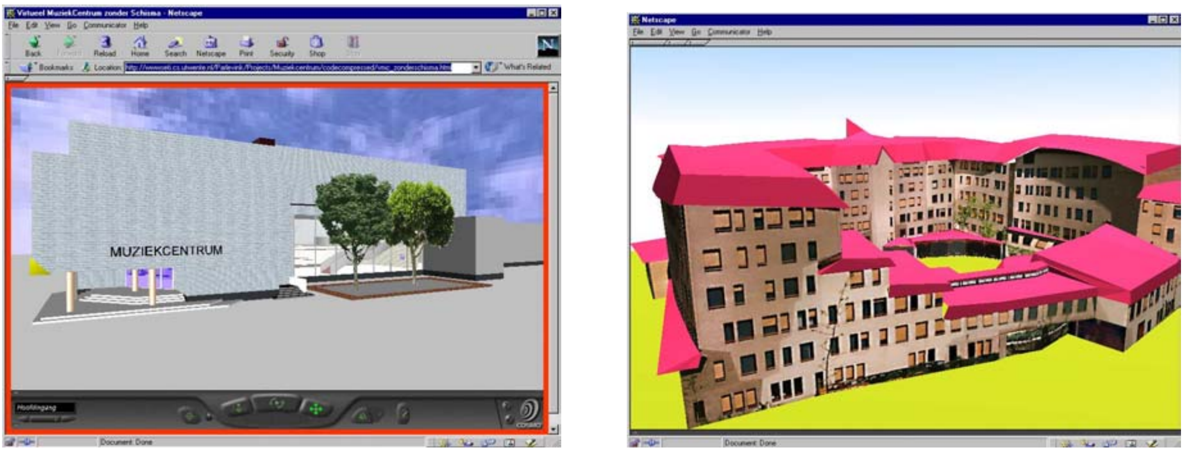


Figure 1-5: 3D models of real-world objects (Enschede, The Netherlands)

- VR systems operate with large data sets (especially when the real world is focused) and often requires high realism and needs textures, real photographs, or special illumination approaches to achieve the required level of realism. In contrast, the number of objects to be rendered in AR systems are relatively few (one car, one building, etc.). Furthermore the requirements for realism (textures, colours, illumination and shading models) are significantly low compared to VR models. Many objects such as trees, traffic lights, guiding boards that have to be introduced in VR models, are not of interest in AR systems.

1.1.3. Augmented Virtuality

This technique allows a user to explore interactively a virtual representation of video that is obtained from a real space. The video is either observed in real-time (projected on a virtual object) or selected textures are draped on the virtual objects that correspond to the real ones. This has the effect of making a virtual world appear, to a limited extent, as the real world, while maintaining the flexibility of the virtual world. In this respect, the AV world could be viewed as an instantiation of immersive 3D video photographs. Objects have a similar appearance to their real counterparts, but can be manipulated in a virtual setting (Simasarian et al 1994).

An example of AV application is a real video (taken from a camera located on a moving robot) projected on a virtual monitor on the top of virtual robot that moves in virtual environment (Figure 1-6, left, middle). The remote environment is roughly modelled and the operator still can get an idea of the real world. To obtain an accurate visual image of the remote workplace, the operator needs to command the robot to move around the room. The monitor metaphor also restricts the user to be situated close to the robot if he/she does not want to loose the connection to the real world. Practically, the operator has to move the robot to be able to see the video of the real scene.

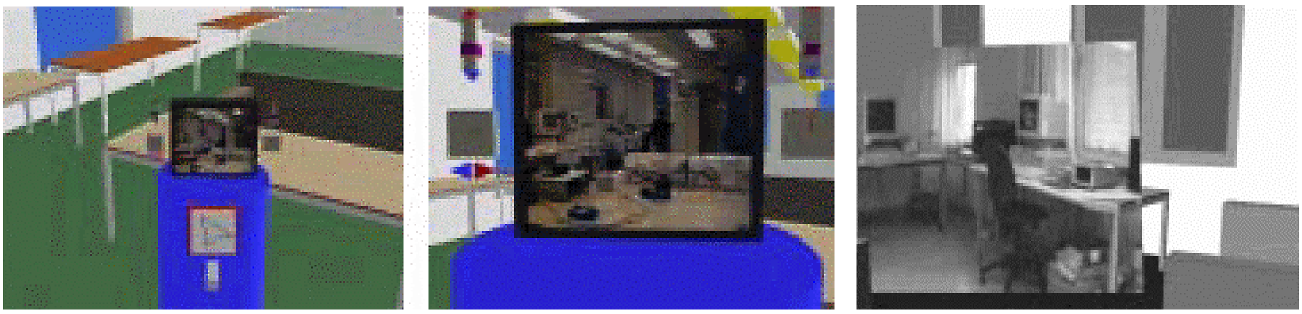


Figure 1-6: Monitor Metaphor: virtual environment with robot, monitor (left) and the operator's view point when 'locked" to the robot (middle) and projection screen (right). (Simsarian et al 1994)

Another example is a projection screen, placed in the virtual environment. It can be updated with live video as the robot moves within the environment but it does not move with the movement of the robot. The main disadvantage is that the images are projected on a fixed flat projection screen (Figure 1-6, right). Thus the image is only perspectively correct from one position (the point where the image was taken). At other positions, the illusion of three-dimensionality is broken and the connection between the 3D model and the image is not evident. Furthermore, it is hard to make the associations explicit between the objects on the screen and the objects within the virtual environment.

Reality portals is yet another possibility to extend the virtual world with real images. Instead of using only one place to view the real world, segments of the real world can be displayed on the actual position in the virtual world (Figure 1-7). Through this process, textures are applied automatically in near real-time, (1-3 frames per second) in the virtual world. As the robot explores the world, these textures are automatically added to the virtual objects and stored in the virtual world database. The virtual world model offers an intuitive spatial sense of how to view these video images and their source. It is much like having a 3D video to navigate around. Some space limitations are also solved because the operator can navigate through the virtual world and see the video spatially displayed.

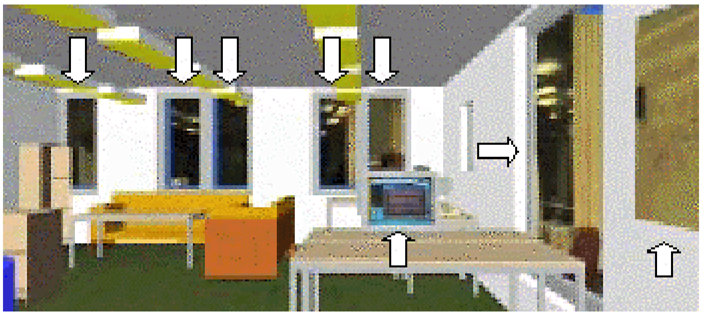


Figure 1-7: Reality portals: real images projected on the actual places (Akesson and Simsarian 1999)

Beyond the use of this approach for remote robot control, some other examples of this approach may be Security monitoring. Common practice of security professionals is to observe a suite of monitors and watch for abnormalities and security situations. Cameras situated around the space could monitor the security space and be visualised as textures to the virtual model of the area of guarding.

1.2. AR as Location Based Services

LBS have been developed as an independent stream, but their goal is similar to that of outdoor wireless AR applications. The information requested by the user has to be provided to the location of the user. The difference between the two technologies is apparent, i.e. LBS do not require mixture of real and virtual scenes. The supplied information (real-world or computer generated) is visualised as text, image or graphics on a handheld device (mobile telephone, pocketPC, notebook, etc.), i.e. immersion is not required and thus not performed. Since the coordinate system of the user is not compared with the coordinate system of the virtual object, the tracking is quite approximate (few meters). However, the current Global System for Mobile Communications (GSM) can locate a mobile user to an accuracy of a 100m, which is apparently not sufficient for many applications (e.g. “follow shortest path”, “find closest restaurants”). In this respect, LBS have a similar problem as AR applications, i.e. how to track the position of the user. Chapter 2 discusses in detail some approaches to increase the accuracy of telecommunication networks and GPS systems to obtain the needed accuracy. One example will be given here. The Italian Mobile Telecommunication (TIM) provides wireless data services (since the end of 2001), such as navigation, real-time traffic information; point-of-interest information such as nearby museums and restaurants; and concierge services such as making airline, hotel and restaurant reservations. Connect TIM is the software that uses the Autodesk MobileConnect (an extension of Connect Telematics, developed jointly with TargaSys, (division of Fiat Auto). Using a GSM or GPRS-enabled mobile device, Connect TIM is activated by an SMS message generated by a personalised SIM ToolKit application developed by TIM. The SMS, containing the subscriber's location details based on TIM Cell location based technology, is sent to the TargaSys contact center. The SMS triggers a personalised database that helps the operator respond to the individual's need. The TargaSys contact centre is staffed by 800 operators, supporting 14 languages and is specialised in these services. The services are completed on voice request.

1.3. Classification of AR systems

Similarly to VR systems, different classifications of AR systems can be made focusing on hardware of the AR system (e.g. the type of tracking system), or visualisation approaches (see-through, video-mixture) or working distance (indoor, outdoor) or communication (wireless, hardwired). The most well known classification is related to the visualisation approach, i.e. the way the mixture is provided to the user. The reality-virtuality continuum diagram shows these two very general classes of AR systems, i.e. Optical See-through and Video-mixing. These may have several variances with respect to where the images (objects) are visualised, i.e. on a desktop screen or on a HMD. The following two sections elaborate on classifications based on the type of display and the range of the AR systems.

1.3.1. Displays

To be able to augment real or virtual worlds apparently some sort of displays (the terms is used in a broad sense) are needed. Milgram et al, 1994 distinguish between several classes of existing hybrid display environments, on the basis of which reasonable clarification of the AR systems can be done:

1. Monitor based (non-immersive) video displays – i.e. "window-on-the-world" (WoW) displays – upon which computer generated images are electronically or digitally overlaid. Practical considerations very often draw the attention to systems in which this is done stereoscopically.
2. Video displays as in Class 1, but using immersive HMD's, rather than WoW monitors.
3. HMD's equipped with a see-through capability, with which computer generated graphics can be optically superimposed, using half-silvered mirrors, onto directly viewed real-world scenes.
4. Same as 3, but using video (rather than optical) viewing of the real world. The difference between classes 2 and 4 is that with 4 the displayed world should correspond orthoscopically with the immediate outside real world, thereby creating a "video see-through" system.
5. Completely graphic display environments, either completely or partially immersive, to which video "reality" is added.
6. Completely graphic but partially immersive environments (e.g. large screen displays) in which real physical objects in the user's environment play a role in (or interfere with) the computer generated scene, such as in reaching in and "grabbing" something with one's own hand.

We can combine the classes from one to 4 in two simpler classes of AR systems, i.e.:

- Monitor based AR (MB_AR) systems (class 1)
- See-through AR (ST_AR) systems, i.e. either video or reality (classes 2,3,4).

Strictly speaking, AR systems should only be referred to as see-through displays (i.e. it should be possible to observe the real world). However, in many laboratories, mixture between real video images and virtual frames are utilised. In such cases, the term augmented reality is also used because the real world is augmented with virtual information.

The last two classes displays have broader meaning. Class 5 displays refer to a technique in which what is being augmented is not some direct representation of a real scene, but rather a virtual world (i.e. generated by computer), it refers to AV, as depicted in Figure 1-3. With technological evolution, it may eventually become less distinct whether the primary world being experienced is predominantly real or predominantly virtual, which may eventually weaken the differentiation between AR and AV terms. Class 6 displays go beyond all other classes in including directly viewed real-world objects. For example, the viewer can observe his/her own real hand directly in front of him/herself. It is quite distinct from viewing an image of the same real hand on a monitor. An interesting alternative solution to the terminology problem posed by Class 6 as well as composite Class 5 AR/AV displays might be the term Hybrid Reality (HR), as a way of encompassing the concept of blending many types of distinct display media.

Recently, a new class of AR systems i.e. Spatially Augmented Reality (SAR) systems is also gaining popularity. In the ST_AR systems the user needs to wear some sort of HMD to be able to observe the virtual objects or the mixture between virtual object and real video images. In many cases these may cause discomfort (weight, contrast of the images, etc) and disturb the current activities. Therefore some recent investigations are towards projecting the view in the real world and thus avoiding the use of HMD. While not applicable for some applications, some other can largely benefit from it. For example, architectures can take advantage of the ability to modify visually part of the real physical environment of tabletop architectural models.

Chapter 2 discusses the principle schemas of AR configurations in detail.

1.3.2. Range/distance

One very important distinction between different systems has to be made with respect to the area they can operate on. The first AR systems were developed as indoor systems working in restricted areas. Many applications already make use of indoor AR systems (laboratories, surgery, entertainment, etc.). With the advances of the technology the AR systems attempts to go beyond the walls of closed environments. The idea of outdoor AR applications is to augment the real world outside the laboratory. For example, to show to the user a 3D model of an ancient building, or a newly constructed bridge, or subsurface pipes, cadastral boundaries etc (Figure 1-8). The user is outside his office, he/she does not have a constant power supplier, does not want to carry heavy equipment, does not want to wait long for information. The goal of AR systems is the same, but the problems increase tremendously compared to indoor AR systems.

Figure 1-8: Out-door AR system (UbiCom)

- The registration of the real and the virtual worlds in indoor AR systems can be done in a relatively simple way. It is possible to use static markers (attached to well-visible parts), relatively small 3Dmodels, a limited number of images or predict the path of the user. Outdoor AR systems have to rely on markers that exist in the real world (often with low contrast) as the required 3D models are usually much larger. One of the biggest problems in outdoor applications are weather changes, sun shinning, shadows, etc. which do not exist in indoor environments
- The exact position of the user can be determined in indoor AR by a variety of tracking devices providing accuracy of a few centimetres. Outdoor AR needs to use absolute or relative positioning systems, in combination with vision systems when the accuracy is not sufficient.
- The requirements for low power consumption are not an issue in indoor AR systems
- Since, the data transmission is wearable, the latency can always be compensated.
- Outdoor application usually need a special transmission channel, which either has to be developed or existing communication services have to be used.

Next chapters address the problems mentioned above in details. Chapters 3 and 4 elaborate on outdoor systems by providing further information on technology and commercial solutions currently available on the market. Chapter 6 reviews projects aiming wireless applications.

References

Akkeson K. and K Simsarian, 1999, Reality Portals, VRST 1999, London Dec, 1999, available at: http://www.sics.se/~kristian/pubs.html

Göbel, M., 1993, The Virtual Reality Demonstration Center, Computers and Graphics, Vol. 17, No. 6, pp. 627-631

Isdale, J., 2002, Jerry Isdale's Home page, available at: http://www.isdale.com/jerry/VR/

Milgram, P., H. Takemura, A. Utsumi and F. Kishino, 1994, Augmented Reality: A class of displays on reality-virtuality continuum, in: Proceedings of SPIE Vol. 2351, Telemanipulation an Telepresence technologies, 31 October 4 November, Boston, USA, pp. 282-292

Milgram, P., Kishino, F., "A Taxonomy of Mixed Reality Visual Display", IEICE Transactions on Information Systems special issue on Networked Reality, Dec, 94, http://gypsy.rose.utoronto.ca/people/paul_dir/IEICE94/ieice.html

Raskar, R., G. Welch, H. Fuchs, 1998, Spatially Augmented Reality, Proceedings of the First International Workshop on Augmented Reality, San Francisco, November 1

Simsarian, K.T, J. Karlgren, L. E. Fahlén, I. Bretan, E. Fréecon, T. Axling, 1996, Achieving Virtual Presence with a Semi-Autonomous Robot Through a Multi-Reality and Speech Control Interface, Eurographics workshop on VR, Monte Carlo, February, 1996. & Virtual Environments and Scientific Visualization '96, M. Gobel, J. David, P. Slavik, J.J. van Wijk (eds), SpringerComputerScience

TargaSys, available at: http://www.targaconnect.com/index_nf.htm

Telecom Italia Group (TIM), available at http://www.tim.it/eng

2. AR principles

This chapter focuses on components of an AR system and particularly on "traditional" AR solutions. This is to say that most of the technologies are originally developed for indoor, hardwire systems. New issues related to outdoor, wireless AR systems and technologies are addressed in Chapter 3.

As discussed in Chapter 2, an AR system provides a mixture of real and virtual images in the user's Field-of-View (FOV). Figure 2-1, left gives a general idea of the way to obtain the augmented view. The objects of the real world observed by the user (world reference frame) are sent to the computer, which generates the virtual objects (in virtual reference frame). The real and the virtual objects (scenes) are mixed and rendered in such a way to give the user the perception of observing one integrated scene. Depending on what kind of equipment is used, different approaches can be followed, which result in diverse type of systems architectures. However, four very general components (and corresponding technologies) are always present in an AR system, i.e. *displays*, *tracking systems*, *devices for interaction* and *graphics systems (computer).* This chapter concentrates on displays and tracking systems, since the type of display and tracking system have the largest influence on particular system architecture. The display is one of the critical components where the level of immersion is concerned. The tracking system (which is responsible for accurate positioning and orientation in the real world) is the most important component with respect to the correct registration of virtual and real objects. Most commonly, the devices for interaction also have to be tracked. The graphics system is responsible for generating the virtual objects and in most cases it is a conventional one.

The chapter is organised in three sections. The first section explains the principle of AR system with respect to the displays used as they were presented in Chapter 1 (i.e. Monitor Based, See-Through, SAR). The second section reviews systems and approaches for tracking. The last section summarises the problems related to the display of mixed scenes and body tracking.

2.1. Setups of AR systems

The section presents and shortly describes the approach of creating an augmented view in MB_AR, ST_AR and SAR systems.

2.1.1. Monitor-based AR system

The Monitor-based AR system allows the user to observe the real world and the superimposed virtual objects on a regular display, thus without need to wear special glasses. This approach is widely used in laboratories for testing systems and creating low-cost demonstrations. Figure 2-1, right shows the setup of the system. The video images from the real world are enhanced with the virtual scene (generated by a conventional graphic system) and visualised on the screen. Clearly, to be able to integrate the virtual object within the video-images of the real world, the exact position of the object with respect to the real world is required. Since the visualisation is on a regular display, frames from the real images are combined with the frames generated by a computer.

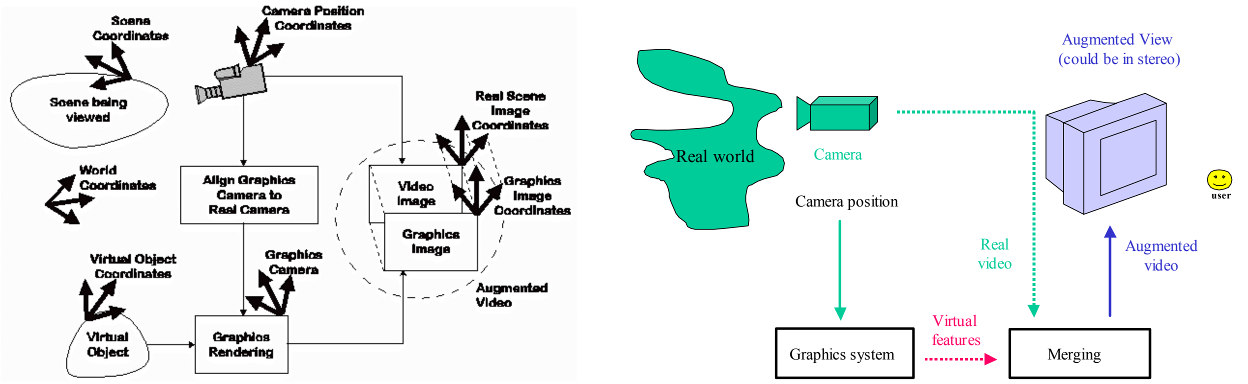


Figure 2-1: Basic components to achieve the augmented view (J. Valino, left) and Monitor-based AR (right)

2.1.2. See-Through AR systems

The ST-AR systems are much more complex because they allow the user to observe the surrounding environment. Most of the research and development efforts are toward development of ST-AR systems, since the user can achieve maximal perception of the real world. Most commonly display augmentation is achieved by using mirrors to superimpose computer-generated graphics optically onto directly viewed real-world scenes. Such displays are already a mature technology as either panel-mounted or HMD's (see bellow).

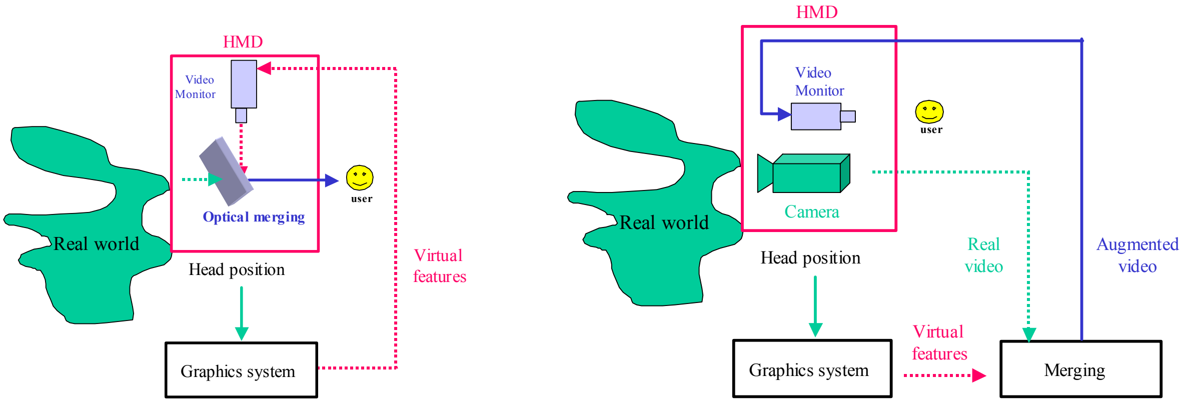


Figure 2-2: ST-AR systems: optical see-trough (left), video see-trough (right)

The principle schema of such a display is given in (Figure 2-2, left). The virtual (computer generated) scene is projected at the view of the user taking into consideration the position and the direction of the head (obtained from a tracking system). As the user moves, the virtual objects have to be regenerated with respect to the new position of the user. A number of critical issues such as the accurate position of the user, accurate and precise calibration and viewpoint matching, adequate field of view, etc have to be resolved when designing optical ST displays. Other issues (more perceptual in nature) include the problematic effects of occluding computer generated and real objects. Perceptual issues become even more challenging when ST-AR systems are constructed to permit computer augmentation to be presented stereoscopically.

Some of these technological difficulties can be partially eliminated by replacing the optical ST with a video-based HMD, thus creating what is known as "video see-through". Such displays exhibit advantages from both a technological and perceptual point of view, even as new issues arise from the need to create a camera system whose viewpoint is identical to that of the observer's own eyes. Figure 2-2, right shows the principle schema of a video ST-AR system. The real scene is recorded by a video camera. The camera performs a perspective projection of the 3D world onto a 2D image plane. The internal (focal length and lens distortion) and external (position and orientation) parameters of the camera determine exactly what is projected onto the image plane. Then, the generation of the virtual image is done by a standard computer graphics system in an object reference frame. The graphics system requires information about the parameters of the real scene so that it can correctly render the virtual objects. The parameters of the real scene are used to position and orient the virtual camera that is used for generating the image of the virtual objects. This image is then merged with the image of the real scene (or with a model of the real world) to provide the augmented reality view.

2.1.3. Spatially Augmented Reality systems

This approach is very similar to conventional AR applications, except for the display that is used (http://www.cs.unc.edu/%7Eraskar/Tabletop). In SAR, the generated 2D imagery is attached to a fixed physical display surface instead of being attached to the user's moving head. The views are directly projected into the physical space of the user, i.e. 2D images "paint" the surface for projection. To create an illusion that virtual objects are registered to real objects, similar data is needed as for ST-AR systems, i.e. the position of the user, projection parameters of the display devices and the shape of the surfaces of real objects in the physical environment (to be able to render on it the virtual object). There are many differences as well. The occlusion relationships in SAR are different than in see-through AR systems, i.e. a real object can occlude the virtual objects but a virtual object cannot obstruct the view of a real object. For example, lifting a hand in front of the face will occlude the virtual object behind it, but no virtual object can hide the real object although it is intended to float in front of it. Another difference is that SAR methods use a fixed world co-ordinate system to render computer-generated objects.

SAR shares the same advantages as Spatially Immersed Displays (SID) such as Panorama and CAVE (see next section), where the users are spatially surrounded by the same virtual environment and can communicate between each other, modify the environment and observe changes together. The most crucial problem with projector-based SAR is its dependence on display surface properties (Raskar et al 1998). A light coloured diffused object with smooth geometry is ideal. It is practically impossible to render vivid images on highly specular, low reflectance or dark surfaces. The ambient lighting can also affect the contrast of the images. Another problem might be the shadows cast by users. SAR also allows only one active head-tracked user at any instant in the environment because the images are created in the physical environment rather than in individual user space. Time multiplexed shuttered glasses can be used to add more users that are active and head-tracked.

2.1.4. Available displays for AR systems

In general, many different displays can used in AR and VR systems depending on the purpose of the application. Some of the most well-known visualisation technologies are CAVE, HMD, See-through Displays, Virtual Retinal Displays and SID. Further reading on classifications and types of displays can be found on the web site of SCI, Virtual Worlds, Visual Displays, i.e. http://www.hitl.washington.edu/scivw/visual-faq.html. CAVE will not be discussed here, since it is mostly used for VR applications where the user observes and interacts with completely-computer generated worlds.

Figure 2-3: Displays: from completely isolated from real world view to see-through

Head Mounted Displays are basically a set of goggles or a helmet with tiny monitors in front of each eye to generate images seen by the wearer as three-dimensional. Often the HMD is combined with a head tracker so that the images displayed in the HMD change as the head moves (Figure 2-3). The progress in the HMD is quite significant. While the first HMD were heavy and rather large, new prototypes do not differ much from sunglasses. A very extensive overview on HMD can be found on http://www.stereo3d.com/hmd.htm. A comparison between different displays is given on http://www.genreality.com/comparison.html.

See-trough displays are special clone of HMD that allow the user to see the virtual image superimposed over the real world. The wearer can "see through" the virtual image (Figure 2-3, the two images on right). The approaches to achieve such effect are different. Most of the solutions rely on small cameras that visualise the computer generated images in the view of the user.
Micro Optical (http://www.microopticalcorp.com/), *Olimpus* (http://www.eye-trek.com/) *Personal monitor* (http://www.personalmonitor.com/), *Sony* (http://www.sony.net/Products/ISP/index1.html) and *Hitachi* (http://www.hitachi.com/) are only few of the companies that provide see-through glasses. The glasses are usually coupled with a small monitor, on which the user can observe the requested information. Some of the solutions are very light (e.g. Micro Optical). The major disadvantage of such displays is that the user cannot get completely immersed with the reality.

Figure 2-4: NOMAD retina scanning display (Microvision)

An interesting solution offers the Virtual Retinal Display (VRD). The VRD, based on the concept of scanning an image directly on the retina of the viewer's eye, was invented at the HIT Lab in 1991. The development program began in November 1993 with the goal of producing a full colour, wide field-of-view, high resolution, high brightness, low cost virtual display. Several prototype systems are currently being demonstrated (http://www.hitl.washington.edu/projects/vrd/project.html). The first is a bench-mounted unit that displays a full colour, VGA (640 by 480) resolution image updated at 60 Hertz. It operates in either an inclusive or see-through mode. The second is a portable unit, displaying a monochrome, VGA resolution image. The portable system is housed in a briefcase allowing for system demonstrations at remote locations. The major advantage of such display is the ability for high resolution and the large Field of View. Theoretically full immersion with the system is possible. Retina-scanning displays are also available but still on a very high price (e.g. Microvision NOMAD display, Figure 2-4).

Actually, for outdoor AR systems only see-through glasses are appropriate. HMD that isolate completely the user from the real world might be too dangerous for outdoor applications. Any misregistration and delay in the system can result in life critical situations.

If a SAR is intended, in which the virtual information is projected onto the physical objects, projection displays (such as shutter glasses, SID, CAVE) need to be used. Such systems have the advantage of allowing many people to observe the same simultaneously (appropriate for discussing new design projects). SID utilise wrap-around (panoramic) video displays to create an unencumbered, ultra-wide field of view, walk-in immersive environment. Displays are typically produced by front or rear surface video projection onto cylinder, dome, torus, or rectilinear screens. High resolution over a wide field-of-view can be maintained by projecting multiple video ports which are tiled or soft-edge blended over the screen surface to create a continuous, seamless or near-seamless, geometrically correct image when properly rendered. SIDs may or may not utilise stereoscopy or head-tracking depending on application requirements.

2.2. Tracking systems

This section presents the basic principles related to tracking user's body, head, hands etc. Examples of indoor (or limited range) tracking systems, i.e. *mechanical*, *magnetic*, *acoustic* and *vision*, are discussed in detail.

As already mentioned, to be able to track the user within the monitored area, the position, direction (orientation) of movement and the speed has to be determined. Different techniques have been developed to tackle this problem. In general, the position can be determined using two main approaches:

- Relative localisation, which consist of evaluating the position and orientation by integrating information provided by diverse (usually encoder or inertial) sensors. The integration is started from the initial position and is continuously updated.
- Absolute localisation, which is the technique that permits the vehicle to determine its position in the domain of motion. These methods usually rely on navigation beacons, active or passive landmarks, maps matching or satellite-based signals like Global Positioning System (GPS).

A wealth of research (Hit Lab, 1997) employing a variety of sensing technologies, deals with motion tracking and registration as required for augmented reality. Each technology has unique strengths and weaknesses. Existing systems can be grouped into two categories: *active*-target, and *passive*-target. Active-target systems incorporate powered signal emitters, sensors, and/or landmarks (fiducials) placed in a prepared and calibrated environment. Demonstrated active-target systems use magnetic, optical, radio, and acoustic signals. Passive-target systems are completely self-contained, sensing ambient or naturally occurring signals or physical phenomena. Examples include compasses sensing the Earth's magnetic field, inertial sensors measuring linear acceleration and angular motion, and vision systems sensing natural scene features.

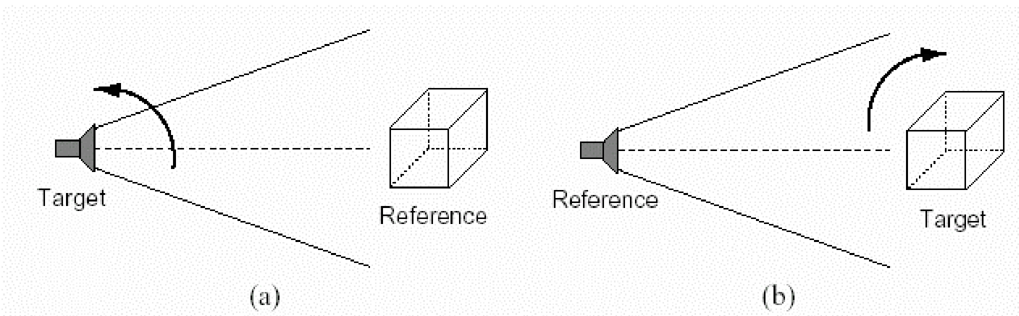


Figure 2-5: Inside-in, Inside-out systems (M. Ribo 2001)

Furthermore different parts of the human body can be tracked, i.e. head, hand, full-body. Head trackers can be described with respect to a small set of key characteristics that serve as performance measures for their evaluation and comparison. Some of these characteristics are resolution, accuracy, and system responsiveness (others such as robustness, registration, and sociability are not considered here).

- Resolution is related to the exactness with which a system can locate a position.
- Accuracy is the range within which the position can be considered correct. This is often expressed by a statistical measure such as root mean square.

System responsiveness comprises simple rate (the rate at which the sensors are checked for data), data rate (the number of computed positions per second), update rate (the rate at which the system reports new positions) and latency (the delay between movement of the object and the backbone computer).

Sturman 2001, classifies the tracking systems into three groups:

Inside-in technology (Figure 2-5, a) employs sensors and sources that are both on the body. These trackers, generally, do not provide 3D world-based information and are restricted to small areas. An example of inside-in technology would be a glove with flex sensors.

Inside-out technology (Figure 2-5, b) employs sensors on the body that sense artificial external sources (coil moving in an externally generated electromagnetic field) or natural sources (mechanical head tracker using a wall as a reference). These systems do provide world-based information, but their workspace is limited due to the use of external sources. They are also restricted to medium/large sized bodyparts.

Outside-in technology employs an external sensor that senses artificial sources or markers on the body (videocamera based system that tracks the pupil and cornea). These systems are considered the least obtrusive, but they suffer from occlusion (complete obstruction) and a limited workspace.

Table 2-1 provides a short review of all the tracking systems:

Table 2-1: A comparison table of tracking techniques (Sturman, 2001)

Technology	Description	Strengths	Weaknesses
Mechanical	Measure change in position by physically connecting the remote object to a point of reference with jointed linkages	Accurate Low lag No line of sight (LOS) or magnetic interference problems Good for tracking small volumes accurately	Intrusive, due to tethering Subject to mechanical part wear-out
Magnetic	Use sets of coils (in a transmitter) that are pulsed to produce magnetic fields. Magnetic sensors (in a receiver) determine the strength and angles of the fields. Pulsed magnetic field may be AC or DC.	Inexpensive Accurate No LOS problems Good noise immunity Map whole body motion Large ranges - size of small room	Ferromagnetic and/or metal conductive surfaces cause field distortion Electromagnetic interference from radios Accuracy diminishes with distance High latencies due to filtering
Sourceless, Non-inertial	Use passive magnetic sensors, referenced to the earth's magnetic field, to provide measurement of roll, pitch, and yaw, and as a derivative, angular acceleration and velocity.	Inexpensive Transmitter not necessary Portable	Only 3 DOF Difficult to mark movement between magnetic hemispheres
Optical	Use a variety of detectors, from ordinary video cameras to LEDs, to detect either ambient light or light emitted under control of the position tracker. Infrared light is often used to prevent interference with other activities.	High availability Can work over a large area Fast No magnetic interference problems High accuracy	LOS necessary Limited by intensity and coherence of light sources Weight Expensive
Acoustic (Ultrasound)	Use three microphones and three emitters to compute the distance between a source and receiver via triangulation. Use ultrasonic frequencies (above 20 kHz) so that the emitters will not be heard.	Inexpensive No magnetic interference problems Lightweight	Ultrasonic noise interference Low accuracy since speed of sound in air varies with environmental conditions Echoes cause reception of "ghost" pulses LOS necessary
Inertial	Use accelerometers and gyroscopes. Orientation of the object is computed by jointly integrating the outputs of the rate gyros whose outputs are proportional to angular velocity about each axis. Changes in position can be computed by double integrating the outputs of the accelerometers using their known orientations.	Unlimited range Fast No LOS problems No magnetic interference problems Senses orientation directly Small size Low cost	Only 3 DOF Drift Not accurate for slow position changes

2.2.1. Mechanical trackers

Mechanical position trackers, also known as goniometers or exoskeletons, measure a person's body positions via mechanical linkages (Baratoff and Blanksteen, 1993). The exoskeleton must be physically attached to the user. It can be body-based, in which the entire system is attached to the user, who can freely move around. It can also be ground based, where the exoskeleton is attached to the ground (or some rigid structure) and the user can move within the limits allowed by the device. The lag for mechanical trackers is very short (less than 5msec), their update rate is fairly high (300 updates per second), and they are accurate.

Their main disadvantage is that the user's motion is constrained by the mechanical arm. An example of such a mechanical tracking device is the Boom developed by Fake Space Labs (http://www.fakespacelabs.com/).

Inertial tracking devices represent a different mechanical approach, relying on the principle of preserving angular momentum. These trackers use a couple of miniature gyroscopes to measure orientation changes. If full 6-DOF tracking ability is required, they must be supplemented by some position tracking device. A gyroscope consists of a rapidly spinning wheel suspended in a housing. The mechanical laws cause the wheel to resist any change in orientation. This resistance can be measured, and converted into yaw, pitch, and roll values. Inertial tracking devices are fast and accurate, and since they don't have a separate source, their range is only limited by the length of the cable to the control box or computer. Their main disadvantage is the drift between actual and reported values that is accumulated over time, and can be as much as 10 degrees per minute.

2.2.2. Magnetic trackers.

Magnetic trackers are used to capture translation coordinates (x,y,z) and yaw, pitch, roll (y,p,r) rotation coordinates (Capps, 2000). Magnetic tracking is most commonly used as an interface to a virtual world, for instance, by tracking head, hand, or input device motion. Some magnetic trackers can follow a number of devices simultaneously and thus magnetic tracking technology can be an option for full-motion body capture. This information can be used in real-time, perhaps to drive the motion of a virtual character, or can be recorded to give virtual actors realistic motion characteristics. Figure 2-6, left shows a principle schema of a magnetic tracker.

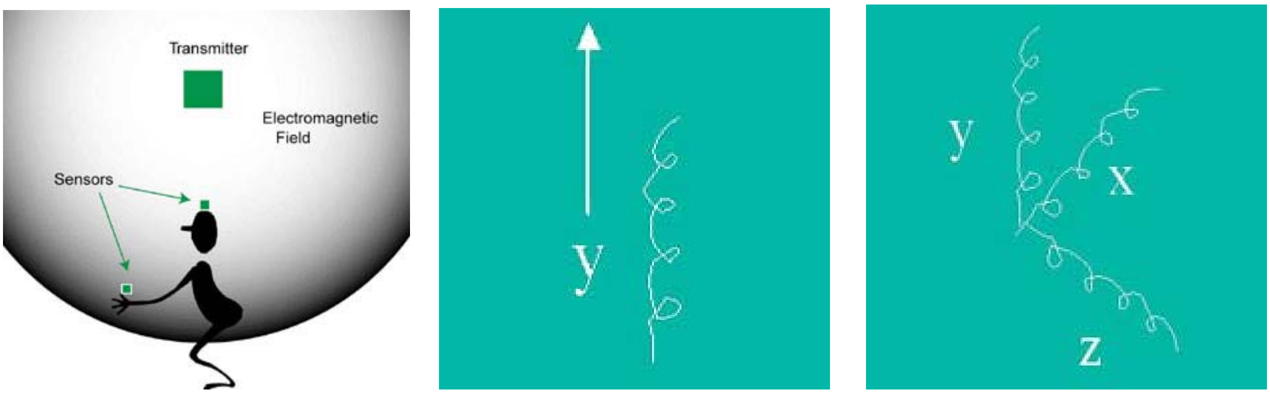


Figure 2-6: Magnetic tracker: general schema (left), 1-DOF (middle) and 3-DOF (right) (Capps, 2000)

Depending on the number of tracked directions, the magnetic systems can have different Degrees of Freedom (DOF). 1-DOF is realised by (e.g. in the y direction) a coil of wire, which is wrapped around the y-axis (Figure 2-6, middle). According to the right-hand rule, if the thumb coincides with the y-direction, the direction of the curl of the fingers is the way the coil must go. Running a current through a coil like this creates a magnetic field in the desired direction. Then the field will create a current in a second completely passive coil, proportional both to the strength of the current in the transmitter and the distance between the transmitter and sensor. Since the strength of the transmitter is known, it is possible to determine how far away the two sensors are. 2-DOF needs more than one single coil. The current caused by the magnetic field is weakened in the sensor (the second coil) the further they're separated. But the current in the sensor is also weaker if the two coils are not in a straight line. Thus, if the sensor is rotated, it gets a weaker signal. The problem is that, it is not known whether the signal is weaker from the sensor's rotation, or from distance.

In the full system (i.e. 6-DOF), the transmitter consists of three coils on orthogonal (x,y,z) axes (Figure 2-6, right). A current is passed through each coil. The sensor consists of a similar set of three coils. Depending on the system, varying signal strengths or time multiplexing is used so that each of the three magnetic fields can be isolated. The filtering device's job is much more important here, as the math is a bit more complicated than just a direct current-to-distance ratio as in the 1-DOF tracker example. The filter can serve a number of other uses, such as filtering jittery readings and the like.

Electromagnetic (EM) trackers have a transmitter that emits Electromagnetic (EM) field along three orthogonal axes that are detected by sensors. The sensors report information about their position and orientation with respect to the source. There are two problems with EM systems. The first is latency, which is the time lag between a sensor movement and the time it is reported. Current systems have a latency of about 0.1 sec. Another problem is accuracy, EM trackers are very sensitive to the presence of metal and become unreliable. An advantage of these trackers is that they can be freely moved and are not perturbed by non-metallic objects, such as the user's body.

2.2.3. Acoustic trackers

Acoustic tracking devices use ultrasonic (high-frequency) sound waves for measuring the position and orientation of the target object (Baratoff and Blanksteen, 1993). Two basic approaches can be distinguished, i.e. *time-of-flight* tracking and *phase-coherence* tracking.

Time-of-flight tracking works by measuring the time that is needed for sound emitted by transmitters on the target to reach sensors located at fixed positions in the environment. The transmitters emit sounds at known times, and only one is active at a time. By measuring when the sounds arrive at the various sensors, the system can determine the length of time it took for the sound to travel from the target to the sensors, and thereby calculate the distance from the target to each of the sensors. Since there will only be one point inside the volume delimited by the sensors that satisfies the equations for all three distances, the position of the target can be determined. In order to find position, only one of the transmitters is needed. Orientation is determined by the differences in location indicated by these calculations for each of the three sensors. The major disadvantage of these trackers is a low update rate, resulting from the low speed of sound in air. Other problems are environmental factors such as temperature, barometric pressure, and humidity that also affect the dissemination of sound in air.

Phase coherence tracking works by measuring the difference in phase between sound waves emitted by a transmitter on the target and those emitted by a transmitter at some reference point. The phase of a sound represents the position on the sound wave, and is measured in degrees: 360 degrees is equivalent to one wavelength difference. This is clear if one thinks of a sound that is a pure sine wave. The graph of the sine and cosine describes a circle as the angle progresses from 0 degrees to 360 degrees. After 360 degrees (one cycle, or wavelength), the graph returns to its starting point. As long as the distance traveled by the target is less than one wavelength between updates, the system can update the position of the target. By using multiple transmitters, as with time-of-flight tracking, orientation can also be determined. Since they work by periodic updates of position, rather than by measuring absolute position at each time step, phase-coherence tracking devices are subject to error accumulation over time.

2.2.4. Trackers using vision

The last tracking technique to be discussed here is the vision. Vision is commonly used for AR tracking (Azuma, 1997). Unlike other active and passive technologies, vision methods can estimate camera pose directly from the same imagery observed by the user. The pose estimate is often relative to the object(s) of interest and not to a sensor or emitter attached to the environment. This has several advantages: a) tracking may occur relative to moving objects; b) tracking measurements made from the viewing position often minimise the visual alignment error; and c) tracking accuracy varies in proportion to the visual size (or range) of the object(s) in the image. The ability to both track pose and measure residual errors is unique to vision, however vision suffers from a lack of robustness and high computational expense. Combining vision with other technologies may offer the prospect of overcoming these problems.

All tracking sensors have limitations. The signal sensing range as well as man-made and natural sources of interference limit active-target systems. Passive-target systems are also subject to signal degradation: for example, poor lighting disturbs vision and distance to ferrous material distorts compass measurements. Inertial sensors measure acceleration or angular rates, so their signals must be integrated to produce position or orientation. Noise, calibration error, and gravity acceleration introduce errors on these signals, resulting in a position and orientation drift. Hybrid systems attempt to compensate for the shortcomings of a single technology by using multiple sensor types to produce robust results. Among all other approaches, the most common is passive-target magnetic combined with a vision system:

1) Inertial gyroscope data can increase the robustness and computing efficiency of a vision system by providing a relative frame-to-frame estimate of camera orientation.

2) A vision system can correct for the accumulated drift of an inertial system.

Figure 2-7: Automatically recognised and tracked templates (Davison 1999]). Red squares indicate template content and its real-world position

The vision system tracks 2D-image motions, which are estimated with the help of the gyroscope sensors. Vision tracking, in turn, corrects the error and drift of the inertial estimates. In a vision system, one of the major issues is the types of features that can be tracked. Several different approaches (Pasman et al, 2001 for more details) can be used namely template, point, lines, corners, colour and combinations of them.

Template tracking is popular for tracking the position based on a piece of real-world scenery. Templates are small image patches that can be used over a wide range of camera positions. Reliable templates can be extracted automatically and their position can also be estimated automatically (Figure 2-7). Template tracking has been shown to have accuracies better than 1 cm if nearby (1 m) features are visible. Such systems can work even when less than three features are in view.

Points on an edge with known orientation is very fast, probably the first real-world camera tracking algorithm that could run in real-time on a standard desktop computer (Harris, 1992) (Figure 2-8). The original Harris paper already indicated an accuracy of 0.5% using photos taken from an airplane, which is of the same order as the feature tracking system.

Figure 2-8 Point tracking, Harris 1992 (left), Line tracking, Schmid and Zisserman, 1997 (middle, right)

Corners (e.g. crossings of lines, or gradient and curvature measurements) can also be used to correct drift in their inertial tracking system using curvature corner detectors and matching those corners with a projection of stored geometry (You et al 1999).

Line matching, however, remains the most often used approach. Kosaka and Nakazawa 1995 use a 3D model of the environment and match lines from this database using a hough transform of the image. They reach sub-centimeter accuracy and 1° orientation accuracy when the distance to a feature is about 20 cm, and they need about 2.5 seconds processing per frame, so this algorithm performs quite poorly when compared to the other alternatives. Schmid and Zisserman 2000 have a similar approach but apply line matching over multiple images. Usually, 97% to 100% of lines in pairs of natural images are matched properly, so theoretically it should be possible to make accurate position estimates (Figure 2-8).

Colour might be a powerful means to enhance tracking robustness. Colour tracking is still not very well explored, perhaps due to the fact that colours are highly invariant when the user moves around or lighting conditions change.

Several projects for robot navigation (based on a vision system) have been initiated to investigate the tracking approaches, i.e. Robivision, FINALE, DROID, RAPiD and ARVID. A short description of the projects is given in Chapter 6. The following text summarises the findings:

- Number of cameras: monocular (FINALE, Robvision INFA, DROID); binocular (Robvision DIST, ARVID)
- Camera calibration: calibration before, real-time calibration (DROID)

- Initial position: most of the cases known (Robvision, Finale, ARVID) but also computed (DROID)
- Indoor applications (FINALE, Robvision, DROID, ARVID) and outdoor (DROID)
- Data structure: most of the systems use their own data structure for storing the model. RobVision aims to use commercial CAD, DROID maintains points filtered with KF, ARVID uses simple CAD structure.
- Features of interest for matching: only vertical lines and landmarks (FINALE), vertical and horizontal lines (Robvision), trapezoid regions obtained by a segmentation of images (colour camera images) [Tsubouchi and Yuta, referred in FINALE], KF points (DROID), segmented regions and edges (ARVID)
- Grouping of features: single features (points or line segments), groups of features (groups of line segments, points, etc.). Most of the system match single features (Robvision, FINALE, DROID, ARVID). Some exceptions are Fennema (quoted in FINALE) who implement a model driven grouping of edges extracted from the camera.
- 3D matching: epipolar point match (DROID), least square match (FINALE, ARVID)
- Use of model information: FINALE, Robivision, ARVID

More information on the current status of tracking technologies can be found in Rolland et al 2001.

2.2.5. Companies providing in-door trackers

Many companies are actively working on developing a diverse range of tracking systems. MotionStar, InterSense, MotionAnalysis, InMotion Systems, PhoeniX Technologies, Polhemus are only some of the companies that produce in-door trackers. Many in-door trackers are commercially available with ranges extending from few square centimetres to few meters and able to track movements of hands (e.g. in surgery) or the entire body (in limited areas). Those systems however, cannot be used for outdoor applications due to the limited range and the wired solutions.

2.3. Analysis (displays, indoor trackers)

The AR approaches described above are relatively straightforward. Practically, two critical aspects influence the performance of the system. One aspect is the correct registration of two distinct worlds (real and virtual) and keeping them updated in real time. The second aspect is related to the display technology for merging the virtual and real objects. The registration of real and virtual scenes is influenced by two factors, i.e. the accuracy of determining the real world and the time delay (latency). The position and orientation of the user (camera) with respect to the real scene must be accurately sensed. Any errors in this measurement (or insufficient accuracy) may cause errors in the registration of the virtual image with the real scene (or real image). The second cause of misregistration is time delays in the system. A minimum cycle time of 0.1 seconds is needed for acceptable real-time performance. Delays in calculating the camera position or incorrect alignment of the graphics camera will result in corresponding delay of the virtual object behind the real scene motion. A static virtual object may look like moving inside the real scene. Furthermore, to appear constant, the AR system must be able to render the virtual scene at least 10 times per second. This is possible within the capabilities of current graphics systems for simple to moderate graphics scenes. For complex virtual objects (with realistic appearance) photorealistic graphics rendering (ray-tracing or photo realistic texturing) is required, which is not fully supported. Fortunately, there are many applications for augmented reality in which the virtual part is either not very complex or will not require a high level of photo realism. Another possibility is to apply advanced rendering approaches allowing faster rendering (e.g. UbiCom project, see Chapter 6).

2.3.1. AR displays

The progress in displays for AR systems in the last decade is apparent. The HMD became smaller and some of them are as large and heavy as sunglasses. The major problems with AR displays are still:

- low brightness and contrast,
- insufficient resolution of the displays (max 800x600),
- the narrow field-of-view.

In most of the optical see-through displays, virtual objects cannot completely hide the real objects behind them (since the see-through objects are not opaque). This may disturb the view against some backgrounds. The text information visualised in the field of view also may appear very unclear and difficult for reading. Furthermore, although the user focuses on physical object in the real world, virtual objects are always projected on the plane of the display. Even though the virtual object is correctly computed and projected, the user still may have the wrong impression, e.g. he may fail to focus them simultaneously. The video see-through displays eliminate these problems (e.g. the real objects can be fully obscured and can be combined with virtual objects using extended graphical tools), but the level of visual experience with the real world is drastically decreasing, e.g. all the objects are focussed at the same distance.

Retina displays may become the best solution outdoor applications, but the research is still at the beginning (first commercial display released in September 2001, very high price, visualisation of mostly text). In principle, the brightness and contrast can be very high, the power consumption can be very low and the field of view is very large.

2.3.2. Indoor trackers

The tracking approaches discussed above are mostly limited in range (often working in prepared environments) and aimed at providing high accuracy. However, as yet low-latency, high accuracy systems for head tracking in unprepared, possibly noisy environment do not exist. Most head trackers may achieve large working space but at the expense of accuracy. These are well-recognised problems. For the relatively mature technology areas of mechanical, magnetic, and acoustic tracking, the exceptions are to provide accurate tracking in short terms. Improvements are particularly likely in the case of magnetic trackers, which are widely used. The most significant improvements in tracker performance, however, are expected to come from the use of hybrid trackers where many of the limitations inherent in a particular technology can be overcome by combining the best features of two or more technologies. The research efforts and commercial systems using computer-vision with tracking implies are still insufficient and therefore an area of slow growth. Several developments in different areas are needed. A review of some robot vision systems, revealed that most of these systems only deal with 2-D gestures, require complex algorithms, and need significant computing power supported by special-purpose hardware. However, these problems are solvable. The long standing trend toward increasingly powerful hardware at cheaper prices should resolve the last problem, and several groups are working on the development of more powerful and efficient algorithms that can deal with multiple feature extraction.

Wide-area trackers as commercial products are still unavailable. Wide-area tracking is likely to become an increasingly important type of tracking, where the lack of tethering and the ability to move freely in room sized areas will make it highly desirable for many different types of AR and VR applications. Chapter 3 provides more information on outdoor and wireless tracking in relation to recent developments in the wireless communication and GPS technology.

References

Azuma, R. "A Survey of Augmented Reality", Presence:Teleoperators and Virtual Environment,.Vol. 6, No.4, 1997, pp. 355-385.

Baratoff, G. and S. Blanksteen, 1993, Tracking Devices, in: The Encyclopedia of Virtual Environments, available at: http://www.hitl.washington.edu/scivw/EVE

Capps, M.V. 2000, Magnetic tracking technology, available at: http://www.cs.nps.navy.mil/people/faculty/capps/4473/projects/mag00/magnetic.html

Davison, A. J.,1999, Mobile robot navigation using active vision. Ph.D. thesis, Robotics Research Group, University of Oxford. Available Internet: http://www.etl.go.jp/~davison/research.html.

Hit Lab, 1997, Tracking Interfaces, 32p, available at: http://www.hitl.washington.edu/scivw/scivw-ftp/publications/IDA-pdf/TRACK.PDF,

Pasman, W. S. Zlatanova, S. Persa, and J. Caarls, 2001, Alternatives for optical tracking, Internal Report 30/5/01, UbiCom program, Delft University of Technology, May, 12p. available at: http://www.gdmc.nl/zlatanova/publications.htm

Rascar R., G. Welch and H. Fuchs, 1998, Spatially Augmented Reality, First International Workshop on Augmented Reality, 1st November, San Francisco, USA, 7p.

Ribo, M. 2001, State of the Art, Report on Optical Tracking, available at: http://vrvis.at/research/..._2001_025_Full.pdf

Rolland, J.P. L.D. Davis, and Y. Baillot, 2001, A Survey of Tracking Technologies for Virtual Environments, Fundamentals of Wearable Computers and Augmented Reality, W. Bar.eld and T. Caudell, eds, Lawrence Erlbaum

Schmid, C., and Zisserman, A., 2000, The geometry and matching of lines and curves over multiple views. International Journal of Computer Vision, 40 (3), 199-234

3. Outdoor, wireless AR systems

This chapter presents and discusses new issues related to outdoor and wireless AR systems. As mentioned before, the differences with indoor systems are in the increased mobility of the user in the working environment (disconnected from cables and not restricted from markers). Often such systems are referred to as "unprepared environments". It should be noted that outdoor systems always rely on wireless technologies, while wireless AR systems often can also be realised as indoor systems. Therefore, in this chapter special attention will be paid to wireless communications for outdoor and indoor environments. Outdoor AR architectures may often rely on a vision system for accurate tracking of the user, which requires utilisation of large 2D or 3D geo-referenced data mostly organised in GIS or Database Management Systems (DBMS). Since the issues related to geo-data are rather specific, they are organised in a separate chapter (Chapter 5).

The chapter is organised into six sections. The first section presents the principle system architecture of an outdoor AR system as special attention is paid again to specific issues in displays and outdoor tracking systems. The subsequent three sections are related to wireless communication networks grouped with respect to the working range (global, local and short). The fifth section is devoted to the communication protocols for exchange of information. The last section highlights important issues of wireless AR systems.

3.1. Wireless AR systems

In principle, wireless AR technology is the same as hard wired, but burdened with the problems of wireless communications. Figure 3-1shows a very general idea of a wireless AR system proposed by Matthew Groves (http://www.servicentric.com/matt/), who claims to be one of the first to came to the idea of wireless AR systems in 1996. True or not Feiner et al present in 1997 the fist outdoor system.

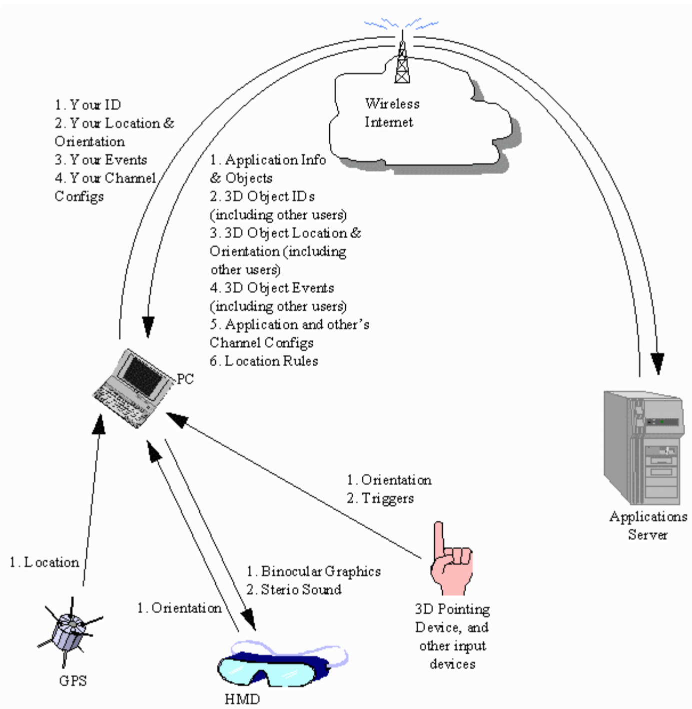


Figure 3-1: Wireless AR application (M. Groves)

3.1.1. Wireless AR system

Although the principle components of a wireless AR system are similar to the ones discussed in Chapter 2, the entire architecture is much more elaborate involving a range of different technologies. The displays are mostly the same (i.e. MB and ST), preference being given to the ST displays. All the drawbacks or benefits of using a particular type of display (see Chapter 2) are relevant for outdoor systems as well. With the advances of communication technology and progress in handheld devices (see Chapter 4) an interesting question would be whether these tiny, low-resolution screens would be able to replace ST displays in a sort of MB_AR system.

The tracking system of an outdoor AR setup is most commonly based on a GPS (to determine location) and an inertial system (to determine orientation and acceleration). The following section discusses some relevant issues.

In addition to displays and elaborated tracking system, there are also application servers (backbone computer), portable computer, 3D positioning device DBMS are involved. In case of using vision system for positioning, a camera has to be used. Figure 3-2 shows a very general schema of a vision AR tracking system. The accuracy of GPS receiver (see the next section) and the inertial system may not be sufficient for accurate positioning of the user. For example, if an urban planner would like to justify the position of a statue in front of a building, he/she might need to have it visualised in the HMD with an accuracy of at least 10 cm. Accurate positioning needs to be achieved with the help of a matching procedure between features extracted from the video images (obtained from the mobile video camera) and features retrieved from a 3D model. See Chapter 2 for a discussion on possible features for tracking and matching (lines, corners, textures, points, etc.).

It is apparent, that the equipment, which the mobile user has to wear, may become heavy and inconvenient. All wireless devices work on batteries, which brings additional requirements for quality, weight and low power consumption. These are well-known issues to the researchers and developers of portable, handheld devices.

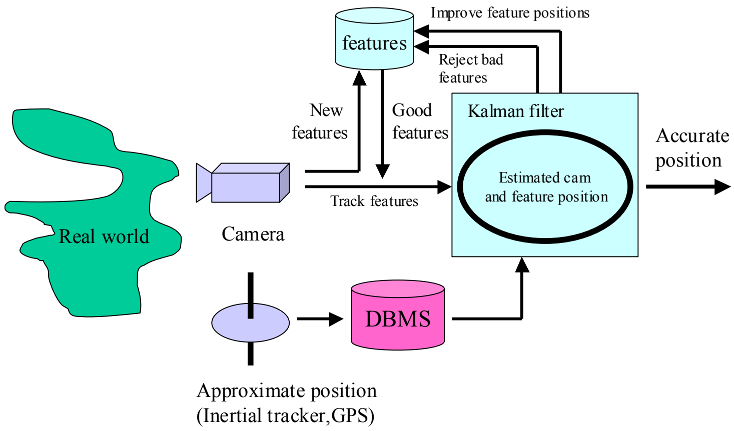


Figure 3-2: Setup of a wireless AR system

3.1.2. Outdoor tracking

In contrast to robot applications, which require motion over relatively small regions (Chapter 2), outdoor applications require a robust position and motion determination. Newly available gyroscope and inertial systems offer a better solution for tracking systems. Still, drift-corrected inertial tracking systems are only able to track a 3-DOF orientation. To correct positional drift in a 6-DOF inertial tracking system, supplementary measurements of fiducial points in the environment are required. Accelerometers and gyroscopes are very fast and accurate, but due to drift, they have to be reset regularly, in the order of once per second depending on the drift of the gyroscopes and accelerometers.

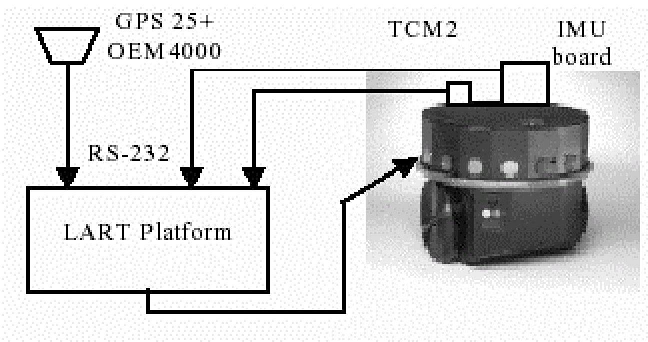


Figure 3-3: System data flow of the Ubicom tracker

Outdoor mobile robotic applications have rarely been attempted because building an effective outdoor mobile robotic system is much more difficult than building an indoor system. As mentioned before, no single tracking technology has the performance required to meet the needs of outdoors mobile robotics. The best way to have a viable solution is combining different technologies rather than waiting for any single technology to solve the entire problem. Problems with outdoor applications are several (You et al 1999). Firstly, fewer resources are available outdoors. Computation, sensors and power are limited to what a robot can reasonably carry. Secondly, the control over the outdoor environment is limited. In an indoor system, one can carefully control the lighting conditions, select the objects in view, add strategically located fiducials to make the tracking easier, etc. But modifying outdoor locations to that degree is unrealistic, so many existing mobile robotic tracking strategies are invalid outdoors. Finally, the range of operating conditions is greater outdoors.

An interesting solution of an outdoor tracking system is developed within the UbiCom project (Chapter 6). The UbiCom project assumes that the real-world objects are distant (e.g., 50+ meters), which allows utilisation of GPS for position tracking (Persa and Jonker, 1999). Then the focus is on the largest remaining sources of registration error (misalignments between virtual and real): the dynamic errors caused by lag in the system and distortion in the sensors. Compensating for those errors means stabilising the position and orientation against user motion. This is done by a hybrid tracker, which combines rate gyros with a compass and a tilt orientation sensor. Figure 3-3 shows the system dataflow. Three sets of sensors are used: the Garmin GPS 25 LP receiver combined with an RDS OEM4000 system to form a DGPS unit, a Precision Navigation TCM2 compass and tilt sensor, three rate gyroscopes (Murata) and three accelerometer (ADXL202) combined in one board, linked directly to LART platform (low power computer). The LART platform contains an 8-channel fast 16 bit A/D converter to acquire synchronous data from accelerometer, gyros and in future temperature data. Real-time temperature information can be useful to compensate the temperature drift sensitive component of the sensors.

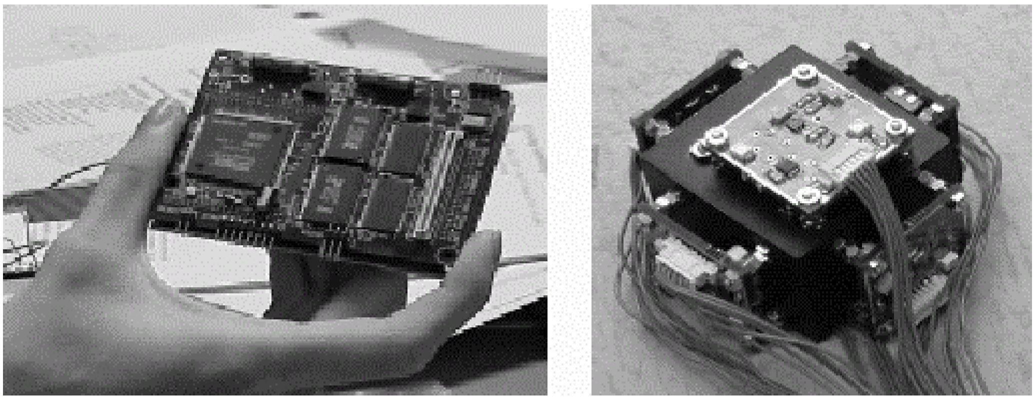


Figure 3-4: The LART board (http://www.lart.tudelft.nl)

The Garmin GPS provides outputs at 1 Hz, with 10 meters typical error, and 2-3 meter typical error in DGPS configuration. The TCM2 updates at 16 Hz and claims ±0.5 degrees of error in yaw. The gyros and the accelerometers are analog devices, which are sampled at 100 Hz or higher by an AD converter, and linked to an LART board. The other two sensors are read via serial lines. An LART board developed at Delft University, based on an Intel StrongArm processor reads the sensors. The LART mobile low-power board is presented in the Figure 3-4.

The solution of the UbiCom tracking system is only one example of the variety of possibilities to determine position, orientation and speed of a mobile user. Chapter 4 provides an extended discussion on approaches for tracking (using GPS, the facilities of the global and local telecommunication networks or combinations), their accuracy and functionality.

3.2. Wireless Wide Area Networks

The availability of a seamlessly permanent connection to the surrounding environment, allowing personal computing devices to interact and get information from the "neighbourhood" makes the wireless communications very attractive to the user. Several major changes in the wireless communications demands are observed in the last years (Verhoeven and van den Bo, 2002). Currently, a shift towards mobile e-mail and internet communications is prevalent that makes the nature of the information that passes through the radio link variable, and therefore less predictable. Each type of information passing through the link has its own sensitivity to particular errors that are made by the radio hardware, which results in different requirements for each system. Other systems are devised to enable ad-hoc connection between devices at high data rates (e.g. Bluetooth). The demands on the radio depend on the number of users sharing the same radio channel, and the user positions.

There are already several wireless networking technologies that are used to provide something that can be referred to as ubiquitous connectivity: cellular mobile radio networks, satellite communications, etc. Figure 3-5 portrays some of the wireless technologies with their range and bandwidth. Among these, Global System for Mobile communications (GSM) networks is the most disseminated all over Europe. The current number of GSM phones is increasing every year (see Table 1).

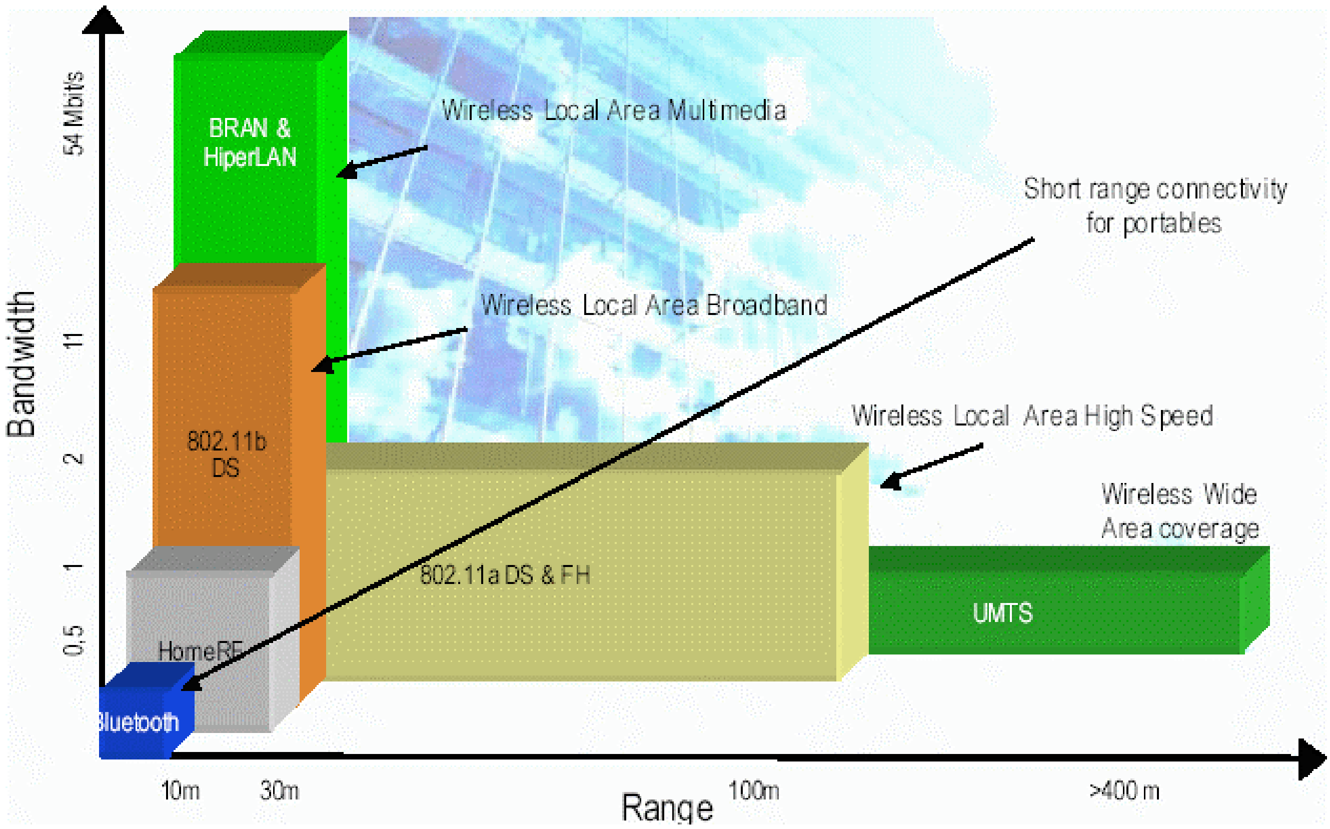


Figure 3-5: Mobility and range (www.xilinx.com)

3.2.1. GSM networks

The beginning of GSM can be traced back to 1982 when the Conference of European Posts and Telegraphs (CEPT) organised a study group, i.e. the Groupe Spécial Mobile (GSM) to develop a pan-European public land mobile system (http://www.gsmworld.com). GSM responsibilities are taken over by the European Telecommunication Standards Institute (ETSI) in 1989 that publishes the GSM specifications in 1990. Commercial service started in mid-1991. Today's GSM covers about 71% of the wireless digital market. GSM is a digital cellular radio network, presently operating in over 200 countries worldwide. It provides almost complete coverage in Europe, and growing coverage in the Americas, Asia and elsewhere. GSM networks currently operate in three different frequency ranges. GSM 900 (also called GSM) operates in the 900 MHz frequency range and is the most common in Europe. GSM 1800 operates in the 1800 MHz frequency range and is found in a rapidly increasing number of countries. GSM 1900 is the only frequency used in the United States and Canada for GSM. Actually, the planners of GSM wanted ISDN compatibility as well. However, radio transmission limitations, in terms of bandwidth and cost, do not allow the standard ISDN B-channel bit rate of 64 kbps to be practically achieved. The most basic teleservice supported by GSM is telephony. As with all other communications, speech is digitally encoded and transmitted through the GSM network as a digital stream.

The GSM network can be divided into three broad components, i.e. mobile unit, base station and network system. The Mobile Station is the unit carried by the subscriber. The Base Station Subsystem controls the radio link with the Mobile Station. The Network Subsystem, the main part of which is the Mobile services Switching Center (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The mobile station (MS) consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility. The SIM card may be protected against unauthorised use by a password or personal identity number.

Table 1
Worldwide Mobile Terminal Sales to End-User Estimates for 2Q02 (Thousands of Units)

Company	2Q02 Sales	2Q02 Market Share (%)	2Q01 Sales	2Q01 Market Share (%)	Growth (%)
Nokia	35,089	35.6	33,432	34.2	5.0
Motorola	15,496	15.7	15,326	15.7	1.1
Samsung	9,342	9.5	6,382	6.5	46.4
Siemens	8,247	8.4	7,245	7.4	13.8
SonyEricsson**	5,309	5.4	7,506	7.7	-29.3
Others	25,220	25.6	27,993	28.6	-9.9
Total	98,703	**100.0**	97,884	**100.0**	**0.8**

*Note: Ericsson sales only in 2Q01. Sony 2Q1 sales included in Others.
Note: This table does not include iDEN sales to end users.
Source: Gartner Dataquest (August 2002)

Ensuring the transmission of voice or data of a given quality over the radio link is only part of the function of a cellular mobile network. A GSM mobile can seamlessly roam nationally and internationally, which requires that registration, authentication, call routing and location updating functions exist and are standardised in GSM networks. In addition, the fact that the geographical area covered by the network is divided into cells necessitates the implementation of a handover mechanism. GSM networks also support data transmission. Current deployed networks allow data transmission using two methods: messaging-switching and circuit-switched data connections (see bellow).

The 3rd Generation Partnership Project (3GPP) is a collaboration agreement established in December 1998. The original scope of 3GPP was to produce globally applicable Technical Specifications and Technical Reports for a 3rd Generation Mobile System based on evolved GSM core networks and the radio access technologies that they support (i.e., Universal Terrestrial Radio Access (UTRA) both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes). The scope was subsequently extended to include the maintenance and development of the GSM. The General Packet Radio Service (GPRS) and the Enhanced Data rates for GSM Evolution (EDGE) are the new radio-access technologies described in the specifications. The 3G stages is expected to reach maturity between 2003-2005. The communication companies are ready with their concept devices for the 3G (http://www.3g-generation.com/motorola_tx.htm) and NOKIA announced the release of the first terminal 3G in September 2002.

The 4G stage of broadband mobile communications and services are expected to be introduced first in Japan, as early as 2006. The major distinction of 4G over 3G communications is increased data transmission rates compared to 3G. 3G rates are expected to reach speeds 200 times that, and 4G to yield further increases, reaching 20-40 Mbps (about 10-20 times the current rates of ADSL service). 4G is expected to deliver more advanced versions of the same improvements promised by 3G, such as enhanced multimedia, smooth streaming video, universal access, and portability across all types of devices. Industry insiders are reluctant to predict the direction that less-than-immediate future technology might take, but 4G enhancements are expected to include worldwide Roaming capability. As was projected for the ultimate 3G system, 4G might actually connect the entire globe and be operable from any location on - or above - the surface of the earth.

3.2.2. Short Message Service (SMS)

One of the basic GSM services, i.e. SMS, is a bi-directional store-and-forward message service that supports the transmission of short alphanumeric messages (up to 160 bytes). For point-to-point SMS, a message can be sent to another subscriber to the service, and an acknowledgement of receipt can be provided to the sender. SMS can also be used in a cell-broadcast mode, for sending messages such as traffic updates or news updates. SMS is being used for exchange of small text messages between the network users, broadcast of advertising information from the network operator or on a cell per cell basis, access to Internet services such as e-mail, sending and receiving, transmission of very low rate date in surveillance systems and transmission of GPS coordinate data from mobile users (people or vehicles) to control centres. As a message-switched system, SMS is very convenient to support low data rate services, where the transmission delay is not relevant at all. As the bandwidth and delay requirements of the services increase, the SMS becomes less and less appropriate.

3.2.3. Circuit-switched data (basic data service and HSCSD)

High-Speed Circuit Switched Data (HSCSD) is a new service that was created to overcome the bandwidth limitations of the basic data service. HSCSD extends GSM user data rates up to 14.4 kbps over a single channel. In addition, users have the capability to use multiple channels to extend the data rate up to 28.8 kbps (http://www.gsmdata.com). GSM users can send and receive data, at rates up to 9600 bps, to users on POTS

(Plain Old Telephone Service), ISDN, Packet Switched Public Data Networks and Circuit Switched Public Data Networks, using a variety of access methods and protocols, such as X.25 or X.32. However, the problem with the communication costs remains. Since the data service is through a voice channel, the communications costs are proportional to the time the circuit is used, as in any other circuit-switched network. The narrow bandwith is the other critical problem

3.2.4. Packet-switched data (GPRS, EDGE and WCDMA)

In a packet-switched network, no resources are exclusively allocated for a given connection, and are used only when there is data to be transmitted – the network user can always be connected and use the network as needed. Therefore the communication costs are lower and are frequently calculated on a per packet basis.

General Packet Radio Service (GPRS) is the packet-switched network service that is expected to be implemented 2003-2004 in most Western European countries. The implementation of GPRS involves significant upgrade of the GSM network, and this has delayed its deployment by many network operators. GPRS offers a packet-switched service at data rates up to 115 kbps and will support the widely used Internet Protocol (IP) as well as the X.25 protocol. The GPRS users are allowed to stay “connected” all the time, using (and paying for) the service only as needed. The users will be able to receive e-mail messages as soon as they arrive to the user mailbox, to browse the Web and to use many other client-server applications. In particular, WAP (see bellow) over GPRS is expected to be the technology that will make mobile e-commerce applications a reality.

The EDGE will be introduced to boost network capacity and increase the air interface data rates. Packet data user rates of up to 473 kbps and circuit switched data user rates of 64 kbps are achievable over EDGE (http://www.nokia.com). In GSM systems, these higher speed data services are referred to as EGPRS (Enhanced GPRS) and ECSD (Enhanced Circuit Switched Data).

The introduction of wider bandwidth services continues with the 3G mobile networks. The Universal Mobile Telecommunications System (UTMS), due within 2 to 3 years, will support even more advanced services. With WCDMA (Wideband Code Division Multiple Access) the network will provide user with wireless access at speeds of up to 2Mbps - some 40 times faster than the typical modems we use to access the Internet today.

3.3. Wireless Local Area Networks

Local Area Networks (WLAN) may also have an important role in mobile computing. Currently available WLANs, namely IEEE 802.11 WLANs (http://grouper.ieee.org/groups/802/11/), support data rates up to 20 Mbps (Figure 3-5) making them very attractive to support demanding multimedia applications. IEEE 802.11 WLANs operate in the 2.4 Industrial-Scientific-Medical (ISM) band, using both frequency hopping and direct sequence spread spectrum. Many manufactures offer WLAN network adapters in the form of PC cards (PCMCIA), and Compact Flash versions of such adapters are due short after the summer of 2000. A user entering a building may be granted the permission to log onto a WLAN and use it to access both local services and the Internet. Besides, the cellular structure of these WLANs may also be used to support positioning techniques as those available for GSM networks.

HiperLAN2 (http://portal.etsi.org/bran/kta/Hiperlan/hiperlan2.asp) specifications have been developed by ETSI Project Broadband Radio Access Networks (EP BRAN) (http://portal.etsi.org/portal_common/home.asp? tbkey1=BRAN). EP BRAN has worked closely with IEEE-SA (Working Group 802.11) and with MMAC in Japan (Working Group High Speed Wireless Access Networks) to harmonise the systems developed by the three for a band in 5 GHz. Several limitations of the 2.4GHz Band (only 80MHz wide, mandates use of spread spectrum technology, WLAN users must not interfere with primary license holders) have contributed to the development of a 5GHz Band.

HiperLan2 uses a new type of radio technology called Orthogonal Frequency Division Multiplexing (OFDM) and is technologically more advanced (Figure 3-6). The HiperLAN2 forum was launched in September 1999, founded by many founders among which Bosch, Ericsson, Nokia, Alcatel, Canon, Panasonic, Motorola, Philips, Samsung, Siemens, Sony, Silicon Wave, Toshiba with the mission to drive the adoption of HiperLAN2 as the global broadband of wireless technology in the 5GHz band, providing undeterred connectivity for mobile devices in corporate, public & home environments

HiperLAN2 is designed to provide high speed access (up to 54 Mbit/s) to a variety of networks including Ethernet, Internet Protocol (IP) -based networks, 3G mobile core networks, Institute of Electrical and Electronic Engineers (IEEE) 1394 and Asynchronous Transfer Mode (ATM) networks. Today, HiperLAN2 is the only standard that meets the demanding requirements of Audio, Video and/or Data applications. In addition for better performance, its key feature and its strength consist in providing the Quality of Service necessary to accommodate audio/video applications for large display devices. Simpler applications, namely data and voice, can then be handled easily.

Characteristic	802.11	802.11b	802.11a	HiperLAN2
Spectrum	2.4 GHz	2.4 GHz	2.4 GHz	5 GHz
Maximum physical rate (apprx.)	2 Mbps	11 Mbps	54 Mbps	54 Mbps
Maximum data rate, layer 3 (approx.)	1.2 Mbps	5 Mbps	32 Mbps	32 Mbps
Medium access control/Media sharing	Carrier sense - CSMA/CA	CSMA/CA		Central resource control/TDMA/TDD
Connectivity	Connection-less	Connection-less	Connection-less	Connection-oriented
Multicast	Yes	Yes	Yes	Yes
QoS support	PCF	PCF	PCF	ATM/802.1p/RSVP/DiffServ (full control)
Frequency selection	Frequency-hopping or DSSS	DSSS	Single carrier	Single carrier with Dynamic Frequency Selection
Authentication	No	No	No	NAI/IEEE address/X.509
Encryption	40-bit RC4	40-bit RC4	40-bit RC4	DES, Triple-DES
Handover support	No	No	No	No
Fixed network support	Ethernet	Ethernet	Ethernet	Ethernet, IP, ATM, UMTS, Firewire, PPP
Management	802.11 MIB	802.11 MIB	802.11 MIB	HiperLAN/2 MIB
Radio link quality control	No	No	No	Link adaptation

PCF - Point Control Function; Concept defined in 802.11 to allow certain time slots being allocated for real-time

Figure 3-6: HiperLAN2 vs. IEEE 802.11 (www.xilinx.com)

The security is based on strong authentication and encryption techniques. Authentication relies on supporting functions such as directory service. Encryption protects the user traffic on an established connection against eaves-dropping & man-in-middle attacks.

Special attention is paid to the power saving. The mobile terminal (MT) may at anytime request the access point (AP) to enter a low power state and provide a sleep period. At the expiration of the negotiated sleep period the MT searches for any wake up indication from the AP. In the absence of a wake up indication the MT reverts back to its low power state for the next sleep period. The AP defers any pending data to MT until the corresponding sleep period expires. Different sleep periods are supported to allow either short latency requirement or low power requirement.

In Europe, HiperLAN2 channels will be spaced 20MHz apart as their number is going to be 19 channels. Each channel will be divided into 52 sub-carriers (48 data carriers & 4 as pilots to provide synchronization).

HiperLAN/2 can be used as an alternative access technology to a 3G cellular network. One may think of the possibility to cover hot spots and city areas with HiperLAN/2 and the wide area with W-CDMA technology (Figure 3-7). In this way, a user can benefit from a high-performance network wherever it is feasible to deploy HiperLAN/2 and use W-CDMA elsewhere. The core network sees it to that the user is automatically and seamlessly handed over between the two types of access networks as the user moves between them.

Four years after the first ideas related to HiperLAN2, some demonstration products are already available. In order to ensure that HiperLAN2 manufacturers can perform product conformance checking, a set of conformance test specifications complements each functional specification. They include a Radio type approval and Radio Frequency conformance specification and a number of Protocol Implementation conformance specifications for the different sub-layers. The first batch of the HiperLAN2 conformance test specifications was approved by ETSI BRAN and was published in January 2001.The second batch came by the end of 2001. Several companies, Mitsubishi, NTT, Panasonic/Matsushita, Sharp, Sony, Stepmind, Theta Microelectronics and Thomson Multimedia demonstrate examples of HiperLAN2 technology from Access Points to Chip Sets and Terminals at the beginning of December, 2002. The promises are that the first products will appear also on the market in a year time.

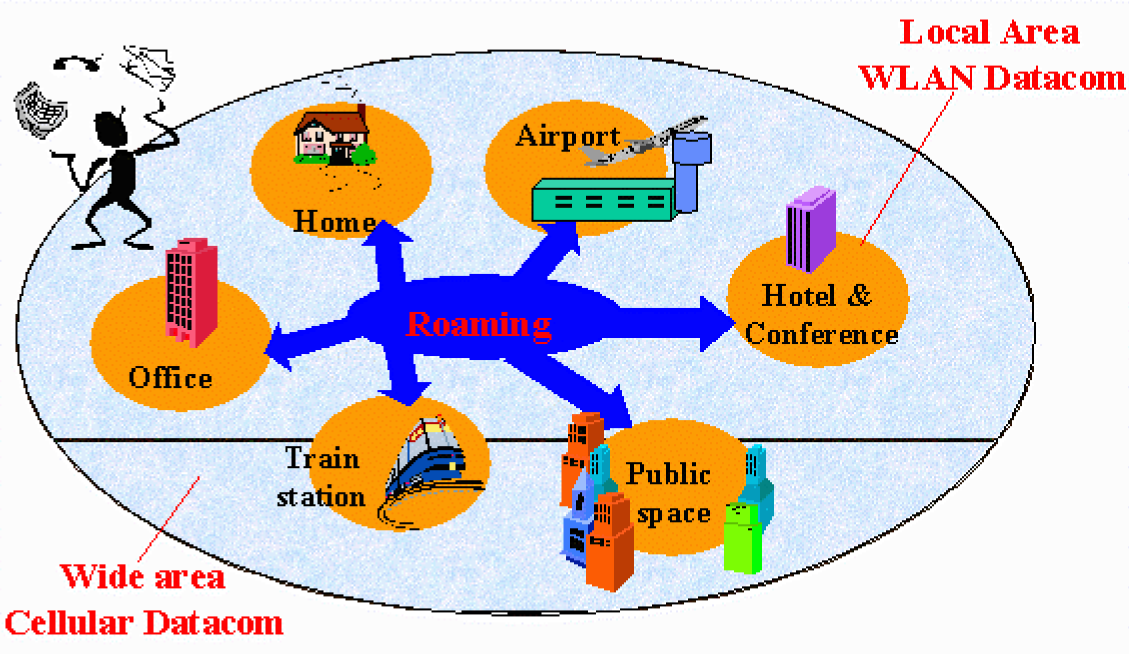


Figure 3-7: : HiperLAN2 applications (M. Johnsson, Chairman H2GF)

3.4. Short ranges

Infrared Data Association (IrDA) (http://www.irda.org/) is used to provide wireless connectivity technologies for devices that would normally use cables for connectivity. IrDA is a point-to-point, narrow angle (30° cone), ad-hoc data transmission standard designed to operate over a range of 1 meter and at speeds of 9600 bps to 16 Mbps, using wireless optical transmission in the infrared band.

3.4.1. Bluetooth

The bluetooth standard (http://www.bluetooth.com/) is a wireless specification that includes both link layer and application layer definitions for data, voice and content-centric applications. Radios that comply with the Bluetooth wireless specification operate in the unlicensed, 2.4 GHz radio spectrum ensuring communication compatibility worldwide. These radios use a spread spectrum, frequency hopping, full-duplex signal at up to 1600 hops/sec. The signal hops among 79 frequencies at 1 MHz intervals to give a high degree of interference immunity. Up to seven simultaneous connections can be established and maintained.

One of the main benefits of the Bluetooth standard, in addition to its global availability, is its broad industrial backing. The Bluetooth Special Interest Group (SIG), founded in 1998 by Nokia, Ericsson, Intel, IBM and Toshiba, has grown to include companies from a number of industries including computing and telecommunications, as well as automotive and pharmaceutical. For manufacturers, a global cross-industry standard means economies of scale, freeing them from the need to develop and produce several variants to accommodate different markets.

Bluetooth is a proposed Radio Frequency (RF) specification for short-range, point-to-multipoint voice and data transfer. Its nominal link range is from 10 cm to 10 m, but can be extended to 100 m by increasing the transmit power. It is based on a low-cost, short-range radio link, and facilitates ad hoc connections for stationary and mobile communication environments [http://www.countersys.com/tech/bluetooth.html].

Bluetooth operates in the 2.4 GHz Industrial-Scientific-Medical (ISM) band, using frequency hopping (FH) spread spectrum. Transmission in Bluetooth is omni-directional and non line-of-sight, allowing transmission through walls and other solid objects. It supports up to 8 devices in a piconet (two or more Bluetooth units sharing a channel) and has built-in security features.

Both synchronous and asynchronous services are supported, including easy integration of TCP/IP and up to three full duplex voice channels. Bluetooth enables portable electronic devices to connect and communicate wirelessly via short-range, ad hoc networks. Many Bluetooth capable devices and adapters started to be available during the second half of year 2000.

3.5. Protocols for multimedia data

Figure 3-8 gives a view of the current protocols and languages for representing handheld devices. Here, the focus will be only on WAP and I-mode. More information on the others can be found at http://www.lutris.com.

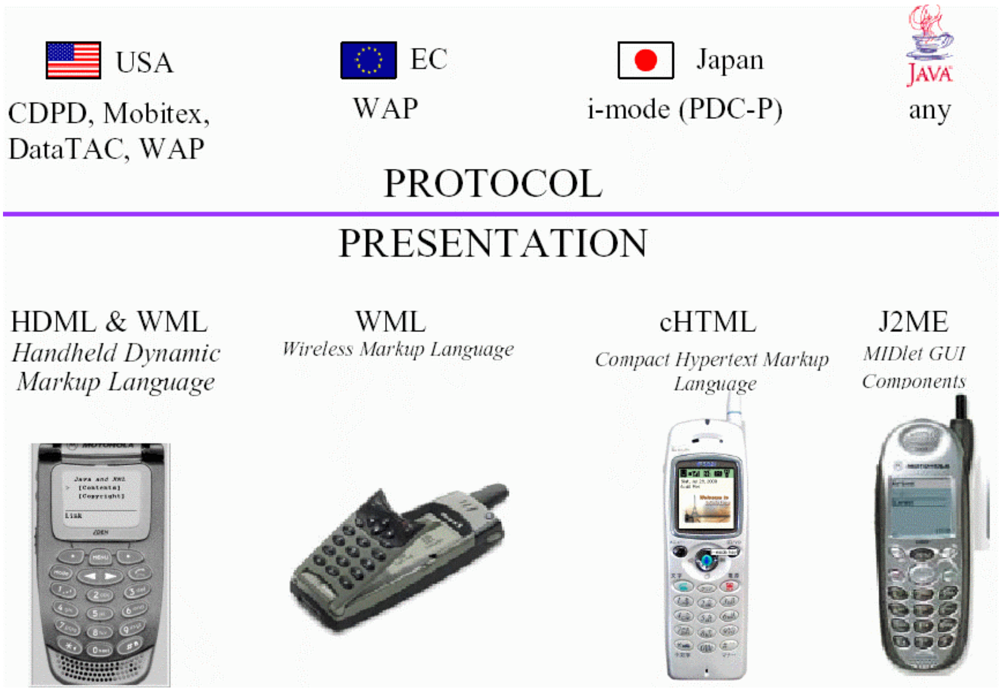


Figure 3-8: The protocols and the presentations they use (K. Bigelow and M. Beaulieu, Lutris,)

3.5.1. Wireless Application Protocol – WAP

The initial Wireless Application Protocol (WAP) (http://www.wapforum.org/what/index.htm) partner companies- Nokia, Ericsson, Motorola and Phone.com (formerly Unwired Planet) - formed a company called WAP Forum Limited to administer the global Wireless Application Protocol specification. WAP Forum consolidated with the Open Mobile Architecture Initiative to Open Mobile Alliance (http://www.openmobilealliance.org) with more than 200 (end 2002) members from phone manufacturers, network operators, SMS Centre suppliers and SMS software suppliers.

WAP embraces and extends the previously conceived and developed wireless data protocols. Phone.com created a version of the standard HyperText Markup Language (HTML) designed specifically for effective and cost-effective information transfer across mobile networks. Wireless terminals incorporated a Handheld Device Markup Language (HDML) micro-browser, and Phone.com's Handheld Device Transport Protocol (HDTP) then linked the terminal to the UP.Link Server Suite, which connects to the Internet or intranet where the information being requested resides. The Internet site content was tagged with HDML. This technology was incorporated into WAP - and renamed using some of the many WAP-related acronyms such as WMLS, WTP and WSP. Someone with a WAP-compliant phone uses the in-built micro-browser. With the help of the browser first a request in Wireless Markup Language (WML) is made. Then this request is passed to a WAP Gateway that then retrieves the information from an Internet server either in standard HTML format or preferably directly prepared for wireless terminals using WML (Figure 3-9). If the content being retrieved is in HTML format, a filter in the WAP Gateway may try to translate it into WML. A WML scripting language is a subset of XML and is available to format data such as calendar entries and electronic business cards for direct incorporation into the client device. The requested information is sent back from the WAP Gateway to the WAP client, using whatever mobile network bearer service is available and most appropriate.

The WAP forum released WAP 1.0 in 1998 and WAP 2.0 in January 2002. WAP 2.0 provides support for the protocols IP, TCP and HTTP and permits applications and services to operate over all existing and foreseeable air interface technologies (including GPRS and 3G cellular). WAP 2.0 provides a rich application environment, which enables delivery of information and interactive services to digital mobile phones, pagers, PDAs and other wireless devices by addressing their key features (e.g. smaller screens, limited battery life, and limited RAM and ROM). The protocol minimises the use of device processing power and optimises network resources in order to minimise costs and maximise performance.

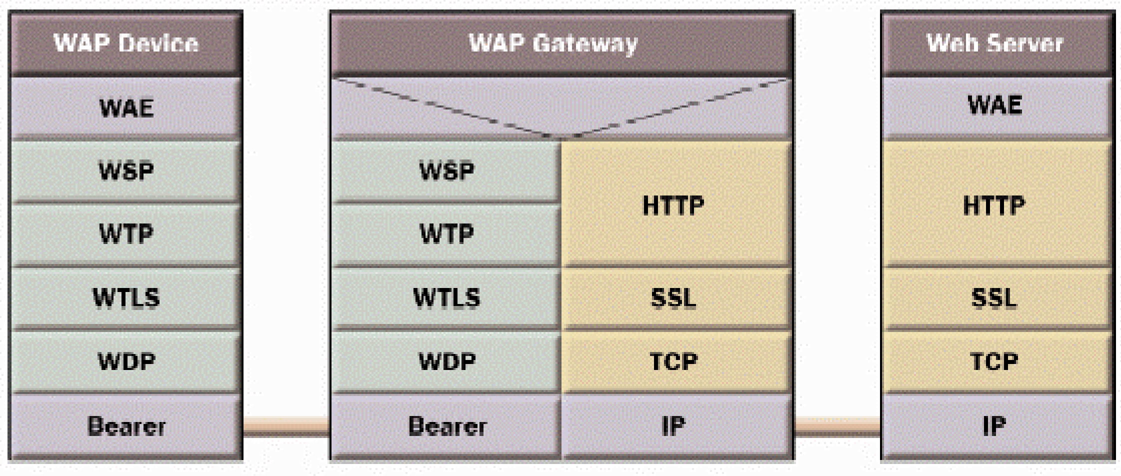


Figure 3-9: WAP Gateway (WAPForum, White papers)

3.5.2. I-mode

I-mode is developed by the company NTT CoMoDo, Japan and was first offered at the beginning of 1999. Only 4 months after that, it obtained over six million subscribers. Similar to the WAP-services as described above, the user needs an i-MODE enabled device in order to use the service. The transmission of the information utilises the Code Division Multiple Access (CDMA) protocol. Since the transfer rate for data is still rather slow (9.6kbs), i-MODE is insufficient for videos and large images. It is mainly appropriate for email (less than 500 bytes) and simple graphics. In order to render the incoming content on the small displays, i-MODE uses a subset of HTML, i.e. compact HTML (cHTML). Even though i-MODE does not require normal web pages to be converted into cHTML, most pages designed for i-MODE enabled devices usually contain some of the special i-MODE-only tags supported by cHTML. Initially available only in Japan and Korea, i-mode is currently occupying some space also in Europe (i.e. KPN, The Netherlands). The most attractive advantage of i-mode is the possibilitiy to pay per received data and not per duration of connection. As i-MODE is based on packet data transmission technology, a device using this technology is constantly online. One of the technical disadvantages is the lack of a scripting language (as WML script for WAP).

3.6. Summary

This chapter discussed the new elements in an outdoor, wireless AR architecture. The most important issue in wireless AR systems remains the tracking of the mobile user. Since the user is supposed to move freely indoors and outdoors, the tracking system has to rely on global and local positioning networks. The review on the current status of wireless communications clearly shows that the progress is significant. The last 10 years in the area of wireless and mobile communications have been very productive, with many technologies and commercial networks becoming available world-wide. Much more is expected to happen in the near future, with more versatile communication services, wider coverage and broader bandwidth availability.

GSM, and future UMTS seems to be the communication platform of choice to support the emerging information services for mobile users. The current 9600 bps circuit-switched data service will rapidly transforming into a 2 Mbps packet-switched data service with UMTS. This is advantageous for AR systems in two directions: 1) the accuracy of the positioning will improve and 2) the communication speed (critical for the lag in the systems) will increase in the coming 2-3 years. The logical consequence should be fast progress in wireless AR systems as well as LBS.

Furthermore, technologies other than GSM should be considered, such as WLANs, IrDA and Bluetooth. These may be very useful for indoor wireless AR setups or to glue small mobile devices such as mobile phones, palmtop and handheld computers, printers, desktop PCs and other devices to the Internet.

Chapter 4 provides further detail on possibilities to use wireless global and local networks to track the user and currently available displays (including hand-held devices) and analyses the present status of the technology.

References

Feiner, S. et al., 1997, A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment, Proc. 1st Int'l Symp. Wearable Computers (ISWC '97), IEEE CS Press, Los Alamitos, California, pp. 74-81.

Persa S. and P.P. Jonker, Multisensor Robot Navigation Systems, in: Douglas W. Gage, Howie M. Choset (eds.), Proc. SPIE, vol. 4573, 2002, 187-194. http://www.ph.tn.tudelft.nl/Bin/publications.person?name=S.+Persa

Verhoeven, C. J.M., C. van den Bo, 2002, Reconfiguration of radio receiver frontends in mobile communications UbiCOM report available at: http://bscw.ubicom.tudelft.nl/docs/default.asp

You, S., Neumann, U., & Azuma, R.,1999, Hybrid inertial and vision tracking for augmented reality registration. Proc IEEE VR, 260-267

You, S., U. Neumann, R. Azuma, 1999, Orientation Tracking for Outdoor Augmented Reality Registration, IEEE Computer Graphics and Applications, available at http://usc.edu/cgit/pdf/papers/CGA1999.pdf

4. AR equipment for outdoor applications

This chapter is dedicated to handheld devices and positioning systems available on the market that may be used for outdoor AR applications AR or LBS. Chapters 2 and 3 already discussed that that the composition of a robust outdoor AR system is a rather complex task. The current level of see-through display technology (the most appropriate one for outdoor applications) also contributes to the complexity of the problem. As suggested in Chapter 3, handheld devices may appear more appropriate to provide mobile users with information (realising Video ST AR) in the coming several years. Therefore this chapter reviews some of the hand-held, portable devices for requesting and obtaining information. Chapters 3 mentioned that the outside, wireless tracking of the mobile user is one of the largest problems in an AR system. An example of an outdoor tracking system demonstrated that a hybrid system is needed for determination of position, orientation and speed of movement. This chapter continues further and investigates other possibilities for outdoor tracking, addressing accuracy and functionality of the systems.

The chapter is organised into three sections. The first section deals with hand-held devices, the second section discuses approaches for outdoor positioning and the third section analyses the current status.

4.1. Hand-held devices

Many types of devices can be used as terminals by the mobile user to access a variety of services. Most of the currently available devices have a lot of limitations. Some have very small displays and small memory, while others have limited or no connection capabilities. Some new devices are being developed and some are being made available that integrate the benefits of mobile phones with those of handheld computers and GPS receivers, to produce very powerful and versatile user terminals.

4.1.1. Cellular phones

Cellular phones are becoming more and more versatile for accessing network services. A cellular phone can be used as a terminal itself or it can be used together with palmtop or handheld computer devices to access network data services. As a display, mobile phones have some limitations. As long as the mobile phones are tiny, practical and easy to carry in your pocket, the display has to be small and cannot view the same amount of information as a desktop computer. Furthermore, the screen quality is poor. One can send pictures with WAP, but if they are too complicated they will merely appear as blurs. It is much harder to write an e-mail on phone than on a PC. When people start to use their mobile phone to read and write e-mails, the need for a better keyboard forces the producers to develop better systems.

4.1.2. Palmtop and handheld computers

The palmtop/handheld computer industry has been very active in the past few years, and a lot of devices are available on the market. Some are oriented to be used as personal organisers, while others are more powerful and programmable computing devices. A common characteristic is the ability to synchronise data in the mobile device with a desktop PC, such as contacts, calendar appointments, task lists and e-mail messages.

One could classify these devices according to their functions or architecture, but it is the operating system that is being used to group these devices into classes.

PalmPilot devices (http://www.palm.com/us/) There are a number of devices developed by Palm Computing that utilise the open Palm Operating System (Palm OS) platform. All these devices use a stylus rather than a keyboard as the input method, and use character recognition features to help in typing data into the applications. The most recent devices have a colour screen. The Palm OS is an open operating system, and this has contributed to the development and availability of a large number of applications, distributed through the Internet. Connectivity with desktop computers and other devices such as mobile phones and GPS receivers is achieved through one serial and one infrared port.

Symbian OS devices (http://www.symbian.com/). Symbian OS is an operating system licensed by the top 5 leading telecommunication and mobile communications companies, i.e. Ericsson, Matsushita, Motorola Inc, Nokia, Philips Consumer Communications and Psion Plc. Symbian is aiming for open development of an Operating System that can be used by a variety of products. The last developments, i.e. Series 60 platform is optimised to run on top Symbian OS. Nokia licenses the Series 60 to other mobile handset vendors who will be able to integrate the software platform into their own application-driven phone designs. Thus far, Matsushita, Siemens and Samsung have licensed Series 60. This presents developers with a compelling opportunity to create a new wave of applications and services for global deployment on handsets from multiple manufacturers

Windows CE devices Another potential operating system for handheld computers is Windows CE from Microsoft. This scaled down version of the Windows OS offers compatibility with PCs. Many palmtop and handheld computer manufactures are shipping devices that use this operating system, including Hewlett Packard, Compaq and Casio. There are two types of devices using Windows CE: palmtop computers and handheld computers. Palmtop products are pen-based devices, with monochrome or colour displays, handwriting features and virtual keyboards, much like a PalmPilot. Handheld computers are more like a tiny notebook, with a physical keyboard but also with a touch screen and pen-based interface.

One major difference to the PalmPilot devices is the number and variety of physical interfaces available. Both palmtop and handheld Windows CE devices usually have a serial port, an IrDA compatible infrared port, audio input and output connectors, built-in speaker and microphone and, most important, a Type I CompactFlash slot. In addition, handheld devices usually have an additional Type II PC card slot and a built-in modem. Some of the more recent devices also have a USB interface.

Pocket PC devices (http://www.microsoft.com/mobile/pocketpc/learnmore/hardware/emea.asp**)** Pocket PC is a relatively new operating system for palmtop devices from Microsoft. The main functionalities are similar to that of WindowsCE devices.

Several different combinations of the devices specified above are also possible. For example, **cellular phones with built-in GPS** (http://www.benefon.com) (still very expensive, i.e.1500 euro), a **cellular phone with embedded palmtop compute**r (http://www.qualcomm.com) or a **palmtop computer with embedded cellular communications features** (http://www.palm.com) (from 130-613 euro). Some examples of cell phones with extended functionality are listed bellow:

Nokia Communicator For the Nokia Communicator (9000, 9110 and 9110i) software already exists (the GPS-SMS Application, V1.0) to capture the GPS NMEA 0183 signal from a standard GPS and send it via SMS. This software provides an interface showing location and satellite information and allows settings such as frequency of transmission of the SMS message. The system is designed to work seamlessly with the Nokia SMS WAP server available from the same site to provide a precise, end-to-end solution to the geo-location problem.

Figure 4-1: Nokia 6650 with headphone set

The *Nokia 6650 phone* (http://press.nokia.com/PR/200209/874947_5.html, September, 2002) is the world's first 3GPP compliant mobile phone operating both in the GSM 900/1800 frequencies and on the WCDMA protocol (Figure 4-1). It also includes a WAP 1.2.1 browser supported by GPRS, Java 1.0 technology for downloading applications to the phone, support for polyphonic ring tones, wallet application for mobile transactions and data connectivity via USB, Bluetooth and infrared. The Bluetooth wireless headset allows handling phone calls and messaging. The phone has a dynamic memory of 7MB. One of the benefits of the WCDMA radio interface in the Nokia 6650 phone is that it allows running more than one data session simultaneously. The first commercial deliveries of the Nokia 6650 are estimated to start during first half of 2003. The phone cell is also the first Nokia phone to incorporate the ability to record video simultaneously with sound . In addition to still pictures, one can capture video clips - with audio – for up to twenty seconds, in 4096 colours. The pictures or clips can be viewed and stored, or sent to either a compatible phone or to an email address as a multimedia message. Users can view and edit the multimedia from the phone on the PC. With the PC Suite, it is also possible to synchronize personal data such as calendar and contacts between PC and the phone. The PC Suite will be delivered to the consumers as a part of the sales package of the Nokia 6650.

Figure 4-2 Palm Tungsten W with GPS

*Palm Devices with GPS***.** These devices can be linked to handheld GPS through their serial port and can receive NMEA 0183 (standard protocol for GPS data, http://www.kh-gps.de/nmea-faq.htm) handling routines.Customisation of this software and examination of its ownership status will be needed. One problem that exists for Palm devices is the need to simultaneously upload and download data that may be beyond their abilities. They have a single serial port which must be used by the GPS leaving only the unstable IrDA link to communicate with the mobile phone required for internet access for upload of the positional data to the server. It is not known if the Palm will be able to simultaneously receive NMEA frames and upload them to the server. Commercial software is available for the Palm to take GPS data and plot the user position on the display over backdrops or as a compass, however this functionality is designed to take place on the client site and less solutions have been found for sending the NMEA frame data to the server. GPSpilot's Tracker software (http://www.gpspilot.com/) is one example (Figure 4-3). Rand McNally (http://www.randmcnally.com) provides the StreetFinder software for visualising the user position over backdrop vector maps and the fitted GPS hardware for the Palm which slots into the serial port, making it less cumbersome than a cable link to a GPS. The new Palm Tungsten W handheld (Figure 4-2) (http://www.expansys.com/product.asp?code=TUNGSTENW) is the fist GSM/GPRS wireless handheld with a built-in keyboard and one-handed navigation. The Palm Tungsten W handheld has tri-band GSM/GPRS wireless radio. Palm claims the Tungsten W handheld is built with one of the fastest radios available today for the GSM/GPRS network, and the most widely supported wireless technology used by hundreds of operators worldwide. Palm also announced business alliances with four key carriers from around the world, including AT&T Wireless, which operates the largest GSM/GPRS network in the Western Hemisphere; Rogers AT&T Wireless (Canada), Vodafone (Europe) and SingTel (Asia). Palm is clearly the leader in the personal digital assistant (PDA) market, holding about 80 percent of the market while Windows CE-equipped handhelds have around 10 percent (International Data Corp from *Wired News*).

Figure 4-3: TripPilot, GPS Pilot

Several vendors are already busy with software running on handheld devices to provide GIS information to a mobile user with the help of GPS positioning or mobile network positioning (see bellow).

Figure 4-4: ArcPad with raster and graphics data (left) and the equipment with GPS receiver

ArcPad software (http://www.esri.com/software/arcpad/) running on Compaq PocketPC, provides a number of possibilities to visualise 2D map (raster and vector, Figure 4-4, left) and at the same is compatible several GPS receivers (Figure 4-4, right). The data obtained from the GPS are displayed on the top of the ESRI shape or raster file (support of Mr.SID image format). More data can be downloaded from and uploaded onto the Internet. The system is designed for urban and municipal government (data collection, field updates, navigation of city infrastructures, update of GIS), utilities, natural resources (gas or oil pipeline mapping, data acquisition of forest recourses, field updates of soil data), environmental impact, coastline erosion studies, identification and navigation of points of interest on background raster image

Some of the current prices (November, 2002) for ArcPad, HP iPAQ H3970 Color pocket PC combined with are:

+ Trimble GPS Pathfinder Pocket receiver for $1195.
+ Haicom CF card GPS (5-10 metres accuracy) for $530
+ Leica GS5 (3-4 metres accuracy) for $2400
+ Leica GS5PLUS (1 metre accuracy) for $4400

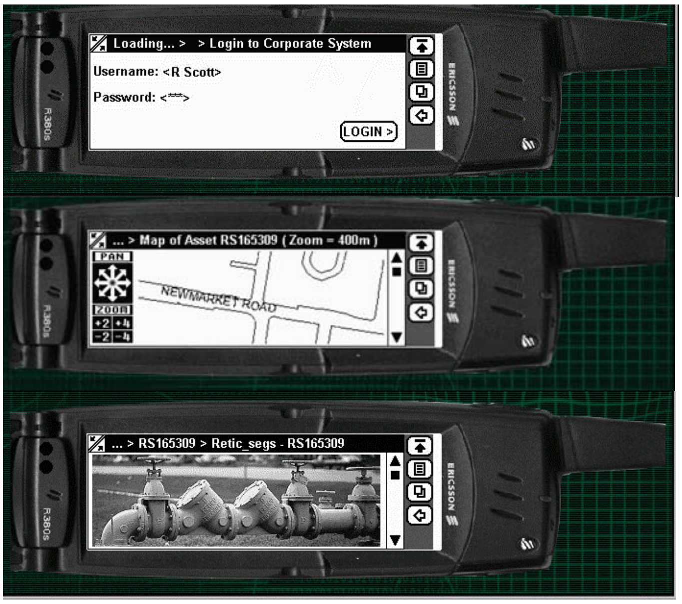


Figure 4-5L Visualisation of pipes on PocketPC

Another software product to process geo-spatial information on the spot is *Intelli Where* (Figure 4-5), a division of Intergraph, (http://www.intelliwhere.com/). The system does not use GPS but the location possibilities provided by telecommunication companies. One solution is IntelliWhereOnDemand (running on PocketPC) allows the user to upload a lot of data (map) from different sources, view and edit them in the field and upload the changes to the corporate system. Real connection to a server is not made. Another solution is IntelliWhere (Location server) using the telecommunication companies (Telcos) and Portals (offering e-mails, web pages, chat rooms, scores instant messengers, e.g. Excite, MSN, Netscape, Lycos, etc.) networks to connect to the database and load/upload information. For example, the utility management person can access his account with lists of tasks for the day and obtain a map and image with the problematic cases for the day. When repeated, he can report back to the management.

Software for visualisation of 3D graphics on handheld devices is also available. One example is Superscape with their Swerve technology (author and client) (http://www.superscape.com/inaction/index.asp). Swerve can be considered a new wireless 3D applications platform, designed specifically for wireless devices (Figure 4-6). The software is supported by RISK processors (http://www.arm.com)

Figure 4-6: Swerve technology for 3D visualization: devices and views

Other examples are PocketCortona from ParallelGraphics (http://www.parallelgraphics.com) and 3D Viewer from IBM) (http://www.research.ibm.com/vgc/pdaviewer/pdaviewer.html). A Java based 3D graphics API for mobile devices is under development (http://www.jcp.org/jsr/detail/184.jsp).The presently low visualization performance will be significantly improved following the rapid development in the range of graphic processors, exceeding even the Moore's law (http://www.intel.com/update/archive/issue2/focus.htm).

4.2. Outdoor tracking - GPS, mobile networks

As mentioned above (Chapter 3), outdoor tracking would definitely require some kind of a hybrid system that will provide absolute location and an inertial system will track the motion and the direction of the movement. The accuracy of positioning has to be very high. Improving the accuracy of mobile positioning is already a significant issue in LBS. The importance of positioning for LBS comes predominately from a legal requirement in the United States and from realisation of the commercial potential of mobile user positioning elsewhere. In Europe acquiring an accurate positional fix on mobile users is seen as a natural extension to increasing the number of location specific services provided to the rapidly expanding mobile user market.

Not surprisingly considering the massive increase in the mobile market a huge amount of research has been undertaken in this area. It should be noted that the next generation of phones are likely to solve the problems faced at present when attempting to position a mobile client. The UMTS, due in 2003 in many countries, will allow “always on, always connected” links to the mobile network, providing a channel through which positional data can be sent. The GPS chip and other positioning technologies, likely to become standard in mobile devices, will provide this data.

4.2.1. Global Positioning System – GPS

The global positioning system (GPS) is a satellite-based navigation system consisting of a network of 24 NAVSTAR satellites that are orbiting in space eleven thousand miles from Earth. The US Military launched the first GPS satellite in February 1978 and civilian use began in the early 1990's. Since then receivers (also, somewhat confusingly, referred to as GPS) have decreased rapidly in price with the least expensive now costing about 200 Euros.

Each satellite transmits a message containing three pieces of information, the satellite number, the position in space and the time at which the message was sent. The GPS receiver reads the message and saves the information. The GPS receiver compares the time at which a signal was transmitted from a satellite with the time it was received using a highly accurate internal clock. This allows the GPS to determine the distance to the satellite. With distance measurements from four satellites, the position on the ground is calculated.

In general, GPS provides two services (http://www.dotars.gov.au/agcc/selective_availability.htm). The Precise Positioning Service (PPS) is a result of observing both the GPS L1 and L2 carrier frequencies and the modulated Precision (P) code and the navigation message. The Standard Positioning Service (SPS) is only available on the GPS L1 frequency via the modulated Coarse Acquisition (C/A) code and the navigation message. The SPS is a single frequency service. Dual frequency observations allow for the removal of correction for the ionospheric delay effects on the observed range measurements. The expected (design) navigational accuracy for dual frequency, P-Code GPS is 9 metres in the horizontal and 10 metres in the vertical at the 90% confidence level Similarly, the potential (design) accuracy of the C/A code (single frequency) is 30 metres. The dual frequency observations, however, are not available in consumer devices. With four or more satellites, a GPS receiver determines a 3D position that includes latitude, longitude, and altitude. By continuously updating the position, a GPS receiver can also provide data on speed and direction of travel.

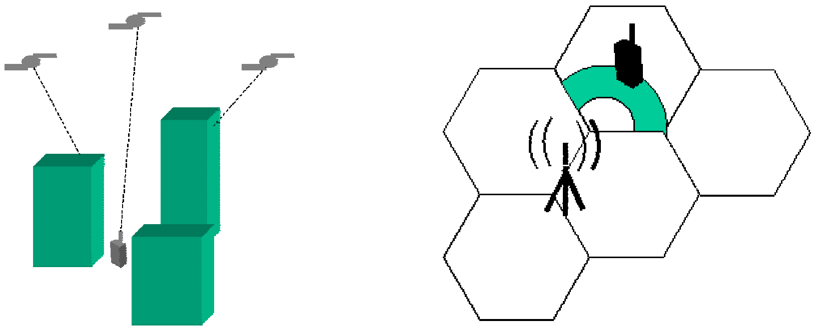


Figure 4-7: Urban Canyon (left) and CGI-TA Solution (right)

There are several sources of error for GPS measurement. Some of these occur due to natural phenomena (atmospheric affects), some due to problems with satellite configurations. Internal clock errors also may have an impact upon accuracy although modern devices are configured to correct for these errors, reducing thus their effect. Since the US Government stopped the degradation of the signal (known as Selective Availability) on the 1st of May 2000, the largest remaining error source is the effect of the ionosphere on the measurements – which, if uncorrected, can bias a single satellite-receiver range measurement by up to 50 metres at zenith and 150 metres at the horizon. Satellite visibility can have very large impact on the accuracy. Especially built up areas may suffer so called “urban canyons” which could reduce the sky visibility tremendously (Figure 4-7, left).

The main source of error can be corrected using a process known as differential GPS (DGPS). DGPS employs a second receiver at a known location on the ground to compute the introduced error and calculate corrections to the GPS satellite measurements. There are a number of subscription services available to provide DGPS corrections transmitted via radio to special add-on devices, which can increase accuracy to 4 metres or less.

4.2.2. Mobile networks based positioning

Network positioning systems exploit the existing network infrastructure developed specifically for mobile phones to estimate the location of the user and communicate this information via the mobile network. There is sufficient network information traffic to provide a rough fix on the user location for existing network infrastructure and mobile terminals. Further analysis carried out on more sophisticated terminals or dedicated servers in the mobile network can analyse mobile information transferred between client and network to substantially increase the accuracy of the positional fix.

Many current GSM phones can display basic cell information to the user of the network cell that the mobile device is located in. The network providers can determine the cell but cannot specify the position of the mobile user within the cell. In many cases even the cell location could be wrong. A typical example is an urban area, in which, a user phoning from a high building can be connected to a transmitter far away from the cell that the building falls in. Therefore, increased client functionality with supporting in-built functionality, or dedicated servers located within the network is needed. These more sophisticated systems can get more precise fixes on location either by comparing the relative times of arrival of signals transmitted by the underlying mobile network stations or by using triangulation from a number of base stations. It can be seen that there are number techniques for gauging user position from network information. Some systems require adjustments to the GSM network whilst others can exploit the network as it stands.

Cell Global Identity and Time Advance Positioning Method (CGI-TA) The cell global identity (CGI) identifies within which network cell the mobile client is located with the help of supplementary information (e.g. postal code information, town names). Using this method, the accuracy is limited by the size of network cell. This can vary from 100 metres in urban areas to tens of kilometres in flat rural areas. The accuracy of this technique can be improved by using the timing advance (TA) information that defines the time taken for information to reach the mobile device from a base transceiver station. The TA parameter provides an estimate of distance from the receiver accurate to about 500 metres, however the technique employs no directional information therefore the user could be located anywhere in a circular band (or a section of a circular band) around the base station (Figure 4-7, right). This approach has the potential to achieve accuracies of around 100-200 metres on the ground. Despite the coarse resolution of positional information the technique has the advantage that it can be employed on existing network infrastructures.

Uplink Time of Arrival Positioning Method (UL TOA) method uses positional information from several base station transceivers and requires minor modification to the network infrastructure in the form of locational measurement units (LMUs) at base stations. These are devoted to receiving information from mobile clients about how long information from base stations took to reach the mobile device. Calculations are performed away from the client at a dedicated server in the mobile network; hence the system works for existing mobile terminals. Accuracy of between 50 to 150 metres can be achieved using triangulation.

Enhanced Observed Time Difference Method (H-OTD). The enhanced observed time difference method is similar to the UL TOA method, however it is a client side solution, requiring no modifications to the existing network and calculations can be performed by the network or on the mobile terminal itself. The observed time difference for information from pairs of base transceiver stations is calculated to provide a measurement of distance from those stations. Using at least three pairs of stations at a position, the mobile terminal can be calculated using triangulation. Using stations that are close to each other decreases the accuracy of predictions. The accuracy of this technique is similar to that of UL TOA and unlike CGI techniques, the most accurate results are found in rural areas.

CellPoint is a private organisation providing GSM operators on the European, Asian and North-American markets with end-user services built on the company's GSM-based positioning technology. The main advantage of this system is that it can be exploited by the existing GSM network using a GSM phone and SIM toolkit without the need for expensive refinements to the network. SIM Toolkit is an *ETSI/SMG* standard for Value Added Services and e-commerce using GSM phones to do the transactions (http://www.cellular.co.za/sim_toolkit.htm). The message is sent via SMS and hence can be sent via a SMS/WAP server to an Internet server.

The *CURSOR system* has been developed by a private company, named Cambridge Positioning Systems (CPS) (http://www.cursor-system.com/). The system ensures accuracy of 50 metres on GSM networks, with even greater accuracy predicted for 3G. The company claims that the system is easy for implementation over competing positioning technologies and is available as a portfolio of software components which, when integrated, deliver a fully standardised E-OTD solution. Software upgrade is uploaded to the handset and to an existing mobile operators network. The performance of the system is quite high in built up areas or areas of high urban density. Currently the system works with different manufacturers - including Ericsson, Siemens and Nokia. CPS operates globally and serves its customers from offices in the UK, the US, Australia, Singapore and Hong Kong.

4.2.3. Hybrid methods

Network Assisted GPS overcomes the coverage problems associated with GPS (i.e. that it is unable to function without line of sight to the satellites) by combining GSM network information with GPS information. This requires a modification to the network with location measurement units (LMUs) added to selected base transceiver stations. This system offers accuracy of around 10 to 20 metres with arguably the main advantage being the increased coverage.

Ericsson Mobile Positioning System – MPS. (http://www.ericsson.com/press/archive/1998Q4/19981105-0039.html) Introduced in November 1998 as part of the GSM pro initiative, this is a GSM solution providing subscriber location without modification to network hardware or subscribers GSM phones, opting instead for a server-side solution. At the heart of the Ericsson MPS is the Mobile Location Centre (MLC), a system that allows user applications to access position information for GSM phones. The mobile positioning system uses a variety of positioning systems including client and server-side network solutions and network assisted GPS. This combination of services and the sway that Ericsson carries when pushing for standards in this area make it probably the most comprehensive solution to date.

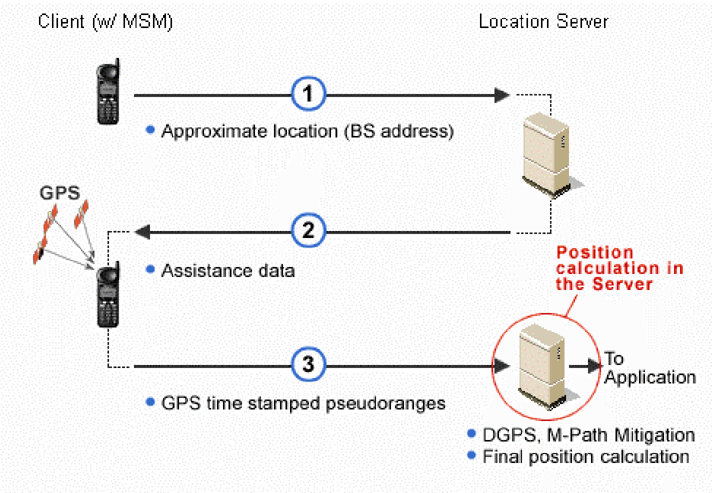


Figure 4-8: Snap-Track system

SnapTrack (http://www.snaptrack.com) a US firm offering commercial network assisted GPS solutions (Figure 4-8). SnapTrack's Personal Location Technology™ is based on a thin-client Wireless Assisted GPS™ system and may be incorporated into cellular phones, pagers, personal digital assistants, and other wireless devices. In fact, the SnapTrack system either runs as software on the handset's own digital signal processing chip or as a tightly integrated enhanced GPS capability at the baseband chip level. While traditional GPS receivers may take several minutes to provide a location fix, SnapTrack's system generally locates callers within a few seconds. Using SnapTrack's GPS Indoors capability, callers are typically located to within five to 20 meters in a wide range of challenging call environments where normal GPS will not work, including inside houses and moving vehicles, under heavy foliage and in downtown urban street canyons. SnapTrack's unique Location on Demand feature also ensures a caller's privacy, putting location information in the hands of the user, not the network.

The mobile device first takes an estimate of its location using network information. Knowing its approximate position it can then reduce its GPS initialising time and get a GPS fix much faster than without network assistance. The system allows very faint GPS signals to be detected thus providing GPS coverage in areas that were formerly GPS black spots. This is done by sharing many of the tasks performed by the handheld GPS across a distributed system of clients and servers.

4.3. Low power computers

Multiprocessor Systems Ltd. (http://www.mps.bg/pages/mpsdx5133.html) offers a low power computer with quite good parameters. Performance achieved is in the 100-200 MIPS range with power consumption in the 25-35 Watts range. The whole computer is realized in a box of 250 x 250 x 50 mm together with the AC/DC power supply. Memory is up to 128 Mbytes EDO DRAM. Cache is up to 512 Kbytes, Hard disk can up to 1,2 Gbyte.

The LART (http://www.lart.tudelft.nl) is a small yet powerful embedded computer capable of running Linux. Its performance is around 250 MIPS while consuming less than 1 Watt of power. In a standard configuration it holds 32MB DRAM and 4MB Flash ROM, which is sufficient for a Linux kernel and a sizeable ramdisk image.

4.4. Analysis (hand-held devices, outdoor positioning)

The major criticism of outdoor AR systems is usually the equipment. It is often commented that AR systems will remain in the research laboratories for the coming 5 years. The equipment that the user has to wear is still

- too heavy,
- the level of ergonomics is low and
- the price is relatively high.

A lot of new components are available already on the market but most of them are developed for the purpose of other applications (VR applications, LBS, Navigation etc.). Practically, there is not a vendor manufacturing components for outdoor AR systems.

4.4.1. Hand-held devices

Clearly, commercial interest is toward improving handheld displays (on mobile phones, PocketPC and other devices), developing software to visualise 2D and 3D graphics, tools to manipulate it and supplying GPS connection to determine the position. Still the operating system varies significantly, which makes development of software difficult. There are already attempts to use handheld displays for navigating through 3D virtual worlds but the investigations are still very limited. In general the display of the handheld devices is rather small that imposes limitations on quality, resolution and size of the view. The most beneficial issues in using handheld devices for AR visualisation are the low price and rapid changes in the developments.

4.4.2. Outdoor positioning

GPS devices are able to offer the most accurate positioning of the user but still there are many drawbacks and difficulties in implementing such solutions. One main problem is the limited satellite availability, particularly due to urban canyons in cities. The other problem lies in the capture of locational information from the GPS and sending this to the server. These are two distinct problems with partial solutions offered by a variety of hardware platforms and operating systems. The weight and the size of GPS receivers are not a problem anymore. These systems are rapidly getting more and more portable and thus able to be integrated in any handheld device. For example, Motorola (http://news.com.com/2100-1040-959085.html) launched a GPS chip (November 2002), sufficiently small (49 square millimetres) and cheap ($10) to be implemented in any consumer-electronics device such as cell phones and notebook computers. The Instant GPS chip will give users the ability to tap into a satellite system and pinpoint their geographic location.

The positioning within mobile networks is very inaccurate (aprox. 100 m) and practically not applicable even for LBS. The major advantage, compared to GPS positioning, is the possibility of working inside buildings. For this purpose it suggests itself as a backup system designed to compliment a superior positioning system. Many manufacturers even claim far greater accuracy for network solutions than those described above.

Hybrid solutions overcome the individual problems of GPS and network solutions. Due to weak GPS signals and limited precision of network solutions, hybrid solutions offer the greatest potential for positioning mobile clients. Both technologies are in a period of dramatic change and increased precision is expected from both techniques. The future offers a range of solutions, from GPS chips in mobile devices to accurate positioning using network information alone. Integrated solutions are likely to become standard to cater for the anticipated demand for location sensitive information.

5. Status of GIS and DBMS

This chapter concentrates on the progress in GIS and DBMS with respect to their readiness for AR systems and LBS. In general, geo-information (2D, 3D model) is becoming an important element of outdoor, wireless systems. This is true for both AR systems and LBS. Geo-information is primarily used due to request from the user. For example, the user would like to be guided to the closest petrol station or restaurant. The shortest path can be shown to the user using different tools (arrows, text, 2D map) and devices (ST-glasses, phone cell, or PDA), but the background operation, which makes the connection to the corresponding server and extracts the necessary data, is generic and hardly depends on the type of the terminal device.

Furthermore, as mentioned in Chapter 2 and 3, many wireless AR systems may need vision (and thus 2D, 3D models) to precisely position the user in the unprepared environment. Outdoor AR applications certainly would need large models of the real world, which most probably will require connection to existing Geographic Information Systems (GIS) and database managements systems (DBMS).

This chapter is organised into 6 sections. The first section argues that the need for geo-information is increasing and lists human activities requiring geo-information “on the spot”. The second section introduces the basic terminology of DBMS. The third section discusses the basics of geo-information storage. The fourth section reviews some of the most important standards for exchange of 3D data over the Internet and between different systems. The fifth section concentrates on modelling aspects of geo-information. The currently supported models are discussed in detail. The last section analyses the current status of commercial systems (considering the tests performed within the Ubicom project) and their suitability for AR or more general for real-time applications.

5.1. Mobile geo-users

At least 80% of public and private decision-making is based on some spatial aspects (Ostensen, 2001). The role of geo-information in all kinds of business processes is getting quite transparent. Location-specific information and Location-based services are terms that become a part of the daily business language to denote the link between the virtual world of information (transactions, events, internet communication) and the real world of information - customers, inventory, shipping and the like. Most business transactions rely on information systems to be executed successfully as the geo-information (location-specific information) is critical for many of them (Sonnen and Morris, 2000). Moreover, many human activities, i.e. urban planning, cadastre, environmental monitoring, telecommunications, public rescue operations, landscape planning, transportation monitoring, real-estate market, hydrographical activities, utility management, military applications, make steps toward the third dimension. The expectations are that the interest will significantly grow when 3D functionality is offered on the market. Once developments in 3D GIS provide a compatible functionality and performance, the spatial information services will evolve into the third dimension.

Who needs geographic information? Practically all business processes that produce, distribute, or utilise spatial information either alone or in conjunction with non-spatial information (see bellow for definition). These range from geographic information, decision support, data mining, data warehousing to modelling and simulation. In this order, the logical question is what is the possibility to obtain and visualise geographic and non-geographic information in an AR system. Who are the potential users and what kind of information will be demanded.

Apparently a variety of companies could benefit from augmenting the real world on the spot. Some examples are urban planning, utility maintenance, disaster management, traffic management, emergency services, etc. The greatest benefit of AR systems would be the possibility to “see” information that is not visible (e.g. underground pipes, cables) or does not exist (e.g. a newly designed construction or an ancient temple). Besides business, geographic information has been always of interest for regular citizens. A report on user requirements for LBS (within the Hypergeo project, Chapter 6) lists a large number of types of information that mobile users (practically a tourist) would like to have provided at the current location:

Attractions and actions. It is considered one of the most popular areas among the mobile users. The users interested in available attractions and places of interest (theatres, museums, castles and palaces, cinemas, restaurants, etc.) the actual number of free places, opening hours, prices, path to places of interest, etc. The search is based on various criteria, e.g. distance from the given place, types of collections kept at the place, owners or previous owners, contact information, visualisation on the map, optimal transport connection.

Important Contacts. Another group of data is the information related to local administrative institutions such as embassies, consulates, tourist offices, etc. The type of information requested is usually contact information, localisation on the city plan or map, important phone numbers, emergency phone numbers (police, fire brigade, ambulance), SOS assistance, tourism Information, etc.

Minimal Local Information. This refers to as information about local culture, local specifics, famous personalities, as again all the request are connected with locally oriented information, maps, city plans. It was realised that if available, users would interested in landscape characteristics, geographical attractions, flora and fauna (typical species), historical events, political systems and society, political representatives, political parties.

Miscellaneous. Indeed information about current exchange rates in local banks and exchange offices, contact information, localisation on maps or city plans, optimal transport connection is requested.

Traffic. One of the most interesting information for users with a personal vehicle is the current traffic situation. Provided connection with GPS and connection with local traffic monitoring systems available, advises are expected on the change of the route (still matching with the itinerary) and offering variant solutions.

This is only a small subset of possible areas of interest of a mobile user visiting a foreign country. Most of the information is location related and requires either navigation to a place or graphic information in the form of 2D 3D models to be visualised. Much of this information can be visualised in see-though displays or hand-held displays.

5.2. Databases

A database is a collection of data that is organised so that its contents can be easily accessed, managed, and updated. Very often the term is used for any types of data that are somehow organised in a computer. In our text, we will relate the term to persistent organisation of data outside the computer main memory. The most prevalent type of database is the relational, a tabular database in which data is defined so that it can be reorganised and accessed in a number of different ways. A distributed database is one that can be dispersed or replicated among different points in a network. An object-oriented database is one that is congruent with the data defined in object classes and subclasses.

Databases contain collections of data records or files, such as sales transactions, product catalogues and inventories, and customer profiles. Typically, a database management system (DBMS) provides users the capabilities of controlling read/write access, specifying report generation, and analysing usage. Databases and database managers are prevalent in large mainframe (large computer) systems, but are also present in smaller distributed workstation and mid-range systems such as the AS/400 and on personal computers. SQL is a standard language for making interactive queries from and updating a database such as IBM's DB2, Microsoft's Access, Oracle, Sybase, and Computer Associates.

DBMS has been traditionally designed as “containers” of non-spatial data (see next sections for definitions), however more and more systems provide storage and maintenance of spatial data. This integrated architecture (Vijlbrief & van Oosterom1992) can be contrasted to traditional GIS approaches such as: the dual architecture (separate DBMSs for spatial and non-spatial data) and the layered architecture (all data stored in a single DBMS, but spatial knowledge is contained in a layer between the application and the DBMS, for example ESRI's SDE). In the integrated architecture, the DBMS is extended with spatial data types (point, polyline and polygon) and functions (overlap, distance, area and length). The first DBMSs offering these capabilities were experimental systems, such as Postgres (Stonebraker et al.1990), O2, Gral (Güting1989), and others (DeWitt et al.1990) and, of course, the functionality was not yet standardized in, for example, SQL (Date and Darwen1997, ISO1992). Immediately after the availability of the first spatial DBMSs, also the first GISs based on these DBMSs became available. These were either based on an extended (object) relational database (GEO++) or on a pure object oriented database (GeO2).

The importance of the integrated architecture was recognized by industry and the OpenGIS Consortium (Buehler & McKee1998) standardized the basic spatial types and functions, or in the OpenGIS terminology the Simple Feature Specification (SFS). The SQL/SFS implementation specification (Open GIS Consortium, Inc., 1998) will also be part of the future ISO SQL3 standard (ISO/IEC 13249-31999). In 1999 the first implementations of the OpenGIS SQL/SFS became available, which marked an important step forward in the maturing of GIS and becoming part of the mainstream ICT. Nowadays several commercial DBMSs are available with support for spatial data types (some support the OpenGIS standard): Ingres (1994), Oracle 9i Spatial *(2*001) and Hebert and Murray1999, Informix (2000) or IBM DB2 (2000).

5.3. Types of geo-data (2D, 3D, vector, raster, CSG)

Among all types of systems dealing with spatial information, GIS has proven to be the most sophisticated system that operates with the largest scope of objects (spatial and semantic), relationships and provide means to analyse them. Traditionally, a GIS system should be able to maintain information about spatial phenomena and provide means to analyse it and thus gain knowledge of the environment. In general, consensus on the demanded functionality of GIS has been achieved a long time ago. The tasks or the functions of a GIS are specified as follows (see Raper and Maguire, 1992): 1) data capture, 2) data structuring, 3) data manipulation, 4) data analysis, and 5) data presentation. The basics related to GIS follows.

The first differentiation within the scope of real data is made between *spatial* and *non-spatial* objects. A spatial object use to be considered a real object having *geometric* (related to shape, size, direction) and *thematic (semantic)* characteristics (Aronoff 1995). In the last few years (with the extended utilisation of 3D data) a third group, i.e. *radiometric* (colour, texture of surfaces) characteristics of spatial objects have drawn attention. A further distinction is made between real objects with respect to distinctness of properties, i.e. objects with well defined spatial extent and properties and objects with unknown or not-well defined spatial extent and properties, i.e. objects with *discernible (determined)* and *indiscernible (undetermined)* boundaries. Many real objects need the monitoring of some of their characteristics with respect to time. The geo-science specialist might need to store and analyse the changes in order to be able to predict and control the process. Similar problems have created the branch of temporal definitions of an object, according to which objects are subdivided into *spatio-temporal* and *non-spatio-temporal.*

The description of geometric characteristics requires a priori clarification of the *abstraction* of space, the *dimension* of space and objects, and the *method for representation*. Conventionally, two approaches to space abstraction are utilised in modelling processes, i.e. *field-oriented* and *object-oriented* (Worboys 1995). The *field-oriented* approach assumes complete subdivision of the space into smaller, regular partitions, e.g. pixel. In the *object-oriented,* the space is "empty" and all the objects are places (embedded) in it, i.e. a lake in a 2D map. Both approaches have advantages and disadvantages and are appropriate for different applications. While the field-oriented approach better suits the representation of continuous phenomena, e.g. height fields, rainfalls, the object-oriented approach represents better *discrete* phenomena, e.g. buildings, roads.

The *dimension* of space is defined in mathematics as the number *n* of a sequence of *n* -real numbers $(a_1, a_2,\ldots,a_n)$, called an *ordered n-tuple.* The basic idea is using a tuple of points to define a position in space, e.g. a pair of points (x and y co-ordinates in Euclidean space) define a position in a plane, i.e. *2D space*. The real world is usually represented as a *2D* or *3D space.* Within the space, the objects have their own dimensionality, i.e. they can be represented by one of the following generic types: 0D (*points*), 1D (*lines*), 2D (*surfaces*) and 3D (*bodies*) objects. The decision as to the representation of real objects (i.e. point, line, surface or body), is highly influenced by the purpose of the model.

To represent the real world, an abstraction (representation) is needed. The possible representations of spatial objects are split into three large groups: i.e. *raster*, *vector* and *constructive primitives*. The "building blocks" in the raster method are regular cells, e.g. pixels (in 2D space), voxels (in 3D space), which fill in the entire object. The representation is simple and easy to maintain, but produces a lot of data for storage, and the overall precision is low. The vector method is based on irregular cells composed of points with co-ordinates. In contrast to the raster method, the cells represent the boundaries of objects. The last representation, known as Constructive Solid Geometry (CSG), uses irregular 3-cells. An object is represented by a CSG-tree, which holds information about the CSG primitives and the operations "gluing" them (i.e. Boolean operations). The approach is widely implemented in the manufacturing industry. In general, the irregular cells describing the boundaries of the objects allow more precise descriptions of shapes and spatial relationships compared to the raster cells and CSG primitives. Moreover, most of the rendering engines operate with the boundaries of objects, i.e. CSG and raster representations have to be further processed to determine boundaries. Therefore many applications give preference to the vector approach of description.

The vector representations are often referred to as boundary representations (B-rep) or surface representations (Mäntylä 1988, Worboys 1995). A large number of spatial models are developed and implemented in GIS, CG and CAD systems based on irregular multidimensional cells. The names and construction rules of the cells in the different models usually vary.

Representation of spatial objects is only one aspect of the GIS model. Another aspect is the possibility to perform spatial analysis. This means that the relationships between the objects has to be investigated. Three different approaches to encoding spatial relationships are discussed in the literature, i.e. *metric*, *topology* and *order*. The metric is a pure computational approach, based on the comparison of numerical values related to the location of objects in the space. For example, the spatial relationship between a house and a parcel (e.g. inside, outside, to the south) can be clarified by a metric operation point-in-polygon performed for each point constituting the footprint of the building.

The order establishes a preference based on the mathematical relation "<" (*strict order*) or "≤" (*partial order*), which allows an organisation of objects similar to a tree. For example, if a building is inside a parcel, the spatial relationship is represented as "building < parcel". The applicability to representing spatial relationships is investigated by Kainz 1989 who argues that it has advantages in expressions of *inside/outside* relationships.

Topology allows the encoding of spatial relationships based on the *neighbourhoods* of objects regardless of the distance between them. The main property of topology, i.e. the invariance under topological transformations (i.e.

rotation, scaling and translation) makes it appropriate for computer maintenance of spatial relationships. The following section discusses some basic topological issues that the thesis utilises.

5.4. Models (representing geo-data, GIS models, geometry, topology)

Discussing data structures, many application-related issues have to be taken into consideration, e.g. the space partitioning (full, embedding), the object components (volumes, faces), the construction rules (planarity, intersection constraints, etc.). The data structures reported currently in the literature can be subdivided in two large groups: structures maintaining objects and those maintaining relationships. While in the first group (object oriented), most of the relationships between objects have to be derived, in the second group (topology oriented), the representations of objects have to be derived. Many structures, which are a typical example of explicit storage of objects, maintain also explicit storage of relationships, i.e. singularities.

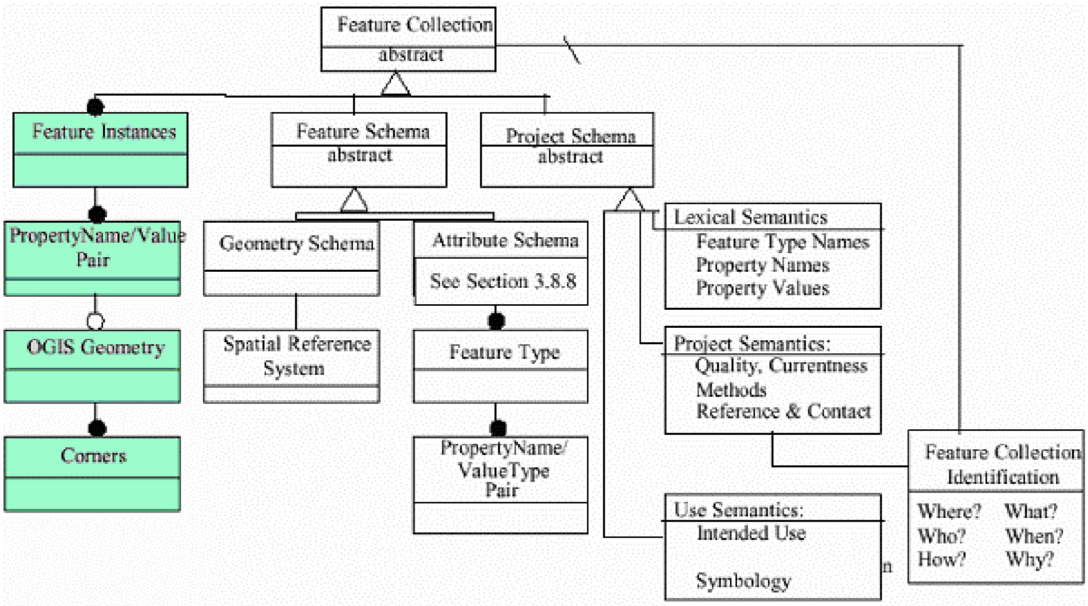


Figure 5-1: The Abstract Feature (OGC)

5.4.1. OpenGIS specifications

According to the OpenGIS specifications, the spatial object (named *geographic feature*) is represented by two structures (Figure 5-1), i.e. *geometric (i.e. simple feature specifications)* and *topological (i.e. complex feature specifications)* describe the spatial properties. The state of a feature is defined by a set of properties, where each property can be thought of as a {name, type, value} triple. The number of properties a feature may have, together with their names and types, are determined by its type definition. Geographic features are those with properties that may be geometry-valued. A feature collection is a collection of features that can itself be regarded as a feature; as a consequence a feature collection has a feature type and thus may have distinct properties of its own, in addition to the features it contains. While the geometric structure provides direct access to the coordinates of individual objects, the topological structure encapsulates some of their spatial relationships. Thus, an application can benefit from the two representations, e.g. area, volume and distance can be completed on the geometric structure, while analysis based on neighbourhood operations can be performed on the topological structure. Currently, the attention of vendors is toward the geometric model.

5.4.2. Topological models

3D FDS. The Formal Data Structure (Figure 5-2) is the first data structure that considers the spatial object as an integration of geometric and thematic properties. A conceptual model and 12 conventions (rules for partitioning of physical objects) define the structure (Molenaar 1990). The data structure consists of three fundamental levels: *feature* (related to a thematic class), four *elementary objects* (*point*, *line*, *surface* and *body*) and four *primitives* (*node*, *arc*, *face* and *edge*). According to the conventions, arcs and faces cannot intersect. A node and an arc must be created instead. Singularities are permitted in such a way that arcs and nodes can exist inside faces or bodies. The role of the edge is dual, i.e. to define the border of a face (relationship *face-arc*) and establish an orientation for a face, which is needed to specify left and right body. The number of arcs constituting an edge is not restricted. Arcs must be straight lines and faces must be planar. The surface has one outer boundary and may have several non-nested boundaries, i.e. may have holes or islands. The body has one outer surface and can have several non-nested bodies or holes.

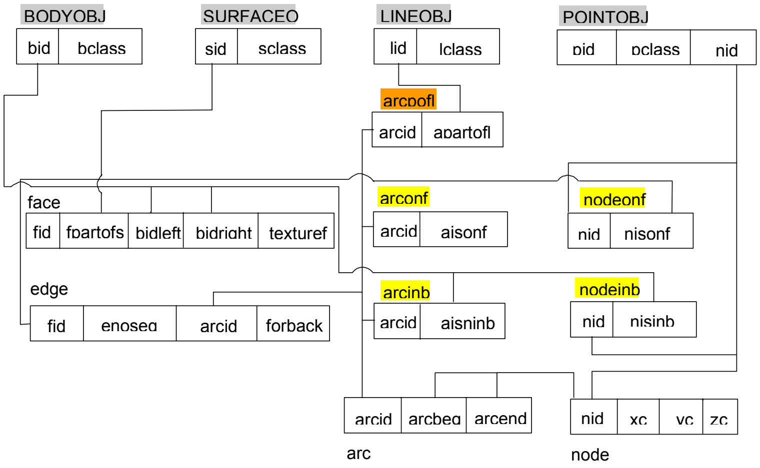


Figure 5-2: 3D FDS

The basis of 3D FDS is the concept of a single-valued map, i.e. (node, arc, face or edge) can appear in the description of only one geometric object of the same dimension (Molenaar 1989). The idea of the single-valued approach is to partition the space into non-overlapping objects and thus ensuring 1:1 relationships between the primitives and the objects of same dimensions, e.g. surfaces and face. Primitives of different dimensions, however, can overlap, e.g. relationships *node-on-face*, *arc-on-face*, *node-in-body* and *arc-in-body* are explicitly stored.

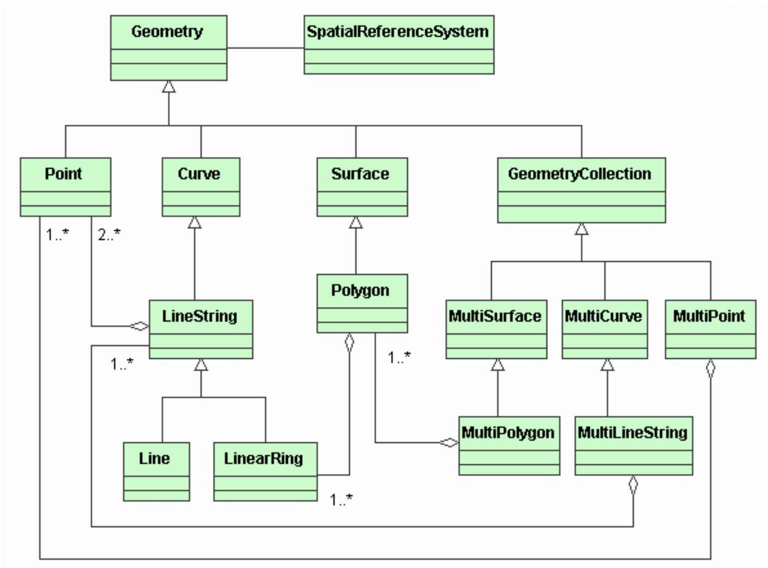


Figure 5-3: The Geometric model (Simple Feature Specifications, OGC)

The cell tuple model. The spatial model introduced by (Brisson 1990) is referred to as *the tuple model*. It defines cells and cell complexes upon the fundamental properties of a manifold. This model is an example of relationship oriented models. Any spatial object can be described as a constant number set of tuples (0,1,2,3 cells) with respect to the relationships with neighbouring elements. From an organisation point of view, the models is very simple and easy for maintenance. There is only one table with a constant number of columns (in contrast to 3D FDS for example, where 13 tables have to be created). The object, however, have to be derived.

5.4.3. Geometric models

While the agreement on an topological model (in 3D) is not achieved yet, the agreement on a geometric model (Figure 5-3) is already a fact. Many DBMS implement this model (with small variations) and many front-end engines (GIS and CAD) provide tools to access, edit and post objects in DBMS.

For example, the characteristics of spatial objects in Oracle Spatial are defined as *geometric type*. These types can be used in the same way as all the other data types such as integer, date, etc. Currently, the supported geometric types are 2D (point, line, polygon) but 3D coordinates are accepted. The generating rules are very simple and intuitive. Lines and polygons are represented as an ordered set of coordinates (2D or 3D). Self-intersecting lines are allowed but self-intersecting polygons are not supported. Polygons with holes are maintained as well. Oracle is a object-relational DBMS and the geometric types are defined using exactly the object-oriented approach. They are defined in the *mdsys.sdo_geometry* object-relational model and contain information about type, dimension, coordinate system, holes of objects, and provide a list of coordinates. The structure of the object is given bellow:

Name	Null?	Type
SDO_GTYPE		NUMBER
SDO_SRID		NUMBER
SDO_POINT		SDO_POINT_TYPE
SDO_ELEM_INFO		SDO_ELEM_INFO_ARRAY
SDO_ORDINATES		SDO_ORDINATE_ARRAY

Thus, the five parameters of the geometry for a 3D polygon with four vertices *v* (X,Y,Z), e.g. *v1* (10, 10, 0), *v2* (11, 9, 1), *v3* (11, 12, 0) and *v4* (9, 11, 1) will have the following values:

SDO_GTYPE = 3003. The first 3 indicates three-dimensional object and the second 3 indicates a polygon.
SDO_SRID = NULL. The coordinate system is not specified, i.e. decoded in the coordinates.
SDO_POINT = NULL. The described type is polygon and therefore the value is NULL.
SDL_ELEM_INFO = (1, 1003, 1). The first 1 in the sequence 1,1003,1 gives details about the geometry type (i.e. a simple polygon connected by straight lines). 1003 indicates that the polygon is an exterior ring. The final 1 specifies the geometry type, i.e. polygon. Furthermore, these particular values certify that the polygon does not contain holes.
SDO_ORDINATES = (10, 10, 0, 11, 9, 1, 11, 12, 0, 9, 11, 1, 10, 10, 0).

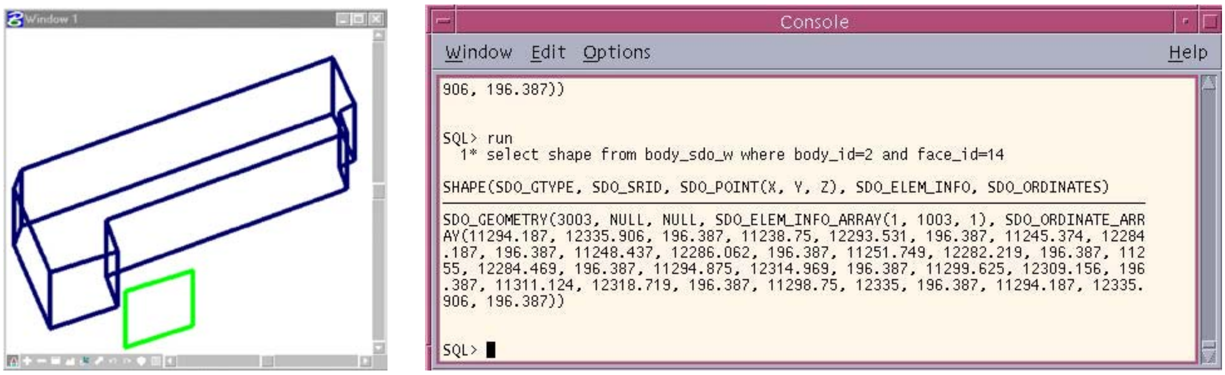


Figure 5-4: Representation of one polygon in Oracle Spatial 9i

Currently, the SDO_GTYPE allows decoding of 7 geometric types namely *point*, *line* or *curve*, *polygon*, *collection*, *multipoint*, *multiline* or *multicurve* and *multipolygon*. The type *collection* gives the possibility of different geometric types to be organised as and considered as individual spatial objects. Figure 5-4 shows the representation of one 3D polygon (a face from a 3D object). As it can be realised, the geometric model does not provide any information on the relationships of the objects. The coordinates of the objects might be repeated several times in the list with coordinates (sdo_ordinate). This eventually may result in inconsistency (e.g. overlapping objects) and requires larger space for organisation of the models. All the spatial relationships have to be determined using only metric computations (which is computational expensive). However, extraction, visualisation, editing of objects is fast and relatively simple. Furthermore, since the model is very simple, minimal development efforts are required by the front-end engines.

5.5. Standards (VRML, X3D, GML)

5.5.1. Virtual Reality Modelling Language VRML

VRML was the first standard (ISO/IEC 14772-1:1997) designed for distribution of 3D graphics on the Web. The VRML is an ASCII file format and has syntax based on structuring units called *nodes*. The most important nodes are related to description of geometry (regular and irregular shapes), illumination (directional, spot, point and ambient lights), materials and textures (draping and mapping of JPEG, GIF, PNG image file formats). The node dealing with geometry, colours and textures, i.e. the *shape node,* has three basic sections: *appearance*, *geometry* and *dynamics.* The *appearance* node cares about the “solid” perception of the shapes, i.e. material (diffuse and specular colours) and texture. Since the concept of simple illumination and shading models is adopted, most of the browsers provide only Gouraud and Phong shading. "Attaching" texture to surfaces of objects is supported in two ways: 1) simply wrapping a surface with an image, and 2) texture mapping. The texture mapping requires a second *node* to be specified, which contains the image co-ordinates, corresponding to the co-ordinates of the geometry. The *geometry* of 3D objects can be described by using predefined primitives (cone, box, sphere, etc.) or by sets of *faces*, which are represented by *co-ordinates* of points. The node maintaining arbitrary shapes as a set of faces is mostly used. It contains two sections: 1) co-ordinate section, which contains all the point's co-ordinates composing an object and 2) description section, which holds an ordered lists of points constituting *faces* that border objects. Combinations of other *nodes*, i.e. *sensors*, *routes* and *interpolators,* introduce dynamics. *Sensors* detect either viewer actions (e.g. mouse move, click, drag), or time changes, or viewer position (visibility, proximity, collision). *Routes* direct the captured event to *interpolators* to alter some *fields* (colour, position, orientation and scale). VRML was accepted quite enthusiastically by many developers and resulted in plenty of VR browsers for visualising and navigating of 3D graphics on the Web (http://www.web3d.org/vrml/vrml.htm). The critical disadvantage of VRML was the lack of a successful compression schema. 3D large models are rather “heavy” for visualisation and navigation.

5.5.2. Extensible 3D - X3D

X3D is considered the successor to VRML and aims at the improvement of all the features already in use in VRML. X3D improves upon VRML with advanced application programmer interfaces, additional data encoding formats, stricter conformance, and a componentised architecture that allows for a modular approach to supporting the standard. It is intended for use on a variety of hardware devices and in a broad range of application areas such as engineering and scientific visualization, multimedia presentations, entertainment and educational titles, web pages, and shared virtual worlds. X3D is also intended to be a universal interchange format for integrated 3D graphics and multimedia. The first draft of the language is already available for discussions at: http://www.web3d.org/TaskGroups/x3d/X3DSpec_CD_Preview/Part01/index.html)

5.5.3. Geography Markup Language - GML

This standard is developed by the OpenGIS Consotium. It is based on the OGC Abstract Specification (http://www.opengis.org/techno/specs.htm), which defines real world objects as geographic features (see above). Thus a digital representation of the real world can be thought of as a set of features. This current GML specification is concerned with *simple features*. While this release of GML does permit coordinates to be specified in three dimensions, it currently provides no direct support for three-dimensional geometry constructs. GML follows the geometry model defined in these specifications. For example, the traditional 0, 1 and 2-dimensional geometries defined in a two-dimensional spatial reference system (SRS) are represented by points, line strings and polygons. In addition, the geometry model for simple features also allows geometries that are collections of other geometries (either homogeneous multi-point, multi-line string and multi-polygon collections, or heterogeneous geometry collections).

GML is developed with a number of explicit design goals, a few of which overlap the objectives of XML itself, i.e. to provide a means of encoding spatial information for both data transport and data storage (especially in a wide-area Internet context), to be sufficiently extensible to support a wide variety of spatial tasks (from portrayal to analysis), to establish the foundation for Internet GIS, to allow for the efficient encoding of geo-spatial geometry (e.g. data compression), provide easy-to-understand encoding of spatial information and spatial relationships, to be able to separate spatial and non-spatial content from data presentation, to permit the easy integration of spatial and non-spatial data, especially for cases in which the non-spatial data is XML-encoded, to be able to readily link spatial (geometric) elements to other spatial or non-spatial elements.

GML is designed to support interoperability and does so through the provision of basic geometry, a common data model (features/properties), and a mechanism for creating and sharing application schemas. Most information communities will seek to enhance their interoperability by publishing their application schemas.

5.6. AR and DBMS

As stated above, besides providing user-requested information (e.g. position of underground cables, owner of a building, etc.), 3D GIS is used for the accurate positioning of the mobile unit and the accurate aligning of virtual objects. Chapter 2 and 3 discussed that many vision systems achieve accurate positioning by matching lines (or other features) extracted from video streams (obtained from the video camera of the mobile unit) and lines (or other features) retrieved from the 3D GIS. Furthermore, the 3D GIS has to be able to provide the needed subset of data within several seconds (it is expected that the AR system will be able to track the user position for few minutes without reference to the database). The rendering subsystem (for visualisation of virtual objects) also needs specific data about the position and the shape of the physical objects in the field of view, i.e. those objects that can occlude the virtual objects. This requires certain accuracy and consistent description of outlines of 3D objects (e.g. man-made objects such as buildings). Apparently all the information required for out-door applications (e.g. working within limits of one town) hardly can be maintained in the memory. Furthermore some of the information has to be extracted from existing GIS, DBMS since it is already available for other applications. To be applicable for such a real-time application, however, the data have to be organised in an appropriate way.

The following sections describe the experiments carried out with current commercial support and maintenance of spatial information within the Ubicom project (Zlatanova and Heuvel, 2002). The idea of the tests was to investigate the performance of the DBMS with respect to the requirements of AR system. Two spatial representations of data were used, i.e. topological (appropriate for alignment of virtual and real objects) and geometric model (appropriate for fast extraction of required data within given region).

5.6.1. Topological implementations

The proposed 3D model is a typical implicit boundary model (Zlatanova and Verbree 2000). Each physical object is associated with four abstractions namely *point*, *linestring*, *surface* and *body*, that are built of simpler elements, i.e. *node* and *face*. Nodes describe faces, linestrings (e.g. pipe lines) and points (e.g. trees, lampposts). The order of the nodes in the face is maintained as wheel. The orientation of the faces is anticlockwise looking at the objects (e.g. buildings) from outside. Faces represent surfaces (e.g. streets, parking lots) and polyhedrons (e.g. buildings). The 3D coordinates are stored with the nodes. All other references are to the ID of the low-level elements. The line features on the facades are encapsulation with their co-ordinates and stored as a separate data set, i.e. *lines*. Each line is considered as a straight line represented by two sets of co-ordinates. The relationships “belong to a face” is explicitly stored in the database.

The conceptual schema mentioned above can be implemented following different approaches. The first straightforward approach is the relational implementation. For each object a separate relational table is created. The implementation of the NODE table is trivial: one column for the identifier of the node and the three columns for the (geodetic) co-ordinates of the points. Other tables have similar structure. For example, the FACE table consists of three columns, i.e. a column with the ID of the face, a column giving indication about the order and the number of the nodes in a face, and a column ID of the nodes. Next possibility is creating *object-oriented* views from the relational tables. Views are especially appropriate for retrieval of standard data sets, e.g. the geometry needed for composing a VRML file. The last possibility is object-oriented implementation. Practically, this is a two-step procedure, i.e. creating objects and creating tables. We use two extended Oracle data types, i.e. *varrays* and *nested tables.* While *varrays* are recommended for objects which elements are always retrieved in their completeness, nested tables are said to be suitable for accessing and retrieving individual elements of an object. We have implemented and tested both representations.

All the reconstructed 3D objects are recorded in these representations, but for performance test another relatively large data set (1600 buildings, Figure 5-7, a) is used. The basic query used for the test is “extract objects needed by the AR system for the accurate positioning” for given position and direction of view. The performance has shown advantages of relational representation and object-oriented views compare to nested tables and variable arrays. Further appropriate spatial indexing and tuning of the database are recommendable for the object-oriented implementations. The best timing for 600 buildings extracted from 1600 buildings is 10 seconds.

5.6.2. Geometric implementations

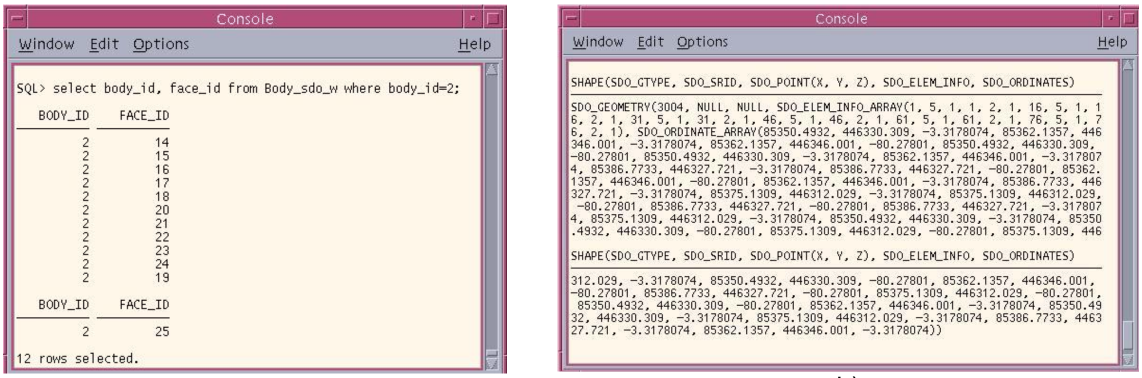
Although promising, the topological implementation may appear inefficient (in terms of response time) for very large data sets (since the 3D model easily can approach a size of several Gb of data). Therefore, a large share of our research was devoted to possibilities to organise the 3D data in Oracle Spatial and use the operations already provided by the vendor.

Table 5-1: Descriptions of BODY_SDO table by: 3D polygons and a 3D collection.

Name	Type	Name	Type
MLINK	NUMBER(10)	MSLINK	NUMBER(10)
BODY_ID	NUMBER(10)	SHAPE	MDSYS.SDO_GEOMETRY
FACE_ID	NUMBER(10)		
SHAPE	MDSYS.SDO_GEOMETRY		

As mentioned above, the currently supported geometric types are 2D (point, line, polygon) but 3D coordinates are accepted. Table 5-1 shows two possible descriptions of 3D objects within the geometric model of Oracle. In the first representation (Figure 5-5, left), each building has unique identifier (ID), stored in the column BODY_ID.

The column FACE_ID contains the unique ID of the face. The geometry of each face is organised as 3D polygon in the column SHAPE. Apparently, several records represent one building. This representation is a bit inefficient, but a “kind” of topology (i.e. stored relationships between the faces and the 3D object) is maintained. For example, the query “find the neighbouring building” can be easily completed by only comparing the IDs of the faces composing the buildings (thus avoiding the coordinate comparison).



a) b)

Figure 5-5: 3D object represented as a) a list of polygons and b) collection of polygons

In the second representation (Figure 5-5, right), the MSLINK is the ID of the building and the SHAPE column contains the 3D coordinates of all the polygons composing one building. Thus, every building is described as a *collection* of polygons. Although the number of records is reduced (i.e. one building is represented by only one record), the redundancy of coordinates cannot be avoided. Each triple of coordinates is repeated at least three times in the list of coordinates (Figure 5-5, b).

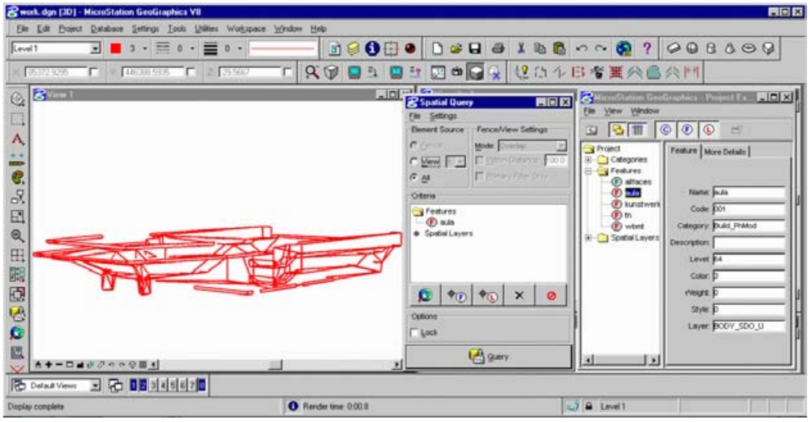


Figure 5-6: Query of a building in GeoGraphics

Regardless what kind of representation is used, the data can be further described in a metadata table, spatially indexed (using several different approaches) and accessed by any application for visualisation and editing. We have experimented with GeoGraphics (Bentley, 2001) to query, edit and post the changes in the database. It is possible, for example, to query, extract and edit only one building (Figure 5-6).

Indeed, the elements that can be edited correspond to the geometry representation in Oracle Spatial, i.e. either a set of “loose” polygons or a *collection* of polygons. GeoGraphics interprets the two representations differently. In the first case the object is visually one thing but a click on it will highlight one polygon. In the second case the object is one group. To be able to edit it, the object has to be “ungroup” into composing polygons. In both cases, the editing operations are restricted to the defined objects (in our case polygons and their vertices).

a) b) c)

Figure 5-7: Oracle Spatial query: a) Vienna 3D model, b) spatial operator SDO_WITHIN_DISTANCE and c) function FOV

Among, the large number of spatial operators provided by Oracle Spatial (utilising the supported geometric types), SDO_WITHIN_DISTANCE is the most suitable for the queries needed for our AR system. Given a position and radius of interest, the function returns all the objects within this radius. We have implemented a SQL/PL function Field-of-View (FOV) that further limits the number of objects with respect to the direction and angle of view. Figure 5-7 shows a VRML file created on the fly as the FOV function is executed. The green sphere is the point of interest (e.g. the user of the AR system). The position, direction and the angle of the FOV are known (i.e. obtained from the GPS receiver and the inertial system). The radius of interest can be specified with respect to the 3D model that is used (in case of many objects it can be reduced to 200-300 m.). The function is executed on a database level, which ensures excellent performance. For example, an area of interest less than 700m (actually much larger that can be seen by the user) can be extracted within 3 seconds.

5.6.3. Discussion on the 3D structuring

Currently, all the representations in the geometric model have showed better performance compare to the topological model, which is not a surprise. First of all, the nature of the query (needed for the accurate positioning) is pure geometric, i.e. 3D coordinates of objects. In the topological model the 3D coordinates are stored in the NODE table, which means that all the tables (i.e. BODY, FACE, NODE) have to be traversed to obtain them. In contract, in the geometric model, they are organised in one table (one or more records). Second, the geometric model is integrated within the DBMS (and thus optimised), while the topological model is organised in user-defined objects and tables. Third, Oracle Spatial maintains spatial indexing for the objects, which is not applicable for the topological model. This is to say that presently, the geometric model is more appropriate for real-time applications compare to the topological model. In principle, the topological model has many advantages compare to the geometric model, e.g. avoids redundant storage, easier to maintain consistency, efficient for visualisation of large data sets due to the less data to be read from disk, efficient for certain query operations (e.g. find neighbours). We believe that once implemented in DBMS, the 3D topological model will contribute largely to the entire functionality and performance of the DBMS.

5.6.4. Discussion on geo-information

The availability and accessibility of geo-information in the market is not as transparent as e.g. of multimedia data. Geo-information is currently maintained in a variety of information systems (GIS, CAD, DBMS) with different accuracy, resolution and dimension (2D, 3D). Most of the true GIS (ESRI, LaserScan) packages are still able to provide analysis only in the 2D domain (i.e. 2D topology), as the third dimension is used only for visualisation. Furthermore the “containers” with 3D data from the real world are still mostly at research stage. 2.5D data is the current solution to satisfy the demand for 3D data. The main difficulties in supplying and disseminating of geo-data result from the complexity of the real world, that influences different aspects of GI-Systems, i.e. collection, organisation (standards), access and analysis of data.

The performance of all the systems maintaining real geo-data only suffices applications (real-time, wireless) that rely on 2D geo-data. Examples of such systems are the different engines of LBS, i.e. geo-locators (e.g. http://www.visa.com, http://www.mapquest.com, http://www.mapguide.com), dispatch (traffic control) systems (e.g. VisiCAD, LaserScan), pedestrian navigation (e.g. Pedestrian navigation system, TU Vienna). TerraExplorer (SkyLine Software Systems, Inc.), the current leader in visualising of large 3D textured data, is the first software with acceptable performance but requires restructured data in the internal representation.

Currently, several positive changes in the research and the market area motivate the more intensive use of 3D GIS:

The nature of GIS is changed (Oosterom et al 2002). The integrated architecture of storing geographic data together with administrative data and the topology in one data base management system (DBMS) is now getting more and more mature.

The importance of the integrated architecture was recognised by industry an intensive work on data standartization is currently observed. Furthermore the OpenGIS Consortium is working on OpenLS (Open Location Services) specifications, which aim is to develop an interface for location services in order to make it available at mobile devices. The interface specifications will be an official OGC Specification and, potentially, can be contributed to other standards which will be used by multi-vendor, specification-based mobile demonstrators.

In the last several years, the understanding of the role played by topology in Location-Based Applications (LBA) is greater than ever. The word is often about location-based applications where all spatial relationships are maintained directly in the database itself, without the need for any specialized GIS application. This solution will provide integrated dynamic topology and spatial analysis from any wireless handheld device. However, it may not appear immediately relevant to the LBS developer. Currently, several simple LBS applications function without integrated topology. They use the mobile device relationship to the carrier's 'cell' location in order to determine an approximate position of the device. Such applications are restricted to the carrier's system and the carrier's customer. Sophisticated applications in the future will rely on dynamic data from a variety of sources, both government and private (institutional) data, and will require advanced 3D topology. Many examples of applications can be given that can benefit from integrated topology management and real-time topology validation (e.g. traffic information, emergency services, road-side emergency). Many Location Based Service applications also require network tracing and related. This functionality can be integrated within the database itself if scalability and rapid deployment is required.

References

Aronoff, S., 1995, Geographic information systems: a management perspective, *WDL publications*, Ottava, Canada

Bentley 2001, Bentley MicroStation GeoGraphics ISpatial edition (J 7.2.x) (2001). Available at: http://www.bentley.com/products/geographics

Brisson, E., 1990, Representation of d-dimensional geometric objects, *PhD thesis*, University of Washington, USA

Date CJ and H. Darwen, 1997, A Guide to the SQL standard. 4th edition, Addison Wesley

DeWitt DJ, P. Futtersack, D. Maier and F. Velez, 1990 A study of three alternative workstation-server architectures for object oriented database systems. Technical Report 907, Computer Sciences Department, University of Wisconsin-Madison

Geographic Marckup Language, available at: http://opengis.net/gml/01-029/GML2.html

Güting, RH, 1989, Gral: An extensible relational database system for geometric applications. Proceedings of the Fifteenth International Conference on Very Large Data Bases, Amsterdam, ACM, New York, pp. 33-44

Hebert J and C. Murray, 1999, Oracle Spatial User's Guide and Reference. Oracle Corporation, Redwood City, CA, USA. Part No. A77132- 01

IBM, 2000, IBM DB2 Spatial Extender User's Guide and Reference. special web release edition

Informix, 2000, Informix Spatial DataBlade Module User's Guide. Part no. 000-6868

Intergraph GeoMedia Professional 4.0, 2001, available at: http://www.intergraph.com/gis/gmpro/

ISO, 1992, Database language SQL. Technical Report Document ISO/IEC 9075, International Organization for Standardization

ISO/DIS 19107, 2000, Geographic information - Spatial schema, Technical Report final text of CD 19107 (15046-7). International Organization for Standardization, TC211/WG2

ISO/IEC 13249-3, 1999, Information technology - database languages - SQL multimedia and application packages - part 3: Spatial. ISO/IEC JTC 1 SC 32, Technical Report Part 3, International Organization for Standardization

Kainz, W., 1989, Order, topology and metric in GIS, in: ASPRS-ACSM Annual Convention, Vol. 4, Baltimore, pp. 154-160

Morehouse S, 1989, The architecture of Arc/Info. Auto-Carto 9, pp. 266-277

Mäntylä, M., 1988, An introduction to solid modelling, *Computer Science Press*, New York, USA

Molenaar, M.,1989, Single valued vector maps: a concept in geographic information systems, in: *International Journal of GIS*, Vol. 2, No. 1, pp. 18-27

Molenaar, M., 1990, A formal data structure for 3D vector maps, in: *Proceedings of EGIS'90*, Vol. 2, Amsterdam, The Netherlands, pp. 770-781

Ostensen, O, 2001, The expanding agenda of Geographic Information Standards, ISO Bulletin, July, 2001, pp. 16-21

Oosterom, P. v, J. Stoter, W. Quak and S. Zlatanova, 2002, The balance between geometry and topology, in: Advances in Spatial Data Handling, 10th International Symposium on Spatial Data Handling, D.Richardson and P.van Oosterom (Eds.), Springer-Verlag, Berlin, pp. 209-224

Open GIS Consortium, Inc., 1998, OpenGIS simple features specification for SQL. Technical Report Revision 1.0, OGC

Open GIS Consortium, Inc., 1999, The OpenGIS abstract specification, topic 1: Feature geometry. Technical Report Version 4 (99-101.doc), OGC

Oracle 9i Spatial (2001) URL: http://otn.oracle.com/products/spatial/

Quak, W., P. Oosterom and T. Tijssen, 2002, Testing current DBMS products with realistic spatial data, in: Proceedings of the 5th AGILE conference on Geographic Information Science, ISBN 84-7632-734-X, 25-27 April, Palma de Mallorca, Spain, pp. 189-194

Sonnen, D. and H. Morris, 2000, Location in CRM: Linking virtual information to the real world, IDC White Paper, 12p., available at: http://www.idc.com

Stonebraker M, Rowe LA and Hirohama M, 1990, The implementation of Postgres. IEEE Transactions on Knowledge and Data Engineering 2(1): 125-142

Vijlbrief T & van Oosterom P (1992) The GEO++ system: An extensible GIS. Proceedings of the 5th International Symposium on Spatial Data Handling, Charleston, South Carolina, pp. 40-50

Virtual Reality Modelling Language, 1997, Web 3D, available at: http://www.web3d.org/technicalinfo/specifications/vrml97/index.htm

Worboys, F.M., 1995, GIS: A computing perspective, *Taylor&Francis*, London

X3D, 2002, Extensible 3D language, Web3D, available at: (http://www.web3d.org/x3d.html)

Zlatanova, S, F.A van den Heuvel, 3D GIS for outdoor AR applications, in: Proceedings of the Third International Symposium on Mobile Multimedia Systems & Applications, 6 December, Delft, The Netherlands, 8 p. (to be published)

Zlatanova, S. and E. Verbree, 2000, A 3D topological model for augmented reality, in: Proceedings of the Second International Symposium on Mobile Multimedia Systems & Applications, 9-10 November, Delft, The Netherlands, pp.19-26

6. Projects

The previous chapters clearly showed that AR systems require diverse technologies to be utilised. For example, many tracking approaches from robot navigation are extended to AR vision systems, LBS projects provide experience on outdoor positioning, mobile communications supply techniques for data transmission and compression. This chapter draws attention to several projects from different areas that have made contribution in the technologies needed for outdoor AR system. The reader can use these projects as a starting point for further survey in particular areas of interest. The projects are briefly described, particularly emphasising on the goals or the reported results.

The chapter is organised into four sections. The first one reviews projects for robot navigation based on vision systems (using 2D or 3D models to precisely position). The second section lists three outdoor AR projects. LBS projects related to providing geo-information (2D and 3D) to the mobile user are presented in section three. Section four concludes on the research and developments in AR technology.

6.1. Robot-navigation projects

The five projects on robot navigation, listed here, are selected because of the interesting findings in the tracking of robots. Robot navigation is usually performed in restricted environments. However, the techniques applied in the following projects are beneficial for AR systems as well. The review will focus only on tracking approaches, since it is more relevant to AR tracking.

6.1.1. Robot Vision (ROBVISION), Institute of Flexible Automation, Vienna UT (http://www.infa.tuwien.ac.at/Infa_home/index_projects.asp):

The main task of the project is robot navigation inside ships. The robot must find the door, enter a section of the boat, make inspections and get out. The robot is equipped with a light source and a camera. The camera records the view at front of the robot and provides the image frames, which are further used for tracking. The tracking system is a complex procedure comprising five major steps:

- Detection of region of interest. The region is that part of the whole image visible in the camera, where visible segments (lines, edges) can be detected. The region follows the orientation of the segment for tracking.
- Edge detection. All the edges that are to be followed in the sequential frames are detected. Almost all the edges are vertically oriented and therefore the edge detection operator needs to search in only one direction.
- Line chaining (fitting line trough detected pixels).
- Pose determination.
- Updating the position and orientation of the track window.

The pose determination algorithm is based on calculating discrepancies between image features and model features (3D model features from CAD projected into the 3D camera co-ordinate system). The assumption is that an initial pose orientation and approximate exterior parameters are known. The 3D discrepancies are considered observations and the algorithm minimises the quadratic errors of the observations.

The project also investigates tracking by using a pair of stereo images.

6.1.2. FINALE, Robot Vision Laboratory, Purdue University, Indiana (Kozaka and Kak, 1992)

The system of navigation is designed for indoor environments (hallways). The system for tracking is based on vertical lines (landmarks). The initial position of the robot is known. The landmarks (features from a simple CAD model) are projected onto the image plane to form an expectation map (i.e. a map of what the robot expects to see from a given position). The image is processed in the uncertainty regions (around the landmarks) and the correspondence between extracted and projected edges is established. This is a key aspect of the system – estimated uncertainties are used to limit the region of camera image for analysis and the candidates for features for extracting. The position of the features is estimated by Kalman filter. The use of Kalman filter is twofold – for uncertainty reduction and position updating. The tracking is based on monocular processing and the assumption that the geometric model is known (everything that is not in the model is considered an obstacle). The initial position and the path are given by a person (supervisor). Fast extraction of vertical lines is based on the fact that the vertical lines in perspective images have one vanishing point regardless the position of the robot (this is true for navigation on a flat floor or flat surface). The candidate edges are transformed in Hough space to determine the lines. A back transformed line is rasterised and filtered with a threshold of one pixel with respect to the edge map (i.e. line is again set of pixels). The match between image (the lines from the Hough space) and model lines is done by a probabilistic function. The data structure is specially designed for the system and allows fast rendering. It is based on the notion of BaseFace (vertical planar face) represented by two vertical lines and the x,y coordinates of their floor points. All other faces are referred to the basic one in a tree structure. The root of the structure is the path of the robot motion, the non-leaves are the basic faces and the leaves are all the other human significant features on the basic wall.

6.1.3. DROID, Department of Electronics and Computer Sciences, University of Southampton, UK (Harris, 1992)

The system performs 3D interpretation of a sequence of digital images implementing automatic extraction, tracking and 3D localisation of image features. Two images are used for determination of a list with 3D features (BOOT phase) which are after that purged and retired with the help of two other images (RUN phase). The features extracted are points and corners. The system has several steps:

- Steps Bootstrap process: Initialisation of the 3D scene representation from feature points found in the first images.
- Boot-strap matching: Filtering with the Kalman filter and initial estimate of the ego-motion is given.
- Boot ego-motion The computation of the ego motion is performed. Prior knowledge of the camera position may be imposed by some constraints. Once the ego-motion is determined the 3D co-ordinates of the points can be estimated.
- Steps Run mode: The run mode provides 3D representation that becomes more accurate with the number of images that are processed. Kalman Filter achieves the needed accuracy, as the points that are not visible anymore in a scene are removed. Most of the operations are performed in Disparity space (X/Z, Y/Z, 1/Z) for the purpose of speed and numerical stability.
- Run matching. The matches are between the extracted image points and the existing Kalman Filter points projected onto the image plane.
- Run ego-motion. The ego-motion is determined by finding the camera pose so that it brings the projected Kalman Filter into best alignment with the matching observed feature points.

The method does not use any information from CAD applications (no initial knowledge about the scene) which leads to a systematic error after a long sequence of images. The error in camera position can be 1 m and the matching can still be performed.

6.1.4. Real-time Attitude and Position Determination (RAPiD) (Harris, 1992)

The system uses a model-based 3D tracking algorithm for detection of moving objects. Control points (well visible points) instead of whole edges are used for pose estimation. The points and the orientation of the edges are projected onto an image. The system then searches for changes in intensity in the direction perpendicular to the edge. The distance from each edge to the changed intensity is calculated and an objective function is formed. The matching of the model is done by minimisation of the objective function. After many iterations (thousands) it is possible to get deformation of the model, because control points are not longer correctly positioned with respect to each other. There is a way to avoid this effect (see the original). To predict the position of the object on the next frame a Kalman Filter is used.

6.1.5. ARVID, Laboratory of Image Analysis, Institute of Electronic Systems, Aalborg University, Denmark (Christensen et al, 1994)

In-door system with the assumption of dynamically changing environments, i.e. objects such as doors, windows, etc are static while chairs and tables and other small object can be moved. The robot has a binocular camera set. The principle of tracking is as follows:

- Projection of the expected field of view on to the image (back surface removal is performed). The projections are used for matching against the detected segments.
- Edge detection – by a gradient search (above a given threshold) perpendicular to the predicted (projected) line.

- Least squares fitting (to limit the image processing the edge detection is performed only around the projected lines).
- Estimation of the camera position and direction.

The accuracy of the system is 5cm and 2 degree. The system uses co-operative stereo to match regions. Large areas such as walls are segmented, matched and compared with the predicted regions computed from the CAD model. These areas are then assumed to be parts of the static structure.

6.2. AR projects

Universities that have carried out research on AR systems are Columbia University, The Department of Computer Science (http://www.cs.columbia.edu/facultyjobs.html, projects: MARS, KARMA, Windows on the world, Architectural Anatomy, Augmented Reality for Construction), the ETC lab, University of Toronto (http://vered.rose.utoronto.ca, projects: ARGOS, Input/Manipulation3Denvironments) , LORIA Tech. (http://www.loria.fr/, projects: 3Dregistration) and Delft University of Technology (http://tudelft.nl, projects: UBICOM). Here we will concentrate on three AR projects, which are realised outdoors.

6.2.1. Mobile Augmented Reality System (MARS)

(http://www.cs.columbia.edu/graphics/projects/mars/mars.html) (Höllerer et al 1999)

MARS is the first outdoor system, although indoor realisation has also been developed. Actually, only the displays and the tracking systems are different in the two setups. Figure 6-1 shows an overview of the MARS system architecture. The main components of the AR system are Sony LDI-100B and LDI-D100B 800 -600 triad resolution, colour, see-through displays for indoor and outdoor augmented reality (Virtual IO i-glasses that create a large screen view in front of the user, http://amiga.emugaming.com/virtualio.html), hand-held computer Mitsubishi AmiTY CP, with a Pentium MMX 166 MHz CPU, runningWindows95. The wireless communication infrastructure comprises Lucent WavePoint II base stations and Wave-LAN PC cards. The indoor immersive system is tracked with an InterSense IS600 Mark II hybrid ultrasonic and inertial 6DOF tracker. All applications access a main database that contains a model of the physical environment and of the virtual information added to it. When each user interface is started up, it reads the most recent state of the database. Internally, the data is organized in a relational format, using Microsoft SQL Server.

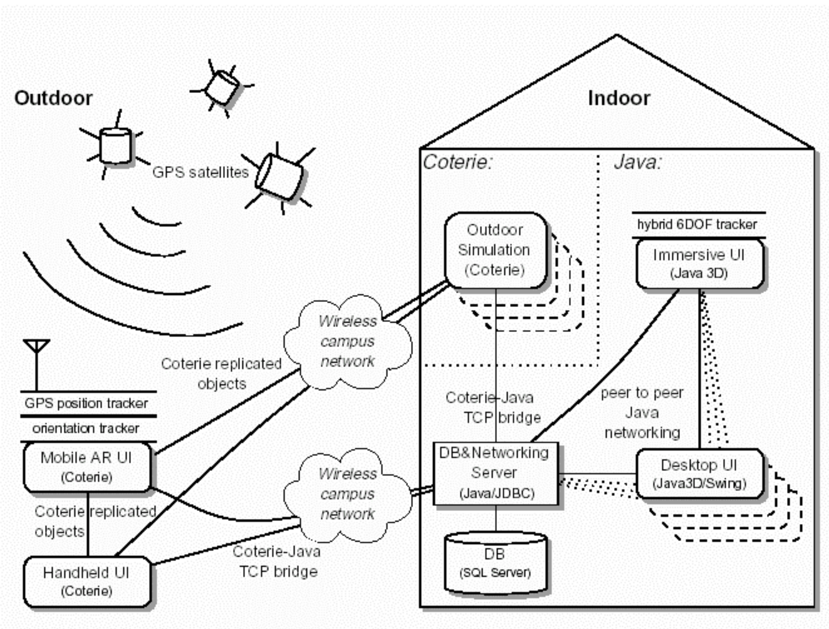


Figure 6-1: MARS architecture (Höllerer et al 1999)

The system is developed for several different displays:

- Outdoors (Figure 6-2, left): the mobile user is equipped with a centimeter-level real-time–kinematic GPS, an inertial/magnetometer orientation sensor, a prototype backpack computer system and a see-through and hear-through head-worn display.

- A hand-held display that offers a map-based user interface, either in conjunction with the backpack or standalone.
- Indoors: a desktop or projection-display user interface, based on a 3D environment model,
- An immersive version (Figure 6-2, right) of the indoor user interface relies on see-through displays, in conjunction with 6DOF head and hand trackers, and 3DOF object trackers.

Figure 6-2: MARS: outdoor and indoor (immersive) version of display

6.2.2. Subsurface data visualisation, University of Nottingham, UK (http://www.nottingham.ac.uk/iessg/isgres32.html)

The project involves key research institutions from UK, i.e. the University of Nottingham, the British Geological Survey and eight commercial organisations among which Leica Geosystems Ltd, Pipeline Integrity International Ltd and Rio Tinto Technology Development Ltd. This project aims at development of an AR system that allows users to see underground invisible features such as major geological structures, gas or water pipelines or zones of contaminated land for example.

The system integrates real-time kinematic GPS and internal navigation systems, enabling centimetre accuracy. The virtual images are obtained from existing map data and mixed with real-world images. The composite video is projected in three types of displays HMD, laptop and virtual binoculars. Among all the displays, the authors consider the variant with the virtual binoculars the most appropriate. The tracking system is mounted on binoculars that avoids the disadvantages of the first two approaches (motion sickness with the HMD, lack of real immersion using laptop).

Figure 6-3: Subsurface Visualisation: HMD, virtual binoculars and a virtual view (University of Nottingham, IESSG)

6.2.3. Ubiquities Communications (UbiCom), TU Delft, Delft, the Netherlands (http://bscw.ubicom.tudelft.nl)

The UbiCom program is part a successor of the Mobile Multimedia Communications (MMC) project (http://www.mmc.tudelft.nl) that was funded by the Dutch Technology Foundation STW in the period 1996-2000. The research and developments within the UbiCom project have been planned for the period 1999-2002. UbiCom's AR system is a vision wireless system. The user carries a wearable terminal (Figure 6-4, left) and a lightweight see-through display (Figure 6-4, middle). In the display the user can see virtual information (Figure

6-4, right) that overlies the real world. The wearable system relies on a radio link that connects the user to the computing resources (backbone) and the Internet. A camera integrated within the head mounded device captures the user's environment and send images to the backbone. Line features extracted from the real images are matched to a 3-D description of the real world stored in a DMBS, to determine the user's position and to answer questions from the user that relate to the environment. The UbiCom system is currently the first system that uses data from DBMS to obtain the accurate positioning of the user.

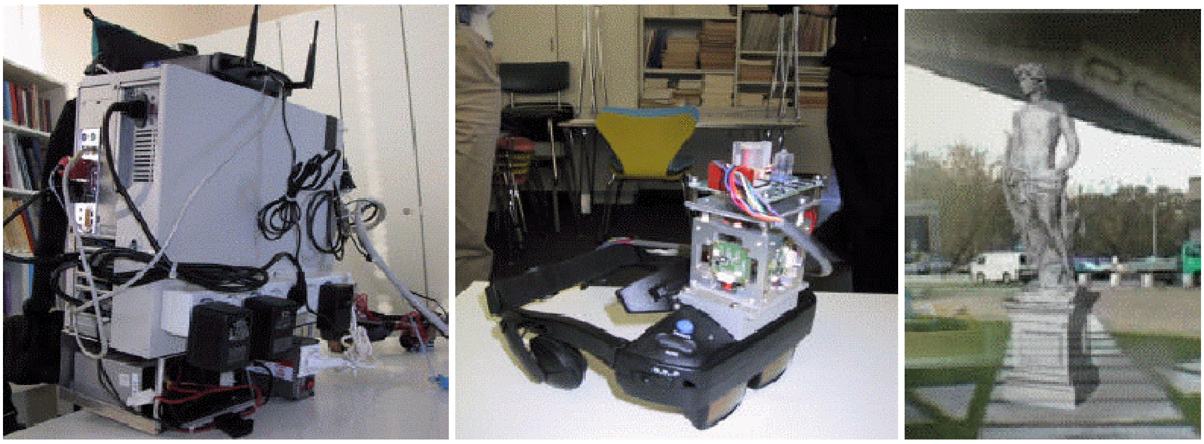


Figure 6-4: UbiCom's experimental platform: the wearable terminal (LART board, graphics subprocessing system, WaveLan, batteries and voltage converters), the head mounted device (see-through display, Inertial cube) and a view with the virtual statue.

The project concentrated on three major conceptual issues related to the successful completion of the whole system:

- low power consumption, since for wireless systems the power constraint is of utmost importance,
- system approach, taking into consideration the mutual inter-relations between the different components. For example, since latency is crucial from the user's perspective, the system's architecture was designed with latency constraints in mind,
- negotiated quality of service (QoS), i.e. different applications would usually have different computation and communication demands, therefore the system should be able to offer a certain negotiated service quality.

The results of the projects can then be summarized into the following four general groups:

low-power wireless communications transceiver - radio front-end circuits (Relaxx and ALF integrated circuits) and a functional model for a power-adaptive radio front-end have been developed & defined. (van den Bos, 2001).

signal processing - design of appropriate modulation schemes that are useful for multiple antenna research and for radio front-end design. (Bohdanowicz, 1999).

graphics and sensor processing - two innovations, namely (1) a free-running low latency front-end engine for 3D graphics with an end-to-end delay of less than 10 milliseconds, and (2) a dynamic scene simplification system, that switches between different representation accuracies depending on the viewpoint and distance to the rendered object. This slower process can be offloaded to a backbone computer system. The process of scene simplification has been integrated with the adaptive resource contract (ARC) concept developed in UbiCom. The results have a great impact on the design of graphics subsystems for mobile applications (Pasman and Jansen, 2001).

To enable low latency rendering, low latency outdoor tracking based on a combination of inertial system (gyros, accelerometers) and differential GPS is developed. (Persa and Jonker, 2000). The vision system introduces further accuracy to the position of the user and alignment of the virtual objects. The 3D data is organized in a 3D topological data structure, which is implemented in an Oracle 9i DBMS. The topological structure as well as all the database operations currently developed aim at providing a minimum set of data (needed by the vision system) in a restricted interval of time (less that 2-3 seconds) (Zlatanova, 2001).

QoS protocols **-** A new concept to master the collaborative components is developed. This concept is called ARC: Adaptive Resource Contracts. The ARC concept and its derivatives give a totally new view on how to optimally distribute resources over competing components. (van Dijk and Lagendoen, 2000).

Due to power limitations, all system components must be power aware. Within UbiCom innovative results are achieved in power awareness, e.g. in scaling operating power and clock frequency of general purpose CPU's under control of video and audio decoding software. UbiCom is one of the first programs worldwide that considers this innovative solution to power constrained processing in mobile systems (Pouwelse et al 2000)

Finally, a programming system and compiler, based on Java, are developed for the programming of heterogeneous embedded systems. The system has been tested on a system consisting of Pentium and Trimedia processors, and on a system consisting of multiple LART-boards. The compiler is publicly available and can be downloaded from the website http://www.pds.its.tudelft.nl/timber (Reeuwijk et al, 2000).

6.3. Projects on LBS

6.3.1. GiMoDig (Finland, Germany, Denmark, Sweden, 2001-2004)

http://gimodig.fgi.fi

The idea of the project is to develop methods for delivering geo-spatial data to a mobile user by means of real-time data-integration and generalisation, as the access provided has to be through a common interface, to primary topographic geo-databases maintained by the National Mapping Agencies. Figure 6-5 portrays the principle schema of the database organisation and the middleware software. The major objectives can be summarised as:

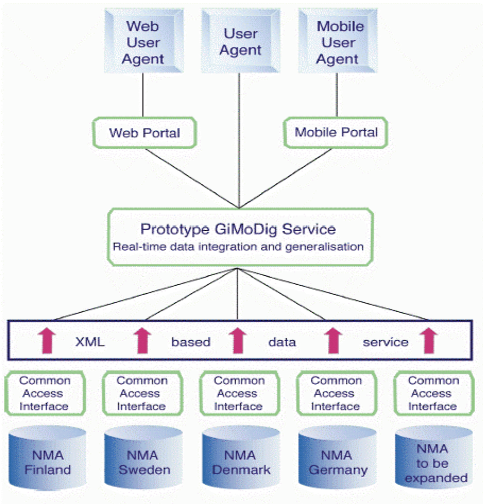


Figure 6-5: Principle schema of the system

- Real-time generalisation for mobile devices to be able to provide different graphic representation in real-time for displays of varying scales on small, mobile devices with different display resolutions.
- Harmonisation and real-time integration of geo-spatial data to reduce and eliminate the problems between national primary geo-spatial databases, generally very heterogeneous in thematic and spatial definitions
- Investigating requirements for mobile use to adapt the real-time generalisation and integrations (transformation) of data
- Dissolving map projections in real time.
- Real-time transformation of spatial data between different national geo-databases
- Investigating and developing methods for transferring vector-formatted spatial data to a mobile user using emerging standards, like XML, and testing the applicability of the standards for Web-based spatial services in an international pilot project involving national primary geo-data sets.

Figure 6-6: 3D models with Nokia GL on Communicator 9210 (Nokia Research Center, Finland)

6.3.2. TellMaris (Germany, Finland, Norway, Denmark, Latvia, Russia, 2001-2004)

http://www.tellmaris.com/

The main scientific objective in TellMaris is development of new technology to support interaction with 3D maps (models), as the potential audience are the tourists. The aim is to retrieve tourist information (including 3D maps) on mobile handheld devices and thus provide new means for search and retrieval of tourist information in the three dimensional space. The goal of TellMaris is to develop a hierarchical data structure that can store both the terrain surface and 3D objects on top of it. A solution has to be found for dynamic downloading of updated, relevant tourist information. Another key innovative research issue is to develop compact data structures to store 3D geo-data and simple GIS functionality in client computers with a minimum of resources related to storage capacity, memory, energy supply and CPU.

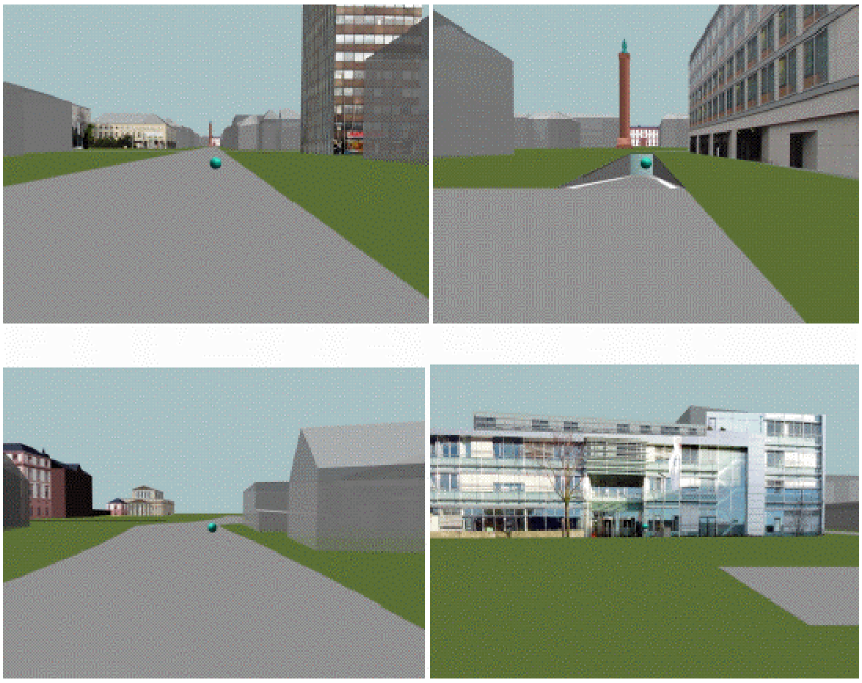


Figure 6-7: Sequence of 3D road map to the Fraunhofer University (V. Coors, 2002)

The data basis necessary for three-dimensional city information systems is delivered by the construction and the continuation of 3D city models presently performed by different cities (e.g. Stuttgart, Hamburg, and Berlin). To make these three-dimensional city models available in the location-based services context, the location and warehouse services must be able to process three-dimensional data and make them accessible from a mobile terminal. The project uses commercial DBMS to store the data. The research is concentrated on 3D topological models. Figure 6-7 show 3D images of the video navigation to the Fraunhofer Institute, Darmstadt. Only some of the buildings are represented with textures to attract the users attention.

6.3.3. WebPark project (UK, the Netherlands, Switzerland, France, Portugal, EU funded)
http://www.webparkservices.info/index.html

Figure 6-8: WebPark on handheld device

The European project WebPark focuses on providing visitors of protected and recreational areas with location-aware services (Figure 6-8). These services enable users to request information from several databases (mostly 2D maps) from their mobile phone or PDA and filtering the information based on location, time and user profile relevance. WebPark is based on OpenGIS, 3-tier architecture and web mapping technology. The services are accessible from any HTML/WML/i-MODE enabled browser. WebPark services interface to multiple location technology, from GPS to location determination technologies of mobile operators. All communication, storage and interfaces are based on open standards such as OpenGIS for spatial data, and LIF for location information processing and management.

6.3.4. HyperGeo (France, Spain, Portugal, Germany, Slovenia, Czech Republic, Greece, UK, 2000-2001)

The technical objectives were to develop and integrate, in a single system, innovative software components enabling the users to formulate advanced requests, to access information in both pull and push modes, and to display the information in efficient "multi-layered" form. The business objective was to prepare the way for innovative services offering primarily for mobile users needing to access geographic information for their activity. The mobile user is the main, but not exclusive, target. Fixed users, being interested in geographic information, were also investigated. The project developed a Tourist Information system for different users and investigated new methods to make efficient use of remote geographic information, in particular for mobile users.

6.3.5. Paramount (Germany, Austria, Spain, EU project, started February 2002, 18 months)
(http://www.paramount-tours.com/)

This is a project also related to the provision of geo-information to the mobile user. The project aims at development of three types of services for tourists in mountainous areas.

INFOTOUR: This service component will provide various local information and navigation functionalities to the user, e.g. routing, 3D views of surrounding, information on points of interest (huts, summits, public transportation stations etc.) and local weather forecasts.

SAFETOUR: In addition to the information described above this service will provide safety relevant data, i.e. warnings of thunderstorms, information on avalanche risks, information on the severity of trails. Moreover, some functionalities shall be implemented allowing for tracking registered users in dangerous terrains and alerting/coordinating search& rescue services in emergency cases.

The DATATOUR service will directly involve the PARAMOUNT users in the data acquisition and maintaining process. As this is a critical and security sensitive matter this service will only be available to a group of registered users. This group will collect the following information:

- Trails (logging)
- Information on severity of trails (personal evaluation)
- Capturing / updating information on Points of Interest

The processing and verification of the data collected will be performed automatically on server side.

The communication between the servers, that are providing the services described above, and the mobile devices (Pocket PC with GPS/Compass module and mobile phone unit) is realized by the usage of GPRS mobile telecommunication. The data are transferred via HTTP protocol using XML.

6.3.6. Projects at Fraunhofer Institutes in the year 2001

Quite many projects related to wireless outdoor applications have been focussed by the Fraunhofer Institutes, which is an indication of what kind of developments is required by industry. List of the relevant ones is given bellow:

ARIS (Augmented reality image synthesis)–seamless integration of VO (virtual objects) in an augmented environment through consistent illumination between real and virtual objects. Camera tracking by vision system with and without markers. Two applications to be used for e-commerce solutions (currently only catalogues can be listed): Interactive desktop system for integration 3D VO (furniture) in a set of images of the real environment (rooms) taking into consideration the illumination. Projection of the VO in the real environment

OpenSG PLUS – portable open source scene graph. An EU project started in 2000 to create real-time graphics programs (for AR and VR). OpenSG 1.0 has been downloadable since October 2001. Currently, the work is on stereo rendering and on single and multiple pipelines, NURBS tessellation, high quality rendering, 3D object rendering (two more years)

FirtualFires - simulator for training in fire emergencies. Objectives: development of efficient methods for handling large data sets to visualise disaster in real time, comparative study on the impact of different fire fighting methods

Mobile Application Supportive Pals (MASP) – developing tools that take into account the specifics of a mobile user (multimedia conferences tools)

WAP for graphical objects (funded by Heinz Nixdorf) – adaptation and visualisation of very large 3D data scenes on mobile devices; progressive and error free transmission of very large, dynamic and interactive 3D scenes, cooperative visualisation and manipulation of dynamic scenes on distributed systems allowing users to work on a 3D scene at the same time. A new occlusion-culling algorithm was implemented.

The virtual showcase - projection bases AR for cultural heritage and scientific application (EU project). It is a projection based multi-user display that offers innovative ways of accessing, presenting and interacting with scientific and cultural heritage. Databases for high quality presentations will allow museums to exchange single objects without physical transfer. Three museums are currently involved in the project. Actually, stereoscopic images will be superimposed and provided to multiple users.

ArheoGuide (EU funded project): AR system that allows visitors of park to see a computer-generated object that can be shown to the user when he/she approaches a particular place. The users specify their knowledge; select tour and the system guide them through the site giving them video and audio info. The first site selected for the trial was the Olympia, where the first Olympic games took place. The system is a typical vision system to establish the position of the user on the basis of a sequence of images stored in the database (indexed and coordinated with the position they were taken from). The system then computes the transformation between the current user image (from the video camera) and the one in the database.

GEIS - AR system for education. Can be seen as a game. The children receive "magic" equipment such as binoculars, orientation sensors and interaction tools. At the same time "ghost" (ghosted images) appear in front of the historical scene. They invite children to solve tasks and to dive into the historical environment. The test site is Heidelberg. If the user enters a place that is interesting the game continues as indication is given that the place is interesting

6.4. Other projects and applications

Many applications are currently using AR system, but most of them are mostly indoor applications. James Valino (http://www.se.rit.edu/~jrv/research/ar/) and Jun Rekimoto (http://www.csl.sony.co.jp/projects/ar/ref.html) collected a long list with web pages of Universities and groups dealing with AR research. Here we will mention only few of them:

UNC Tracker Project (tracking)

Ronald Azuma's Augmented Reality page (registration)

Knowledge-based Augmented Reality for Maintenance Assistance (KARMA)

Telepresence Research Group (telepresence)

Shader Lamps (animating real objects with image-based illumination)

Augmented Reality William Hoff, Colorado School of Mines

Augmented Reality work at the University of Toronto Paul Milgram

Mihran Tuceryan's Augmented Reality page (applications, animations)

BUILD-IT groupware tool

FNRS - Augmented Reality

Augmented Reality Chair for Pattern Recognition, University of Erlanger-Nuremberg

Industry applications:

ARVIKA-Consortium (for industry)

Surgery:

Image Guided Surgery home page

Ultrasound Visualization Research

6.5. Summary

This survey has revealed a lot of research on indoor AR applications and has exhibited little evidences of research related to outdoor applications. Furthermore, very few of them have been successful (e.g. the system developed by the University of Nottingham) in providing the aimed augmented view. Some of the projects report working tracking systems and acceptable alignment of virtual and real objects but the equipment is still rather heavy. Outdoor tracking is hardly possible without an accurate GPS receiver, which is usually rather heavy and expensive for regular use. The vision systems used to support the tracking have still not been sufficiently explored outdoors. Some successful robot navigation systems most commonly fail when implemented outdoors, due to a number of "real-world" factors (changing weather, shadows, contrast, moving objects, etc.). The retrieval of existing geo-information and its appropriate supply to the mobile user is still at its infancy. However, the number of projects utilising geo-information increases with every year. Most of them are formulated as projects on LBS.

References:

Bohdanowicz, A., 2001, On Efficient BER Evaluation of Digital Communication Systems Proc. SCVT 2001 (8th Symposium on Communications and Vehicular Technology), Delft, The Netherlands, Aug. 2001

Bos, C. van den, and C.J.M. Verhoeven, 2001, Architecture of a reconfigurable radio receiver front-ends using overall feedback, Proc. ProRISC, Veldhoven, 29-30 November 2001.

Christensen, H.I., Kirkeby, N.O.S., Kristensen, S., Knudsen, L.F. and Granum, E., 1994, Model-driven Vision for In-door Navigation. Robotics and Autonomous Systems, 12:199-207. Also published in: LIA Tech. Report, LIA-93-06 ; Proceedings from Conference on Sensor Fusion VI, Boston, 1994.

Coors, V., 2002, Resource-adaptive 3D maps for LBS, 23rd Urban Data Management Symposium "30 years of UDMS - looking back, looking forward", 2-4 October, Prague, Czech Republic, pp. I.29-I.37

Dijk, H. van, K. Langendoen, H.J. Sips, "ARC: a bottom-up approach to negotiated QoS," IEEE Workshop on Mobile Computing Systems and Applications (WMCSA 2000, Monterey, December 2000, pp. 128-137.

Harris, C., 1992, Tracking with rigid models, Active vision, the MIT press, chapter 16, pp.59-73

Höllerer, T., S. Feiner, T. Terauchi, G. Rashid, D. Hallaway, 1999, Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System Computers and Graphics, 23(6):779--785

Kosaka, A. and A.C. Kak, 1992, Fast vision-guided mobile robot navigation using model-based reasoning and prediction of uncertainties, Computer vision, Graphics and Image Processing, Vol.56, No.3 November, pp.271-329

Pasman, W. and F.W. Jansen, 2001, Distributed Low-latency Rendering for Mobile Augmented Reality, Proc. IEEE and ACM Int. Conference of Augmented Reality (ISAR 2001), October 29-31, 2001, NY.

Persa S., and P.P. Jonker, 2000, Hybrid Tracking System for Outdoor Augmented Reality, R.L. Lagendijk, R. Heusdens, W.A. Serdijn, H. Sips (eds.), Proc. 2nd Int. Symposium on Mobile Multimedia Systems and Applications MMSA2000 (Delft, Nov.9-10), 2000, 41-47.

Pouwelse, J., K. Langendoen, H.J. Sips, 2000, Power consumption trade-offs for wireless audio access, International Workshop on Mobile Multimedia Communications (MoMuC 2000), Tokyo, Japan, October 2000.

Reeuwijk, C. van, F. Kuijlman, H.J. Sips, and S.V. Niemeijer, 2000, Data-parallel programming in Spar/Java, Proceedings of the Second Annual Workshop on Java for High-Performance Computing, pages 51-66, Santa Fe, New Mexico, May 2000.

Zlatanova, S., 2001, 3D modelling for augmented reality, Proceedings of the 3rd ISPRS Workshop on Dynamic and Multi-Dimensional GIS, 23-25 May, Bangkok, Thailand, pp. 415-420

7. Analysis on AR systems

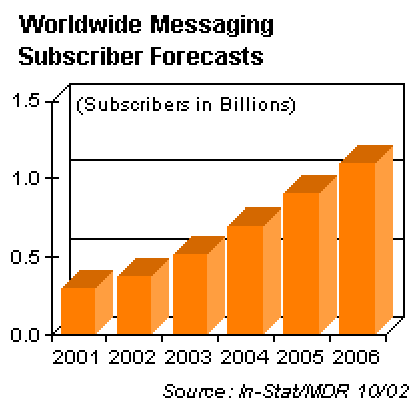
This chapter discusses the state-of-the-art in the development of AR systems for outdoor applications and the problems associated with it. The following sections analyse the present status in four sections related to display, tracking system, wireless connection to backbone computers and databases. The first section discusses the displays and the AR approaches that can be realised in the near future. The second section addresses the tracking systems and more particularly the outdoor tracking approaches. The third section outlines timelines for wireless networks. The vision of some telecommunication companies is also presented. Views on utilisation of DBMS for AR applications and LBS are summarised at the end.

7.1. Displays

The overview on the displays has clearly shown that the display of information is one of the largest problems in AR systems:

The commercially available see-through HMD are still very limited. The cost is relatively high and weight is still a problem. Furthermore, the quality of the displayed image is still insufficient, i.e. brightness and contrast are very low, field of view and resolution are limited. The first commercially available retina scanning displays appeared very recently (2001). Despite some progress (possibility to occlude real objects, solutions for removing parallax errors) in the last five years, see-through display technology is still not at a level appropriate for an outdoor application. It is rather optimistic to expect that we will have a functional solution in the coming five years. On the one hand, the technical problems of outdoor applications to be solved are still many (related not only to the technical specifications of the see-through glasses, but also to the approaches for rendering, tracking systems, etc.) and require further research and investigations in laboratories. On the other hand, since the number of successful outdoor application is still very limited, the interest in such research (and thus the available funding) is limited. The see-through display technology will continue to progress with respect to particular applications, e.g. the NOMAD see-through display developed for pilots.

However, there is already demand for “augmenting” the real world with additional information. An evidence for this demand is the interest in LBS and the intensive research in this area. Since, appropriate see-through displays are not available yet, new devices have to be used. There are two possibilities: using handheld devices as displays and developing completely new devices (e.g. virtual binoculars), simplified, cheaper, portable versions of HMD. Industry developments within phone cell and handheld devices are spectacular in the last five years. In many countries the number of GSM subscribers reaches 80% (e.g. Italy, Spain)



According to an investigation of In-Stat MDR (http://www.instat.com/) the number of messaging subscribers (305 million at the end of 2001) is estimated to be more than 1 billion by the end of 2006 (the figure on the left). While smaller to the messaging market, the wireless Internet market is growing at the same pace. The wireless Internet market will grow from 74 million wireless Internet subscribers, at the end of 2001, to more than 320 million subscribers by the end of 2006.

In-Stat/MDR also found that:

Japan is the obvious early leader in the wireless Internet market, primarily due to the innovations of NTT DoCoMo, based on Personal Digital Cellular technology. However, competition is growing in Japan. DoCoMo's next hope, its WCDMA-based Freedom of Mobile Access (FOMA) service, is largely failing due to minimal coverage, high device and service pricing, and a lack of applications that set that technology. The Korean market is coming on in the Wireless Internet space, largely fuelled by CDMA technologies, and the US is not performing as badly as some might expect. Europe is largely failing with GPRS technology, and not including SMS and other messaging services, is falling behind the rest of the world in terms of wireless data adoption. However, the subscribers are there and they have to be provided with services.

In this respect the displays of the handheld devices will be further improved to visualise more and higher quality graphics, the memory integrated will be increased perhaps with every new device and the weight and pricing will stay low, appropriate for the average customer. More and more handheld devices will be enabled with cameras, GPS receivers and connection to other devices and PC computers. Is it possible to exploit all these functionality for AR purposes? For example, is it possible to record a video of surrounding buildings, send it to the server and ask for underground pipes? On the backbone, the video can be augmented with the needed information and sent back to the user (to be receptively played) on his/her personal handheld display. The project TellMars already reported interesting observations on navigating in a town using a 2D and 3D map. The 3D model (in contrast to expectations) does not need to be very detailed. Just the opposite, only the points (objects) of interest have to be highlighted. Similarly, could be that the resolution and the size of the handheld display will not be a limitation for the visualisation of video AR. Investigations for utilisation of handheld displays are still very limited.

7.2. Tracking systems

Tracking in outdoor (unprepared) environments is still a great challenge. Positioning, motion speed and view direction cannot be determined with the required accuracy. The current systems require an extensive calibration of all the sensors. In some cases the drift is so high that after a few minutes the system has to be initialised.

The GPS receivers (to obtain the position) have currently two disadvantages with respect to outdoor AR systems: the accuracy is still low (Figure 7-1) and the satellite visibility in urban areas is often very limited. This requires utilisation of differential GPS (that increases the cost of the system) or the development of a supplementary vision system, or utilisation of other alternative approaches for positioning. The accuracy of the wireless networks is even worse when compared to that of GPS systems.

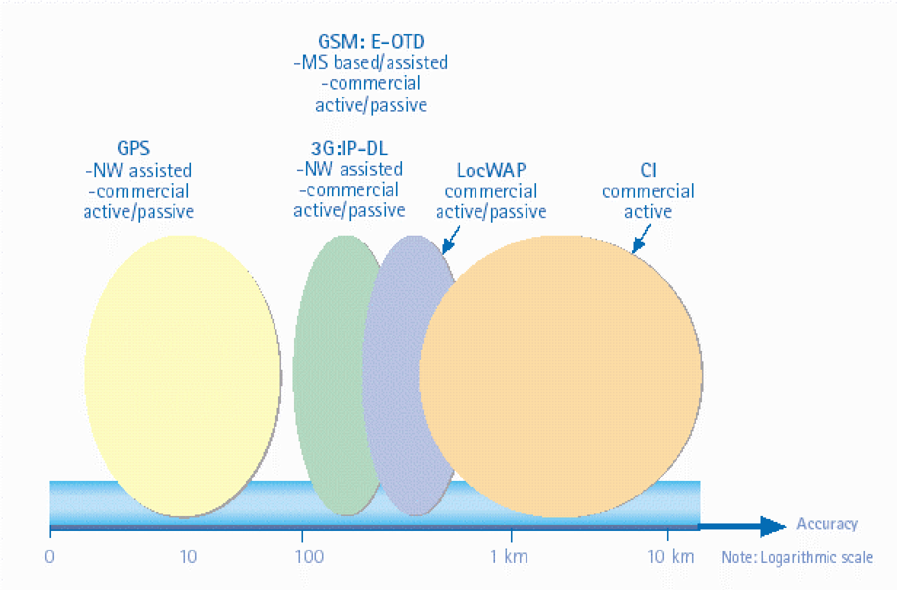


Figure 7-1: Location accuracy (NOKIA)

The utilisation of a vision system involves development of robust algorithms for tracking features on real video images and matching them with features stored in a database. Tracking features has already a long tradition in robot navigation (several projects are listed in Chapter 6), but still the best approach for outdoor system has to be developed. Non-prepared environments are much more unpredictable than indoor ones.

- To date, investigations on impact of weather changes (sun shining, rain, clouds, wind) and the effect on images have not been made. Due to different weather conditions, the contrast changes that may result in a very particular set of tracking features (on the images) that does not correspond to features available in the database.
- Most probably an outdoor application will operate at a street level, which is the most changing environment. Different decorations of shops, advertising boards, moving objects, changing canopy, flowers in gardens etc. Clearly, it would be very difficult to keep track of all these changes even along one street. A survey on these issues was also not found in the literature.

Moreover, most of the vision systems mentioned here assume a known initial (very accurate) position. This assumption is too strict for outdoor applications. If used, it will limit the AR system to a restricted area. An alternative is having several points for initialisation, but it is appropriate for relatively small-size areas (e.g. within a tourist area, Chapter 6: GEIST, ArcheoGuide projects).

Consequently, research on robust, reliable algorithms for initialisation of an outdoor AR tracking system has to be conducted as well.

All these issues would require, exhaustive algorithms, which raise new questions: where to run the algorithms (on the backbone or on the mobile device), which are the “cheapest” features in terms of storage, query, transportation and computational cost.

Local and global wireless networks or connection to another nearby devices (e.g. PC computers), are yet another alternative for determining the position. Currently, the wireless networks hardly can provide accuracy better that 100m. However, the interest in more precise positioning is very high (and in many cases a requirement for successful services) and it is logical to expect a standard working solution (in combination with GPS or a software that is able to detect the position within a cell) in coming 4-5 years.

7.3. Wireless communication

Wireless communications will be one of the most important themes in the next several few years. Two important trends are observed in communication technology development, i.e. exponential growth of both the mobile and Internet market. The number of user mobile phones is expected to grow to 1700 million by 2010. Worldwide, the number of Internet hosts is doubling every 8-9 months. These trends have a large impact on the services and applications. The expectations are for a high Quality of Service between the devices (see Vendors views, NOKIA). In this respect new architectures have to be developed for integration of existing and emerging broadband technologies (applications and services) and open architecture for wireless broadband Internet access.

The Wireless Strategic Initiative (EU project, http://www.ist-wsi.org/) aims at covering all aspects of the wireless world from user issues, business models to radio interfaces. The work is going to be concentrated on three general aspects namely reference models, system concepts and timelines. The reference models will describe the building blocks of the Wireless World and how they interact at corresponding points. The system concepts are devoted to technological principles and system options within the reference model. Timelines will give the schedule for the developments in the wireless world. The Wireless World Research Forum (legally founded in August 2001) already discussed the timelines and the road map at front of the wireless communications. The first Vision on the Wireless world is already available on the web as the Book of Visions 2000 (http://www.ist-wsi.org/BookofVisions2000.pdf) and 2001 (http://www.wireless-world-research.org/BoV1.0/BoV/BoV2001v1.1B.pdf). These documents are a summary of the expectation of some of the largest vendors in wireless communications, i.e. Alcatel, Ericsson, Nokia and Siemens and several Universities and Institutes. Six general levels of interactions are foreseen in the communication between the user and the devices around them. A short overview follows:

Figure 7-2: PAN, Instant Partners and Immediate Environments (Book of Visions, 2000)

Level 1. The closest interaction with the Wireless World is the communication between the user and all the devices that are closer to him/her and might even become part of the body (Figure 7-2, left). Typical examples are phone cells, notebooks, cameras, etc. Expectations are that both in clothes and wearable items communication facilities will be built in. When requested they will start to discover each other and distribute a common virtual terminal over us. This is called a Personal Area Network (PAN) vision and is certainly feasible in today's technology but needs much closer integration with the overall concept.

Level 2. At the next level come all the elements of the real world nearby, such as computers, TV sets, refrigerators. Currently, people do not interact with them but this will change in the future. TV sets should know the programs one is interested in, toasters might know the minutes needed for a slice of bread. This level is named Instant partners (Figure 7-2, middle). Learning and adapting environments will start to address real and fundamental user needs, as the difficulty of using current technologies is irritating to many people. If, for example, one is a non-smoker or vegetarian he/she does not want to tell this a 100 times, in different ways, to all your devices.

Level 3. One step further (Figure 7-2, right) is the interaction with the people around us as well as with more complex systems like cars. For example, the car will recognize the personal setting for the chair, rear-view mirror, etc. It is believed, that in the future the wireless possibilities should enable an easier and maybe richer interaction with people close by than with people on an other continent. For example, it should be possible to connect to the person one floor below in another easier way instead of using the mobile network. Current chat communities are just a glimpse of what people might desire in the future.

Figure 7-3: Radio Access, Interconnectivity, Cyber world

Level 4. The possibility to rely on ubiquitous coverage of a wide area system will remain a fundamental requirement. Current infrastructures might be augmented by flying base stations, high-speed local media points or dedicated road technologies. One might expect more specialised radio interfaces, which are more horizontal components of the Wireless World and have shorter innovation cycles. This level is referred to as Radio Access (Figure 7-3, left).

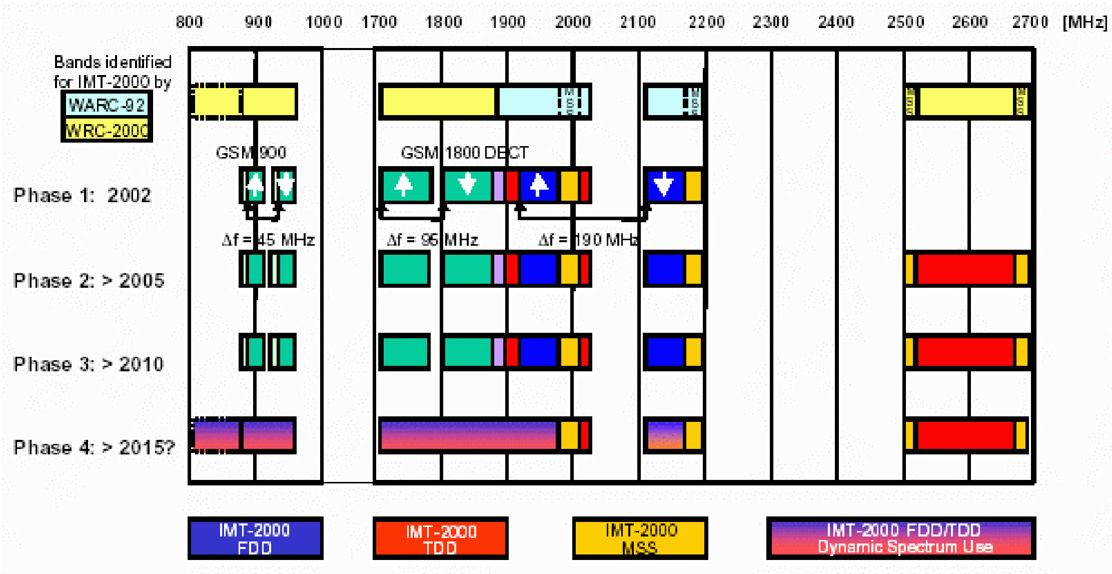


Figure 7-4: Steps toward wider bandwidth (Siemens)

Level 5. The next level Interconnectivity (Figure 7-3, middle) is related to the universal interconnectivity emerging from today's mobile Internet core networks. It is expected to become a very important task in the coming 10 years. The value of communications technologies is often said to grow proportional to the square of the number of the connected devices. Various specialised radio interfaces and terminals will be a key requirement for the support of this level Therefore a radio convergence layer and a number of APIs (beside the evolved IP transport and networking layers) will be needed.

Level 6. The last level Cyber World (Figure 7-3, right) will be the highest level of interaction where all the possible communications between different people, servers, databases with information, etc. will be possible. The Cyber World will be as important as the real world. Actually, the Cyber World will stay in connection with personal agents, knowledge bases, communities, services and transactions. According to WSI the Wireless World will be the technology to allow us to become permanent residents in the CyberWorld.

Perhaps the most important step is the step toward wider bandwidth. Siemens has proposed four general phases (considering mostly Germany, Figure 7-4). In the figure IMT-2000 is the official name of the ITU standard wideband code-division multiple access (WCDMA). In principle, GPRS is expected to be implemented in 2003-2004 in most Western European countries, as mostly WAP would be supported. As mentioned in Chapter 3, the i-MODE protocol is also adopted by some telecommunication companies. Which one of the two protocols is going to survive is still unclear. It depend on many factors, the market, the Markup Languages they utilize (XML and cHTML) and the policy of the communications companies. I-mode has clear prevalence of the Japanese market, while WAP technology is more popular in Europe and USA. XML is much more extensible, while cHTML is easier for programming. Currently, a WAP-Gateway is required to translate between HTML and WML for almost every data-transfer. However, it is expected that XML will in some respect replace HTML, since it allows for more dynamic content and various different applications. It might be a hint that a WML-based service will be more advantageous than an HTML-based one. Presently, WAP requires more complicated technology, but in the long term, it will enable a user to do more with his device.

Nokia (http://www.nokia.com/networks/systems_and_solutions/) sees several important areas of development, which have to be addressed in the coming years. Nokia considers the next 5 years as years of infrastructure evolution from circuit to packet switching (Chapter 3). Currently most of the packets are treated equally, which need further changes. Not all data needs to be treated equally, e.g. different treatment can be applied for voice and e-mail. To guarantee this requirement, extra capacity can be built into the network, which however, can be a quite expensive and difficult solution. Another more elegant way is the possibility to estimate and control the data flow. Efficient Quality of Service (QoS) has to be provided, as at least several functions are needed such as QoS monitor, translator, packet classifier, admission controller, resource manager, etc. Although some investigations are already done, still many developments are need in this area. The core network structure will become simpler and the IP will be commonly provided. The interconnections with other networks will also increase and will raise new security topics (protocols, fire walls, border gateways). Nokia's 3G solutions for the next generation communications are:

1. Multimedia messaging Service (MMS): MMS is end-to-end, person-to-person, mobile-to-mobile, mobile-to-Internet and Internet-to-mobile application. It will provide rich content (images, video, audio, data and text).

2. Rich call: listen to what I say + see what I mean. Rich call services can already be provided with the first phase of the 3G launch. Audio conversation enhanced by receiving images and other data.

3. Mobile Internet: Mobile Internet services in 3G, which offer personalised context-dependent applications. Since the voice recognition will enable voice browsing many keyboard size problem is drop off.

4. Browsing will be an evolution from today's WAP browsing to graphics and multimedia. Java applets applications are going to be run on the client site (Superscape and ARM, RISK processor, 3D visualisation on mobile devices).

5. Multimedia streaming and downloading. Continues services as streaming broadcast 24-hour TV news broadcasts and stock price tickers, audio streaming (e.g. MPS3).

6. LBS: navigation, tracing, location-dependent information, safety application and tariff information. Mobile Internet services have tobe highly rich in relevant information since the typical phone screen is 1% of the size of a computer. The information has to be personalised, time-critical and location-dependent.

7. Mobile eBusiness: the expectations are for a multi-billion business by 2005. Because of ease of use it is expected that the mobile e-commerce market will grow exponentially. Establishment of a Mobile Electronic Transaction (MeT) initiative is to create a framework for handling secure mobile electronic transactions via mobile devices. Currently, this service is not provided because they are merely copied from the PC service environment (i.e. authentication through username and password). But evolving the WAP with WAP identity module (WIM), Wireless Transport Layer Security (WTLS) (see Chapter 3 for abbreviations) and Wireless Public Key Infrastructure (W-PKI) is a perfect solution for secure mobile business

8. Personal Trusted Devices (PTD) will be able to handle a large variety of new services as bank payment, ticketing (currently NS and KPN offers a service to buy a ticket over a mobile phone).

7.4. Database systems

The research in DBMS has to be directed toward the third dimension:

DBMSs are already capable of maintaining spatial data. In the coming 2–3 years, 3D volumetric objects (and thus possibilities to compute volume and check validity) will also be possible (e.g. Oracle Spatial promises 3D objects in the 10^{th} version). The maintenance of 3D objects will make possible a large number of 3D spatial analyses. This will also increase the interest in providing 3D services. Requirements and urgent database issues may differ with respect to the components of the AR system. If see-through displays are used, the system would benefit from existing real objects and relatively small virtual objects needed to be extracted from the database. However, if the outdoor AR systems rely on vision systems to precisely position supplementary information (lines, corners, points, or other features) has to be organised in the database. The problems of data organisation, extraction of necessary data and matching with real world models are emerging. If hand-held displays are used then the problems of the VR systems (an the large data sets) are becoming important.

In any case, outdoor applications require utilisation of databases. Some emerging topics for research in the coming 2-3 years are:

- Development of system architecture for access and query of spatial information stored in DBMS. For example, a particular GUI for composing queries (running on handheld devices) and parses/composers running on the server side (performing the query and composing the answer, e.g. VRML file).
- Architectures for spatial information retrieval. For example, the user may require information that is not related to the current location. Although connected to nearest servers (e.g. the municipality of the closest town), the user may need information about a town that would be approached after 3 hours. It may look like that current navigation systems already provide such a service, but it should be noted that they are only 2D. It is not conceivable that the memory capacity of a portable device would allow storage and navigation through large 3D models (as in 2D cases).
- Compression of 3D data. Currently, a middle-size model (100 000 triangles) that needs to be sent to a hand-held device may result in a 3Mb VRML file. Such file will be delivered (via 3G network providing a speed of 384 Kbit/s) for about 60 seconds, which is definitely far beyond the expectations of the mobile user. Present compression techniques allow size reduction to 1Mb, but it is a still rather long time.
- Topological issues for 3D objects: data structures, spatial indexing and clustering, spatial navigations (shortest path, nearest neighbour, etc)
- Storage and retrieval of texture needed for 3D visualisation (attraction of attention)
- Algorithms for generalisation and data reduction
- The “cost” of vector data? Raster data are largely utilised (and in many cases preferred) for distribution over the Internet. 3D visualisation using animations created on the fly and sent not as vector data but as MPEG files?

Reports published before in this series:

- GISt Report No. 1, Oosterom, P.J. van, Research issues in integrated querying of geometric and thematic cadastral information (1), Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 29 p.p.
- GISt Report No. 2, Stoter, J.E., Considerations for a 3D Cadastre, Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 30.p.
- GISt Report No. 3, Fendel, E.M. en A.B. Smits (eds.), Java GIS Seminar, Opening GDMC, Delft, 15 November 2000, Delft University of Technology, GISt. No. 3, 25 p.p.
- GISt Report No. 4, Oosterom, P.J.M. van, Research issues in integrated querying of geometric and thematic cadastral information (2), Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 29 p.p.
- GISt Report No. 5, Oosterom, P.J.M. van, C.W. Quak, J.E. Stoter, T.P.M. Tijssen en M.E. de Vries, Objectgerichtheid TOP10vector: Achtergrond en commentaar op de gebruikersspecificaties en het conceptuele gegevensmodel, Rapport aan Topografische Dienst Nederland, E.M. Fendel (eds.), Delft University of Technology, Delft 2000, 18 p.p.
- GISt Report No. 6, Quak, C.W., An implementation of a classification algorithm for houses, Rapport aan Concernstaf Kadaster, Delft 2001, 13.p.
- GISt Report No. 7, Tijssen, T.P.M., C.W. Quak and P.J.M. van Oosterom, Spatial DBMS testing with data from the Cadastre and TNO NITG, Delft 2001, 119 p.
- GISt Report No. 8, Vries, M.E. de en E. Verbree, Internet GIS met ArcIMS, Delft 2001, 38 p.
- GISt Report No. 9, Vries, M.E. de, T.P.M. Tijssen, J.E. Stoter, C.W. Quak and P.J.M. van Oosterom, The GML prototype of the new TOP10vector object model, Report for the Topographic Service, Delft 2001, 132 p.
- GISt Report No. 10, Stoter, J.E., Nauwkeurig bepalen van grondverzet op basis van CAD ontgravingsprofielen en GIS, een haalbaarheidsstudie, Rapport aan de Bouwdienst van Rijkswaterstaat, Delft, 2001, 23 p.
- GISt Report No. 11, Geo DBMS, De basis van GIS-toepassingen, KvAG/AGGN Themamiddag, 14 november 2001, J. Flim (eds.), Delft 2001, 37 p.
- GISt Report No. 12, Vries, M.E. de, T.P.M. Tijssen, J.E. Stoter, C.W. Quak and P.J.M. van Oosterom, The second GML prototype of the new TOP10NL object model, Delft, 2002.
- GISt Report No. 13, Vries, M.E. de, T.P.M. Tijssen en P.J.M. van Oosterom, Comparing the storage of Shell data in Oracle spatial and in Oracle/ArcSDE compressed binary format, Delft, 2002, .72 p. (Confidential)
- GISt Report No. 14, Stoter, J.E., 3D Cadastre, Progress Report, Report to Concernstaf Kadaster, Delft 2002, 16 p.
- GISt Report No. 15, Zlatanova, S., Research Project on the Usability of Oracle Spatial within the RWS Organisation, Detailed Project Plan (MD-NR. 3215), Report to Meetkundige Dienst – Rijkswaterstaat, Delft 2002, 13 p.
- GISt Report No. 16, Verbree, E., Driedimensionale Topografische Terreinmodellering op basis van Tetraëder Netwerken: Top10-3D, Report aan Topografische Dienst Nederland, Delft 2002, 15 p.