

ARAGON: an integral use of Augmented Reality in an archaeological site.

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Abstract

ARAGON (*Aplicación de Realidad Aumentada de primera Generación*, First Generation Augmented Reality Application) is a prototype Augmented Reality (AR) system designed for interacting in real time with a virtual reconstruction of a cultural heritage site. Specifically, the system presents an AR scene of the defensive wall one of the four walled cities that existed in South America, the city of San Felipe y Santiago de Montevideo, Uruguay. Aiming at a virtual time travel through a historical moment of the place, this scene incorporates graphic and textual information of the city as it was by the year 1807, including topography, defensive systems, main buildings, access routes, human characters, means of transportation and other details of that time.

The system is built as a swiveling AR stand that permits a 360-degree visualization of the surroundings by using two LCD screens (welded back to back) and two corresponding cameras. The live feed from the cameras is loaded with multiple layers of geolocated digital information (both images and text) and then presented through the monitors. These monitors have an integrated touch panel that allows the user to modify the layers' transparency and the volume of the background sound and music. By using this interface, users can build the type of presentation they want to see at any given moment, from a fully rendered three-dimensional reconstruction of the site to an x-ray presentation based on wireframes, with or without informational tags, sounds or music.

This paper discusses and analyses the current advances of the project on the use of Augmented Reality in archaeological sites, and presents future possibilities towards a sustainable management of endangered heritage sites.

Research Aims

The presentation of heritage sites for raising cultural awareness is the main focus of this project, but not the only one. The technology presented here is also considered a stepping-stone towards the construction of a specialized design tool. In particular, one of our targets is the development of a flexible and user-friendly system for on-site verifications of novel proposals in the fields of Architecture, Landscape Architecture, and Urban Planning. It is also expected that the system will assist municipal authorities in for example the control of visual pollution for new projects and the promotion of residents' feedback about urban redevelopments. Another focus for future development is the pre-visualization of alternate, more sustainable scenarios in the case of heritage sites threatened by oblivion.

1. Introduction

1.1. Research Interest

The composition of multiple layers of digital information into a real-life scene in real time (Augmented Reality, AR) opens the doors for an immense array of possibilities in almost every field of human activity, from medicine to art, and from engineering to education.

Our project aims at presenting the history and details of an archaeological site to the general public. The site is located at the foot of the defensive wall of colonial Montevideo, Uruguay, which was in place from 1741 until it was determined to be demolished, in 1829 [1].

1.2. Research environment

This research and development project is the brainchild of a long-term international collaboration between two research laboratories, *(to be disclosed)* Grupo de Informática Gráfica Avanzada (GIGA, Advanced Computer Graphics Group) of the University of Zaragoza and *(to be disclosed)* Laboratorio de Visualización Digital Avanzada (vidiaLab, Advanced Digital Visualization Laboratory), Universidad de la República, Uruguay.

ARAGON (*Aplicación de Realidad Aumentada de primera Generación*, First Generation Augmented Reality Application) is part of a broader research plan, whose objective is the development of hardware and software for the generation and visualization of interactive, high-quality AR scenes for educational purposes. ARAGON is closely related to a previously developed project of archaeological virtual reconstruction, the Calera Project [2], which prompted the idea of creating an AR device to complement an outdoor museum exhibit. Thus, this system was developed not only for showing scenes and exhibitions indoors, like in museums or laboratory environments, but also for outdoors on-site presentations. The target audiences range from groups of tourists or young students in collective on-site

presentations to single users accessing the AR scenes for specific purposes, like archaeology researchers or history graduate students.

Therefore, it presents a major challenge: to cope with a wide range of different use situations, from the introduction of a simple virtual layer into actual reality towards a detailed archaeological reconstruction. For that reason, the starting requirements include 1) a detailed three-dimensional model of the synthetic scene to be combined with the real-time output of a camera, 2) high visual quality by means of advanced mapping methods, 3) real-time rendering process, and 4) interaction with the user by using peripherals like touch panels and inertial sensors.

1.3. Related Work

Digital reconstructions of archaeological sites have been developed following many different paradigms. An approach to museum-based virtual archaeology [3] is for example the Cave Like System designed by GIGA, which shows a 3D digital reconstruction of Sinhaya, a X–XIIth century Muslim suburb in the city of Zaragoza. [4] This Virtual Reality system is based on archaeological evidence from excavations and accurate historical documents. Precise lighting algorithms were developed to provide a photorealistic look, while real actors composited into the synthetic scenes give life to the reconstruction. Although the system provides a highly detailed immersive experience it is not an augmentation of actual space, but the recreation of an alternate historical virtual environment.

Other presentation setups are monitor-based augmented reality systems, like MovableScreen [5], a revolvable system used to superimpose information on one or more large scale images on the walls of the exhibition and visible on the background. The system brings to museums a realistic presentation of remote archaeological or cultural heritage sites. Considering the type of technology applied and the direction of our project, this kind of system was regarded as appropriate for further development.

However, unlike museum exhibits, on-site augmented presentations present a wider set of difficulties to overcome in order to generate high-quality information overlays. Klinker et al. [6] present an approach based on augmenting pre-recorded video sequences. Here, the proper alignment of the real world with the virtual world, one of the key issues of AR, can be done off-line using automatic and interactive calibration techniques. Then, the alteration of virtual objects can be performed live, running on a video sequence. The system however does not interact with live reality but with a recorded video and, strictly speaking, is not real AR [7].

A more traditional approach to AR is presented in projects like ARCHEOGUIDE [8], with mobile units of wearable computer systems, consisting on a portable computer and a see-through Head Mounted Display (HMD) equipped with camera and speakers. The system displays overlays of ancient Greek architecture and Olympic sports events directly at the site. Still, cumbersome gear and large GPS precision equipment rendered this approach unsuitable for our objectives, as we describe later on section 3.

2. Theoretical Framework

Contemporary visitors to heritage sites already experience the landscape through both physical and virtual interactions, as a result of the reintegration of digital bits of mobile information into daily physical reality, according to Mitchell [9]. They reach the place guided by GPS, take and comment digital pictures that they share in real time through internet-enabled smartphones, and rate the site on-line, probably altering the pattern of future visitors and therefore having an indirect impact on its development. The developed system (ARAGON) aims at the intensification of a mixed-reality experience, as defined by Milgram et al. [10], progressing towards a virtual time travel through the history of the site.

Augmented spaces, as presented by L. Manovich, are actual physical spaces characterized for having data *density*, similar to real numbers “as every point in it potentially contains various information delivered to it from elsewhere” [11]. This density implies a potentially infinite number of tagged points, with a correlated infinite number of levels of detail across multiple scales. Thus, we found that augmented spaces are not only multidimensional as Manovich argues, but also multiscalar. And it is this multiscalar capacity that makes AR specifically well suited to build applications that allow users to interact not only at the level of objects but also at the level of cities and territories.

3. Classification and synthesis of contemporary AR tendencies

AR is a fast-paced and growing field of contemporary technological development. In previous chapters we mentioned several directions for possible development. Here, we present the detailed discussion and evaluation of the different options considered in order to appropriately fulfill the objectives of our project.

In particular, the recent development and popularization of smartphones put handheld monitor systems on the top of our list. The option has a good history of successful developments, like the UMPC hardware setup described by Zöllner et al. [12], and a growing array of commercial applications for smartphones. The possibility of supporting multiple users, each carrying its own device due to the extended market availability, was also considered as a very positive feature. However, from a developer point of view, current AR browser incompatibilities among brands coupled with the bi-dimensional output were not so positively considered.

See-through Head Mounted Displays, both digital and optical are the traditionally favored display system in the AR community. They provide a good three-dimensional user experience, and are usually acceptable for daylight use (when the ghost-like appearance of superimposed layers in optical systems is not an issue.) However, similarly to the shift in the VR community towards projection-based immersive systems [12], the weighty hardware together with a sickness-prone slow rendering frame rate are also preventing these systems from a faster development in AR. In addition, considering the cost of each single-user device, it was regarded as not suitable for our objectives.

A transparent projection screen is a straightforward AR system. Content creation is a very simple task and, if not considering parallax drawbacks, it can generate a precise superposition of virtual objects. Parallax, however, is a main problem when targeting multiple users, and the inevitable ghostly appearance of the overlaid information can become a critical issue outdoors, where the general illumination cannot be easily controlled.

Techniques like Head Mounted Projectors (HMP) and Spatially Augmented Reality Displays, also called 3D Mapping, present similar problems. They generate satisfactory results indoors, or at nighttime, but projection-based displays show in general a poor performance in plain daylight.

Finally, we evaluated the potential of screen-based AR systems. Although it is a traditional two-dimensional device, three-dimensional capabilities can be introduced with the use of stereoscopic techniques. Content creation is also a simple task and a good level of detail can be easily achieved. Furthermore, augmentations based on a video camera input do not present optical parallax and are apt for multiple-user presentations. Thus, a screen-based AR system was considered as the most appropriate technology for our project.

4. Enriching actual reality

Our project consists on the creation of the hardware and software necessary for proper interaction with a pre-composed AR scene, for educative purposes on the fields of archaeology, history, geography, architecture, landscaping and urban planning. The AR scene presents a virtual three-dimensional reconstruction of the defensive wall of one of the four walled cities that existed in South America: the city of San Felipe y Santiago de Montevideo, Uruguay. This scene incorporates graphic and textual information of the city as it was by the year 1807, including topography, defensive systems, main buildings, access routes, human characters, means of transportation and other details of that time. The accuracy of the results was guaranteed by the collaboration of expert archaeologists not only during the process of historical research and fieldwork, but also by the verification of the final product.

4.1. Hardware

A swiveling AR stand allows the visualization of a 360-degree panorama of the surroundings by using two LCD screens (welded back to back) and two corresponding cameras (Fig. 1). There are several ways to interact with the screens: by rotating the stand around to change the viewpoint and by setting different transparency values to each of the five layers of information.

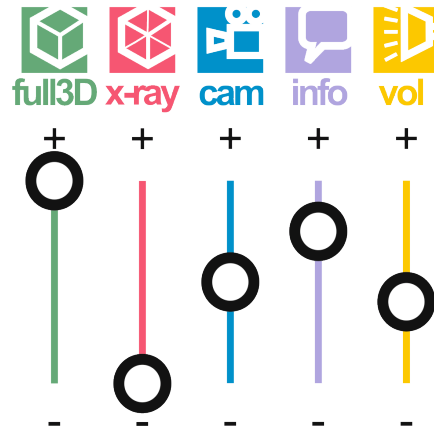


Figure 2: Control panel showing the four original data layers plus background music volume

The initial version of the software presented four layers: two virtual images named “full3D” and “x-ray”, the camera input “cam”, and the text information “info” (Fig. 3), and also it includes a volume control “vol” for background sounds and music. A fifth layer was later produced by architecture students, as the outcome of a university course that explored the capabilities of the stand (see section 6 Results below).

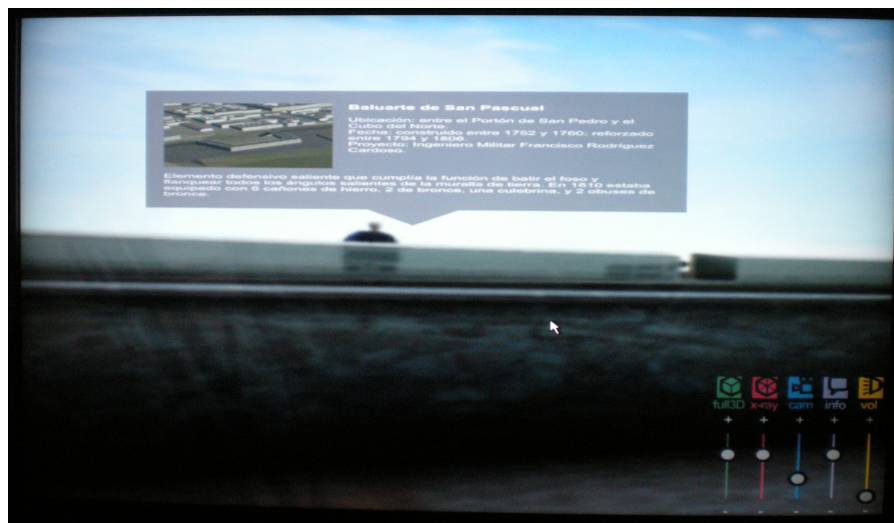


Figure 3: Screenshot showing the deployment of text tags, associated to the text layer “info”.

4.2.1. Design and deployment

The software was developed in C++ with the toolkit openFrameworks [14], which not only has a rich variety of libraries, but it also is cross-platform. The developed product has been successfully tested in Microsoft Windows (XP and Vista) and Apple Mac OSX (10.6.). The system was designed following a modular pattern in order to be able to modify any component in a simple way. Thus, it is possible to

use other cameras, add new layers, or change sensors without introducing substantial modifications to the code.

Three-dimensional models are rendered in advance, before runtime, and the produced images are used as textures for mapping a cylinder surrounding the viewpoint and creating a panoramic view. The coordination of virtual images and the ones obtained by the camera was done by tagging geographically (in absolute coordinates) the three-dimensional models and controlling the latency of the camera.

4.2.2. Interaction

As mentioned above, the user can interact with the system in two ways: by rotating the stand and/or through a touch panel. The rotation of the stand is detected by the accelerometers of an inertial sensor attached to the structure. The software periodically polls the sensor and draws the virtual layers (renders and information) according to each new viewpoint. The touch panel allows the user to modify the layers' transparency and the volume of the background sound. The interaction devices of both opposite LCD screens are synchronized for better performance. Fig. 4 presents one of the stages while the device was being tested, still in the laboratory. Note in the lower right corner the graphical interface, still under development.



Figure 4: Testing the device in a lab environment.

5. Reconstruction and development process

5.1. Colonial Montevideo (1807)

On the early morning February 3rd, 1807 San Felipe y Santiago de Montevideo, a strategic Spanish colonial city in South America, was being attacked by the British Empire. Although locals "defended the town and citadel of Monte Video with

great spirit" [15] the attack could not be repelled and the British entered and occupied the city, although just for a short period of time. This invasion however, marks the beginning of the decline of the power of the Spanish crown in the region and could be considered effectively the end of the Spanish colonial period of the city. Conversely, by 1807 the colonial architecture of the city can be seen at its apogee, and thus, that year was considered of particular importance for this project.

San Felipe y Santiago had been founded 83 years ago, in 1724. The construction of the required fortifications, against indigenous populations but also as a strategic military base, began in 1741 [16]. By the time of the British attack, the defensive walls that enclosed the peninsula stretched from coast to coast: from *Cubo del Norte* (North Battery) in the bay, to the *Cubo del Sur* (South Battery), in the sea. This long polygonal wall line had the main fortification, the *Ciudadela* (the Citadel) in the middle and highest point, dominating the system. [17]

Not long afterwards, by 1829, a new country was springing up. The General Assembly in charge of drafting the constitution for the newly independent Uruguayan state determined the demolition of the fortifications. At that time, the defensive walls were a symbol of the obnoxious colonial period and as such they were to be promptly demolished and forgotten by the inhabitants of the new nation. [18] Today, a few segments of the wall are still standing integrated now into the fabric of the city (Fig. 5).



Figure 5: Montevideo defensive wall overlaid on top of the contemporary urban fabric according to P. Chiancone [19]

5.2. Virtual Montevideo (2013)

Thanks to its spacial and temporal proximity it was possible to collect all necessary and sufficient graphical and textual information to reconstruct the city as it was around the year of the British invasion. [20]

Archival research and in-situ verifications were the base for this project and a guide for the execution of every task of virtual reconstruction. Nevertheless, the modeling of an entire city presents a series of organizational challenges. Thus, the outcome of the research was systematized and synthesized in order to make it useful for modelers, texture builders, and animators. The elements to be modeled were grouped, numbered and codified as follows:

Project elements:

- Topography
- Main buildings
- Defensive walls
- Private houses

- Urban features
- Others (boats, sky, sea, etc.)

Each model unit (a building, a defensive battery, a boat, etc.) was quantified in order to estimate rendering times in relation to the memory capacity of the machines. We considered from 1500 to 1000 polygons for very detailed elements, 999 to 100 for medium detail and less than 100 for not detailed elements.

The practical tasks were divided in: 1) geometric modeling, 2) mapping (textures), 3) animation (cameras and lights), 4) Rendering (audio and video).

The first stage, the geometric modeling, included the preparation of a prototype model in low resolution. The prototype contained all the general volumetric information of the elements but without details. Once this prototype was finished it was possible to expedite the following stages in a parallel process. In this way, mappings in low resolution, light studies and the first animated sequences were all based in the prototype. Most of these tasks were performed in AutoCAD [21] and the advanced modeling, mapping and final animations were done in 3ds Max [22]. Textures were generated from photographs of real walls, roofs or streets, and later processed for general coherence. For better visualization of the virtual model it was necessary to predefine a *graphic style* for all textures in order to avoid confusing mixes of, for example, hyperreal maps (needed for close ups) next to high-contrast maps (required for animations and real-time interactivity). This graphic style was generated by a trial-and-error process in which several versions of the same texture at different resolutions were used or combined, depending on the location of the cameras.

Besides the stitched panoramas required for the construction of the AR scene, several high quality still images and animations were generated for public outreach. As mentioned above, the prototype model in low resolution simplified this stage and encouraged us to experiment in many different directions. At the end, the most interesting shots were not the most acrobatic, but those that simulated probable paths followed by common inhabitants, like entering to the city through one of the doors on the defensive walls, or looking at a sunset from the roof of one of the main public buildings.

6. Results

In September 2010, ARAGON was presented to the local authorities of the city of Montevideo and officially inaugurated at *Al Pie de La Muralla* (literally, “At the foot of the wall”), a cultural center located in the old city that actually has a part of the old defensive wall incorporated into its internal structure. During the festivities related to the *Día del Patrimonio* (Heritage Day) the station was used by more than one thousand visitors.

In parallel, the device was being used by students of the School of Architecture, *Universidad de la República*, Uruguay, as material equipment for the course “Augmented Reality in Architecture”. In this course, students worked in teams for the preparation and deployment of another layer of information to be incorporated into ARAGON. The new layer, named “Buildings”, contained virtual

reconstructions of existing buildings geolocated in the AR scene. Although the newly incorporated data were actual contemporary buildings and some of them could be seen directly on site, their integration into the virtual scene improved the general understanding of the relative location of historical elements. As mentioned above, the system works by superimposition of images, and it does not deal with issues related to object occlusion.

Two years later, during the Heritage day in October 2012 the upgraded version of the stand was open to the public, now outdoors, at the *Museo de las Migraciones; Muralla Abierta* (Museum of Migrations; Open Wall). Again, hundreds of visitors were able to appreciate differences and similitudes, breaks and continuities in the historical construction of the urban landscape. As a point for future reflection we would like to mention that visitors were not particularly eager to interact with the device by themselves, but became much more motivated and confident as soon as guided by the staff or by other younger visitors.

ARAGON is going to be known commercially as ERACON, which stands for Configurable Augmented Reality Station in Spanish language, according to an international patent application recently filed.

7. Conclusions

This paper describes in detail the design process and implementation of a AR stand designed for interacting in real time with a virtual reconstruction of a cultural heritage site. The augmented scene presents the defensive walls of the city of San Felipe y Santiago de Montevideo, Uruguay, as it stood by 1807, at the apogee of the colonial architecture period of the city.

Besides the design and construction of the required hardware and interactive software, precise three-dimensional models of the city and its textures were developed for compositing onto the scene. This scene can be explored not only by rotating the stand, changing the viewpoint of the users, but also by modifying the transparency value of the virtual layers. Thus, the archaeological site can be experienced as a fully rendered reconstruction overlaid on top of the actual reality, or as a wireframe structure, suggesting the size and location of the historical wall and buildings of the colonial city.

The device was used in different situations with remarkable success, from an indoor museum environment to an actual heritage site outdoors, and it was also explored as educational software and hardware. It is expected that this enhanced experience will keep on benefiting not only common users and students but also research specialists, who can now approach this and other heritage sites in a holistic new way.

8. Future Work

Multimodal interaction with virtual characters or avatars is changing the way we communicate and interact with other users. The use of animation engines developed by Open Source tools and based on programming languages that support scripting make possible the management of scenes populated by three-

dimensional virtual characters. Animation engines are used for the development of applications based on specifications similar to slideshows, enhanced by virtual characters. This new type of slideshow application presents the content of the slides while using an avatar for communication with the audience. The application controls and synchronizes voice and expressions with facial movements and gestures.

Along that line, the following step is to integrate a *presentation manager module* into ARAGON in order to implement multimodal interaction with virtual characters or avatars. In particular, we plan to achieve the following objectives:

- The completion of the didactic material already produced with intermodal interaction in order to gain better user motivation. This point is related to the observed reluctance of new users to get to operate the device by themselves, mentioned above in Section 6.
- The creation of knowledge in the generation of high-quality presentations to be used not only by disciplines related to virtual archaeology, but also by the general public. Interaction in real time with animated characters could be used during the phases of analysis, design, verification, and diffusion of archaeological sites. This knowledge on interactive presentations can be easily transferred to other areas like education, communication and entertaining.
- The extension of the study of real time interaction with avatars, which in turn brings the necessity of readapting previous models and updating human resources related to the new modes of presentation.
- The production of other multimedia products, now interactive, as support for the learning/teaching process in design (and other disciplines), fostering high-quality interactions during the intermediate stages of the creative process and not only for the presentation of a final result.

Another line of future work, partly in motion already, is the implementation of similar AR devices as agents for the promotion of cultural landscapes in areas where heritage sites are endangered.

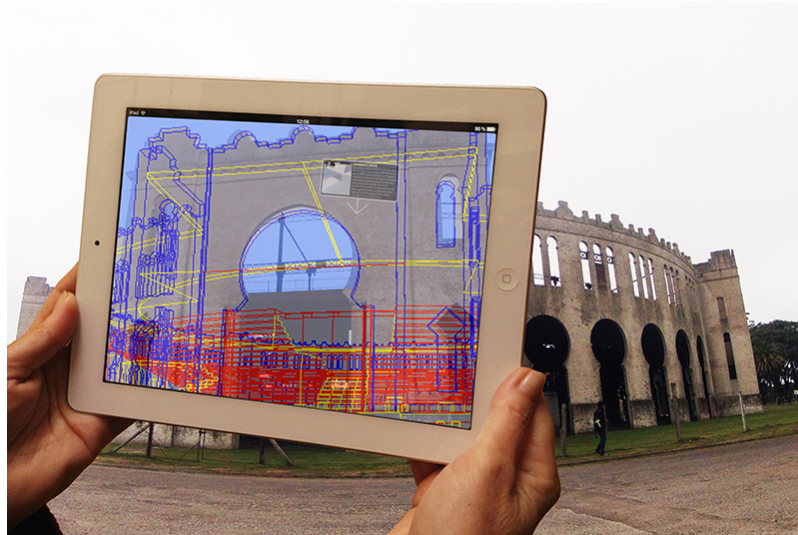


Figure 6: Proposed use of AR on the *Real de San Carlos, Colonia, Uruguay*.

In particular, the *Plaza Real de San Carlos* (Fig. 6), an abandoned bullfighting ring located in Colonia, Uruguay, requires immediate action. However, the lack of knowledge of the value of the site coupled with a difficult management system of historical monuments is working against a proper assessment of the potential of the site.

In this case, the proposal aims not only at a virtual reconstruction of the heritage site, but also at the pre-visualization of possible alternate realities. Here, new uses are to be incorporated into the structure, maintaining its original values while projecting the site into a sustainable future.

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