4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage
VAST (2003)
D. Arnold, A. Chalmers, F. Niccolucci (Editors)

Design and Application of an Augmented Reality System for continuous, context-sensitive guided tours of indoor and outdoor cultural sites and museums

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Abstract

The exploitation of augmented reality and mobile computing for the implementation of context and location-sensitive tours of archaeological sites and museums is explored in this paper. The LIFEPLUS system is presented as a novel approach offering advanced interactive audiovisual presentations to visitors of ancient Pompeii in Italy. The hardware architecture and main functionalities are presented.

Keywords:
Augmented reality, electronic museum guide, personalization

1. Introduction

3D graphics and complex imaging techniques are commonly used in many scientific fields, as well as, in video games. Their flourishing is attributed to the availability of very powerful computer systems at affordable prices. One has to look at the available PCs, servers and game consoles in the market to understand how this peaceful revolution was made resulting in more computing power for a 5 year-old child playing a video game today than to a scientist at the best laboratory 5-10 years ago.

But what about the cultural heritage sector? Well, despite the availability of cutting edge technology, its adoption by such institutions and authorities has been rather slow. The “traditional” use of signs and paper guidebooks is still common practice due to their minimum intrusion in sensitive areas and artefacts, and their minimal cost of installation and production, respectively.

Nevertheless, there are notable examples of such institutions and sites, which became aware of the advantages of these technologies and decided to explore their potential for providing their visitors (and scientists) with powerful tools. Their aim was, first, to raise awareness of cultural heritage to the general public and attract more visitors and, second, to aid historians and archaeologists in better conducting their research and offer them better ways to present their findings both to the scientific community and to the general public. The overall outcome of this effort could create increased revenue to finance the restoration and preservation of important cultural assets and as a positive “side-effect” could promote cultural tourism.

This paper explores briefly the efforts into developing high-tech systems for cultural heritage applications and presents a novel approach currently under development; this is the LIFEPLUS system; an EU IST 5FP research project.

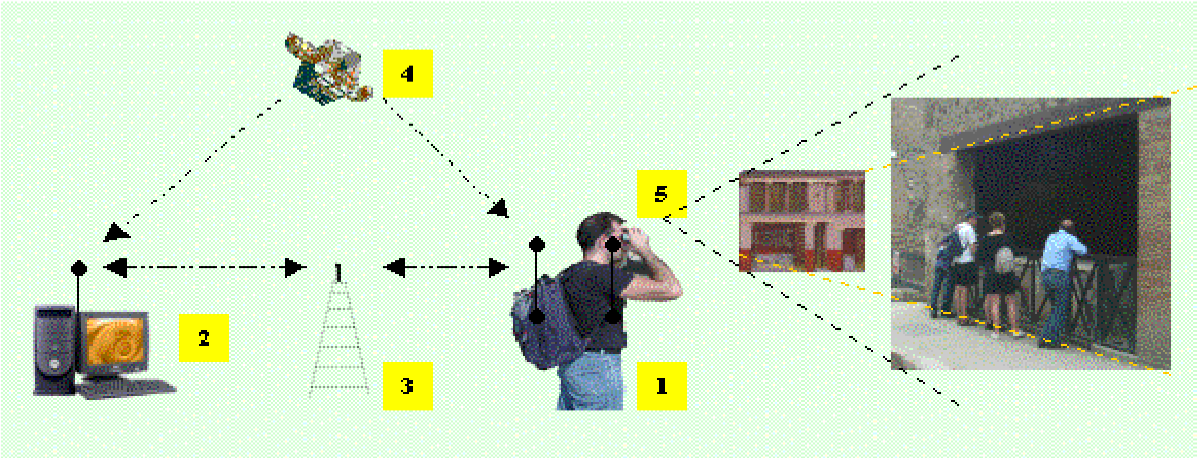

Figure 1: *LIFEPLUS hardware architecture (1. mobile AR device, 2. central server, 3. communications infrastructure, GPS satellite, 5. AR binoculars*

2. Brief State-of-the-Art in Cultural Heritage Systems

The use of technology in museums and archaeological sites dates beck to the 80s with the use of walkmans with audiotapes, which contained a narration with historical information on serially presented museum artefacts and site buildings. Users would follow a tour with the help of a printed plan without any serious control of the presentation, except the pause button of the device.

In the 90s, these basic audio guides were transformed in audio-CD guides where the tour was still indicated on a paper plan but the user could easily select in any order the information on any specific item-of-interest by choosing the appropriate track on the CD. These devices are still used worldwide with a different CD for each language they support.

In the last few years, small handsets are starting to replace the older audio guides. They are in essence small computers equipped with hard disks where audio files in a variety of languages are stored [1]. The user is still responsible for requesting the appropriate content either by tapping the corresponding code number or, in some models equipped with infrared sensors, by approaching an exhibit and pointing the handset at it (the latter is only applicable in indoor museums.

In parallel, static, virtual museums were developed based on CD-ROM and web sites. They offer high quality graphics and navigation inside virtual replicas of museums where exhibits can be observed and in some cases manipulated by the on-line visitor [2].

At the turn of the century, PDAs (Personal Digital Assistants) with relatively high processing power were made available. Their use as audio guides started to gain ground. The user can select the information he requires from a digital plan displayed on the device's pressure-sensitive screen. Such systems are already in operation at some museums [3]. Pilot applications have further developed this concept to make full use of the capabilities of PDAs and present synchronised interactive audio-visual content [4, 5] and in some cases coupled with user position tracking for automatic operation [6, 7].

The same concept has been implemented on pen-tablets. These are portable devices the size of an A4 page and used like e-books. Their processing capabilities enable the presentation of high quality graphics, Virtual Reality (VR) and Mixed Reality (MR) presentations with synchronized sound and automatic presentation though complex position and orientation tracking mechanisms [7, 8]. In parallel, with the development of VR techniques, CAVE and VR theatres were proposed for immersive static presentations of these synthetic worlds [9].

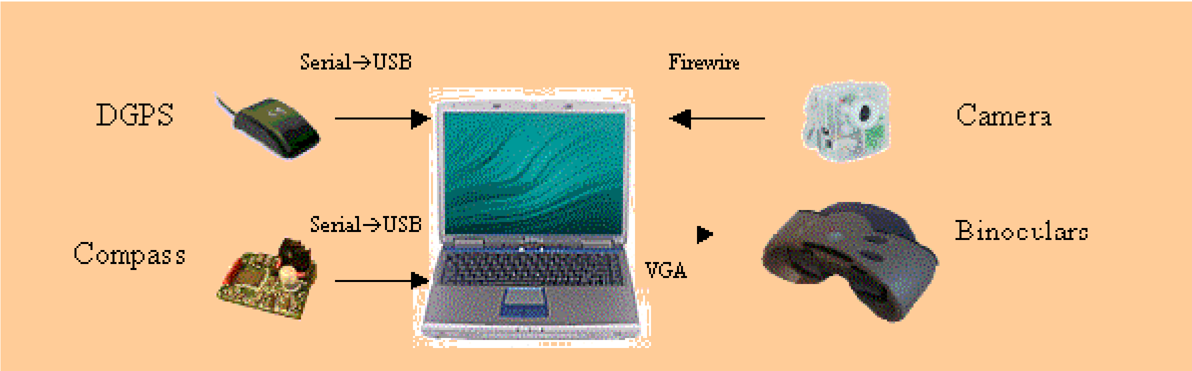

Figure 2: *Mobile AR device hardware set-up*

The latest development is mobile Augmented Reality (AR) systems where the real (natural) view is enhanced with computer graphics and presented through a suitable Head-Mounted Display. These systems offer immersive experiences typically in indoor or outdoor spaces, either with the use of special installations (intrusive) or without (non-intrusive; suitable for archaeological sites) [7, 10, 12-20].

The system that is presented in this paper falls into the latter category of mobile AR systems. Its name, LIFEPLUS, stands for "Innovative revival of life in ancient frescoes and creation of immersive narrative spaces featuring real scenes with behavioured virtual fauna and flora".

3. LIFEPLUS System Architecture

LIFEPLUS is an innovative portable electronic tour companion and guide for archaeological sites. Its philosophy is that of *continuously and automatically providing guidance and personalized audio-visual information to visitors of indoor and outdoor archaeological sites and museums*. The main goals of the system are (numbers refer to the system architecture diagram in Figure1):

- Development of a mobile AR platform (1).
- - Design and implementation of efficient and easy-to-use user interaction mechanisms (1).
- Design and implementation of accurate real-time indoor and outdoor user tracking mechanisms (1).
- Provision of continuous guidance in an archaeological site (1-4).
- AR monument and frescos reconstruction (1, 5).
- Access to digitised 3D artefacts and manipulation in real time (5).
- Revival of ancient life and storytelling for the illustration aspects of community life (1, 2, 5).
- Multimedia content archiving, management and reuse in a variety of applications (2).

The LIFEPLUS system can be divided into 2 main applications or modules:

- *AR Guide*. Responsible for providing continuous guidance, audio-visual information on history and findings, and AR reconstructions of ruined buildings and frescos.
- *AR Life Simulator*. Responsible for storytelling and AR reconstructions of ancient life scenes in their original setting.

Both applications make extensive use of multidimensional data either in the form of 3D models or video animations. Our discussion will concentrate on the AR Guide as it involves the majority of the hardware and software components of the system. As far as its hardware is concerned, LIFEPLUS comprises three main functional units:

- Central Server
- Mobile AR platform
- Communications infrastructure

3.1. The Central Server

This is the supporting unit of the system, which is accessible by site staff and the system administrator. It is, in essence, an archival system made up of a multimedia database where all the digitised content relating to the particular installation site is maintained. It includes 3D models of museum artefacts and buildings, animations, audio clips, and text. Beside this storage space (ORACLE-9-based), graphical authoring tools exist for the editing of the multimedia objects. These tools are also used for assigning metadata descriptions to the archived data. This action is designed to facilitate context-based searching, grouping and formation of AR tours, and content reuse in other applications. The Dublin Core Metadata Element Set [11] is the heart of the data and metadata representation, which has been extended to cover the specific needs of AR tours. Its use together with common multimedia standards (JPEG, TIFF, GIF, Animated GIF, MPEG, WAV) ensures the reuse of existing digital content and interoperability with museum and archaeological database systems.

As far as the implementation of the authoring tools suite is concerned, we have used Java Swing Jframe and Remote Message Interface (RMI), which offer a sufficient way for Client/ Server application implementation and communication. SQL Data Manipulation Language (DML) statements are also used. The advantage of this approach is that since SQL is a worldwide standard for database content management, switching the current ORACLE selection into another DB should not be a problem. DML is a subset of SQL containing statements for Inserting, Deleting and Updating table rows. In order to loosen the bond between the database backend and the LIFEPLUS logic, a configuration file schema is selected. For every available database manipulation action LIFEPLUS calls a reference to a file defined statement.

Our implementation uses the following entities for the design of an Archeological Site tour:

- Site Nodes
- Scripts
- Tour

The server also incorporates a DGPS server application. Its function is to provide a correction signal used in improving the accuracy of the calculation of the touring visitor's position in the site (refer to the section on the mobile devices).

3.2. Communications Infrastructure

This is the wireless link between the server and the mobile units. Its purpose is the real-time transfer of control information and the optional downloading of multimedia content from the server's database to the mobile devices. The latter is not necessary as the system administrator may chose to install all necessary data to the mobile devices' hard-disks and simply update them when necessary. The disadvantage of this approach is that the user is given a fairly limited choice of content. Nevertheless the few tens of GB of storage space on the mobile devices are usually more than enough to cater for his needs.

If the content downloading option is desired, the choice of a Wireless Local Area Network (WLAN) is the optimal choice for speed and concurrent handling of several users. We have chosen the IEEE 802.11b standard as the most widely accepted standard for such use. It operates at speeds of 11Mbps and is sharable among several users. It can cover fairly large distances (up to a few hundred meters) depending on the topology of the site. The same network can also be used for control traffic (DGPD signals, etc.). If future needs involve heavier data traffic, then the chosen WLAN could be upgraded to higher data throughput.

If only control data is to be transferred (and possibly small volumes of multimedia content) then the use of a GPRS link at 33Kbps (9600Kbps in GSM mode) or an

RF link is suitable. Both imply a point-to-point link and can serve well distances of up to a few hundred meters (the latter can support larger distances but this involves the use of higher power and more powerful batteries which are typically not necessary in our applications).

In all cases antennae and other hardware need to be installed in such a way as not to cause any physical damage or visual disturbance. For this reason, installation at the periphery of the site or camouflaging behind walls or other structures is necessary.

3.3. The Mobile AR Platform

This is the part of the system visible to the ordinary visitor of the site or the expert who participates in the AR experience. This mobile device is built on off-the-shelf hardware components to minimize cost and allow easy extensibility (refer to Figure 2). It consists of:

- Dell Latitude X200 laptop computer with Pentium III Processor at 933 MHz, 632 MB RAM, 30 GB storage space, and Intel 82830M graphics accelerator card. It is the main processing and control unit, responsible for handling sensory data, communication with the server, user profiling, image tracking and rendering, and user interaction.

- *Garmin GPS35-HVS DGPS Receiver.* It is used in calculating the user's position in the outdoor archaeological site. The system is based on reception of at least four GPS satellite signals and a correction signal from the DGPS server. The resulting accuracy of the differential system is less than one meter, rendering it appropriate for use in LIFEPLUS. The receiver supports the NMEA 0183 standard data format and the RTCM SC-104 standard format for differential corrections.

- *Precision Navigation TCM2 Digital Compass*. It is used for the calculation of the user's orientation and the determination of the object he stares at and is interested in receiving more information. The device is a magnetic sensor providing roll, yaw, and pitch measurements with an accuracy of 0.5º and allowing calibration and offset setting to counterbalance any magnetic fields present in the area it is used. The compass supports the NMEA 0183 standard data format.

- *Unibrain Fire-i Colour Digital Camera*. This light VGA-quality camera is used to capture the user's natural view from his perspective. Its live video stream is then fed to the video tracker module for adapting the virtual models used to create the final augmented view. The camera outputs an IEEE-1394a (FireWire) stream at 400 Mbps. It provides a VGA output at 640x480 pixels and features automatic white balance and backlight compensation for fast adaptation to all indoor and outdoor lighting conditions.

- *n-Vision VB-30 High Resolution Hand-Held Display*. This is the visualization device enabling the AR experience. It comes in the form of a pair of binoculars upon which the camera is mounted and a set of three push buttons are integrated. This way, video see-through is achieved and the user can see the natural view in front of him, mixed and augmented with computer graphics. The binoculars display video streams in SVGA quality and resolution of 800x600 pixels.

- A choice between one of the following communications infrastructure:

    - Lucent Orinoco WLAN adapter card. Transmitter-receiver PCMCIA card to allow laptop computer to connect to an IEEE 802.11b-based local area network at 11Mbps. This network supports the downloading of multimedia content, DGPS correction signal and control information.

    - GPRS modem to connect to a GPRS public network. The service provides speeds of a maximum of 33 kbps (or 9600 kbps in GSM mode) and allows the transfer of DGPS and control signals and moderate multimedia traffic.

    - RF modem allows DGPS and control data communication over a wireless point-to-point link.

The integrated mobile device offers autonomy of over 1 hour between battery recharges and weights less than 5 kg. It is carried in a small backpack for easier transportation and protection against damage. The set-up presented above is suitable for both indoor and outdoor use. The hybrid tracking module (DGPS, compass, video tracking) ensure accurate operation even in the absence of GPS satellite signals and the binoculars and camera assembly provide perfect contrast and high degrees of realism.

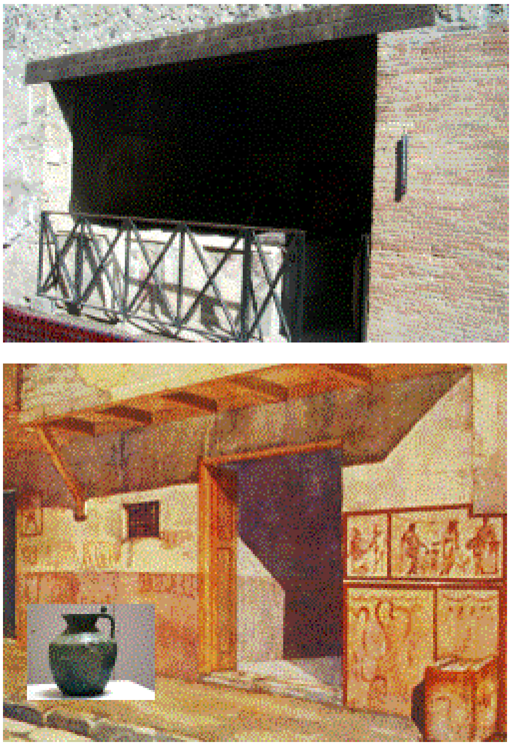

Figure 3: *Today's view of the exterior of the tavern of Vetutius Placidus and its virtual reconstruction.*

An important aspect of the AR tours is the personalization feature it offers. The mobile devices can capture the user's profile through a graphical form with simple multiple-choice questions. This information is then automatically related to the metadata describing the multimedia content and a personalized tour is created. This is, in turn, automatically presented according to the user's behaviour as it is captured by the tracking system.

An important point in the operation of the mobile devices is the incorporation of the context sensitive data into the guidance and presentation context of the AR tour. Our approach is based on a configuration file, which the site administrator can edit graphically and structure the basic tour offered by the device. In other words he selects a path through the site by fixing viewpoints (defined by their geographic coordinates and a radius marking the area around them where multimedia content is available and will be presented to the user). These viewpoints are then populated with all the multimedia content he wants to present the users of the system. A set of rules and conditions (precedence, enable replay of an item, profile, etc.) are then set. The synchronization software module on the mobile device parses the data in this configuration file and reads the sensory data (position, orientation) and the user's profile. This way it can select the appropriate multimedia objects and play them at the right place, time and order, i.e. when the user is at a viewpoint and staring at a building or other point of interest.

Finally, regarding the AR Life Simulation, this is based on the following software components developed by Miralab, EPFL, and Bionatics:

- Virtual fauna Simulation where 3D human models are created and animated according to a storytelling scenario (e.g. tavern owner explaining how bread was made in ancient Pompeii).
- Virtual Clothes Simulation module where photo-realistic, high quality motion animation of different garments and fabrics is performed.
- Virtual Hair Simulation module where photo-realistic, high quality hair modelling and animation is done.
- Virtual Flora Simulation Module where high quality 3D models of plants are animated in their natural environment.

4. LIFEPLUS in action

The LIFEPLUS AR Guide prototype was tested at the archaeological site of Pompeii in Italy. The system, still under development, was operated in the real environment of a major archaeological site where it is expected to find application in the near future.

The simulated visit started at one of the entrances to the ancient city and followed the main streets used in ancient times. The choice of the route was based, first, on the monuments and other significant buildings at its sides and their suitability for introducing history and aspects of community life, and, second, on the conditions for testing all system modules and especially the wireless infrastructure, user tracking, profiling and synchronization of the audio-visual content. Their satisfactory operation was verified even in the presence of partial occlusions of the user's view by other visitors.

The following features were tested:

- AR Guide application. Integrated tours along the selected route.
- VR Life Simulation at a pre-selected viewpoint.
- DGPS functionality on the mobile devices, DGPS server, and differential signal transmission over wireless interface.
- Site surveying and 3D modelling.
- Navigation aid.
- Multimedia object synchronization.
- Location, orientation and user behaviour-sensitive automatic data presentation.
- AR building reconstructions.
- Slide show.
- Avatar narration.
- AR life presentation and storytelling.
- Multi-modal user interaction.
- 2D and 3D markerless tracking.

The tests were conducted with a group of 6 archaeologists and technology experts to verify functionality and identify shortcomings. Full-scale trials with site visitors are planned for early 2004.

Considering the basic personalized presentation, it was dynamically adapted and enriched with more detail according to the user's walking speed and time spent at each point of interest. The more time spent, the more additional information was given in the form of narration in his language of preference.

The visualization device and the graphical interaction mechanism feature easy operation and create a feeling of immersion into the augmented world without cutting the user off his real environment. An example of the visual experience is illustrated in Figure 3.

The system offers an intuitive electronic guide to Pompeii. The AR reconstruction of a ruined building together with the real-time access to related museum exhibits proved its power for better explaining history and, more importantly, virtually reconstructing what was damaged through the centuries. The guided tour is made livelier with the addition of an avatar guide who undertakes the task of narrating the personalized information to the user.

The AR experience offered by LIFEPLUS suits perfectly the needs for enhanced visibility of archaeological sites and museums. Edutainment scenarios can be written for several user profiles including students, archaeologists, families, and groups of tourists.

5. Lessons learnt and future improvements

The LIFEPLUS system was successfully tested at Pompeii. The tested prototype proved the feasibility and potential of the designed system. In its initial prototype form it offers limited features and it is not yet integrated with the AR Life Simulator.

Currently the system has the following limitations, which are dealt with in the implementation of the second prototype:

- The AR Guide and the AR Life Simulator run as two individual applications sharing some hardware components (e.g. camera, and visualization unit).
- Currently 2D video tracking is supported in real time for the AR Guide and 3D tracking is still under testing for the AR Life Simulator.

- AR Life revival and Building Reconstructions are currently offered only at 1 predefined viewpoint. More are under implementation for the next prototype.
- Personalization is still limited to real time data and user behaviour. Extension to statistical methods for content classification should be implemented.
- The size and weight of the mobile devices are the most serious drawback of the system. Our efforts concentrate on the integration of the two applications and their porting into lighter and more powerful hardware that could more easily be transported by site visitors.

The main innovation of the system is the unconstrained use at both indoor and outdoor sites and continuous guiding and flow of information to the user in an intuitive and automatic way. These features are enhanced even further with the dynamic personalization module.

It is within our plans to integrate the AR Guide and Life Simulator and add new features to make the system friendlier to the ordinary site visitor. Along these lines we are developing a new wearable AR platform, capable of supporting a version of the integrated system and featuring scalable graphics. In addition, the dynamic nature of the personalization of the content will be enhanced with the use of efficient learning algorithms.

In its final form, LIFEPLUS is designed to be a mobile application that will enrich today's AR tours with AR storytelling and photo-realistic life simulation of human models and plants.

For more information the reader may contact Dr. Vassilios Vlahakis at vvla@intracom.gr or consult the project's web site at:

http://www.miralab.unige.ch/subpages/lifeplus/

Acknowledgements

The authors would like to thank the archaeological authorities of Pompeii for their help and permission to test the LIFEPLUS AR Guide. We also address our special thanks to our partners Dr Renzo Carlucci, Mr Giancarlo Conia, and Mr Fabrizio Bernardini from A&C2000 Srl, Professor Pietro Giovanni Guzzo and Dr. Lucciana Giacobelli from the Archaeological Superintendence of Pompeii, and Dr Marxiano Melotti from the University of Milan, all in Italy.

References

1. Acoustiguide digital audio guide for museums http://www.acoustiguide.com.
2. Louvre Virtual Museum http://www.louvre.fr.
3. Chateau de Versailles PDA audio guide, Versailles, France, http://www.chateauversailles.fr.
4. University of Tokyo's Personalized Digital Museum Assistant (PDMA), Tokyo, Japan, http://www.um.u-tokyo.ac.jp/dm2k-umdb/publish_db/books/dm2000/english/01/01-17.html.
5. Egyptian Museum PDA guide, Cairo, Egypt, http://www.businesstodayegypt.com/issues/0301/739A/0301739A1.asp.
6. Molndals Museum PDA guide, Sweden, http://www.museum.molndal.se/indexn.asp
7. V. Vlahakis, N.Ioannidis, J. Karigiannis, "ARCHEOGUIDE: Challenges and Solutions of a Personalized Augmented Reality Guide for Archaeological sites", "Computer Graphics in Art, History and Archaeology" Special Issue of the IEEE Computer Graphics and Applications Magazine, September-October 2002, pp.52-60.
8. MUSE pen-tablet guide for Pompeii, Italy, http://www.archimuse.com/mw2003/papers/garzotto/garzotto.html.
9. Fraunhofer IGD's Dunhuang Caves, Darmstadt, Germany, http://www.rostock.igd.fhg.de/IGD/Abteilungen/AR2/Archiv_Projekte/Dunhuang/index_html_en.

10. Tokyo University's Digital Museum mobile AR guide, Tokyo, Japan, http://www.um.u-tokyo.ac.jp/dm2k-umdb/publish_db/books/dm2000/english/01/01-16.html.

11. Dublin Core Metadata Element Set http://www.dublincore.org/.

12. D. Pletinckx et al., "Virtual Reality Heritage Presentation at Ename", IEEE Multimedia, Vol. 7. No 2, Aril-June 2000, pp.45-48.

13. S. Feiner et al., "A touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment", Proc. ISWC97, Cambridge, MA, USA, 13-14 Oct. 1997, pp.74-81.

14. T. Hellerer et al., "Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System", Computer & Graphics, Vol. 23, No 6, 1999, pp.779-785.

15. U. Kretschmer et al., "Meeting the Spirit of History", Proc. Eurographics VAST 2001, Glyfada, nr. Athens, Greece, 28-30 Nov. 2001, pp.141-152.

16. J. Newman, D. Ingram, A. Hopper, "Augmented Reality in a wide area sentient environment", Proc. IEEE ACM ISAR 2001, New York, USA, 29-30 Oct. 2001, pp.77-86.

17. W. Piekarski et al., "A Mobile Augmented Reality Interface for Terrestrial Navigation", Proc. 22nd Australasian Computer Science Conf., Auckland, New Zealand, 18-21 January 1999, pp.122-133.

18. G. Reitmayr, D. Schmalstieg, "Mobile Collaborative Augmented Reality", Proc. IEEE ISAR 2001, New York, USA, 29-30 Oct. 2001, pp.114-123.

19. T. Starner et al., "Augmented Reality through Wearable Computing", Presence, Special Issue on Augmented Reality, Vol. 4, 1997, pp.386-398.

20. B. Thomas et al., "A wearable Computer System with Augmented Reality to support terrestrial navigation", Proc. IEEE ACM ISWC98, Pittsburgh, USA, 19-20 October 1998, pp. 168-171.