A Prototypical Interactive exhibition for the Archaeological Museum of Thessaloniki

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Abstract:

In 2010, the Institute of Computer Science of the Foundation for Research and Technology-Hellas (ICS-FORTH) and the Archaeological Museum of Thessaloniki (AMTh) collaborated towards the creation of a special exhibition of prototypical interactive systems with subjects drawn from ancient Macedonia, named "Macedonia from fragments to pixels". The exhibition comprises seven interactive systems based on the research outcomes of ICS-FORTH's Ambient Intelligence Programme. Up to the summer of 2012, more than 165.000 people have visited it. The paper initially provides some background information, including related previous research work, and then illustrates and discusses the development process that was followed for creating the exhibition. Subsequently, the technological and interactive characteristics of the project's outcomes (i.e., the interactive systems) are analysed and the complementary evaluation approaches followed are briefly described. Finally, some conclusions stemming from the project are highlighted.

Keywords: Interactive exhibits; edutainment; cultural systems; interaction design.

1. Introduction

Advances in interactive systems can have a substantial impact in museum settings in various ways: digital information can enrich the visual aspect of an exhibition, offering for example magnification of detail; accompanying texts can be longer than the average caption, without taking up wall space from the exhibition; multimedia presentations are available on demand. However, the most important parameter is that all this content requires interaction and this means that a museum visitor is no longer a passive viewer, but an engaged participant who plays an important part in her/his own museum experience.

In 2010, the Institute of Computer Science of the Foundation for Research and Technology-Hellas (ICS-FORTH) and the Archaeological Museum of Thessaloniki (AMTh) collaborated towards the creation of a special exhibition of prototypical interactive systems with subjects drawn from ancient Macedonia, named "Macedonia from fragments to pixels"[1]. The exhibition (Zabulis et al. 2011) comprises seven interactive systems based on the research outcomes of ICS-FORTH's Ambient Intelligence Programme. The digital content of these systems includes objects from the Museum's permanent collection and from ancient Macedonia in general. Several of the artifacts presented are not available to the public, either because of their fragile state or their location.

The exhibition has been organized in seven units:

1. Gold Macedonian wreaths from the AMTh's collection
2. Gods and heroes
3. The myth of Meleager and the Calydonian Boar
4. Travel in space and time with a piece of paper
5. Discover an ancient farmstead
6. The painting of a Symposium from the Macedonian tomb of Agios Athanasios
7. A room with view… on Aigai

The resulting exhibition is very different from a typical archaeological exhibition, as the public can have a new relationship with exceptional artifacts of the past through the use of new technologies, enjoying an interactive experience that combines learning with entertainment. In this way, visitors have the opportunity to approach classical antiquity in a novel manner: by exploring digital reproductions of ancient masterpieces. Rare and fragile artifacts are now at the public's fingertips with the use of modern and user friendly technology. All systems are multilingual and support interaction by one or multiple

[1] http://www.makedonopixels.org

visitors. The exhibition is hosted by the AMTh at its premises and is open daily to the general public.

The paper is structured as follows. Section 2 reviews related efforts towards the creation and installation of interactive exhibits in museums, as well as relevant approaches to supporting analogous types of interaction. Section 3 describes the collaborative process followed by ICS-FORTH and AMTh for realizing the exhibition. Section 4 describes the interactive, functional and technological characteristics of the developed exhibits, while Section 5 outlines the complementary approaches followed for their evaluation. Finally, Section 6 concludes the paper.

2. Related Work

Interactive museum exhibits can be broadly classified in four categories:

- *Hybrid exhibits*: augmenting a museum artifact with graphics (e.g., Bimber et al. 2006); or audio commentaries (e.g., Kortbek and Grønbæk, 2008).
- *Side exhibits*: placed adjacent to a real exhibit, providing indirect exploration of, and interaction with, it (e.g., Hornecker and Stifter, 2006).
- *Isolated, but linked, exhibits*: having "a conceptual affinity with the original artwork" (Kortbek and Grønbæk, 2008); they are related to a real exhibit but installed in separate, dedicated, locations (e.g., Ferris et al., 2004; Kortbek and Grønbæk, 2008).
- *Stand-alone exhibits*: containing content related to an exhibition (or museum), but not directly linked to a specific artifact (e.g., Robertson at al., 2006); often they are used to explain or demonstrate abstract concepts, scientific principles, etc., and sometimes they comprise a separate exhibition (e.g., Fleuret et al., 2008).

2.1. Designing interactive exhibits

Durbin (2002) describes the design process and observation results of "interpretative devices" integrated within the displays of the British Galleries of the Victoria and Albert Museum. Lehn et al. (2001) examine the ways in which visitors encounter and experience exhibits and how these experiences are shaped and affected by social interaction. Hope at al. (2009) focus on issues of family interaction and cooperation in a technological-augmented museum, while Walter (1996) and Heath et al. (2005) provide observation study results from the use of electronic guides and interactive exhibits respectively, and identify several problems and trade-offs between interactive media use and social interaction. Hall and Bannon (2005) propose a number of heuristic design guidelines targeted to creating interactive museum exhibits for children. Knipfer et al. (2009) present a framework for understanding informal learning in science exhibitions and explore the learning potential of related advanced applications.

2.2. Interactive exhibits in museums

The "Re-Tracing the Past" exhibition of the Hunt Museum was designed to show how novel interactive computer technologies could be introduced into a museum setting (Ferris et al. 2004) and comprised two room-sized spaces, one enabling visitors to explore mysterious objects, and another to record their personal opinion about them. The "Fire and the Mountain" exhibition comprised four hybrid exhibits (Fleuret et al., 2008) aiming to promote awareness about the cultural heritage of the people living around the Como Lake. The Austrian Technical Museum in Vienna opened a digitally augmented exhibition on the history of modern media (Hornecker and Stifter, 2006). ARoS, an art museum in Denmark employed four interactive exhibits targeted to an exhibition of the Japanese artist Mariko Mori (Kortbek and Grønbæk, 2008). The Ragghianti Foundation held an exhibition entitled "Puccini Set Designer" (Sparacino, 2004) that used new technologies to convey to the audience Puccini's work as set designer.

2.3. Non-instrumented, location-based interaction

The term "non-instrumented" denotes that users do not have to carry any object pinpointing their location. This approach offers more natural interactions, and has very simple logistics (e.g., no need for a lending / return process), a fact that can be very important for a museum. One of the earliest examples of such interaction is the KidsRoom (Bobick et al., 1999), an interactive playspace simulating a children's bedroom where young children are guided through an adventure story. More recently, Laakso & Laakso (2006) developed a multiplayer game system using one top-view camera where player motion is mapped to digital character 2D motion. Another very popular contemporary example are interactive floors (physical sensor-based, like Magic Carpet (Paradiso, 1997) or vision-based, e.g., iGameFloor (Grønbæk et al., 2007) which are mainly being used for playing games. In the domain of museum applications, Kortbek and Grønbæk (2008) explored three different ways for supporting location-based interaction: (a) a coarse grained passive infrared sensor; (b) pressure sensors embedded in the floor and a small staircase; and (c) camera tracking. In "Immersive Cinema" (Sparacino, 2004), one ceiling-mounted camera is used to track a user's position on a floor segmented in five areas. A different, but quite interesting approach was followed by Robertson et al. (2006) in Bystander. They employed a ceiling-mounted IR camera to track users' position and motion, which are subsequently combined into flocking behaviour used to drive the browsing of collections of photographs and texts.

2.4. Playful interaction

Playfulness is a design characteristic that has been embraced by many HCI practitioners as a means for achieving user engagement and motivation (e.g., Khan and Shah, 2006). Wakkary and Hatala (2007) have considered playfulness equally with functionality and learning while developing "ec(h)o", a tangible object (a wooden cube) that acts as a museum guide. Petersen et al. (2004) proposed aesthetic interaction (a concept that they use almost interchangeably with playfulness) as a new perspective on interaction, aiming to create involvement, experience, surprise and serendipity. As part of the WorkSPACE Project, they used a ball as an input device for moving and exchanging digital documents in a workroom with interactive surfaces.

2.5. "Tabletop" augmented-reality

Augmented Reality (AR) is a variation of Virtual Reality (or VR) which superimposes digital information in the real world (Azuma, 1997). The most common approach is to use a handheld (e.g., mobile phone, PDA), or a wearable display (e.g., Sparacino, 2004) to overlay visual digital information onto real-world live video, acquired through a camera. Another approach is to project information in the real world, as was originally suggested for example by Wellner (1993) for DigitalDesk. In this direction, Reitmayr et al. (2005) augment paper-based cartographic maps using a PDA and a rectangular image browser prop consisting of a white piece of cardboard with a black border that is used to browse images or other information registered with locations on the maps. Holman et al. (2005) project a windowing environment on physical paper to simulate the use of digital paper displays. The pieces of paper and the user fingers are augmented with IR markers in order to be tracked. Also, Spindler et al. (2009) developed a system that tracks a sheet of paper augmented with IR-reflecting markers which is used to explore the 3D space over a tabletop. The authors identify four different types of data spaces (volumetric, layered, zoomable, temporal) and suggest related navigation techniques.

2.6. Vision-based, multi-touch interaction

Computer-vision based multi-touch displays use one or more cameras to detect user interaction. Typically, in order to overcome the dynamic visual clutter created by the displayed image, IR cameras are used in conjunction with IR light emitting sources, which are projecting light towards the screen (e.g., Matsushita and Rekimoto, 1997; Leibe et al., 2000; Microsoft, 2008). Various system configurations have been proposed based on whether the cameras and the user are on the same side of the screen or on opposite sides.

2.7. Prop-based interaction

Using everyday objects for supporting interaction has a two-fold effect: on the one hand, ease of learning and usability are considerably increased, since users are already familiar with their use, while, on the other hand, a "wow" effect is created, as familiar, common, objects object gain "magical" properties. As Tognazzini (1993) notes, "The magician's tools should be disguised to look like objects in the real world". Hinckley et al. (1994) have used passive props with embedded six degree-of-freedom trackers to support neurosurgical planning. Pausch et al. (1993) used a real flashlight to move virtual cameras and spotlights, and Ishii and Ullmer (1997) use a transparent lens as well as various "phicons" (physical icons) to interact with the surface of the metaDESK.

3. The Exhibition Development Process

In 2009, in the context of the "Ambient Intelligence and Smart Environments" Programme of ICS-FORTH (Grammenos et al., 2009), a multidisciplinary team was set up aiming to explore and experiment with the creation of novel interactive edutainment exhibits for museums and assess their utility, usability and potential impact. The preliminary results of this activity were presented, among others, to the Archeological Museum of Thessaloniki, who expressed vivid interest towards realizing a permanent installation of such systems at AMTh. Eventually, a bilateral project was setup between the two organizations, comprising two multi-disciplinary teams. ICS-FORTH's team counted 16 members, including researchers, interaction designers, programmers, computer scientists, electronic engineers, and graphic artists, and was mainly responsible for designing, developing, installing and supporting the interactive exhibits. The Museum's team included four archaeologists, two architects / museologists, and several technicians whose main tasks were to provide the required digital content, as well as to design and construct the exhibition spaces and contribute to the design of the interactive exhibits so that they would best serve the requirements and functional role of the

Museum. In brief, the overall process followed can be summarized as follows (Figure 1).

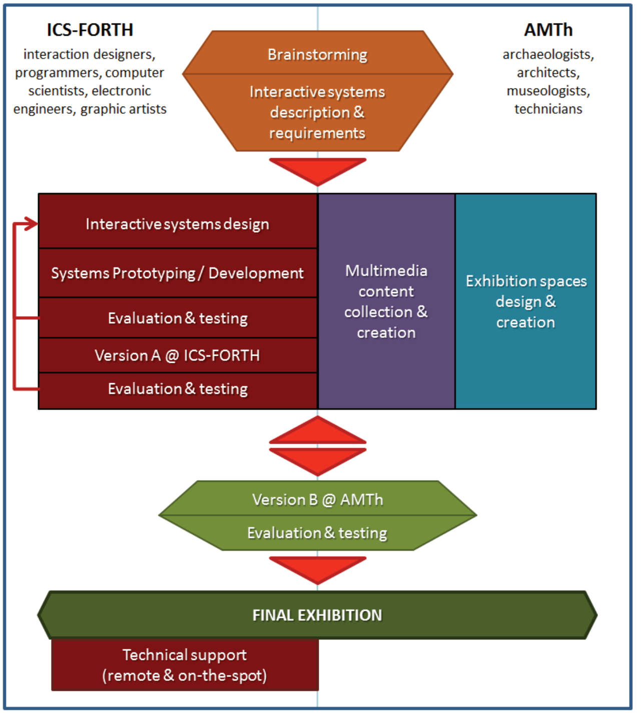


Figure 1: Process followed for creating the exhibition

During the initial brainstorming phase of the project, the number, nature, location and basic theme of the interactive systems that would be installed were agreed. In this context, it was decided to install five exhibits in a dedicated, specially designed hall of the Museum, and to integrate two more in the Museum's permanent exhibition on ancient Macedonia.

Subsequently, the two teams started working collaboratively and in parallel towards designing the installation spaces, shaping the interaction design and technical requirements of the exhibits and collecting and formulating appropriate multimedia content. In this context, a highly user-centred, iterative process was followed where the outcomes of the work of one team frequently resulted in changes to the work of the other. Different types and levels of prototypes, ranging from simple sketches to functional digital applications were employed so that all project members could have a clear understanding of the systems that were being created, how they would interact with their users, what kind of multimedia content they would provide and how.

When a system under development reached a fairly stable level, it was installed in a dedicated space simulating a museum room on the premises of ICS-FORTH and was further tested and evaluated by experts as well as by a highly diverse group of potential end-users.

When all systems were ready, they were installed at the Museum, and were further tested and evaluated for a couple of weeks with archaeologists, museum guards and visitors, a process that led to further refinements of both their interface and digital content. For all systems, a working copy was also assembled, so that early prototype failures could be replicated and studied.

On-going technical support is mainly performed remotely through screen sharing applications, teleconferencing, e-mails and phone calls. To date, occasional site visits by FORTH technicians to the Museum were due to exceptional hardware failures.

4. The Exhibition

The exhibition comprises seven systems, five of which are located in a specially designed hall of the Museum, while the remaining two have been incorporated into the Museum's permanent exhibition on ancient Macedonia and installed nearby the archaeological exhibits that they are related to. The applications running on all systems were developed using Flash ActionScript, while the low-level services that drive the hardware sensors were implemented in .NET (C#), C++ and CUDA. An in-house middleware layer based on CORBA was employed (Georgalis, Grammenos & Stephanidis, 2009) by all the exhibits to allow the interactive applications and various software services to communicate, despite their heterogeneity. The middleware is the connecting thread that allows components of any layer to communicate with each other, thus effectively supporting seamless exchange of information and cooperation, potentially even among different exhibits.

4.1. Panoptes

Panoptes (Grammenos et al., 2011b) is a digital exhibition-catalogue system which allows visitors to browse its content and dwell on details of images, read accompanying texts and follow threads of information (Figure 2). Panoptes presents the AMTh gold Macedonian wreaths collection, the most extensive such collection in the world. These wreaths are among antiquity's most exquisite examples of ancient jewelry.

Panoptes builds upon the concepts of playful (Khan and Shah, 2006) and aesthetic (Petersen, 2004) interaction combining functionality with playfulness and serendipity, thus offering an

Figure 2. Panoptes, the all-seeing

alternative to information kiosks used at museums for browsing item collections.

The system comprises a wooden "wall", two framed touch screens, a webcam, a light sensor and a custom windmill sensor. The larger screen presents a high resolution photo of the currently selected artifact. The smaller one presents information about the artifact and also includes some soft buttons. The large screen supports two types of interaction:

- *Hotspots*: Each image can include any number of hotspots. If the user touches one of them, the corresponding area is highlighted and a word balloon pops-up with related information (Figure 4). If the user touches any part of the image that does not include a hotspot, then all the available hotspots are highlighted (Figure 3) in order to provide feedback about their position.
- *Magnification*: If the user drags her finger on the image, she starts drawing a line with which she can circle an area of interest. When the user moves her finger off the screen surface, the selected area is magnified. The user can subsequently iteratively zoom into the selected area.

A visitor can browse all the available artifacts by blowing at the windmill (or just rotating it with the hand). The windmill's speed affects the browsing speed but also triggers alternative music pieces originating from old music boxes.

The smaller screen contains a framed photo of the current artifact, visually linking its contents with those of the larger screen, brief information that depends on the artifact type, a descriptive title and a short text. The screen also offers buttons for browsing/navigating through the collection of artifacts, accessing a gallery of all artifacts

Figure 3. Panoptes: available hotspots

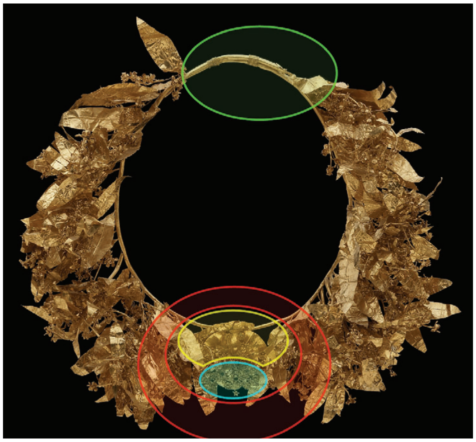


Figure 4. Panoptes: hotspot selection and information presentation

through which the user can select one for viewing, and language selection.

4.2. Cryptolexon

Cryptolexon (Figure 5, Figure 6), the hidden crossword, is a game, which combines entertainment with knowledge and which was observed to be popular to people from all age groups. Names of ancient gods and heroes are hidden, within a lattice of letters, for the visitors to discover. On the easiest level, players can find the twelve gods of Mount Olympus; as the degree of difficulty increases, heroes and lesser known local gods are also included. The system uses a touch screen. Visitors can discover the hidden words by dragging a finger from the start to the end of each word or, alternatively, by touching each word's first and last letter. Once a word has been found, information is presented about it.

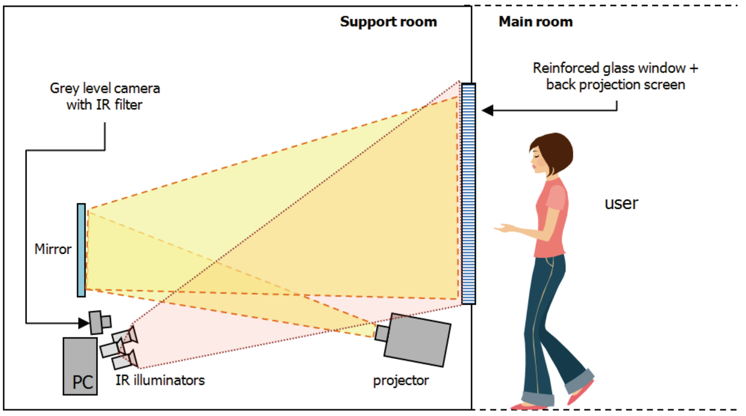
Figure 5. Cryptolexon, mystery word puzzle

Figure 6. Cryptolexon: letter matrix

4.3. Polyapton

Polyapton (Grammenos et al. 2011b; Michel et al. 2009) is a very large interactive screen that can be used by several visitors who wish to explore multifaceted information on a subject at the same time (Figure 8). Polyapton presents one of the best-preserved ancient Greek paintings. It is a wall painting depicting a symposium, from the Macedonian tomb of Agios Athanasios near Thessaloniki. The tomb is not open to visitors, who have, through this system, a rare opportunity to enjoy the painting in its full glory. The system provides the ability to multiple users can interact concurrently with this system.

Figure 7. Polyapton schematic installation layout



The system builds upon the combination of IR illumination and semi-transparent back projection screen (e.g., Matsushita and Rekimoto, 1997; Leibe et al., 2000; Microsoft, 2008) and consists of (see Figure 7) a grey level camera equipped with an IR filter, 8 IR illuminators, a projector that is projecting through a mirror on a rear-projection acrylic rigid screen backed up by a thick layer of glass, and a workstation equipped with a firewire video acquisition card. All the electronic equipment is hidden inside a control room. In addition to multi-touch, the system supports interaction using two props (objects), that are detected using computer vision techniques: (a) a plastic magnifying glass (working like the transparent lens in Ishii. and Ullmer, 1997); and (b) an IR flashlight (the use of which was inspired byPausch et al. 1993).

The basic principle of operation of Polyapton (Michel et al. 2009) is that the light emitted by IR illuminators towards the screen passes through it and is strongly reflected by the objects that are in contact with the screen. Images of the projection screen are then acquired by the camera. A highpass spectral filter on the camera blocks the visible light and casts the camera sensitive only to the infrared light reflected by the objects behind the screen (if any). Note that the acquired image does not contain the displayed video by the projector, as this occurs in the visible spectrum. Geometric correction needs to be applied to acquired images. One type of geometric correction is responsible for canceling out distortions introduced by the camera lens (barrel distortion). Another type of geometric correction rectifies perspective effects introduced by the relative placement of the camera with respect to the projection screen. Moreover, the response of the camera to the reflected IR light needs to be tuned through a photometric calibration process that assigns different threshold values to different screen portions. The resulting binary image is fed to an algorithm (Argyros, Lourakis, 2004) that identifies blobs and tracks them over time. The final output of this computer vision system includes

Figure 8. Polyapton, using the plastic magnifying glass prop

morphological properties of the detected and tracked blobs, together with their trajectories in time.

The top part of the screen presents a magnified view of the wall painting. Upon touch, any available hotspots are highlighted. If a hotspot is selected, then a bubble appears which may contain a photo or video and some explanatory text. Except touching, users can interact with this part of the screen by using a plastic magnifying glass (where the 'glass' part is missing) and an infrared torch (also projecting visible light as feedback to the user). When the magnifying glass is overlaid on the screen a magnified image of the painting is presented "inside" it (where the "glass" part should be). When the infrared torch is lit and directed towards the screen, the part of the wall-painting "lit" by it is shown restored. Below the magnified view there is a "thumbnail" presenting the whole wall painting. On it there is a green rectangle denoting the part of the image that is presented in the magnified view above. Users can drag this rectangle to scroll the magnified view. To both sides of the thumbnail there are touch buttons, which upon touch provide some contextual information about the wall painting, which would not be appropriate to provide through hotspots. Finally, at the bottom of the screen there are buttons for changing language and invoking a help video.

4.4. Macrographia

Macrographia (Zabulis et al. 2010; Zabulis et al. 2012) is a system that presents very large images, which visitors can explore by walking around in a room (Figure 9). The images are projected on a screen and are analyzed part-by-part depending on the location of each visitor in the room. Macrographia presents the "Wall-painting of the Royal Hunt" from the tomb of Philip II at Vergina, ancient Aigai, a large

Figure 9. Macrographia: A room with view… on Aigai

work of art, presented almost in real size. This is the largest ancient Greek painting that has been found to date, its length exceeding 5.5 meters. It is dated in 336 BC, the year when Philip was murdered, and decorates the front of the tomb of the great king. g. Widely admired as a rare masterpiece of ancient Greek art, the painting shows ten hunters chasing five different animals in a complex landscape.

The pertinent system is based on a camera network that observes multiple humans in front of a very large display. This network enables the observation of visitors from multiple views. The acquired views are used to volumetrically reconstruct and track the humans robustly and in real time using the method of (Argyros, Lourakis, 2004), even in crowded scenes and challenging human configurations. The system includes one or more computers that acquire the corresponding images, process them, and extract a spatial representation of the persons in the room. Given the frequent and accurate monitoring of humans in space and time, a dynamic and personalized textual/graphical annotation of the display can be achieved based on the location and the walk-through trajectory of each visitor.

The digital representation of the wall-painting is conceptually separated in five zones perpendicular to the display, based on a semantic interpretation of the themes that appear in it. The room is also conceptually separated in four rows parallel to the display, which correspond to different distances of observation. To prevent from continuous alternation in the case of visitor lingering across the boundary of a cell of the grid, the cell size is assumed magnified by 10% comprising a grid of partially overlapping slots. At the room entrance, signs guide English speaking visitors to enter the room by moving rightwards and Greek-speaking visitors to enter the room by moving leftwards. The corresponding textual annotation for each

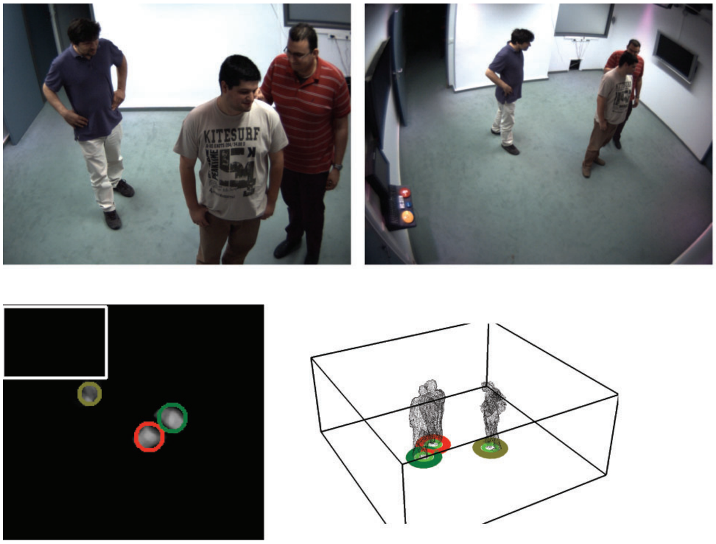


Figure 10. Person localization and tracking. (Top) Original images from two out of eight views, (below) person segmentation and 3D reconstruction. Person tracking results are rendered as circles, superimposed on the ground plane of the 3D reconstruction. Circle colors correspond to track ids. Tracking retains the correct id for all persons although it is often that visitors may come in contact or occlude each other to the cameras.

distance is presented at the bottom of the screen. Within the context of a zone, the presented content is varied graphically and conceptually according to the distance of observation. When a visitor enters a zone, the presented content matches the viewing distance. The visitor has the capability to explore the corresponding theme by stepping back to get a more abstract view or step closer and focus on the details of the exhibit. This capability is communicated to visitors through real-time visual feedback, which helps them perceive the distance they have to walk in order to move to the adjacent row. When idle and upon visitor entrance, the system presents the wall-painting in its current state. As one or more visitors approach the display, graphical outlines are superimposed to the corresponding region(s) of the display reviving the deteriorated forms. In the next row, the system presents a fully restored version of the painting. In the closest row, the restored version is grayed out, and a specific detail is highlighted, using a combination of color and animation. When multiple visitors stand in the same zone, the person closest to the display determines the content of the presented textual annotation. When this person leaves, the next in line (if any) becomes the closest one to the display. By tracking visitors and assigning a unique identifier to each one, the system also retains attributes for each of them. Using an attribute for the language, which is set upon visitor entrance, the textual components of the presented content are provided in the language selected by each visitor. Finally, the time each visitor has spent in each slot is logged in order to gather and visualize statistical data concerning the visits.

4.5. Multimodal diverse travel

Multimodal diverse travel (Grammenos et al. 2011a; Grammenos et al. 2011c) enables more than one visitor at the same time to interactively explore information about various areas and points of a map of Macedonia (Figure 11). The system follows the paradigm of augmentation of maps using real world objects suggested by Reitmayr et al. (2005), extending it by supporting multi-user interaction, finger-based input and concurrent tracking of diverse border colors. Multimodal Diverse travel is comprised of a wooden table, a projector, a color camera, and a conventional PC with audio speakers. Additionally, rectangular pieces of plain white cardboard are employed which feature a colored frame. A computer vision system tracks the position and pose of the paper surfaces, as well as the activation of any related interactive areas by the users' fingers which may touch this surface. The vision system detects the quadrilaterals corresponding to the cardboards based on the knowledge of the color of the border of each cardboard using a color similarity metric (Smith and Chang, 1996). Then, the silhouettes of the detected contours are traced and fitted with straight lines. The system estimates the transformation that maps the detected quadrilateral(s) to rectangular regions, using a homography. The identity of each cardboard is maintained over time. To increase robustness and suppress jitter, the trajectories of the polygon corners are tracked using Kalman filtering modeling location and velocity. The 3D location and pose of the cardboard is estimated given the size of its edges in the image and its size, during setup, by placing the cardboard in a frontoparallel posture on the surface of the table. Additionally, rectangular areas dynamically defined by the application (i.e., "soft" buttons) are continuously checked for differences using a background subtraction method. The image projections of these areas are tested for the occurrence of skin-colored blobs, using the method in (Argyros, Lourakis, 2004) and, at the same time the neighboring area of the nested quadrilateral is checked for occlusions. Finally, all the information generated by the vision system is passed through a custom middleware layer to an application, which implements the system's user interface.

The table surface is covered by a printed map of Macedonia, Greece. The printout does not contain any text or other kind of data. Initially, the location (as red spots) and names of ancient Greek cities with archeological interest (in English and Greek) are projected on the map surface. At the one side of the table surface, brief bilingual instructions are also projected.

Figure 11. Multimodal Diverse travel

On two of the sides of the table, there are two cases containing several pieces of white cardboard which are at the visitors' disposal. Each cardboard piece has a colored frame. One of the four sides of the frame has a different color compared to the remaining three. This side is considered to be the cardboard's "bottom" side, i.e., the side against which all text is aligned. The color of the other sides is used to denote the cardboard's language (e.g., green is for Greek and orange for English). Multiple users can concurrently use the table, as the system can track multiple cardboards simultaneously.

The visitors' interaction with the system operates as follows:

- When a visitor places a cardboard piece over the table surface, an image is projected on it, showing a satellite view of the respective printed map area ("map mode" – see Figure 12). Furthermore, a magnifying glass is projected on the paper's centre. If a city's name intersects with a piece of paper, then the name's letters are rotated so that they are aligned with the paper's orientation.

Figure 12. Multimodal Diverse travel in "map mode"

Figure 13. Multimodal Diverse travel in “info mode”.

- As the visitor moves the cardboard around, the size of the magnifying glass changes. The closer it gets to a city’s location, the bigger it gets, in order to facilitate city selection. If the magnifying glass is located over a city, then a multimedia slideshow starts (“info mode” – see Figure 13). The slideshow comprises a series of pages, each of which may contain any combination of text, images, and videos. At the bottom area of the slideshow, a toolbar is projected containing an indication of the current page and the total number of pages (e.g., 4/23), as well as buttons for moving to the next/previous page. The visitor may interact with these “soft” buttons using his/her fingers (see Figure 13). The information projected on the cardboard is always rotated so that it is kept aligned to the “bottom” side.

In order to visually link the information presented on a cardboard piece to the site it refers to, a virtual connecting string is used. When the cardboard is close to the site, the string is green and thick. Then, as it gets further, its color gradually changes, first to orange and then to red, and its thickness is reduced. Finally, if the cardboard is moved beyond a minimum distance, the string “breaks” and the paper’s surface returns back to “map mode”.

4.6. One day in a farmstead

This system (Grammenos et al. 2011a; Grammenos et al. 2011c) allows visitors to retrieve information about an ancient farmstead of the 4th century BC that has been excavated at Asprovalta near Thessaloniki (Figure 14). This is achieved by enriching a scale model with multimedia information in one of the main exhibition areas of the Archaeological Museum of Thessaloniki. A key requirement of this setup was to create a self-contained “add-on” system, requiring minimal interventions to the installation space. Thus, in order to accommodate the space limitations, an ultra-short throw projector is used, and a camera with a wide angle lens.

Figure 14. One day in a farmstead

The system interactive behavior is similar to that of the *Multimodal Diverse travel*, with the following differences (a) when the paper tablet is located over a point of interest, a short animation is presented that starts from a view of the piece of the model located underneath and is gradually transformed into the respective area of the actual excavation site, so that visitors can visually correlate them; (b) due to the glass surface, no information is projected outside the tracked papers.

4.7. Peridexion

Peridexion (Figure 15) is a system that offers museum visitors the possibility of exploring an object and/or a subject in depth. Peridexion presents a masterpiece of 6th c. BC Athenian black-figured pottery, the Crater of Lydos, and three exceptional examples of Roman sculpture from the AMTh collection, all of which draw inspiration from the legend of the hunt of a monstrous boar in Calydonia, Aetolia. This

Figure 15. Peridexion, the dexterous

myth is not widely known today, as most relevant ancient texts have not survived, but was at times very popular in antiquity, and a source of inspiration for artists for a very long time. The objects included in this presentation span eight centuries.

The system has a touch screen that presents a view of an object at a time. Visitors can select the object or the view they wish to see and then discover points of interest and relative multimedia information, or zoom in on any detail at will. The system is located at the exhibition "At the kingdom of Macedonia", unit: "Myth and worship", next to the real artifact.

5. Evaluation

During the development stage of the project (i.e., middle-top part of Figure 1), formative evaluations have been conducted employing ethnographic field methods (Blomberg et al., 1993), using a combination of the "observer participant" and "participant observer" approach. To this purpose, the exhibits were installed in a dedicated space, resembling an exhibition area of a museum. Participants were invited on an ad hoc basis, among people of all ages and cultural / educational background visiting (e.g., politicians, scientists, school classes) or working in ICS-FORTH facilities, including their families. Typically, evaluation sessions involved a facilitator accompanying the visitors, acting as a "guide" and another distant observer discretely present in the exhibition space. Since there were numerous evaluation sessions, alternative approaches were used, depending on the exhibits' characteristics to be assessed. For example, when, at earlier stages, the interactive behavior of the exhibit was tested, the facilitator would first provide a short demonstration to the participants and then invite them to try it for themselves. Alternatively, when ease of use and understandability were assessed, the facilitator would prompt participants to freely explore the exhibit without any instructions. During and after the sessions, the facilitator held free-form discussions with the participants eliciting their opinion and experience, identifying usability problems, as well as likes and dislikes. The facilitator kept a small notepad for taking notes. After the visitors have left, the two observers would discuss the session, keeping additional notes, often reenacting parts of it, in order to clarify or further explore some findings. During this phase more than 200 persons of various ages and educational and technological backgrounds have participated. Overall, the opinion of all participants about the exhibits ranged from positive to enthusiastic. Usually, when visitors were first introduced to the exhibits there was a short "wow" phase, during which they seemed fascinated by the technology and tried to explore its capabilities, but, interestingly, after that, most of them spent considerable time exploring the exhibits' content.

During the installation phase of the project (i.e., lower part of Figure 1), summative evaluation sessions also took place both at the premises of ICS-FORTH, as well as at the Archaeological Museum of Thessaloniki (e.g., see Zabulis et al. 2012). For the purposes of evaluating the experience of the users with the various systems, attitude Likert scale questionnaires were created based on Brook's System Usability Scale (SUS) questionnaire (Brook, 1996). This type of questionnaire was chosen because its questions cover most aspects of usability such as system complexity, learnability, likeability, and effectiveness. The questionnaires also included a part for collecting background information about the respondents. Providing detailed evaluation results is beyond the scope of this paper, but overall, the questionnaire results reinforced the fact that all developed systems achieved the goal of providing engaging and entertaining educational experiences to their users, a fact that was also validated in practice when real visitors interacted with them in the museum.

6. Conclusions

On the whole, the project can be deemed as highly successful. Taking into account the formal and informal opinion of both experts in the field, the museum staff and everyday visitors, the developed systems accomplished to augment and provide added-value to the overall museum visiting experience. There are numerous recorded comments made by visitors that range from positive to enthusiastic, while results stemming from more formal "in situ" evaluations (e.g, Zabulis et al. 2012) reinforce these findings.

The exhibition has received a lot of publicity, initially through the mass media and the Internet, and subsequently through word-of-mouth "advertising". The public's response was beyond any expectation, while schools need to enrol in a waiting list in order to get a chance of visiting the exhibition. Up to the summer of 2012, it is estimated that more than 165.000 people had seen the exhibition, out of which 42.000 were children 6 to 16 years old, in the context of organized school visits.

From a scientific point of view, the project generated several innovative research results which were documented in academic publications, a number of which stemmed from the collaboration between domains, such as computer vision and human-computer interaction (e.g., Polyapton (Grammenos et al. 2011b; Michel et al. 2009), Macrographia (Zabulis et al. 2010; Zabulis et al. 2012), Multimodal Diverse travel and One day in a farmstead (Grammenos et al. 2011a; Grammenos et al. 2011c). Additionally, the project provided an invaluable platform for studying interactive exhibits in situ, in an environment which is visited daily by several hundreds of visitors of diverse ages and nationalities.

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