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MixAR Mobile Prototype: Visualizing Virtually Reconstructed Ancient Structures *In Situ*

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Abstract

Archeology and related areas have a special interest on cultural heritage sites since they provide valuable information about past civilizations. However, the ancient buildings present in these sites are commonly found in an advanced state of degradation which difficult the professional/expert analysis. Virtual reconstructions of such buildings aim to provide a digital insight of how these historical places could have been in ancient times. Moreover, the visualization of such models has been explored by some Augmented Reality (AR) systems capable of providing support to experts. Their compelling and appealing environments have also been applied to promote the social and cultural participation of general public. The existing AR solutions regarding this thematic rarely explore the potential of realism, due to the following lacks: the exploration of mixed environments is usually only supported for indoors or outdoors, not both in the same system; the adaptation of the illumination conditions to the reconstructed structures is rarely addressed causing a decrease of credibility.
MixAR [1] is a system concerned with those challenges, aiming to provide the visualization of virtual buildings augmented upon real ruins, allowing soft transitions among its interiors and exteriors and using relighting techniques for a faithful interior illumination, while the user freely moves in a given cultural heritage site, carrying a mobile unit. Regarding the focus of this paper, we intend to report the current state of MixAR mobile unit prototype, which allows visualizing virtual buildings – properly aligned with real-world structures – based on user's location, during outdoor navigation. In order to evaluate the prototype performance, a set of tests were made using virtual models with different complexities.

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1. Introduction

The deterioration or complete destruction of ancient buildings and monuments is a major concern for archaeology researchers and professionals who intend to study and analyze such structures to recover their cultural value. An increasingly used approach relies on the production of virtual models – through computer aided design (CAD) software or procedural modeling, for example – to produce the most accurate representation based on existent information about the structures. On the other hand, the incorporation of such virtual models in AR/Augmented Virtuality (AV) systems has been used to promote the scientific participation of the general public in culture, history or archaeology, considering the importance of digital heritage in modern society. The ability of such kind of environments in combining the real world with virtual information has the potential to provide a compelling and attractive user experience that, on the edge and regarding the current context, seeks the induction of the sensation of being travelling to the past. The inherent business model behind these kinds of systems usually targets museums, tourism and related fields.

Several approaches apply AR/AV in archaeology areas aiming to augment real-world structures with virtual models in both indoor (*e.g.*: [2]) and/or outdoor environments (*e.g.*: [3]). However, most of them work with too heavy and expensive equipment, which makes difficult the commercialization of the product in both "business to business" and "business to consumer" segments. Moreover, AR/AV systems do not allow the control over environmental parameters such as illumination or soft transitions among virtual traversable buildings.

To overcome the referred issues, [1] MixAR project proposed an adaptive Mixed Reality (MR) system that aims to achieve the visualization of *in situ* virtual ancient building reconstructions, properly superimposed and aligned with real-world ruins. Moreover, it also plans to provide navigability among building interiors and exteriors through the soft transition feature given by a MR manager module. Also, indoor lighting conditions are meant to be overridden with virtual illumination sources in order to approximate the reality of the reconstructed building to its epoch and cultural context.

In this paper, we intend to present the current progress on the development of the MixAR mobile prototype. Currently, the prototype allows users to freely navigate in outdoors environments while visualizing virtual models superimposed on their correspondent real-world structures, considering a previously prepared configuration that manages the experience. In order to accomplish such task, the user uses a mobile unit that acquires context data from the real world with its GPS, inertial sensors and camera. Also, a server supports one or more mobile units by exchanging information crucial to the experience through web services. Finally, in order to evaluate the overall performance of the system, a set of tests were made using virtual models with different complexities. These preliminary tests took place in our university campus, Universidade de Trás-os-Montes e Alto Douro (UTAD).

Regarding paper organization, the following section addresses a set of related works using AR and AV approaches – with emphasis on cultural heritage domain – along with some important tracking techniques. Section 3 presents an overview of the MR system. Sections 4 and 5 detail the mobile prototype and present some preliminary results. The last section points out some conclusions and presents future directions for the MixAR mobile prototype.

2. Background

AR has been successfully applied to several areas such as medicine, maintenance, entertainment, archeology, tourism and education. There are several AR projects directed towards the archaeology field. [4] and [5] are examples of outdoor systems in which the former presents the development of a system that has a fixed position in space while the latter describes the implementation of a system that allows the user to freely navigate throughout the outdoor scene. Regarding indoor systems, [6] specifies a system that allows the visualization of archeological artifacts; [7] proposes a system that uses two different approaches, fixed and mobile, for augmenting existing artifacts with a surrounding virtual environment that aims to provide historical context. A similar system with two approaches is presented in [8], goal is to provide museum visitants with background knowledge about the artworks and guidance, leading the visitants through the exhibition space in a determined order. Moreover, an example of a system capable of operating in both types of scenes, indoor and outdoor, can be seen in [9]. Alternatively, other authors explored AV approaches through the development of systems mainly focused in collaboration (*e.g.*: [10]). Some applications for the medical and educational fields can be found in [11] and [12], respectively. Although AR and AV approaches are used in these previous applications, they are not provided within the same experience.

MR systems require an accurate registration. This is a well-known problem that refers to the precise alignment between virtual and real objects. Without it, the illusion that both worlds, real and virtual, coexist in the same space is severely compromised [13]. In order to achieve such task, a tracking operation must be performed. This is critical, as MR systems rely completely on it to correctly augment scenes and therefore create their MR experiences. For such, emphasis on tracking techniques is given in this section from hereafter. These continuously recover the camera pose (*i.e.* its position and orientation) relative to the scene, or, equivalently, the 3D displacement of an object relative to the camera [14]. The tracking techniques can be divided in three classes [15]: sensor-based, vision-based and hybrid techniques.

Sensor-based techniques can rely on a variety of trackers, such as Global Positioning System (GPS), mechanical, magnetic, ultrasonic and inertial [16]. However, they commonly have issues with tracking accuracy and/or the need to alter the real world with devices, which is considered invasive to the environment. On the other hand, vision based techniques can achieve a precise registration. This type of techniques can follow one of two approaches: Marker-based (*e.g.*: [17] [18] [19]) or markerless (*e.g.*: [20] [21]). The former uses fiducial markers placed on the environment and are therefore not suitable for use in archeological sites. In contrast, the latter uses existing features of the environment. They can be divided into two main types: model based and Structure from Motion (SFM) based [22]. Model-based techniques (*e.g.*: [23]) require information about the real world prior to tracking [24], such as a 3D model that is later used to calculate the camera pose. By contrast, SFM based techniques (*e.g.*: [25]) do not require 3D information prior to tracking, this enables one to augment unknown environments [14]. However, there is no control over where the augmentation occurs, which makes it impracticable in some systems.

There is also the possibility of combining tracking techniques – hybrid approaches – in order to cover each other's weaknesses and combine their strengths [13]. Such systems started to be commercialized during the 1990's and used mainly sensor-based techniques for orientation and position tracking [16]. Eventually, as image-based tracking techniques became more robust they were also combined with sensor-based techniques (*e.g.*: [26] [27]) as well as with other image-based techniques (*e.g.*: [28] [29]).

The following section presents an overview of the MixAR system, the modules that constitute the system are described and its general architecture is depicted.

3. System overview

MixAR is a complete system that aims to provide the *in situ* visualization of virtually reconstructed ancient buildings superimposed on ruins, including its interiors and exteriors. Some modules support the achievement of this goal: a mobile unit responsible for providing and managing the MR experience to users; a high performance server to store, manage and deliver relevant data to the MR experience as well as to act as a remote processing unit; a network infrastructure to support the communication between the aforementioned mobile unit and server. Figure 1 depicts the general architecture of the system.

3.1. Mobile unit

The mobile unit is the main focus of current work. It is composed by a visualization component, a context component and a processing component. The context component captures information from the real scene and feeds it to the processing component, which in turn runs computer vision algorithms in order to present the final augmented scene through the visualization component.

Initially, this unit interacts with the MR Server to request the Geographical Information System (GIS) configuration and virtual models needed for the MR experience. Later, during the experience, some server-side services are consulted to update the mobile unity in order to allow the proper presentation of virtual models, at the correct time and place. The communication is ensured through the network infrastructure.

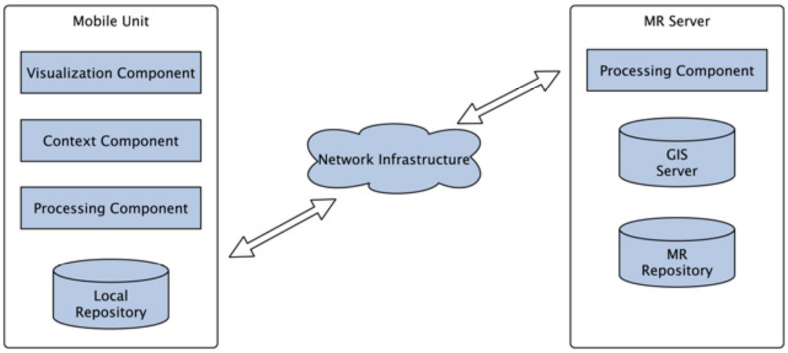

Fig. 1. MixAR general architecture [1], constituted by three components: a mobile unit carried by the user; a MR Server that stores retrievable contents and handles burden processing tasks; finally, a network infrastructure establishes the communication among Mobile Unit and MR Server.

3.2. MR server

MixAR server side is composed by a GIS and a repository that is used to store and retrieve virtual models and configurations to mobile units. GIS module provides a way of georeferencing the terrain portion in which the MR experience takes place. The module is also endowed with the possibility of defining levels of detail (LOD): a well-known strategy in computer graphics that aims to manage performance and computational resources through the presentation or occultation of certain virtual models parcels, depending on its distance from the viewer. Each LOD definition is stored in a database that is consulted to build the configuration set which is transferred to the mobile unit, along with the models.

In addition, three service interfaces are provided to let the use of server's processing capabilities while updating mobile units. Such services are described in the following topics:

- Get last date of update: permits to know if the mobile unit contains the most recent configurations; if not, configurations and 3D models are transferred to mobile unit, overwriting the existent contents.
- Get nearest building for tracking: it is invoked every time user walks a distance superior to half of the minimum LOD radius; it retrieves the building ID that should be prepared for tracking, taking into consideration user's position.
- Get buildings per LOD: returns a list of building ID's from user surroundings, segmented by LOD; this data is then used by mobile units to load the buildings with the proper detail; as it will be seen in the following sections, this service is not being fully used in this development stage.

After introducing MixAR system's architecture for contextualization purposes, it is time to present the Mobile Unit MR prototype that is the main focus of this work.

4. MixAR mobile prototype

This section presents the specification and implementation of the prototype. The specification contains a description of the functional requirements for the mobile unit succeeded by the architecture used in order to support such requirements. Afterwards, the data storage structure is presented. The specification is then concluded by presenting the workflow of the operations performed by the prototype. Finally, the implementation of the mobile unit prototype – considering the specification – along with the hybrid tracking technique, will be discussed.

4.1. Specification

A major goal of the mobile prototype is to achieve a MR environment where virtual and real worlds merge [30]. More specifically, the goal is to overlay virtual reconstructions of ancient buildings and monuments on top of their current structures present in the real world. In order to do so, the real world must be tracked so that virtual content can be correctly placed within, hence the tracking operations. Furthermore, cultural heritage sites must be preserved, for this reason the tracking must be markerless so that the environment remains unaltered.

Another goal of the prototype is that users remain updated by presenting them the correct virtual models, based on their position and context data. Such task requires an information set, formed by 3D models and scene configuration files, that is retrieved from MixAR server at the first execution of the prototype or whenever an update is available. Scene configuration files are used to contextualize the prototype about the archeological site in visitation. Based on it, the prototype is capable of controlling the tracking process and augmenting real-world structures with virtual models, properly shown to the user depending on its position and LOD. These augmentation models refer to the 3D models that are superimposed to the ruins, after a successful context-aware tracking.

In order to fulfill prototype requirements, an architecture was defined, presenting the several components that constitute the mobile unit. A supporting data model was also designed to standardize the share and use of information among MixAR system. Lastly, an activity diagram allowed to plan the behavior of the mobile unit during an archaeological site visitation, specifically, considering the virtual environment updating process. They will be addressed in the following subsections.

4.2. Mobile unit architecture

MixAR mobile unit architecture is described in figure 2. The core modules are the tracking and rendering. The tracking module determines the camera pose through the context data provided by the location, inertial and optical sensors, in a process that, in this case, relies on searching and matching pre-learned features with real-world structures. To accomplish this task, we used a hybrid approach that combines model-based and Structure from Motion (SFM) based techniques. The rendering module is responsible for merging the virtual reconstructions with the real-world frames – captured through the optical sensors – and displaying the result to the proper device output.

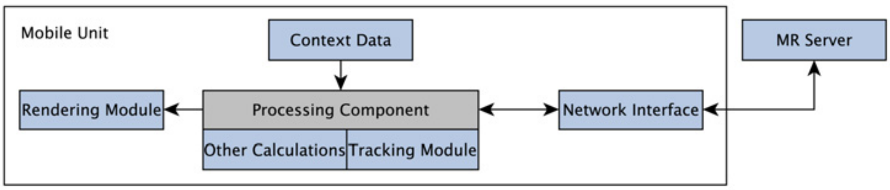

Fig. 2. Architecture of the mobile MR prototype.

4.2.1. MixAR data model

A data model – compliant with MixAR definition presented in [1] and transversal to the entire system – was designed in order to support the mobile prototype data manipulation. Thus, each MR experience is stored by *gisconfiguration* table which is associated to *buildingbase* and *lod* table. *Buildingbase* table aims to store and retrieve the information about the buildings that make part of MR experience. Building's coordinates are stored in the *coordinate* table. They represent building's center and also constraint polygon, accordingly with the coordinate type specified by *typecoord* table. Finally, *lod* table holds some definitions related with the rings radius – centered on user – that specifies the LOD of each building in scene: the nearer the building, the higher the level of detail [1]. Figure 3 depicts MixAR data model.

4.2.2. Activity diagram for mobile unit update

Figure 4 presents the workflow of the prototype. Initially, all the elements related to the experience are downloaded from the server. Afterwards, the user position is identified and the state is updated accordingly. Virtual models and tracking configurations are updated in runtime when a displacement equal to or greater than half the radius of the minimum LOD is detected. The cycle is repeated until the user closes the application.

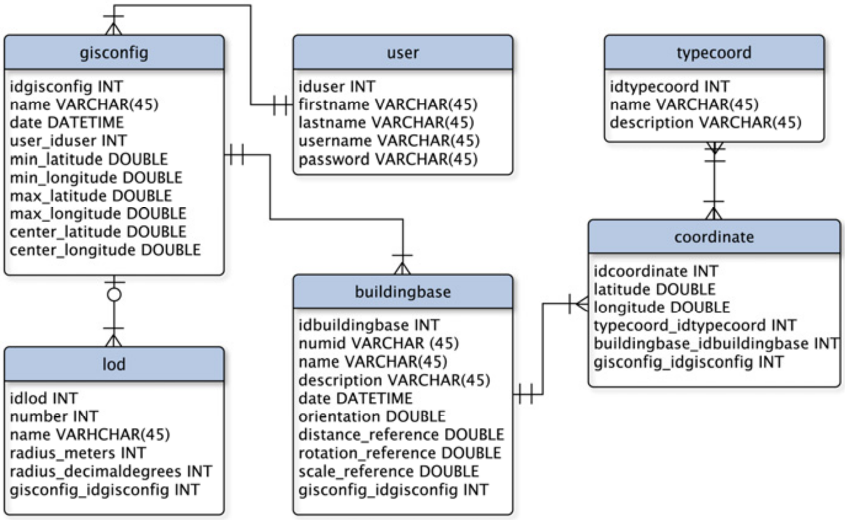

Fig. 3. Database structure present in the MR server.

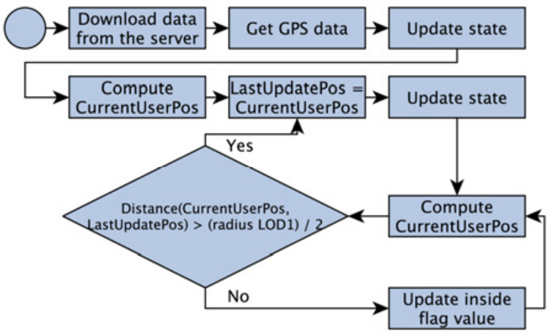

Fig. 4. Workflow of the operations performed by the prototype.

4.3. Implementation

The architecture, data storage model and workflow were successfully implemented in a Unity3D solution. During the development and after experimenting the set of tracking techniques available on Metaio SDK, we opted to use the hybrid technique as the tracking approach in our application, due to its apparent superior precision and robustness, comparatively to the others.

In terms of behavior, the application starts its execution by downloading the 3D models along with the tracking configurations from the server. Then, the GPS position is acquired and the closest building is prepared for tracking (initialization state). Consequently, a visualization aid model is presented to the user in order to help him during the alignment of the line model – provided along with the tracking configuration – with the real-world target structure, in a task that highly relies on orientation sensors, specifically, gyroscope and accelerometer. A successful alignment alters the state to “tracking” and triggers the presentation of a model representing the ancient building. At this point, SLAM and edge based methods are performed simultaneously through multi-threading, in a process that continuously tracks edges and extracts features to create and extend a 3D map. If the device camera loses the field of view of a considerable tracking area, the tracking state changes to "lost" and a recovery process starts based on SLAM, which tries, for a given period of time, to reinitialize the tracking from the last known position and orientation. In case of failure, the application resets the current 3D map and restarts the process from the first step. Finally, a user displacement higher than minimum LOD radius triggers the dynamic change of configuration and the reapplication of the aforementioned tracking process, from the initialization state.

5. Preliminary tests and results

Before the tests itself, an offline task regarding scene preparation and configuration took place. Firstly, three real-world structures were selected to be tracking targets: a shipping container – due to its geometric simplicity – and also the entrances of Engineering and Library buildings from our campus, UTAD. In order to fulfill the requirements of the adopted tracking approach the line, surface and visual aid models were produced in Blender [31], as it is illustrated on Fig. 5. Here is a brief explanation about them:

- Line model: represents each structure contours and is used to find the correct camera pose through the alignment of the virtual edges with the real-world edges obtained from captured frames;
- Surface model: is used to determine the 3D location of projected feature points through SLAM tracking as well as to detect the visible lines of the line model, based on self-occlusion;
- Visual aid model: aims to provide visual orientation to the user during the manual alignment of the implicit line model with the edges of the real-world structures which, in case of matching, triggers the augmentation of the real-world structure with proper virtual content.

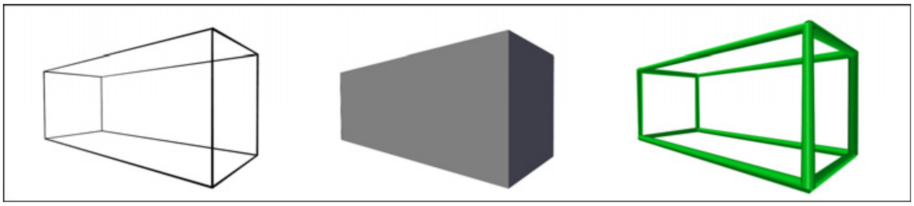

Fig. 5. Illustration of an edge, surface and visual aid model, respectively. For modeling purposes Blender [31] was used, an open-source 3D modeling software.

Each line and surface models were then properly bundled with a configuration file that is used by Metaio SDK for runtime tracking purposes.

Moreover, three distinct models were also produced – using the procedural tool proposed by [32] – to augment the scene during successful trackings. Table 1 presents the properties related to the complexity of each model, the number of vertices, textures and faces, which will be considered for further performance analysis.

Table 1. Properties of the different models used for augmenting real-world structures.

Structure	Augmentation	Number of vertices	Number of textures	Number of faces
Container	A	6.504	10	3.552
Library	B	16.170	17	8.780
Engineering	C	30.989	19	17.349

After the offline scene preparation, the application prototype was tested in order to determine system effectiveness and also to measure the mobile unit performance. The testing device was a Samsung Android Tablet [33]. It has an ARM-based quad core CPU with 2.4 GHz, 2GB of RAM, 16GB of internal storage capacity, a built-in display of 8.4” with a resolution of 2560x1600, an 8MP rear camera, and also other relevant built-in components such as GPS, gyroscope/accelerometer and a WLAN adapter. Besides, a common web hosting solution was subscribed to provide client-server communication. Network infrastructure available in our campus – Eduroam – was used as wireless communication channel.

Regarding test conditions, camera resolution was set to 800x600 while the internal algorithms – managed by Metaio SDK – worked with frame samples of 400x300 to reduce the computational burden impact caused by the use of the hybrid tracking approach.

For testing purposes, the developed application was modified to ignore the tracking function during the first frames aiming the determination of the computational burden of Metaio SDK at its minimum processing state, in which only a few components were working, specifically, camera and renderer: an average of 26.6 FPS was achieved. Then, the regular behavior takes place and the tracking functions are switched on to measure the FPS values in each state and for each tracking configuration regarding container structure and also Engineering and Library buildings.

The container set had the best performance achieving an average of 17.3 FPS during its initialization, 16.4 during tracking and 16.3 regarding the lost state. The performance measurements on the Library resulted in an average of 7.5 FPS during initialization, 14.2 while tracking and 7.6 during lost state. Lastly, the Engineering set achieved an average of 11.5 FPS in initialization, 15.5 during tracking and 12.5 in lost.

Despite having the most complex model (Table1), the engineering set outperformed the library one. However, Table 2, which presents some information about the virtual structures used for tracking, shows that library surface model has more vertices and faces than engineering. Thus, we suppose that tracking calculations based on line/surface model have a higher impact in terms of computational burden than the augmentation structure complexity.

The augmented models superimposed on the shipping container, Library entrance and Engineering main door, are depicted on Fig. 6, through screenshots taken from the running application and during successful trackings.

Table 2. Properties of the visual aid, line and surface models used for tracking each structure. Line models do not have faces, hence the lack of such column.

	Visual Aid Model		Line Model	Surface Model	
Structure	Vertices	Faces	Vertices	Vertices	Faces
Container	816	564	8	8	12
Library	468	542	24	40	60
Engineering	567	622	24	24	36

Fig.6.Different structures augmented by their correspondent virtual models.

6. Conclusions and future work

This paper presented the specification and the current progress status of the mobile prototype implementation, in the context of the MixAR project. The prototype allows users to freely navigate in outdoor environments – considering tracking configurations previously created – while visualizing virtual models superimposed on their correspondent real-world structures. To achieve such goal, mobile unit sensors are used along with tracking configurations retrieved from the server. The performance tests made revealed that, apparently, the tracking module has more impact on computational burden, depending on the complexity of the structures used for tracking, specifically, line and surface models. However, more tests are needed to corroborate this finding.

Future work will be towards the implementation of a MR management module and a virtual extensive environment. On one hand, an adaptive MR module will manage the use of AV or AR approach, depending on the context, inside the same experience. The module is also responsible for soft transitions between approaches and relighting issues, where the system must override existent lights in order to obtain a more realistic experience. Finally, a virtual extensive environment intends to continuously present buildings in the user surroundings, rather than only the closest one, in a task that requires inertial and location sensors.

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