ARCHEOGUIDE: First results of an Augmented Reality, Mobile Computing System in Cultural Heritage Sites

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Abstract:

This paper presents the ARCHEOGUIDE project (Augmented Reality-based Cultural Heritage On-site GUIDE). ARCHEOGUIDE is an IST project, funded by the EU, aiming at providing a personalized electronic guide and tour assistant to cultural site visitors. The system provides on-site help and Augmented Reality reconstructions of ancient ruins, based on user's position and orientation in the cultural site, and real-time image rendering. It incorporates a multimedia database of cultural material for on-line access to cultural data, virtual visits, and restoration information. It uses multi-modal user interfaces and personalizes the flow of information to its user's profile in order to cater for both professional and recreational users, and for applications ranging from archaeological research, to education, multimedia publishing, and cultural tourism. This paper presents the ARCHEOGUIDE system and the experiences gained from the evaluation of an initial prototype by representative user groups at the archeological site of Olympia, Greece.

Keywords:

Augmented Reality, Mobile Computing, Position Tracking, Image Rendering, Avatars.

Project URL:

http://Archeoguide.intranet.gr.

1. Introduction

ARCHEOGUIDE is a novel system bringing state-of-the-art visualization technology and mobile computing in cultural heritage. It provides personalized Augmented Reality tours [1] and reconstructions of ruined cultural heritage sites in order to help visitors and scientists better appreciate and enjoy the past glory of these sites. It features portable units carried by users during their site tours, communication networks, and a central database. This multimedia database is the central depository for the multimedia material making up the tour presentations. It is also used to support scientific research and promote cultural education in European countries and beyond.

The system bridges the gap between recreation and science and renders culture and history more accessible to a wider public. Unlike traditional audio commentary systems widely adopted in cultural sites all over the world, ARCHEOGUIDE offers a more lively and realistic experience. The 3D reconstructions of monuments and artifacts are presented to the user through a special augmented reality interface while he has constant visual contact with the natural surroundings and listens to audio commentary. This feature renders the system more user-friendly and avoids the shortcomings of other similar systems where the user is isolated, or immersed in a purely synthetic world.

Respecting the sensitivity of cultural heritage sites, the system poses no risk of damage to the site, visual or visitor disturbance, or interruption of the normal operation of the site. In addition, it presents a very simple interface for creating new content and enriching the database with scientific information.

This paper is organized in 10 sections. The system architecture is described first and details are given on its modules. This is followed by a presentation of the user evaluation of the system and an analysis of these results. Emphasis is put on presenting a complete description of ARCHEOGUIDE for the benefit of the reader and other technical projects in cultural heritage. Details on the system setup and use scenarios are given and conclusions are drawn for use in the future system development.

2. Overview of System's Architecture

A description of ARCHEOGUIDE's architecture is contained in [12]. In this paper we provide more detailed information for the purpose of completeness and for helping the reader better understand the user feedback following the evaluation of the system.

ARCHEOGUIDE is based on a client-server architecture. It comprises three modules: the Site Information Server, the Mobile Units, and the Communication Infrastructure. These modules are depicted in Figure 1 and analyzed below.

2.1. The Site Information Server

The Site Information Server, or server for short, is a central PC comprising a multimedia relational database. It serves as the main depository of the system, storing audio-visual and textual information covering the site and its monuments, as well as, related artifacts and information. The database is organized thematically and

Figure 1 System Architecture.

supports querying according to attributes like geographic position (coordinates), item type (e.g. temple), time (e.g. chronological era), level of information (e.g. general, detail, scientific), theme (e.g. relates to sports), and versioning (e.g. stage in the restoration process). Its contents can be accessed by the mobile units who request material according to user preferences, position, and selected tour.

A Database Manager (DBM) is in charge of the operation of the database. It exports a remote access interface for communication with mobile units and other servers (e.g. Web servers, museum servers) and allows querying and retrieval of its contents.

The server is accompanied by authoring tools. These tools can be used by the site manager for creating new multimedia content, organizing it, and defining new tours in the site. The same tools can also be used for creating and updating existing guidebooks and CD-ROMS. Alternatively, they provide archeologists and scientists with a user-friendly graphical interface for documenting the contents of the site and update it with the latest research in the field. Figure 2 illustrates the graphical user interface (GUI) of the authoring tools. It is based on Windows and supports all standard features and operations familiar to computer users.

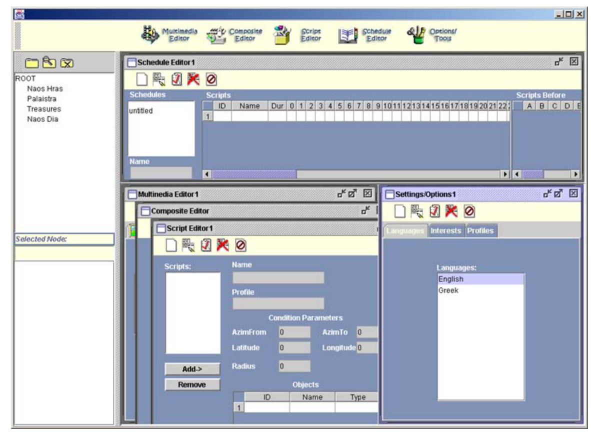

Figure 2 Authoring Tools GUI.

2.2. The Mobile Unit

The clients are a group of Mobile Units (MU). There are three different implementations of MUs based on laptop, pen-PC, and palmtop computers, each providing similar features according to their processing capabilities.

The top-of-the-range MU, the laptop-based one, is built on a Toshiba Satellite 800MHz laptop computer, with 256 MB RAM. A Differential GPS receiver (Garmin GPS-35 LVS) and a digital compass (Precision Navigation TCM2) are hooked on the laptop to provide position and orientation tracking of the touring user. A PC camera with automatic luminance adjustment for capturing live video from the user's viewpoint, and a special Augmented Reality (AR) Head-Mounted Display (HMD) (Sony Glasstron PLM-S700) in the form of a pair of see-through sunglasses for displaying AR worlds featuring monument reconstructions on top of their natural surroundings are also attached to the laptop.

The DGPS receiver collects data from a constellation of 4-12 satellites to calculate the exact location of the user. The accuracy of the calculations is improved by a correction signal transmitted from a DGPS beacon situated at a precisely known position. This accuracy is typically measured at less than one meter.

The compass is based on a digital inclinometer sensor to measure the user's heading with an accuracy of 0.2° and allows for magnetic field measurements and automatic calibration. This approach provides superior precision and suffers no interference from electromagnetic fields in the archaeological site.

The position and orientation information is used by the

MU to determine the position of the user in the archeological site and the monument ruins he is staring at. Based on this information, the system matches the corresponding, calibrated images (retrieved from the site database and being captured from a slightly different angle) with the live video captured from the camera in the user's heading. The matching is performed by a phase-correlation image registration technique [13] used to calculate a warping transform. This transform is then used to rotate, translate, and scale a 3D VRML model of the reconstructed ruins the user stares at, so that it can be rendered on top of the live video image. The image matching and rendering currently run at 15 frames/sec resulting in realistic augmented views even when the user is moving at a fast pace or turning his head. The resulting AR image is displayed on the HMD. The user sees a realistic representation of the monument in its ancient glory and at the same time he has visual contact with his surroundings, in contrast with other systems where he is isolated. Audio commentary is coupled to the visual presentations, giving descriptions and additional information.

The hardware components of the MU are integrated in a compact way and are carried by the touring user. The user wears the HMD and a bicycle-type helmet upon which the camera and the compass are mounted. They are connected to the laptop and the DGPS receiver, which are carried in a backpack for protection and easy transport.

The pen-computer implementation of the MU is built on a Fujitsu Stylistic 3400S flat panel PC with 64 MB RAM. The machine features a pressure-sensitive screen where the user can write and interact with it with a special pen, and DGPS and digital compass devices like the ones described above. This lighter version of the MU displays pre-rendered 3D reconstructions of ancient ruins on its screen, accompanied by information and audio-visual content of related artifacts (e.g. statues originally found in the visualized temple and currently stored in a museum). The presented information is closely related to the position and orientation of the user as it is tracked by the system. The visual content is archived in the site database and downloaded to the MU together with the accompanying audio commentary. Navigation help is also offered to the user. A digital map (catopsis) of the site is displayed on screen together with his current position and the direction he is heading for. Figure 3 illustrates the map. The heading of the user is indicated by a red-yellow compass updated in real time.

The lightest version of the MU is built on a Compaq iPAQ Colour Pocket PC. This is a lightweight and very compact standalone device supporting user interaction via a special pen operating on its screen. It presents the user with similar information as the pen-computer but it is the user's responsibility to request the material corresponding to the monument he is looking at as the system has no means of determining it automatically.

Figure 3 Navigation Interface.

The user can consult an on-screen digital map to navigate in the site. However, his position and orientation are not displayed. This choice (of not using a DGPS receiver or a digital compass) is based on the compactness of the device, which would otherwise have to be sacrificed.

2.3. Communication infrastructure

ARCHEOGUIDE uses two wireless networks for the communication needs of its components. The first one is used for the communication between the Mobile Units and the Site Information Server allowing the transfer of the audio-visual content of the site tours. It is a wireless LAN based on the IEEE 802.11 Wireless LAN Standard. The mobile units and the server can hook up into the WLAN with a Lucent ORiNOCO wireless network PCMCIA card and accompanying antenna plugged into their PCMCIA slots. The network uses a group of 3 Access Nodes (comprising antenna and transceiver modules) to fully cover the archaeological site of Olympia. The traffic handled by the network includes images, VRML models, and audio clips and up to 50 mobile units can connect to the network at any moment.

The second network is a point-to-point wireless link used by a DGPS reference station to communicate correction signals to the MU's DGPS receiver. This station is a LF DGPS beacon transmitting data over the wireless link in the 300kHz band under the RTCM SC-104 specification.

3. Overview of System's Software Architecture

This section gives a brief description of the software components of the SIS and the MU. Server components have been implemented in Java for maximum portability, whereas mobile unit components have been developed in C++ for maximum speed, as they must operate in real time.

3.1. SIS Software Components

The Site Information Server consists of the following components: Data Manager, Authoring Tool, and GIS Authoring Tool.

The Data Manager (DBMS) is built on Oracle 8 and supports querying and interfacing of the database with the other system components. The multimedia material is stored (in several standard formats) outside the DBMS itself to avoid having to manage a very "heavy" database. It is stored in a special directory of the server's network file system, which requires special privileges for browsing and/or editing, and is pointed to by a URL.

The Authoring Tool is used by content creators in order to insert, delete and manipulate objects in the multimedia database. Through this interface users can traverse the archeological site's database structure in a tree view, change this structure, manipulate multimedia objects, group multimedia objects into composite objects, list multimedia and composites to construct scripts and, finally, create schedules from existing scripts.

The GIS Authoring Tool (GISAT) is a module of the ARCHEOGUIDE Authoring Tool. This module enables the user to perform the following operations:

- Visualize the archaeological area in Olympia, as shown from above, using an orthophotomap of the site in high resolution.
- Perform basic graphical operations on the image, such as zoom-in, zoom-out, and distance measures.
- Recognize the coordinates of each point in the image by a mouse click. Since the image is registered in both geographical and projection coordinates systems, each mouse click is identified by two coordinate pairs: (longitude, latitude) and (X, Y), in WGS84 and UTM systems, respectively.
- Define new and manipulate existing site node entities, which reside on the Server Data Manager. Specifically, the user is provided with Select, Insert, Delete and Query options to define or manipulate the geometry of the Server Site Nodes.
- Define new and manipulate existing viewpoint entities, which reside on the Server Data Manager. Specifically, the user is provided with Select, Insert, Delete and Query options to define or manipulate the geometry of Server Viewpoints.

The SIS tools are accessed via a standard windows Graphical User Interface, depicted in Figure 2. Standard operations like Create, Cut, Paste, Save, Edit are supported with the contents listed in a tree-like structure for easier visualization. The root of the tree comprises the whole site with nodes corresponding to smaller regions (e.g. the Temple of Zeus), and leaf nodes to multimedia objects (e.g. images).

3.2. Mobile Unit Software Components

The Mobile Unit consists of the following components: MPS Controller, Image Tracker, AVALON renderer, and Graphical User Interface (GUI). All these client components operate concurrently, with the controller instructing continuously the renderer what to render based on the data read from the tracking system, and the user interactions. The controller's interaction with the image tracker is done indirectly via the image renderer. The controller is also responsible for requesting multimedia objects from the site database over the wireless network. So, the MU is implemented as a multithreaded process with the Multimedia Presentation Synchronization unit (or Controller for short) being the main thread of control. Other threads include the handler for the image tracker, the AVALON renderer, and the GUI.

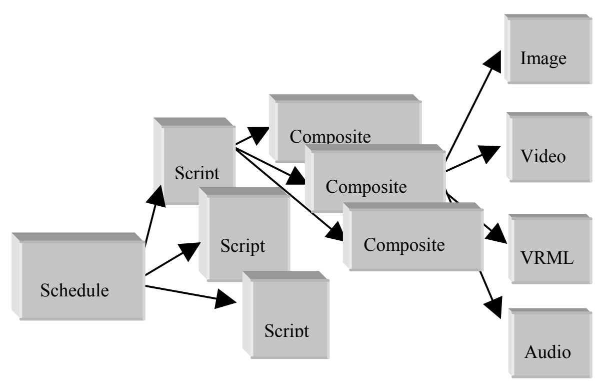

Figure 4 Tour Schedule Hierarchy.

An important concept is that of the personalization of information and the hierarchical structure of tour scripts. As mentioned earlier, the multimedia objects are stored in the site database together with several attributes. These attributes are used to select these objects and create tours adapted to the user's profile. This profile is created by the user at the beginning of the tour when he is prompted by the controller to reply to simple questions scoring his interests, background, age, sex, and language of preference. This way, the tour is adapted to cover regions fitting his description (e.g. emphasis on sports), the available time for his visit, the detail and the level of information (implied by his background and age), and the language of choice. Based on these parameters, the objects that constitute a tour are hierarchically ordered as shown in Figure 4. At the finest level of granularity, there are audio, image, and VRML objects [16]. These are grouped to form composite objects, containing the actual data to be rendered along with additional profile meta-data characterizing it. For example, a VRML object contains a string describing the URL location of the VRML file containing a VRML scene – e.g. the temple of Zeus – plus data about the Earth co-ordinates of the reference point of the VRML, plus a direction vector (together with scale information if necessary). The controller evaluates the condition associated with each object. If met, it instructs the appropriate renderer to present it. At a higher level of complexity, tour scripts represent an ordered sequence of multimedia objects, all of which are to be presented if the script is presented. Scripts may have partial order constraints, which essentially implies that the content creator may require the visitor to view one script before presenting another. Scripts are also logically associated with a geographical area. The rendering of the objects of each such script is the responsibility of the renderer and is accomplished with the help of the position and orientation tracking system. Finally, at the top of the hierarchy, we find tour schedules that represent partially ordered sequences of scripts. This structure aims at helping the controller synchronize the presentation of these scripts.

The image tracker is the component responsible for matching the image seen by the user (and captured by the camera) and the reference images stored in the site database, and calculating the transformation needed to render the VRML models on the video sequence [3], [6], [7], [9], [10], [11], [13], [14], [18].

The transformation parameters are passed to AVALON, which performs the rendering at speeds up to 15 frames/sec.

The interaction between the user and the system is supported by a Graphical User Interface (GUI). Three different versions exist corresponding to the various implementations of the MU.

In the laptop-version, the flow of information is controlled by effectively treating the user as an active pointing device. Instead of using a mouse, he positions himself to predefined points-of-interest (or viewpoints) in the site. His position and orientation triggers the presentation of the corresponding audio-visual material on the HMD. The user can intervene and alter the flow of information by skipping a presentation (by moving away, or heading to an other direction), or requesting additional information by means of an optional gamepad.

In the pen-computer version, the user takes a similar active pointer role and interacts by means of a special pen used to “write” on the computer screen. He can view augmented reconstructions with a standard web browser, listen to related audio clips, and request additional material.

In the palmtop implementation of the MU, the user can see augmented pictures, read related information, and listen to audio commentary through a pocket web browser. No tracking of his location is available and he is responsible for selecting the material of his interest.

It should be noted that all the multimedia material is downloaded from the SIS database unless it already exists in the MU database (e.g. downloaded by the previous user of the device).

An example of the User Interface presented by the pen-computer is illustrated in Figure 5. A similar one exists for the palmtop device, whereas the laptop user sees only the augmented images on the HMD.

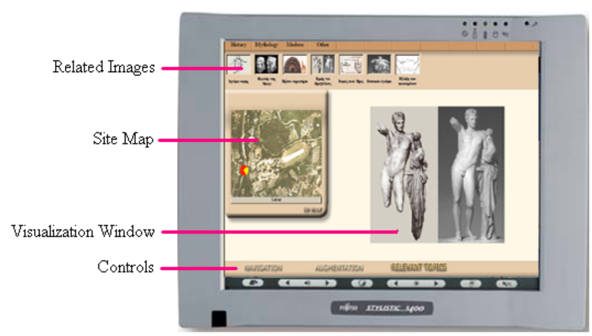

Figure 5 User Interface of the pen-computer MU.

4. Augmented Reality Presentations

The ARCHEOGUIDE system presents its user with Augmented Reality views of reconstructed ruins. The calibrated 3D models of the reconstructed monuments are rendered on the video or still image (according to the version of the MU) to construct augmented images like the ones shown in Figure 6.

A special category of these presentations is made available to users situated inside the stadium. This category includes the reconstruction of Ancient Olympic Games with avatar athletes competing in the stadium.

In order to achieve this goal, virtual human models have been created and animated with high realism and historical accuracy in terms of the necessary movements (and/or artifacts) to execute each sporting modality. Special care was taken in modeling and animating the virtual athletes (Figure 7), based on specific bibliography and historical descriptions, published by international experts on ancient Greek civilization, about the ancient Olympic athletes and games [4].

(a) Original Image

(b) Augmented Image

Figure 6 Augmented Reality presentation.

Figure 7 Models of ancient Greek athletes.

The problem of creating virtual humans in a 3D environment addresses two issues: modeling the geometry of the human body and simulating the correct behaviour and movements. The details of the modeling process can be considered out of the scope of this paper. Nevertheless, our approach is based on the customization of a pre-existing 3D human body, in order to achieve a model with ancient Greek athlete look (Figure 7), and model the movements it should describe, according to the bibliography, for each sport [4]. Defining human character behaviour includes its animation to execute "human like" movements [17]. Methods for animating virtual characters can be roughly divided into two approaches: motion-based captures and simulation-based. Motion capture is typically done off-line and played at runtime. The drawbacks of motion capture include the relatively high cost of capturing data, the lack of flexibility of pre-recording, and the fact that the motion must be performed by someone [17]. Simulation relies on computation of a mathematical model to generate the motion of the 3D model. This can be done on-line or off-line. If the model is too "heavy", i.e. the existing hardware is not able to compute the minimum number of frames per second to achieve smooth motion, the animation should be calculated off-line, recorded and presented as a video clip. Otherwise, the animation can be calculated in real time, enabling some control over the movement parameters. Taking advantage of such control, it is somehow easy to adapt a simulation to include variations on the animation parameters, such as limb, length, or walking speed. This can be very useful in implementing animations that vary in time according to the stimuli received from the user or other objects in the scene. [2], [8], and [15] contain useful texts on modeling, animation and simulation.

At this stage of development, it is possible to use the ARCHEOGUIDE system prototype to present the *Diaulos* (two-stadium-long race), the javelin throw, the discus throw, the race in armour and the long jump, augmenting the corresponding animated models in the real scenario. To implement the animations of collective sports, like the *Diaulos*, the same model was replicated, differentiating each one by changing its muscular mass and the time duration of the associated animation. This way, it is possible to achieve a more realistic representation for these kinds of sports. To implement the simulation the H-ANIM [5] specification was used, which intends to be a standard representation for human characters. Figure 8 illustrates a frame of the avatar video presented to system users at the stadium of Olympia. The competing avatar athletes are rendered on the live camera image of the stadium. Realism is enhanced by the individual behaviour of each athlete and the fact that the user is not isolated but can, instead, see other visitors present in his field of view.

An additional feature aimed at giving more realism to the presentations of the pen-PC and palmtop-based versions of the MUs is the augmented panorama. This presentation features 360º views of the natural surroundings with augmented reconstructions rendered on top. This enables the user to have a more realistic experience from the selected viewpoints. In the case of the pen-PC, the DGPS receiver and the digital compass readings are used to automatically align and rotate the panorama with the position and directions the user is staring at. This, effectively, minimizes the user's interaction with the MU and provides real-time panoramic views. In the palmtop-based MU, the user can click a direction button to rotate the panorama. This is necessary, as this unit features no position and orientation tracking mechanism. These augmented panoramas feature high quality reconstructions, as is the case for the standard augmented images. Accuracy and realism is enhanced by occlusions and shading of the augmented models.

5. Trials Preparation Procedure

The system was evaluated at the archaeological site of Olympia, in Greece, by representative user groups. This section describes the procedure followed for the evaluation.

First, a site survey was performed to collect topographical data and was combined with photographic images used to create a 3-D representation of the site. Monuments of interest were identified and the temple of Hera, the temple of Zeus, the Philippeion, and the Stadium were selected for the initial prototype scenario.

Figure 8 Avatar athletes competing in the Stadium.

Based on this list of monuments and the site representation, and taking into account occlusions, tour paths were defined that allowed visitors to view these monuments. This way, tree-covered areas have been avoided and optimum GPS data reception has been achieved by locating an adequate number of satellites (between 4 and 12). Similarly, candidate locations have been identified for the installation of the wireless LAN antennae. Three points have been selected outside the perimeter of the site, providing good radio coverage to the selected path and minimum esthetical disturbance.

Second, viewpoints have been selected and marked in the site. These are locations providing the best views of the selected monuments. The user is guided by the system to stand on these points for visualizing the augmented reconstructions.

Third, GPS reception was tested. The DGPS device provided an accuracy of less than 1 meter.

Fourth, the digital compass was calibrated and tested to ensure that no strong magnetic field is present that can compromise the accuracy of its readings.

Fifth, a set of photographs has been taken from the selected viewpoints and from slightly different angles. These photographs are used as references in the image-tracking algorithm.

Sixth, a set of 3-D reconstruction models of temples has been designed based on archaeological and architectural reconstruction data. These models correspond to the reference images and are rendered on the live video or the still images (depending on prototype version) to create the augmented views.

A group of 50 representative users was selected. It comprised visitors of various ages, sex, academic background, nationality, interests, and computer skills. This selection ensured that all use scenarios would be tested and feedback would cover all features of the system. Emphasis was given in ensuring that the disturbance to the normal operation of the archaeological site was kept to a minimum.

The visitors were given a briefing on the system and assistance during its use. At the end of their tour, they filled in a questionnaire scoring their impressions on the system and commenting items they thought significant.

The questionnaire starts with a section recording the user's profile and comprises 5 sections. The first three sections deal with the three implementations of the mobile units (laptop, pen-PC, palmtop-based), and the last two sections with general questions and comments, respectively. A scoring scheme is used where the user can score between 1 (lowest) and 5 (highest). For general questions a choice between *Yes, No, Not Sure* is available.

The first three sections test for:

- User's comfort in using each system implementation
- Clarity of audio-visual output (audio descriptions, augmentations, related objects, animations)
- Realism of audio-visual presentations
- Efficiency and ease-of-use of the multi-modal user interfaces
- Flow of information
- Suitability of information

- User's satisfaction of his tour with each system version.
- Would the user use the system again?

The fourth section tests the overall user's impression of ARCHEOGUIDE and compares the three versions for:

- User satisfaction
- How informative each version is
- Ease-of-use

Finally, the last section logs user comments in order to identify in depth his impressions on the ARCHEOGUIDE touring experience.

6. Results

The general impression of the users was that ARCHEOGUIDE is a good system and an interesting application that they would like to see in other cultural sites too. They were happy to use it and considered it a useful learning tool that enhanced their visit. They were, in general, satisfied by the type of AR, 3D, video and audio presentations.

The most enthusiastic of all were visitors of younger ages, who can be identified as those with the highest level of computer skills. These visitors are accustomed to computer graphics and viewed ARCHEOGUIDE mainly as a video game or leisure activity.

As we move to older ages with fewer, if any, computer skills, the system is perceived as a leisure and learning experience. There is some amount of uncertainty on its use from computer illiterate subjects, though these problems were greatly overcome with the help of the engineers who participated in the tests.

Elderly citizens were interested in testing the system but the majority of them felt uneasy when first approaching it and curious to check its capabilities.

People with limited understanding of foreign languages (mainly elderly and southern Europeans) were dissatisfied by the limited language support (only Greek and English) of the prototype.

The most serious complaint came from the use of the pen-computer-based MU. All users pointed out the low contrast of its screen, making it very difficult to view it under direct sunlight.

Further on, the limited available multimedia content (only the temples of Zeus and Hera, the Philippeion, and the Stadium) was a negative factor as only part of the site was covered. Consequently, the system could be used only in the four most important monuments; other areas were not supported.

A serious concern deals with the pricing policy for the rental of the equipment and its insurance in case of damage or accident.

For the top-of-the-range version, the realistic AR presentations were highly appreciated but objections arose on the size and weight of the equipment.

The pen-computer-based MU was rated low due to its low visibility display but was appreciated for its smaller dimensions and weight, as well as the fact that it comprised a single unit.

The palmtop-based MU scored high in its user's preferences for its very compact and lightweight design. The screen was clearly visible under all lighting conditions, including direct sunlight, and its size was a reasonable price to pay for easy carrying it in the site.

Both the pen-PC and the palmtop MU received good comments for the augmented panoramas they feature.

Finally, concern was raised on the availability and the wait time to rent and use a mobile unit.

7. Conclusions

The results of the user evaluation of the ARCHEOGUIDE system at the test site of Olympia were very encouraging. The system was enthusiastically accepted by visitors, especially those of younger ages. Several aspects remain to be solved. However, we should stress that most of the negative comments were expected as the prototype under evaluation exhibits a limited number of features compared to the final system. Current work focuses on the enrichment of the multimedia database with high quality, scientifically accurate material covering all areas and monuments of the test site, as well as, most major European languages. Linked to that, is the further development of the personalization features used in the adaptation of the tour to the user profile. Additional work is being performed in improving the hardware of the mobile units regarding its size and weight, and the visibility of the portable screens under all lighting conditions. Tests at other cultural sites are planned.

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9. Consortium Members

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Navigation Interface.

Augmented Reality presentation: original and augmented image.

Avatar athletes competing in the Stadium.

Vlahakis, Karigiannis, Almeida, Stricker, Gleue, Christou, Carlucci, Ioannidis: **ARCHEOGUIDE: First results of an Augmented Reality, Mobile Computing System in Cultural Heritage Sites,** pp. 131-140.

One generated view of the Darmstadt model.

Kretschmer, Coors, Spierling, Grasbon, Schneider, Rojas, Malaka: **Meeting the Spirit of History,** pp. 141-152.