Mobile Augmented Reality for Environmental Management (MARE)

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Abstract
Access to real-time data while in field observations is often a requested issue in environmental management. Additionally, it is easier to see that information spatially distributed where it makes sense, leveraging users of the task of searching for the context where the retrieved information can be applied. Augmented Reality (AR) is a technology that allows the superimposition of synthetic images over real images, providing augmented knowledge about the environment in the user's vicinity. AR will also make the task more pleasant and effective for the user, since the required information is spatially superimposed over real information related to it. This short paper describes ANTS (Augmented Environments), an AR project for environmental management providing geo-referenced information to the user. The system's architecture has a flexible design based on a client/server model, where several independent, but functionally interdependent modules are articulated. Therefore, modules can be moved from the server side to the client side or vice-versa, according to the client processing capacity. The system is being deployed in laptop computers and work is in progress to deploy the system using Personal Digital Assistant (PDA) devices. A 3D model and a geo-referenced database are used in the server for user positioning, and presentation components are used in the client to superimpose synthetic information over real images. Several applications for the system are being developed and will also be discussed in this short paper.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems – Artificial, augmented, and virtual realities. H.2.8 [Database Management]: Database Applications – Spatial databases and GIS. I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction techniques.I.6.3 [Simulation and Modeling]: Applications.

Keywords: Augmented/Virtual Reality, Modelling/Animating Nature, Interaction/Multimedia-Techniques, Data Visualization.

1. Introduction

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

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

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

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

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

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

Moreover, technological limitations are a significant issue while developing AR applications for mobile devices. Small displays, small screen resolution, limited processing power, low data bit rates, out of coverage gaps in wireless networks or network latency are examples of the problems that need to be addressed while developing AR systems. The user interface should give a pleasant experience overcoming these issues and giving users just the relevant information.

This paper describes ANTS, an AR system for environmental management that contributes towards the solution of these problems, and presents the applications that are being developed to test and exemplify its usage. These applications comprise:

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

The system currently uses a video see-through HMD. Work in progress aims its migration to PDA and similar devices, such as 3G phones, as reported in section 3.

The following section reviews related research approaches. Section 3 describes the project infrastructure and the PDA client being developed. Section 4 presents the applications where the AR system is being applied. The paper ends with conclusions and future work directions.

2. Related Work

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

Main problems associated with AR systems are [1, 17]:

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

Accurately tracking user's position and viewing orientation is vital to minimize AR registration errors. A recent overview of tracking systems can be found in [5]. In prepared and controlled laboratory experiments, accurate registration methods have been demonstrated [2]. However, tracking in unprepared environments is still an enormous challenge [1, 3], particularly concerning outdoor and mobile AR applications. In [4] a method for estimating registration errors is used to generate probabilistic error estimates for points, in either 3D world coordinates or 2D screen coordinates.

Each tracking system reveals different problems related to the technology they use: vision-based trackers are computationally intensive, magnetic trackers have low-accuracy and mechanical trackers are cumbersome. Hybrid technologies are then used to exploit strengths and compensate weaknesses of individual tracking technologies [2, 3]. Accuracy in mobile AR systems changes over time and interface should adapt itself adjusting to changes in tracking accuracy [6]. In [7] authors developed a method to build a computer augmented environment using a portable device, called NaviCam, that has the ability to recognize the user's situation by detecting color-code IDs, in real environment. Additional information is then superimposed in the video-see-through display.

The first outdoor system was the Touring Machine [8]. This system assists users interested in visiting the Columbia's University campus, overlaying information about points of interest in their neighborhood. It combines a video-see-through display with an handheld display using different interaction technologies to take advantage of their complementary capabilities. A more recent version of the system rather than linking individual labels or web pages to locations, supports context-dependent, narrated multimedia presentations that combine audio, images, video, and omni directional camera imagery. Additionally, 3D graphics are overlaid in the user interface and presentation content, showing models of buildings that no longer exist and views of visually obstructed infrastructures. When selecting points of interest the user is also guided to them [9, 10].

In [16] seven different interfaces illustrate several approaches to AR interfaces. In this project, virtual and real worlds are apart and information is exchanged between them over an abstract channel that carries all information, to provide an augmented reality experience. Mobile devices are improving their computational power. Indeed, in the Vienna University of Technology, the Handheld AR project is developing a PDA-based AR system to be used in the SignPost project. This system allows a user to stroll over an unknown building showing him or her several navigational hints. (**http://www.ims.tuwien.ac.at/research/handheld_ar**).

Human senses are unable to detect several dangerous conditions, namely harmful radiation or toxic gases. In the University of Michigan, an application is being developed to allow humans to detect potentially hazard conditions, combining the collected data in a three geometric database, and using augmented reality to present this information to the users (**http://www-vrl.umich.edu/sel_prj/ar/hazard/**). BITS (Browsing in Time and Space) interface was developed for the exploration of virtual ecosystems. It allows users to navigate and explore a complex virtual world, interact with surrounding objects and make annotations indexed in time and space [11].

The Archeoguide project is developing a wearable AR system that will give visitors a feeling of how a historical site, as Olympia in Greece, was during previous periods of time [12]. AR systems are still in their infancy with a few commercial systems in use, mainly for augmentation of broadcast video to enhance sports events and to insert or replace advertisements in a scene [14]. Displays, trackers, and AR systems in general need to become more accurate, lighter, cheaper and less power consuming. Only a few have evolved beyond lab-based prototypes [1, 13].

3. ANTS Infrastructure

ANTS project tries to overcome the problems stated in the previous sections and provides contextual information, using a HMD or a PDA for environmental management. With a flexible design, the ANTS's architecture is composed by a set of modules distributed between the client and server entities (Fig. 1). Some modules can be moved from or to the client entity according to its available processing capacities and the applications requirements.

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

3.1. System architecture

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

- GPS data: The absolute position of the user is indicated by a GPS system. This type of system is used in combination with the other techniques below, in order to overcome the limitations and lack of precision associated with it.

- User tracking using appropriate devices: A tracker is used in order to obtain the current orientation of the user's head.

- Environment mapping: knowledge of the physical form and position of the entities on the environment that is being augmented.

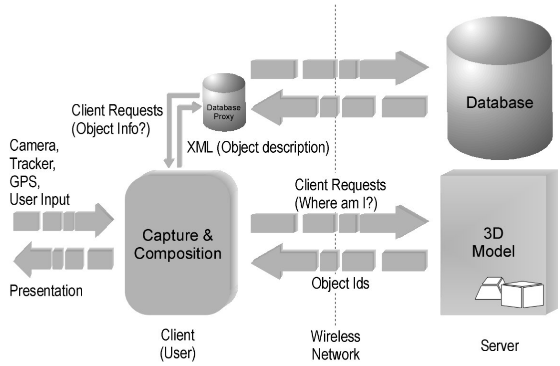

Figure 1: *ANTS Architecture and Information Flow (PDA)*

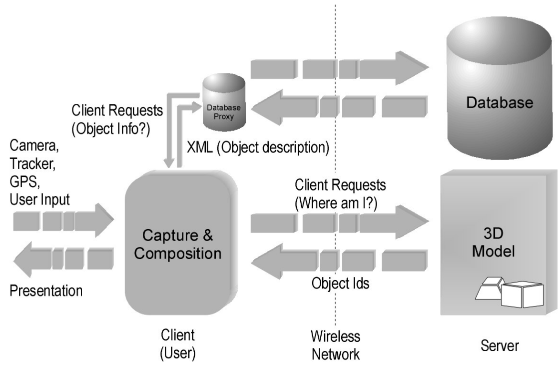

Figure 2: *ANTS Architecture and Information Flow (PDA)*

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

For more information, the multimedia geo-referenced database is queried using the UOIs returned from the 3D model. The retrieved multimedia objects' data is then superimposed over the real image, in the AR composition module. The server components are accessible through HTTP, a common standard, allowing different devices to perform requests.

The main modules composing ANTS's architecture can be seen in figure 1 and are described in the following subsections.

3.1.1. 3D Model Server

The 3D Model Server works as a bridge between the virtual and real worlds, establishing a relationship between the physical space and the corresponding virtual representation. With this server it is possible to locate and depict the user and its surroundings, for a correct mapping of the contextual information. The 3D Model Server stores and edits the 3D model of the environment, which is used to return information about the position, orientation and dimensions of physical structures.

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

The simple 3D model is a tool to quickly obtain a representation of an urban landscape regarding its volumetric objects and their relative representation. While editing the model, the user only has to input the height of each object.

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

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

- Inside objects: all objects where the user is inside. It can be more than one as there is no requirement that the model is restricted to physical non-overlapping entities.
- Visible objects: all objects in front of the user and inside of a view volume, defined by an angle much in the same way as the field of view of a camera.
- Surrounding objects: all the other objects that are not visible objects or inside objects, and that are inside the action volume. These objects are further classified in "Left" and "Right" to enable user orientation when displaying information.

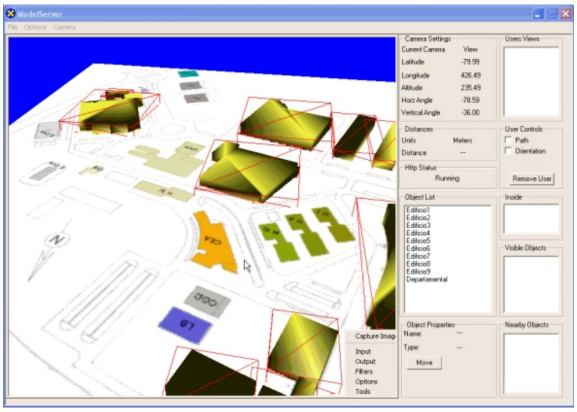

Figure 3: *3D model editor*

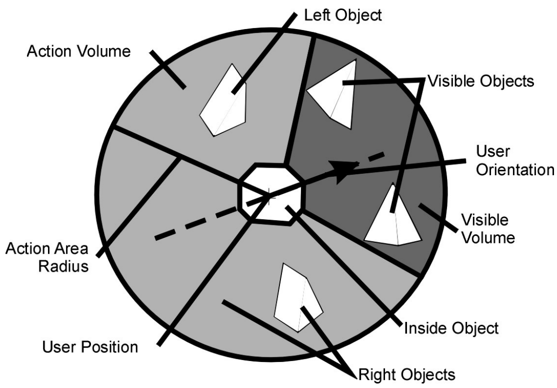

Figure 4: *Object classification*

Developed with Microsoft Direct 3D, this tool allows for a rapid production of a first approximate 3D model of the real world, often sufficient for augmented reality applications.

3.1.2. Geo-referenced database

All information related to the various elements filling the space under analysis is stored in a geo-referenced database. Using the object identifiers contained in the list of objects in the user's vicinity returned by the 3D model, the system is able to query the geo-referenced database and retrieve the related contextual information. A list of multimedia elements to be shown to the user, whether text, graphics, images, audio or video, can then be obtained. As a result a XML file is returned describing the multimedia elements to be delivered to the client for visualization purposes.

3.1.3. AR Composition Module

The main goal of this module is to superimpose the data elements retrieved from the geo-referenced database with the support of the 3D model over the image of the real world captured by the video camera, and display the composed image in the HMD or PDA screen.

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

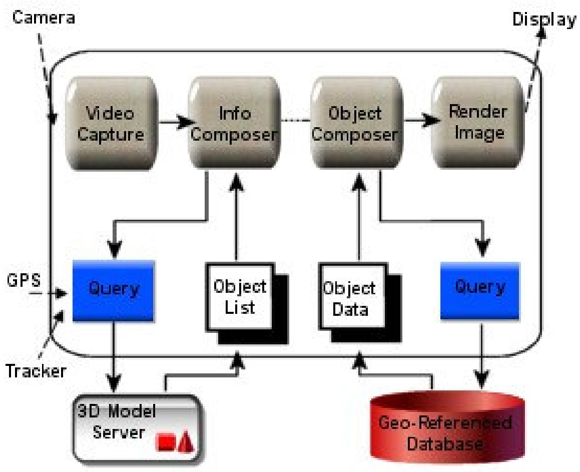

Figure 5: *AR User Module Architecture*

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

```
- <OBJECTS>
  + <INSIDE_OBJECT>
  - <VIEW_OBJECT>
    - <OBJECT>
      - <ID>6</ID>~
      - <TYPE>BUILDING</TYPE>
      - <NAME>Oceanario</NAME>
      - <SCREEN_POS>0.3223,0.273
      </SCREEN_POS>
    </OBJECT>
  </VIEW_OBJECT>
  - <SIDE_OBJECT>
    - <OBJECT>
      - <ID>12</ID>
      - <TYPE>TRANSPORT</TYPE>
      - <NAME>Teleferico</NAME>
      - <SIDE>1</SIDE>
    </OBJECT>
    + <OBJECT>
  </SIDE_OBJECT>
  - <DIRECTION_OUI>45.78095,8.22123
  </DIRECTION_OUI>
</OBJECTS>
```

Figure 6: *3D Model Response Example*

Figure 7 illustrate the results of composing the captured image with the data about the surrounding environment, using the InfoComposer. At the top, there is a list representing the objects on each side of the user field of view, the surrounding objects. The information about the surrounding objects, allows the user to change his or her orientation in order to place them in the field of view. Being currently developed, the PDA version of the AR Composition module only shows the objects seen by the user at any instant (fig. 8). Notwithstanding, the arrows are shown without labeling and the users are able to select them, sending a request for that information.

Figure 7: *Outdoor AR example*

Avoiding this step saves computational power, which is important in a mobile device like the PDA. Thus, a more smooth visualization of the environment can be supplied to the user. When the user needs additional information, he or she will request it and it will be rendered over the real image for a while. This technique also avoids cluttering the scene with unnecessary information, given the small size of the display.

Figure 8: *PDA AR example*

Attached to each visible object there is an icon and a label. If the user selects one of these icons, the object composer, using the UOI of the corresponding object, will query the geo-referenced database to obtain more detailed information. The returned data elements are then composed with the real image. As with the InfoComposer, ObjectComposer accepts data elements of several types including images, video or text. The resulting composed image is returned to user display fully finished, avoiding flickering. A version of this tool is already operating for a HMD and laptop interface. At the present time, a new version, using Pocket PC 2002 tools, is being developed for use with a PDA interface, since there is no support for DirectShow in this platform.

4. Applications

Although ANTS' infrastructure and image registration methods could be applied in the development of other AR systems, we focused on environmental management, for which geo-referenced and GIS functionalities are fundamental. At the moment three main applications are being developed to be deployed in the Parque das Nações and the Tagus Estuary (Lisbon):

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

Contextual geo-referenced information augments the real environment giving the user real time access to information not available through conventional observation methods. The user is then able to explore and analyze a spatial location, enabling him or her to see-through the elements that compose the area where he or she is located at: water, soil and physical elements.

4.1. Visualization of Water quality

While observing a water body, such as a river or a lake, the user may need to ascertain corresponding water quality data or simulate a pollutant to check its behavior in order to prevent future hazards. Interacting directly with a pollutant transport model and visualizing selected parameters generated by this model, allows the user to simulate several possible scenarios and use that information to prevent future environmental aggressions (Fig. 9). All additional information is generated dynamically, calculated in real time and can be seen and controlled by the user.

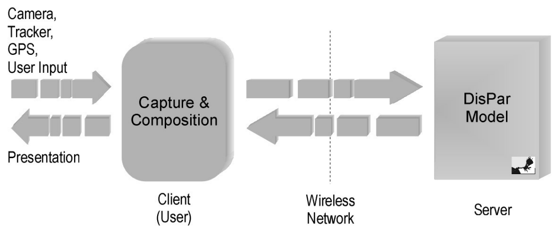

Figure 9: *Client-Server for water quality application*

This application is being deployed in a Compaq iPAQ with GPS, camera, orientation tracker and wireless network capabilities. The user is tracked in real time, which allows the system to supply him or her information about the water quality parameters in his or her vicinity. In order to see evolution of the model the user will have two distinct views.

In the first view, user position is marked with an icon in the map of the region where the model is evolving. This view is similar to the approach used in the PC view of the model and allows a more general view of the model. The user's position is always in the field of view, although users are allowed to zoom in or zoom out, to see a more detailed view of the region near them or to see a more general view of a wider region, respectively. In this view, the user is also able to adjust model parameters to simulate the desired situation. In figure 10, an image of a simulation, using DisPar transport model, is presented. The DisPar (Discrete Particle distribution model) model is a mathematical formulation to solve advection-diffusion problems in aquatic systems [15].

Figure 10: *DisPar "Image courtesy of FCT/UNL, (c) 2003, used with permission"*

Since Compaq iPAQ has a small screen, and the interaction with the model requires a huge number of parameters to be defined, templates are used to enhance interaction with the DisPar transport model. Template icons, representing pollutant agents, are embedded with predefined values and the user just has to choose between them and select the initial point in the map where the pollution will begin.

In the second view, the user is able to see the evolution of the DisPar transport model in his or her vicinity, superimposed in the view of the real environment. In this case, the water body will be replaced by the model evolution in the corresponding position.

4.2. Visualization of characteristics and temporal evolution of superficial solid structures

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

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

This application is being targeted into two different devices, a laptop computer and a PDA. Therefore, the interface is adapted to adjust to the features and different interaction techniques of these devices. The content deployed in this application is used and adjusted, if necessary, by each platform.

4.3. Visualization of subsoil structure

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

This application is also being deployed for the Parque das Nações in Lisbon. Similarly, to the application seen above it is targeted into two different devices, a laptop and a PDA. While in a stroll, the user may wish not to be in an immersive environment, so the PDA may be a better interface, allowing the user to see the environment directly and look for additional information on the PDA. Depending on the task being performed, different interfaces may be more suitable to accomplish the goal.

5. Conclusions and future developments

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

Additionally, the user is able to choose between two different clients of the system. While using a laptop-based client, the user is given an immersive experience using the HMD. Alternatively, the user can handle a PDA, allowing him or her to directly observe the environment, and watch the PDA looking for additional information.

These tools are evaluated in three different applications: water quality, information related to superficial solid structures, and the structure of the subsoil. Future developments include improvement of the referred prototypes and applications, as well as the development of the system's remaining components, namely the integration of an image tracking module. Additional developments for supporting mobile phones are also planned.

Acknowledgements

The ANTS project is founded by the Fundação para a Ciência e a 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.

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