Augmenting Reality with Geo-Referenced Information for Environmental Management

Teresa Romão[(1)(3)]; Nuno Correia[(2)]; Eduardo Dias[(1)(3)]; Adelaide Trabuco [(2)]; Carlos Santos[(2)]; Rossana Santos [(2)]; Edmundo Nobre[(3)]; António Câmara[(3)]; José Danado[(1)(3)]; Luís Romero[(2)]

[(1)]Computer Science Department
University of Évora
Rua Romão Ramalho 59
7000 Évora Portugal
Tel: +351-266745300
{tir, aed}@di.uevora.pt

[(2)]Computer Science Department
New University of Lisbon
Quinta da Torre
2825 Monte da Caparica
Portugal
Tel: +351-212948536
nmc@di.fct.unl.pt

[(3)]Environmental Systems Analysis Group
New University of Lisbon
Quinta da Torre
2825 Monte da Caparica
Portugal
Tel: +351-212948536
asc@iilab.com

ABSTRACT

When interacting with natural or urban environments there are many situations where the ability to access data in real time becomes relevant. Augmented Reality (AR) technologies allow real time superimposition of synthetic objects on real images, providing an augmented knowledge about the surrounding world. Using a Head Mounted Display, the user of an AR system can visualize the exterior world with additional virtual information that is generated in real time and in a contextual way.

This paper presents ANTS (Augmented Environments), an AR project for providing geo-referenced environmental information. The project uses a flexible client-server approach that allows to move more or less components to the client, depending on processing power and application requirements. The geo-referenced database and 3D model for user positioning are located in the server and the presentation component, for image composition and display, is the most fundamental part of the client. The applications for environmental management, include monitoring water quality using models of the pollutant transport, the visualization of the temporal evolution of physical structures and the evolution of subsoil structures, such as phone and power supply networks.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces And Presentation**]: Multimedia Information Systems – *Artificial, augmented, and virtual realities.* H.2.8 [**Database Management**]: Database Applications – *Spatial databases and GIS.*

GIS'02, November 8-9, 2002, McLean, Virginia, USA.

General Terms

Management, Performance, Experimentation, Human Factors.

Keywords

Augmented reality; Geo-referenced information; Contextual information; Positioning; Mobile information services; Real-time spatio-temporal geographical information; Image retrieval based on content.

1. INTRODUCTION

There is usually a lot of information about our surrounding world which, despite being available, may not be easily accessible. When looking at a real environment, regardless of whether it is natural or urban, access to contextual geo-referenced real-time data concerning the visual world is often quite relevant.

Augmented Reality (AR) technologies allow the superimposition, in real time, of synthetic images on top of real images, thus permitting an augmented knowledge of the surrounding world. Using a Head Mounted display (HMD), the user of an AR system can visualize the exterior world with additional virtual information that is generated in real time and in a contextual way. In order to have efficient AR systems all the information must be geo-referenced and the underlying support system must handle some of the functionalities usually supported by Geographical Information Systems, namely the mapping between the virtual and the real world.

AR enables users to have a better perception of the surrounding world and a more efficient interaction with it. Virtual objects superimposed on real images exhibit information that users cannot detect directly through their own senses. This information helps users to better execute their tasks and minimize execution time. There are several complex technical and scientific problems when implementing AR systems including:

- The register of synthetic images on real images
- Position identification
- Information retrieval
- Presentation

The work reported in this paper is a contribution towards the solution of these problems, using, as case study, applications for environmental management. Some of these issues have been handled previously in GIS systems and, as such, some of the functionality currently used in GIS was integrated in this work. The main objectives of ANTS are:

- Establish a more appropriate configuration in AR Systems for natural and urban environments. This includes the definition of the overall architecture, considering different devices for access and presentation, and the implementation of each of the modules (described in detail in the next sections).
- Study new methods for image registry and navigation in augmented environments. We are using a 3D model of the environment to help the definition of the appropriate contextual information for a specific location.
- Study an AR infrastructure that makes it easier to:
    - Visualize the evolution process of natural, urban and artificial environments;
    - Provide information about geo-referenced elements in the environment.

The registration methodologies and the AR infrastructure developed in the ANTS project will be tested in three distinct environmental applications, all of which are related to the Tagus River estuary and the Parque das Nações area, in Lisbon. These applications entail:

- Visualization of water quality in artificial lakes and natural water streams;
- Superimposition of synthetic objects on real images of either urban buildings and/or natural landscapes;
- Projection of synthetic images on the ground, which reveal the soil's composition at the user's present spatial location (for example, the location of underground water supplies, water distribution networks and subsoil structure).

AR technologies may become very useful in the study and management of environmental systems, allowing real time visualization of data generated by simulation models during local observations. For example, the proposed system will allow the visualization of selected parameters generated by a water quality and transport model during a field observation of a particular area of the Tagus River estuary.

The next section summarizes research work related with this project. Section 3 presents the system as it is being implemented, and has been succinctly described above. Section 4 describes applications for the proposed system. Finally, we present some conclusions and orientations for future work.

2. RELATED WORK

Augmented Reality works by superimposing, in real time, synthetic elements over real images in the field of view of an HMD with see-through capabilities [5,12,13]. An HMD enables the AR system user to see both the outside world, as well as additional information generated contextually. Consequently, the user has a wider grasp of their surrounding real environment. The main problems associated with augmented reality systems are [1,3]:

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

Registration is a topic of continuing research. Many research works have been given emphasis to the correct implementation of 3D image registry mechanisms over a real scenario [4]. Accurately tracking of user's position and viewing orientation is crucial for AR registration. A recent overview of tracking systems can be found in [21]. Many approaches to position tracking require the user's environment to be equipped with sensors [15], beacons [8] or visual fiducials [10].

While some recent AR systems demonstrate robust and compelling for registration in prepared, indoor environments [24], tracking in unprepared environments is still an enormous challenge [3], particularly concerning outdoor and mobile AR applications. Many systems employ hybrid-tracking techniques to exploit strengths and compensate weaknesses of individual tracking technologies [2,25]. In [17] are described the early stages of an experimental mobile AR system that adapts its user interface automatically to accommodate changes in tracking accuracy. Ultimately, tracking in unprepared environments may rely heavily on tracking visible natural features [6,19].

In [20] the authors propose a method for augmented environment construction using a portable device named NaviCam, which is able to identify the user's position by detecting colour codes in the real world.

The first outdoor system was the Touring Machine [13]. This system, developed at the Columbia University, includes tracking (a compass, inclinometer and differential GPS), a mobile computer with 3D graphics board and a see-through HMD. It provides the user with world-stabilized information about an urban environment (the names of buildings and departments on the Columbia campus). More recent versions of this system render models of buildings that previously existed on campus, display paths that users need to take to reach objectives, and play documentaries of historical events that occurred at the observed locations [16].

At the University of Michigan, an AR application is being developed in the area of environmental engineering, related to the management of dangerous wastes (http://www-vrl.umich.edu/sel_prj/ar/hazard). BITS (Browsing in Time and Space) interface was developed for the exploration of virtual ecosystems. It allows users to navigate and explore a complex virtual world, interact with the objects that comprise it and make annotations indexed in time and space [11].

The recently started ArcheoGuide project is developing a wearable AR system for providing tourists with information regarding a historic site in Olympia, Greece [22]. At the University of Toronto, extensive work has also been done in the field of wearable computers [18].

Apart from a few commercial AR systems, which includes the augmentation of broadcast video to enhance sport events and to insert or replace advertisements in a scene [9], the state of the art in AR today is comparable with the early stages of VR – many systems have been demonstrated, but few have evolved beyond lab-based prototypes [3,7].

3. ANTS–AUGMENTED ENVIRONMENTS

The ANTS project addresses the problems stated in the previous sections and provides functionality in different areas, ranging from capturing images and determining the user's position, to retrieving information from the database for presentation purposes. These different functionalities are supported by an architecture integrating a set of modules distributed between two entities: the remote server and the client that interacts with the user (Fig. 1). The architecture has been designed to be flexible and move more or less functionality to the client depending on the available processing power of the client device.

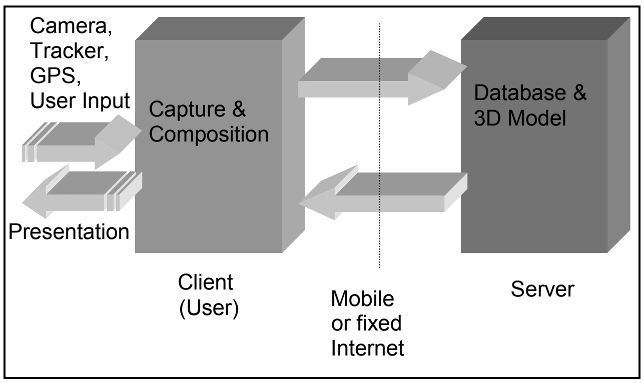

Figure 1: Client-server architecture of the ANTS system.

In the initial prototype, the user's equipment includes a laptop computer equipped with a video camera and a Head-Mounted Display (HMD). The result for the user is a real-time composite video being displayed on the HMD, obtained from the superimposition of synthetic elements (text, graphics or even other videos) over the real scene being captured by the camera. This type of augmented reality technology is usually referred as video see-through [3]. Optionally, the user can visualize the results on the laptop screen. We are also considering clients that run on PDAs or 3G mobile phones for a later phase in the project. The details of the current hardware setup are the following:

- Creative Labs Video Blaster ® WebCam Go: used to capture the image visualized by the user (in the prototype phase);
- Daeyang E&C Cy-Visor Mobile Personal Display DH-4400VP: used to show the composed image to the user;
- Intersense Intertrax 2: used to capture the movements of the head and adjust the view accordingly.

3.1 System architecture

The main modules composing the ANTS system architecture are presented in Fig. 1. The user's actions control the process of enhancing or augmenting the information under visualization. When the application starts, the actual position of the user has to be identified by the system. This positioning process combines:

- GPS data: The absolute position of the user is indicated by a GPS system. This type of system is used in combination with the other techniques below, in order to overcome the limitations and lack of precision associated with it.
- User tracking using appropriate devices: A tracker is used in order to obtain the current orientation of the user's head.
- Explicit indication: Sometimes, mainly in the bootstrap process, the user can indicate its position explicitly.
- Visual clues: Image recognition techniques will be used in order to recognize control points and determine the position of the user.

From this moment on, whenever the user asks for information the system locates his position as accurately as possible, and using those coordinates retrieves the information corresponding to that location. The determination of the data associated to a certain location involves the use of both the 3D Model and the multimedia database. The multimedia elements retrieved from the database are then composed in the real image, which comes from the video camera and the resulting video is conveyed to the user. The more relevant modules, which allow for the execution of the referred tasks are presented in Fig. 1 and described in the next subsections. The server components are accessible through an Http server, thus allowing requests from different clients and platforms.

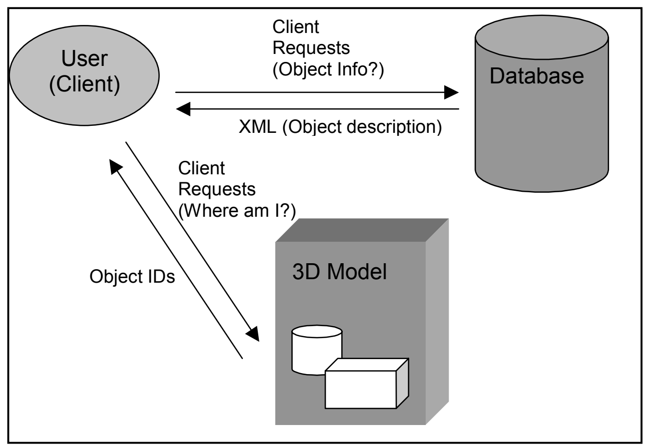

Figure 2: Fundamental modules and information flow.

3.1.1 3D model

This module encapsulates a 3D model for exploring the physical space. It establishes a relationship between the user's experiences in the physical space and the corresponding computational representation. It is also used to calculate distances and to locate the user through control points.

3.1.2 Geo-referenced database

This module stores all the information regarding the different elements of the space under analysis for augmentation purposes. By working cooperatively with the 3D model module, it allows the system to locate an element and retrieve the corresponding contextual information. The stored information can be found through an identifier that is returned by the 3D model. A list of multimedia elements to be shown to the user can be obtained by using the set of queries supported by the database. These elements can be of several types including text, graphics, images, audio and video. The result of a query is an XML file that describes the multimedia elements to be delivered to the client application for visualization purposes (Fig. 2). This database is populated by the users of the system. Currently we are using a MySQL database, but other SQL based database engine could be used.

3.1.3 Object recognition/image processing

A user's position can be determined by using a geo-referencing mechanism providing absolute coordinates (e.g. using GPS technology), or through the recognition of control points or landscape elements like the sea or the sky. Image processing techniques based on colour and texture can detect these control points and landscape elements. Image processing techniques combined with a tracking system also provide ways to obtain information on the user's movement. When the user moves the video capture device – currently a video camera - it becomes possible to calculate the optical flow on the image and consequently the real displacement. We foresee this module as an extremely important aid in the process of locating users due to the limitations of the available absolute positioning technologies (GPS). The need for robust and efficient algorithms for the detection of arbitrary objects, and the large volume of data available for processing, makes this a key topic in future research, given the current constraints in terms of processing power. For some applications the location of the user can be found from tags that are embedded in the environment. These tags can be implemented using radio emitters (e.g., Bluetooth), whose signal is then received by the client device. However, this requires the physical space to be instrumented before the augmented navigation starts.

3.1.4 Composition

The object composition module combines the images obtained in real-time by the video camera with the synthetic information retrieved either from the database or from the module managing the 3D model. The result is a sequence of images – video frames – combining these elements on one plane, which are then sent to the visualization device. The 3D model referred above is used to determine the visible information at each moment and how it should be projected on the plane, keeping in mind the position, dimensions and orientation of the objects it refers to.

3.2 Current Implementation

Most of the ANTS system architecture has been implemented mainly in the areas of presentation, 3D Model, database and server. An image recognition module has also been implemented and integration is underway. Next, we present the tools that were developed in the scope of the project. The first one is used to help the definition of the physical space that will be augmented. The other one is the client application that is used to compose and present the final image to the user.

3.2.1 Ants3D (3D model editor)

The editor presented in Fig. 3 allows the definition of a set of solids over a background image. The objective of this tool is to quickly obtain an approximate model of an urban landscape regarding its volumetric objects and their relative positions. The format being used for the external representation of a model is compatible with the widely used 3D commercial application formats, such as 3D Studio. The application was implemented using Microsoft Direct3D. Using ANTS3D, the area occupied by a certain landscape element can be defined together with its height and an identifier can be assigned to it. This identifier will later be used in search operations, to identify the objects in the database. This application will be updated in terms of editing capabilities, but it must be clear that it does not intend to become a substitute for commercial 3D editors. Instead, it allows for the rapid production of a first approximate 3D model that, in some cases, can be sufficient depending on the degree of precision and performance required by the application. In other cases where high precision and strong performance are important issues, ANTS3D can be used to generate a first approach in the building phase and to link the multimedia elements with the landscape.

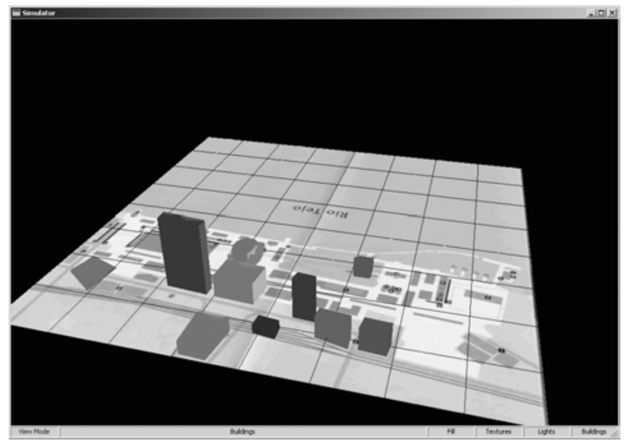

Figure 3: ANTS3D model editor.

3.2.2 ANTSViewer

ANTSViewer is the client application used for the visualization of the synthetic elements over real-time video. The main task of this tool is to combine the image captured in real time with the data that is retrieved from the database. Different media are considered and can be overlaid in the real image: video, image and text, in different formats. The tool is a DirectX (more specifically DirectShow) application. ANTSViewer reads the information about a specific location from an XML file and combines each of the grabbed images with the data that is described in the XML file. Each of these enhancements to the original image is composed in the bitmap retrieved from the video camera. The resulting image is presented fully finished to the user, in order to avoid flickering. Figure 4 shows an example of one of these images that resulted from the composition of the captured video frame with a bitmap and title images.

Figure 4: ANTSViewer.

4. APPLICATIONS

Although the image registration methods and the AR infrastructure developed in the scope of the ANTS project can be applied in the development of a variety of AR applications, covering different scientific and working areas, we are concerned with environmental management, for which geo-referencing and GIS functionalities are fundamental. At the present time three main driving applications are being developed and will be tested in the Tagus Estuary (Lisbon), more specifically at Parque das Nações:

- The visualization of water quality levels in natural water bodies and artificial lakes;
- The superimposition of synthetic images of past or predicted scenes on real images of man-made structures or natural environmental configurations;
- The projection of synthetic images on the ground, which reveal the soil's composition at the user's current spatial location.

The herein described AR system allows the user to explore and analyse a spatial location, having real time access to contextual geo-referenced information not available through conventional observation methods. The user is able to see-through the elements that compose the area where he is located: water, soil and physical elements. The reality is augmented with geo-referenced information.

4.1 Water quality

This application can be used in the following scenario: when observing a certain water body, such as a river or a lake, the user may need to immediately ascertain corresponding water quality data. Using the system described in this paper, or more precisely this application, the user is able to interact with a pollutant transport model and visualize selected parameters generated by this model. This dynamically generated additional information is superimposed on the real images and can be seen and controlled by the user. This means that the additional data is calculated in real time, as opposed to being stored in a static database.

The model, which supports the development of this application, is called DisPar (Discrete Particle distribution model). The DisPar model is a mathematical formulation to solve advection-diffusion problems in aquatic systems [14].

4.2 Temporal evolution of superficial solid structures

This application allows a user to navigate through a certain spatial area and have access, in real time, to additional information related to the objects that compose that area. These objects may include natural elements or man-made structures. Two possible examples of this application are the superimposition of the image of a digital terrain model of a landfill before being renovated into a park, or the superimposition on a building of the synthetic image of its restoration.

Therefore, the user is able to simultaneously see the same spatial area or the same object at different stages of its life cycle. This spatial parallelism takes advantage of our notable capacity to compare and reason about multiple images that appear simultaneous within our eye span [23]. This human capacity facilitates the detection and analysis of changes in the natural and artificial components of a landscape.

At the moment, this application includes the anchor buildings of Parque das Nações in Lisbon (former area of the Expo 1998) and some of the plants that compose the gardens.

4.3 Subsoil structure

A possible scenario for the use of this application consists in locating infrastructures for public supply networks (water, sewage, telephone) in order to avoid damage when intervention to the subsoil is necessary. Through the use of this application the user is able to look at the soil and see synthetic images revealing its interior (subsoil) constitution at that point in space and time projected on it. This application can also be used for the exploration and analysis of the subsoil composition in geological terms or for locating watersheds.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

In the scope of the ANTS project, we are developing an augmented reality technological infrastructure for environmental management. This infrastructure should be effective concerning information presentation and management, as well as in the location and identification of objects within the user's visual field. These characteristics allow the ANTS infrastructure to contribute to the resolution of the fundamental problems found in the construction of AR systems. Thus, the system described in this paper allows for the creation of new AR tools, which aid in environmental management by facilitating the perception and interaction with the involving spatial area and its natural and artificial components. These tools are evaluated in three different applications: water quality, the temporal evolution of superficial solid structures and the structure of the subsoil.

The system's architecture follows the client-server model and is based on several independent, but functionally interdependent modules. It has a flexible design, which allows the transfer of some modules to and from the client side, according to the available processing capacities.

Future developments include the improvement of the referred prototypes and applications, as well as the development of the system's remaining components, namely the integration of the image tracking module. Additional developments for supporting heterogeneous devices, such as PDAs and mobile phones are also planned.

6. ACKNOWLEDGMENTS

The ANTS project is funded by the Fundação para a Ciência e Tecnologia (FCT, Portugal) (project nº MGS/34376/99-00). We would like to thank YDreams (www.ydreams.com) for support in the work described in this paper.

7. REFERENCES

[1] Azuma, R. A Survey of Augmented Reality. Presence, 6, 4 (1997), 355-385.

[2] Azuma, R., Lee, J. W., Jiang, B., Park, J., You, S. and Neumann, U. Tracking in Unprepared Environments for Augmented Reality Systems. Computers and Graphics 23, 6 (1999), 787-793.

[3] Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and Macintyre, B. Recent Advances in Augmented Reality. IEEE Computer Graphics and Applications, 21, 6 (2001), 34-47.

[4] Azuma, R. and Bishop, G. Improving static and dynamic registration in an optical see-through HM*D* in Proceedings of SIGGRAPH '94 (Orlando, 24-29 July 1994), 197-204.

[5] Bajura, M.; Fuchs, H. and Ohbuchi, R. Merging virtual objects with the real world: Seeing ultrasound imagery within the patient**.** Computer Graphics, 26, 2 (1992), 203-210.

[6] Behringer, R. Registration for Outdoor Augmented Reality Applications Using Computer Vision Techniques and Hybrid Sensors in Proceeding of IEEE Virtual Reality'99 (Houston TX, 13-17 March 1999), IEEE CS Press, 244-251.

[7] Brooks Jr., F.P. What's Real About Virtual Reality?. IEEE Computer Graphics and Applications, 16, 6 (1999), 16-27.

[8] Butz, A., Baus, J. and Kruger, A. Augmenting Building with Infrared Information, in Proceedings of the Int. Symposium on Augmented Reality (ISAR 2000) (Munich, Germany, 5-6 October 2000), IEEE CS Press, 93-96.

[9] Cavallaro, R. The FoxTrax Hockey Puck Tracking System. IEEE Computer Graphics and Applications, 17, 2 (1997), 6-12.

[10] Cho, Y., Lee, J. and Neumann, U. A Multi-Ring Fiducial System and an Intensity-Invariant Detection Method for Scalable Augmented Reality in Proceeding of the First IEEE Int. Workshop on Augmented Reality'98 (San Francisco, CA, 1 November 1998), A. K. Peters, Natick, Mass., 147-165.

[11] Dias, A.E.; Silva, J.P. and Câmara, A.S. Bits: Browsing in Time and Space in Comp. CHI'95 Human Factors in Computing Systems (Denver, CO, 7-11 May1995), 248-249.

[12] Feiner, S.; Macintyre, B. e Seligmann, D. Knowledge-Based Augmented Reality. Communications of ACM, 36, 7 (1993), 53-62.

[13] Feiner, S.; Macintyre, B.; Hollerer, T. and Webster, A. A Touring Machine: Prototyping 3D Mobile Augmented Reality for Exploring the Urban Environment in Proceedings of International Symposium on Wearable Computing'97 (Cambridge, MA, 13-14 October 1997), 74-81.

[14] Ferreira, J.S. and Costa, M. A Determinist Advection-Diffusion Model based on Markov Processes. Journal of Hydraulic Engineering, ASCE, 128, 4 (2002), 399-411.

[15] Harter, A., Hopper, A., Steggles, P., Ward, A. and Webster, P. The Anatomy of a Context-Aware application, in Proceedings of the Fifth ACM/IEEE Int. Conf. on Mobile Computing and Networking (MobiCom'99) (Seattle, WA, August 1999), 59-68.

[16] Hollerer, T., Feiner, S., Terauchi, T., Rashid, G. and Hallaway, D. Exploring MARS: Developing Indoor and Outdoor User Interface to a Mobile Augmented Reality System. Computer and Graphics, 23, 6 (1999), 779-785.

[17] Hollerer, T., Hallaway, D., Tinna, N. and Feiner, S. Steps Toward Accommodating Variable Position Tracking Accuracy in a Mobile Augmented Reality System in Proceedings of Second Int. Workshop on Artificial Intelligence in Mobile Systems (AIMS'01), (Seattle, WA, 4 August 2001), 31-37.

[18] Mann, S. An historical account of the 'WearComp' and 'WearCam' inventions developed for applications *in 'Personal Imaging'* in Proceedings of the IEEE first ISWC'97 (Cambridge, MA, 13-14 October 1997), 66-73.

[19] Neumann, U. and You, S. Natural Feature Tracking for Augmented Reality. IEEE Trans. Multimedia, 1, 1(1999), 53-64.

[20] Rekimoto, J. and Nagao, K. The World through the Computer: Computer Augmented Interaction with Real World Environments in Proceedings of ACM UIST´95, (Pittsburgh, PA, 15-17 November 1995), ACM Press, 29-36.

[21] Rolland, J. P., Davis, L. D. and Baillot, Y. A Survey of Tracking Technologies for Virtual Environments, in Barfield, W. and Caudell, T. (eds.), Fundamentals of Wearable Computers and Augmented Reality, Lawrence Erlbaum, Mahwah, N. J., 2001, 67-112.

[22] Stricker, D., Dähne, P., Seibert, F., Christou, T., Almeida, L., Carlucci, R. and Ioannidis, N. Design and Development Issues for ARCHEOGUIDE: An Augmented Reality based Cultural Heritage On-site Guide, in Proceedings of International Conference on Augmented, Virtual Environments and 3D Imaging (ICAV3D 2001) (Mikonos, Greece, 30 May-1 June 2001), 1-5.

[23] Tufte, E. R. Visual Explanations: Images and Quantities, Evidence and Narrative. Graphics Press, Cheshire, Connecticut, 1997.

[24] Yokokohji, Y., Sugawara, Y. and Yoshikawa, T. Accurate Image Overlay on Video See-through HMDs Using Vision and Accelerometers in Proceeding of IEEE Virtual Reality (New Brunswick, NJ, 18-22 March 2000), IEEE CS Press, 247-254.

[25] You, S.; Neumann, U. and Azuma, R. Orientation Tracking for Outdoor Augmented Reality Registration. IEEE Computer Graphics and Applications, 19, 6 (1999), 36-41.