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AUGMENTED REALITY FOR ARCHAEOLOGICAL ENVIRONMENTS ON MOBILE DEVICES: A NOVEL OPEN FRAMEWORK

Dr Ioannis Deliyiannis[1], Dr Georgios Papaioannou [2]

[1] *Interactive Arts Lab, Department of Audio and Visual Arts, Ionian University, Corfu, Greece*
[2] *Museology Lab, Department of Archives, Library Science and Museology, Ionian University, Corfu, Greece*

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Corresponding author: Dr Georgios Papaioannou (gpapaioa@ionio.gr)

ABSTRACT
The wide availability of networked mobile devices provides a reliable platform for the development of the so-called communication engine for museums and cultural tourism. This research presents and discusses a novel open framework, which can be employed to augment the visitor's experience and present targeted information in a personalised audio-visual interactive manner on users' personal mobile devices. The proposed approach employs state of the art augmented-reality technologies enabling users to sample the information through the use of their personal mobile devices. Instead of using tagging systems such as visible quick response (QR) markers, users are directed to 1) stand on specific appropriately marked information points, 2) scan the area with their appropriately configured mobile device, and 3) access specific geographical or artefact-based ontologies that may include digitally restored buildings in 3D, audio-visual information on specific artefacts and/or other information of interest with directions to access other information points. The proposed framework may be employed at varying levels of complexity, enabling the development of archaeological edutainment scenarios and games. The use of the proposed technology has multiple advantages, such as: 1) highly-specialised hardware is not required, 2) devices can function in both open and closed spaces, 3) the quality of presentation adapts according to the device used, and 4) further information may be accessed as full interaction is supported. In this paper we review the literature and present technologies and related research that may be employed for the presentation of archaeological information. We also describe the proposed open framework, followed by a presentation of a sample application, --Additional uses are proposed in our conclusions.

KEYWORDS: augmented reality, networked mobile devices, archaeological sites, museum technologies, virtual tours, interactive multimedia

1. INTRODUCTION

This work targets the development of real-life paradigms based on the *communication engine* for museums and cultural tourism. In the last two decades, Information and Communication Technology (ICT) has shaped museums' and cultural tourism communication schemes, digital catalogues, databases, websites, online exhibitions, interactivity, virtuality and an increasing wealth and diversity of devices and interfaces characterise ICT communication in cultural heritage settings. This has led the use of various multimedia technologies, which have been actively employed to enhance the user experience, inform, educate and provide information in an entertaining fashion. These technologies include various tools such as video projections, multimedia rooms / applications and wide-screen TVs (Economou, 1998) (CD / DVD players using headphones, touch screens/PC stations and interactive kiosks (E Hornecker & Stifter, 2006) audio and/or digital tour-guide systems with headphones (E Hornecker & Bartie, 2006) museum robotics (Reitelman & Trahanias, 2000; Thrun et al., 1999), and recently mobile smart-phones (Brown & Chalmers, 2003; Yannoutsou, Papadimitriou, Komis, & Avouris, 2009) tablets and Personal Digital Assistant (PDA) devices (Tesoriero, Lozano, Gallud, & R., 2007), while recent examples present multiple innovative examples and approaches (D. Vanoni, M. Seracini, & Kuester., 2012; T. E. Levy et al., 2012). Research projects, papers and special congresses (e.g. CAA[1], Museums and the Web[2], VAST[3], CHNT[4]) have presented, analysed and evaluated ICT applications in cultural heritage in relation to museum settings, visitors' experience and visitors' participation in exhibition content and design (Adams & Moussouri, 2002; Economou, 1998; Keene, 1998; Lepouras & Vassilakis, 2004; Papaioannou & Stergiaki, 2012; Project, 2008; Pujol-Tost, 2011; Roussou, 2012; Sylaiou, Liarokapis, Kotsakis, & Patias, 2009). Our intention is to contribute to both the relevant discussion and to the standardization of interactive multimedia technologies.

Today, the wide availability of multimedia-enabled handheld and networked devices such as mobile phones and PDA's enables the development of advanced working paradigms that may be used to recognise exhibits and by linking to their virtual ontologies can provide information in an interactive and adjustable manner (De Paolis, Aloisio, Celentano, Oliva, & Vecchio, 2011; Ioannis Deliyannis, Giannakoulopoulos, & Varlamis, 2011; Ronchi, 2009; Sauvé, 2009; Torrente, Mera, Moreno-Ger, & Fernández-Manjón, 2009). The way that information is triggered and accessed is a key characteristic to our research as our previous work in complex interactive systems has shown that there may be multiple uses for the same ontology for different user groups (Ioannis Deliyannis, 2007, 2011, 2012b; Ioannis Deliyannis et al., 2011). In order to comprehensively investigate the issues in hand, we examine the process from three distinct yet complementary perspectives: user, content and technology, as shown in Figure 1.

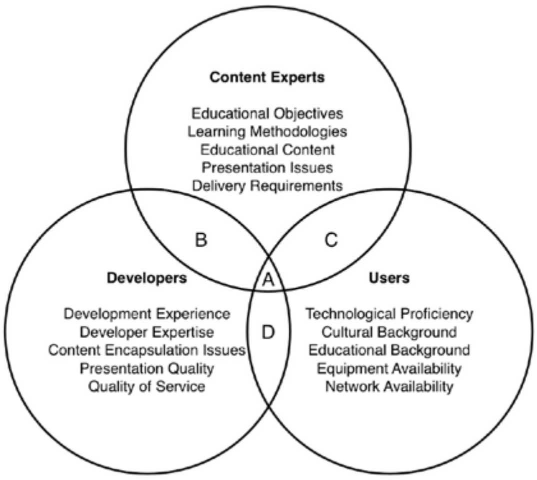

Figure 1 Interrelation between users, content experts and developers

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1 http://www.caa2013.org/drupal/Home (accessed 01/09/2013).

2 http://www.archimuse.com/conferences/mw.html (accessed 01/09/2013).

3 http://www.vast2012.org/ (accessed 01/09/2013).

4 http://www.stadtarchaeologie.at/ (accessed 01/09/2013).

Interaction with content is a key issue commonly introduced in the development of interactive multimedia systems, as it is used as a customisation tool, enabling content interrogation. As a result augmentation is a problem that must be examined from various viewpoints, as it poses multiple issues that need to be addressed simultaneously in order to develop a system that covers both the content presentation demands and user requirements. In that respect, multimedia technologies possess a secondary role, as they are adjusted appropriately in order to provide the content access platform that serves the content and satisfies the user demands.

In the following sections we discuss augmentation, propose a novel framework that utilizes augmented-reality technologies and present a number of case studies developed to demonstrate the proposed approach in practice. The final section formalizes the framework and discusses customization and adaptability issues that often arise in the development of similar systems. In the conclusion, a number of suggestions are listed describing innovative uses of the proposed framework.

2. ARCHAEOLOGICAL CONTENT, INTERACTIVE AUGMENTATION AND CONTENT EXPERTS

In the literature, it is common to categorise interactive systems by contrasting their dynamic capabilities offered to the user (Nardelli, 2010; Trifonova, Jaccheri, & Bergaust, 2008). Use of the term "interactive" within the archaeological context implies that the end-user of such a system may access information in a multimodal manner and the system should provide capabilities that allow users to view, investigate and explore the stored content in multiple modes. In that respect, augmentation of content is classified as a complex task, particularly when full user-content interaction is supported by the end-system (Ioannis Deliyannis, 2012a; I. Deliyannis, 2013). "*Edutainment*" is a characteristic research area where one may find increased information on the development of interactive augmentation (De Paolis et al., 2011; Ioannis Deliyannis et al., 2011; Encarnação, 2007; Green & McNeese, 2007; Oh & Woo, 2008; Ronchi, 2009; Sauvé, 2009; Torrente et al., 2009). Archaeological content possesses a number of characteristics that are taken into consideration in the design of the proposed framework: archaeological artefacts, ruins, buildings and areas are often well represented from the information perspective. They are concisely categorised, documented and depicted, offering an information domain that apart from the addition or correction of facts in its description, requires little maintenance in time. As a result, this particular content is considered as ideal for *interactive augmentation*, a term used in this work to describe the ability of the user to access archaeological content interactively.

Augmentation has evolved and today a plethora of platforms are available for experimentation in the development of new application systems. QR marker technologies detect and decode visual markers in order to link to information. Various open source libraries and multimedia-authoring software (Processing, 2013) may be freely programmed to create high-level interactive multimedia systems. The approach where object identification relies on marker recognition introduces various disadvantages, as the existence of the marker itself may spoil the aesthetics of the environment. The introduction of augmented reality systems based on real-life image recognition provides a much more flexible identification method. *Junaio* and *Aurasma* are two characteristic web-based platforms that provide the basic functionality required for such applications, while users may freely experiment with the platform using their own devices. As a result we have already developed a number of edutainment case studies in order to experiment with the limitations of such technologies, as part of the "Edutainment" course in the Department of Audio and Visual Arts, Corfu Greece. Students were asked to design and develop an interactive scenario using their platform of choice, a process that created various case studies each of which provided a novel interactive approach. These according to their intended purpose and functionality, these include augmented-reality based hidden object games, navigation & storytelling scenarios where video is triggered by artefacts and signs, interactive scenarios and puzzles.

In order to enable content-experts to appreciate the content organisation requirements, we contrast the organisation of a physical museum collection to that of a vertical portal of information often referred to as a "Vortal". When information access is contrasted at the top level, it is evident that both structures share solid content categorisation, enabling visitors and users to either scan through the content, or locate an area of interest and dig in to the information provided. Conversely, at the lowest representation level, physical exhibits and virtual ontologies can be mapped on a one-to-one basis, enabling direct access to information.

The information access route is one of the most important characteristics of such a system that is often overlooked by developers, as the structure usually follows the thematic sectioning followed in the physical world. Virtual museums employ multiple routes and provide content adjustment capabilities. An example of such a route may enable the same exhibits to be presented using adapted information for different target-age visitors such as different members of a family. Another important feature is the capability to identify, locate and examine specific artefacts and their development through time. Examining the development of pottery designs through time can the basis of an educational visit to a museum where each student group can complete a different research scenario and present that in class. This feature can convert a visit from a static presentation of knowledge to an interactive investigation tool that may be used freely by the user enabling content-interrogation (Ioannis Deliyannis, 2011). A third feature would be to over impose digitally drawings, 3D reconstructions and other information regarding artefacts and open spaces, enabling the user to view a reconstructed perspective of the original item or space.

The typical order in which the development of such a system is addressed from the software engineering perspective may be represented as a cyclic process (spiral model): first the content experts organise the collection items thematically in sections and provide an order of presentation for each section if that is necessary. Then the developers provide the platform that supports information access to the user and add the information. Finally, users test the system and provide feedback that triggers further advances in both content and technologies involved enabling further developmental cycles to be implemented.

As the user plays leading role in the process, the research problem here is to provide the developmental flexibility that permits dynamic adjustment of the presentation route based on content-expert guidelines and scenarios,. This requires careful context analysis in order to allow content experts the flexibility to create adaptive multimedia presentations using the same markers for multiple purposes. In computer technology, this is analogue to dynamic URI where the same link (marker) when used by different user groups leads to varying scenarios, depending on certain conditions that may include earlier user choices, presentation scenario, visual marker availability, time-based events etc.

To view this through an example, take a family visiting a museum that uses the augmented-reality applications developed for this purpose. Each family member accesses the tour by first filling in an electronic questionnaire (age-range, personal interests, specific keywords). This input enables the presentation to either adjust its content appropriately, or direct the user to specific sections of the museum. In the first case the main tour may offer full information to adults, while the children receive particularly adjusted content for their age-range. The indication of special interests may be used to focus the presentation on a specific museum section or in a cross-section setting based on a theme, say for the development of pottery and designs through various civilisations. This is a feature that may also be provided as part of edutainment scenarios, where students visiting a museum can be allocated to complete specific tasks, the findings of which will then have to present in class. It is therefore important to provide a theoretical framework that supports this kind of functionality, in an attempt to develop high-order interactive content that supports varying user scenarios, while it enhances the museum experience.

3. AUGMENTED REALITY FRAMEWORK FOR ARCHAEOLOGY (ARFA)

As content customisation and system adaptability are desirable characteristics for the target application-system, the proposed ARFA framework is designed to ease the interactive nature of content. For this reason, information is organised in finite triplets (*visual representation*, *context* and corresponding *audiovisual content*). *Visual representation* is a term that refers to an artifact, a collection of items or photographs taken at a specific location that are characteristic of the area. The developers consider this a trigger item that when it is detected by the mobile device held by the user, it initiates the process. It may consist of a single or multiple images, while multiple *contexts* can also be linked to a *visual representation*. Audiovisual content can be stored within a multimedia database and be accessed on demand, furnishing varying interactive scenarios and the decision-making procedure may either be internal or external. In the main data-structure the user attributes are stored and linked with one or more virtual representations of each artefact, while at the system level each context is linked to its audio-visual content source. The decision process algorithm evaluates user-input and presentation attributes in order to select the appropriate context that should be displayed for each user. Selection of each context information results in the projection of the appropriate information, augmented with real-life footage. This augmented projection is the resulting outcome of the process presented via the device, which composes real-life imagery with audiovisual information.

At a higher-level that serves the storytelling mode, there are different types of narration that may be implemented using the data structure above: from linear to dynamic-dynamic (interactive). Multiple types may also be combined in a hybrid structure termed "*cruise-control*" commonly employed in scientific areas featuring complex data (Ioannis Deliyannis, 2011) that allows the user at selected points of interest to deviate from a linear structure and explore the artifacts of interest. Interaction can be implemented using various modes and techniques, depending on the environment and the level at which information can be sampled: near-item proximity for small-sized findings such as coins, tools and pottery, small rooms and closed spaces containing larger items and ultimately large exhibitions and open spaces. At the small-sized item level the user can access information by pointing at the items themselves. At small rooms and closed spaces, the introduction of appropriate floor or wall-based areas indicates that scanning from that perspective, one may also access information about the room itself and the collection organization. For large rooms and open spaces, beyond the localised information, it is also possible to provide directions to other points of interest enabling physical navigation to be implemented through the device itself.

To summarize the above the *visual representation* of objects, spaces and surrounding environment can be used as links to content without using specific markers. In addition, it is possible to utilize the same objects and environments in order to support various interactive scenarios, by employing state-of-the-art interactive multimedia technologies (Belluci, Malizia, & Aedo, 2012; De Paolis et al., 2011; Ioannis Deliyannis et al., 2011; Khan, Xiang, Aalsalem, & Arshad, 2012; Ko et al., 2011; Paramythis, Weibelzahl, & Masthoff, 2010; Rautaray & Agrawal, 2012; Schraffenberger & Heide, 2012; Tahir, 2012; Xia, 2011). These encapsulate the visual representation of the trigger and link all related audiovisual content instances. Successful recognition of the object and selection of the content triggers a presentation instance, at a pace the user can follow. This renders the mobile device as an investigation tool. A networked multimedia database may be employed to store and access the multimedia information structure, while decision-making may be implemented either remotely or locally on the networked device. In any case, technologies such as the new HTML5 or ready-made platforms such as Aurasma, or Junaio may be employed to fulfill the interaction requirements. The following chapter presents a number of real-life factors that are commonly introduced in case studies.

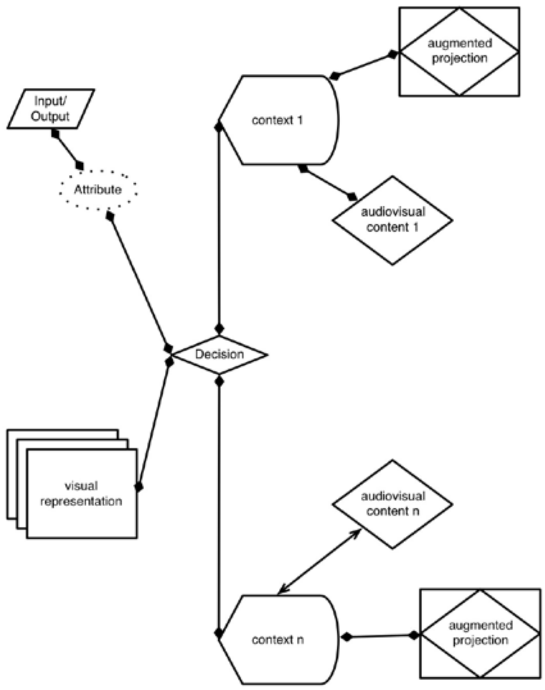

Figure 2 Two ARFA framework context triplets, and their augmented projections triggered by the initial visual representation and decision routine

3. REAL-LIFE CASE STUDIES

The main purpose of this section is to define the practical application framework for archaeological use and inspire further applications. First the collection of a typical archaeological museum is examined and a number of possible uses of such technology are proposed. The collection of the archaeological museum of Igoumenitsa in Thesprotia, Greece that is organized into five exhibition units according to their website[5]: archaeological - historical retrospect (items: Stone tools, hand made clay vessels, Mycenaean clay and metal objects, mobile findings of the Geometric, Archaic, Late Classic - Hellenistic, Roman and Byzantine periods), settlements of historical times (items: Architectural members and mobile findings from the ancient settlements of Elea, Gitana, Doliani and Ladochori), public life (items: Signs, coins, sealed pottery handles, clay sealings, weights and measures, mobile findings from public buildings, weapons, votives from shrines), private life (items: Tools of various professions, toys, musical instruments, loom components and pottery products, bathtubs, beautification paraphernalia, jewelry) and burial customs (items: Authentic graves and skeletons, burial offerings). From the hardware perspective, the development of an interactive presentation environment for the museum where visitors use their own devices in order to explore the collection requires the availability of networking in all areas and the availability of a local multimedia & web-server used to store and provide access to all the media information. At the information forefront, the museum holds a database containing information about all the findings that needs to be made available over the local network, presenting a unique link to the appropriately presented information for each item, covering the ARFA information triplet demands: (visual representation, context an audiovisual content). Beyond accessing the information triplet, the use of Aurasma is proposed as a platform to allow interaction with content. The information provided covers interaction with artifacts, hence there is the need

[5] http://odysseus.culture.gr/h/4/eh41.jsp?obj_id=17461 (accessed 01/09/2013).

to provide further directional information. This may be realized via the creation of location-based information triplets for each room. These are implemented by capturing specific segments of the room's panoramic view from a designated location. This specific location should also be marked using floor markings (stickers or signs) that contain also instructions and the information-access instructions. Single item and area recognition are supported.

The next case study introduces the same technology into the open archaeological space of Paleopolis, Corfu, Greece. Information including historical photographs, 3D reconstruction and audio-based narration and WWW-links to electronic material may be employed to augment the user experience and present location-based archaeological information. In order to demonstrate this process in practice we have developed a test-application featuring a small number of locations. Figure 3 displays the representation of one point of information within Aurasma Studio the web-based component of the application supporting our case study. The highlighted (masked) area aids the recognition process, while the developers can train the system to recognise alternative perspectives and camera angles.

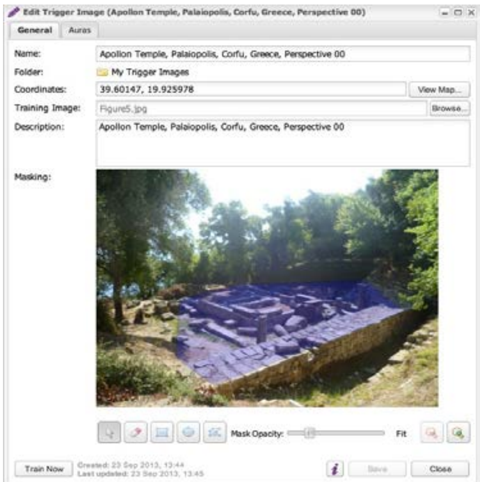

Figure 3 Selection of the actual area of interest using a polygon.

The trigger image shown in Figure 3 when recognized by the application is programmed to display a number of items, one of which is shown in Figure 4. For this instance real-life imagery is linked to historic images with appropriate titles.

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Alternatively, content experts are presented with the option to display video footage about the history of the area or composite presentations, which may utilize mixed audiovisual media. Our experiments have shown that video-based guiding such as documentary clips, digital representations and archaeological presentations in vivo are recommended for
similar settings.

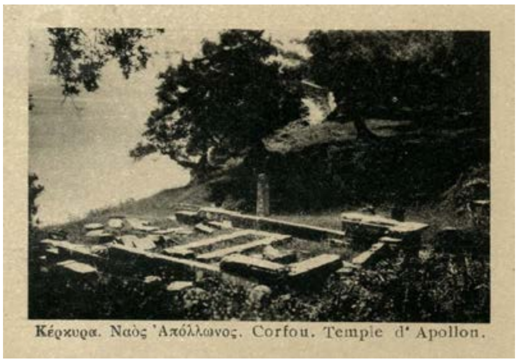

Figure 4 A historical photograph of the ruins.

3. CONCLUSIONS

This work aims to enable archaeologists employ augmented reality technologies in order to cover their particular content presentation requirements and furnish the *communication engine* for museums and cultural tourism with novel technological features. We introduced the ARFA framework while a number of design and development issues are presented and discussed. These include the information triplet, which unifies and links multimedia content to the trigger marker image (*visual representation*); various narrative options that are available for different presentation settings including include closed and open spaces; and the idea of physical information-points where visitors may utilise to receive location-based information by exploring their surrounding space. The fact that most archaeological collections are well documented and the data are accessible electronically is of high importance, while in many cases existing multimedia content, 3D models and documentaries and may be edited and used directly in the target application.

The framework refers to information linking and it may be combined with open access platforms or proprietary augmented reality applications like Aurasma and Junaio, which offer a cost-free developmental test bed. Our further research directions target the development of an application that unifies the information in a Geographical Information System-like environment, enabling also web-based access to the content for those who wish to virtually visit the archaeological sites and collections.

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