Adaptive Augmented Reality for Cultural Heritage: ARtSENSE Project

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Abstract. The paper presents the new concept of Adaptive Augmented Reality (A^2R), employed within the context of the creation of an AR guide for the museum visit, that is being developed in the context of an EU research project. The main objective of the project is to provide a prototype that enables a personalized experience for every individual visitor by adapting to the psychological state of the visitor the content presented through an augmented reality museum guidance system.

Keywords: Adaptive Augmented Reality, Cultural Heritage, Multimodal Sensing.

1 Introduction

Museums and other Cultural Heritage (CH) Institutions have been traditionally providing on-site information and interpretation material to their visitors in two ways: text (through text-panels and labels) or audio guides. With the rapid expansion of new technologies museums start to explore the potential of ICT-enabled multimedia interpretation media. Augmented Reality applications, traditionally used mainly for applications in industry, maintenance, architecture or assisted training have lately started to make their appearance in the museum setting. Using AR for delivering full-fledged multimedia content could provide the visitor with many different types of interpretation resources: text, audio, video or two-or three-dimensional objects, with which a user can interact. AR provides the possibility to overlay this information on the physical environment using more or less immersive and portable AR platforms and displays [1].

M. Ioannides et al. (Eds.): EuroMed 2012, LNCS 7616, pp. 746–755, 2012.

The ARtSENSE project (www.artsense.eu) however proposes a different approach to AR applications for CH, transforming the existing strong correlation of AR with uniquely visual augmentations and adaptations of the content: ARtSENSE proposes a visitor-tailored adaptation of the multimedia interpretation material provided by combining not just one but three types of sensors: visual sensors, audio sensors and psychophysiological sensors. The goal is to estimate the interest and engagement of the visitor and adapt the content provided by the guide accordingly. In order to reach this objective, both the visitor and the museum environment have to be monitored taking under consideration different parameters (visitor's bio-signals, acoustic environment, visitor's gaze and gesture). By combining inputs from all three types of sensors, the multimedia AR guide adapts the content to the visitor's engagement state. Therefore, the ARtSENSE system does not only "augment" the museum visit only with visual and audio content. It takes under consideration different parameters and inputs to adapt the content accordingly and to augment the museum visit in a highly personalized way.

Indeed, the evolving demands of museum visitors, the opening-up of museums to their public and the chase for an even more personalized museum visiting experience, set a new challenge and lead to a new generation of adaptive AR (A^2R) guides that should be able to drive this personalization. Within this context the main claim of the project is that the notion and essence of a multimodal adaptation is the next step in the development of AR systems.

ARtSENSE is a research project with a three-year duration and groups ten partners coming from six European countries, which can further be divided in five technology research partners (Complex Event Processing, Image processing and AR, Cognitive Psychology and Physiological Computing, Acoustics, Interpretative use of ICT technologies in Cultural Heritage), two industrial partners and three museum partners, featuring different types of collections, as well as interpretation policies: The Musée des Arts et Métiers (Paris, France), the Foundation of Art Creative and Tecnhology (Liverpool, UK) and the Museo Nacional de Artes Decorativas (Madrid, Spain) representative of a History of Science Museum, a contemporary artistic creation center and a Decorative Arts museum. This guarantees that the ARtSENSE approach will explore a large range of different types of museums and CH institutions as well as related publics for which the ARtSENSE experience will be tailored. The collaboration and active participation of not just one but three CH partners was grounded on the hypothesis that the deployment of an adaptive AR guide in three complementary types of museums could promote our understanding of the potential of the A^2R approach by encouraging the collaboration among CH professionals while promoting a more extensive coverage of the potential of AR and the A^2R approach as an interpretation medium for the museum visit and potentially other related formal and informal learning environments.

2 Overview of the Scenario

The main objective of the project is to improve the experience of the visitors' by adapting the contents of an AR digital guide depending of their level of interest (A^2R). Therefore, one of the greatest goals and challenges in the project is to determine the

level of interest while the visitor is contemplating an artwork or museum artefact. To reach this goal, a system model has been proposed, where different inputs to the visitor and different outputs from the visitor exist within the same framework and are taken under consideration for the adaptation of the Adapted AR visit.

As it is shown in Figure 1, when the visitor is contemplating an artwork, the stimulus acts as an input to the visitor. Additional inputs that can influence the level of interest of the visitor are: the environment, e.g. sounds that can disturb the visitor, and multimedia content the digital, AR guide is providing, e.g. images, videos, animations, text, audio comments, sounds, 3D visualisations. The latter are provided through the AR see-through glasses, capable of projecting information in the visitor's field of view as a virtual overlay and acoustic recordings (audio commentaries and sound effects) through headphones. Therefore, the artwork, the environment and the AR content delivered to the visitor are all considered as input parameters for the visitor. Additionally, the system monitors several outputs of the visitor in order to determine the psychological state and more precisely the surrounding acoustic environment (sounds and noise that can disturb), the gaze (where the visitor is looking at and for how long), and finally the biosignals or physiological responses of the visitor (heart rate, breath rate, skin conductance level). The result of these modules will be combined to obtain the psychological state of the visitor and determine the level of interest with regards to what the visitor is looking at, or listening to but also in order to determine when a visitor is disengaged.

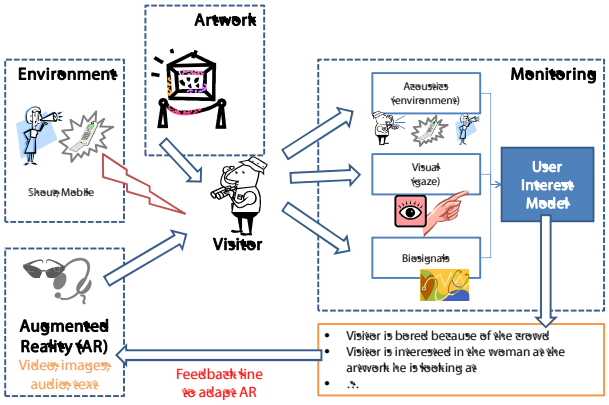

Fig. 1. Overview of the scenario

A great novelty of the project is the feedback loop between the detected psychological state of the visitor and the provision of content via AR (Fig. 1). This biocybernetic loop will allow the adaptation of information provided by the system as AR content, leading to the new concept of A^2R. For example, if the visitor is interested in the artwork he is looking at, more information and more details will be provided by the AR system. On the other hand, if the visitor seems to be lacking interest, other artworks will be suggested and/or different content will be provided taking also under consideration the logs, visiting history, types of content and media that stimulated the visitor's engagement and interest.

3 Use-Case Design Process

3.1 Introduction

One of the particularities of the ARtSENSE project is the close collaboration and active participation of a large team of CH professionals in the conceptual design, the system requirements analysis and the interaction design of the system. According to the phisolophy and theory of User-Centered (UC) and Participatory Design it has been argued that the design of hybrid experiences does not take place neither in the software professionals space nor in the "workers" space but in an in-between region, defined as a third space, provoking and featuring attributes of each one of the bordering spaces, in which the assumptions of both categories of stakeholders should be open and subject to questions [2].

Within the ARtSENSE project and for the first design iteration the CH professionals of all three participating CH institutions were identified as the "workers" and the first group of end-users meant to activily participate in the design phase of the adaptive AR museum guide. In order to integrate in the design phase of the A^2R museum guide all of their know-how, the consortium favored a UC-informed and interdisciplinary design approach. In addition, ethnographic fieldwork also informed the data gathering prior to the system requirements analysis. Ethnographic approaches have been so far applied in interaction design [3], museum and visitor studies [4] and the intersection of these both domains [5]. The goal was to identify how CH professionals comprehend the potential of AR for CH as well as the added value of the A^2R approach.

3.2 Data Gathering

One of the most crucial challenges was to cater for the design of an A^2R museum guide that would accommodate and respect the uniqueness of the collections, the educational policies and strategies but also the aspirations of all three participating CH institutions. Given the emerging character of AR approaches in CH and the novel concept of A^2R it was also important to cater for an iterative design process meant to open first to the CH professionals and then to the main public targeted by the ARtSENSE project, the museum visitors. In order to achieve this three design iterations were designated: 1. During the 1st iteration the accent would be given to an intensive collaboration of technical (research and industry) partners and the CH professionals. 2. During the 2nd iteration the museum public would provide valuable feedback through testing a 1st prototype. 3. Finally the 3rd iteration, occurring in parallel would invite one or more New Media Artists to collaborate with the project team.

During the 1st iteration of the design process, an ethnographic approach was adopted so as to arrive to a collective understanding of the particularities of the museum environment and proceed to the system requirements analysis. Unobtrusive observations of museum visits were conducted, giving an emphasis on the way museum visitors were using available, on-site interpretation media, consisting mainly of text panels, digital audio guides and multimedia kiosks. We also proceeded to

participatory observations of guided visits for different visitor profiles (adults, children, school groups and families) as well as to observations of creative workshops principally addressed to school-groups, children and families. This methodology assisted in identifying to which extent current educational and interpretation policies could inform the design of the A^2R guide. In addition to these activities, mainly targeting the way museum visitors use existing interpretation activities and media on-site we also proceeded to interviews and brainstorming sessions with all of the museum professionals in Madrid, Paris and Liverpool. At a later stage the CH institution teams were coupled with collocated technical partners specialized in acoustics (MNAD), physiological computing (FACT) and the ICT mediated museum learning experience (MAM) In the next section we present the architecture that fulfils requirements for A^2R, gathered in the presented design process.

4 Our Approach - Adaptive Augmented Reality (A^2R)

We define A^2R as the process of adapting the augmented reality to the current context and personal characteristics of a user of an AR system. In order to enable an adaptive experience for museum visitors, our approach is constructed around a four-phase OODA cycle (Observe, Orient, Decide, Act [6]) as shown on Figure 2. In the Observe phase, our approach is concerned with the measurement of covert cues that may indicate the level of interest of visitors. In order to consider how a visitor perceives an artwork, different sensors have been considered: The monitoring of visual behavior allows the system to identify the focus of attention, i.e. which artifact or aspect of the artifact is the visitor contemplating? The acoustic module provides important information about environmental influences on patterns of visual attention or psychophysiology. Finally, a video-based hand gesture recognition provides an additional input modality for explicit interaction with the system (e.g. for selecting certain visual items, navigating through menus).

All data streams are collected and analyzed in real-time in order to yield a dynamic representation of the user attention state (Orient phase). In the Decide phase, covert physiological cues are used to measure the level of interest or engagement with the artwork or with the augmentations presented via the AR device. Based on the interpretation of this complex state, the provision of the augmented content from a repository of available content is made. The presentation of selected content via the AR device (e.g. visual, audio) is subsequently executed during the final Act phase. More in particular, following the Observe, Orient and Decide phase, the Act phase will consult the repository as well as the Metadata model to provide to the visitors a selection of recommendations, based also on the monitoring of the interest that already provided content has so far generated. Note that though at the beginning of each tour, the content to be delivered will accommodate different visitor profiles (e.g. novice, expert, child, adult etc), during the visit due the OODA cycle will provide recommendations specially tailored to the manifested interest of each individual visitor, based on the annotation of both the museum artifact/scene as well as to the type and content of the digital content delivered in the glasses.

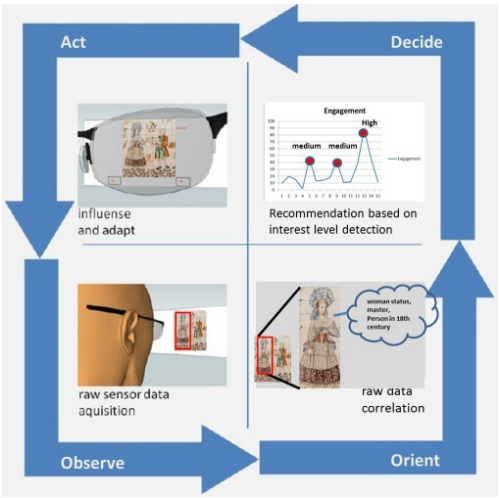

Fig. 2. Observe, Orient, Decide, Act cycle

The proposed approach has been realized through:

- Understanding precisely the user's perception of an artwork, including her/his real-time reactions on the details of the artwork (WHY).
- Discovering the situations during which (WHEN) the user's real-world experiences can be augmented by WHAT virtual object in order to support the (personal) understanding/interpretation of an artwork.
- Continually adapting augmented reality according to the user's real-time needs and preferences, proactively and in the right form (HOW).

In the rest of this paper we focus on the Orient phase and present a purely multi-modal attention mechanism, which also permits a straightforward inclusion of new additional sensors. The proposed mechanism for multimodal integration is not only intended to exclusively serve the visitor's attention capability, but also to provide a rich, complex, and coherent representation that can be directly used for other intelligent tasks.

5 The A^{2}R Museum Visit: System Architecture

5.1 Conceptual Architecture

As it can be concluded from the previous discussions the ARtSENSE system consists of several complex components efficiently combined in order to enable real-time adaptation of the information provided to a museum visitor based on her/his current interest. The high level conceptual architecture is presented in Figure 3. In terms of technical architecture, the main technological challenge is to develop an adaptive AR

system that will be able to adapt the AR content to the current behaviour/preferences of a visitor, in order to provide a highly personalized, AR-enhanced, museum visit. In the following we present more information about components depicted in the architecture.

Sensor Subsystem: connects to the sensor hardware and collects the physical signals of visitors such as gaze, sound, heart rate and other bio signals from sensors.

Publisher/Subscriber Subsystem: uses an Enterprise Service Bus (ESB) to implement the publish/subscribe mechanism in order to transmit the information among all components of the ARtSENSE system.

Knowledge Base Service Subsystem: manages all knowledge bases in the system such as, metadata storage (storage of metadata of the artworks), user information (storage of basic personal information of visitors), feedback model (storage of historical information of recommendations) and event storage (storage of all sensor events). It provides the knowledge query service with a consistent interface to all ARtSENSE components.

Complex Event Processing (CEP) subsystem: processes the data collected by the sensor system to find the situations of interest.

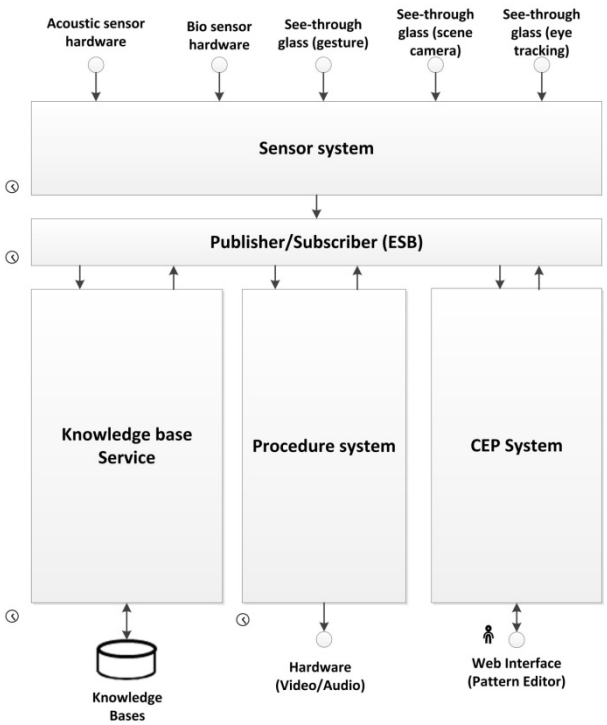

Fig. 3. System Architecture

Procedure Subsystem: reacts to the situation of interest, which means the visitor is engaged by some artworks. It searches the related metadata in the knowledge bases and plays the metadata about the artwork to the visitor. This subsystem is also responsible for the reaction with the user, i.e. presenting the content in the see-through glasses and enabling the selection of the desired options (i.e. getting the inputs from the user).

5.2 Sensors

Visual Sensors and AR Glasses: The ARtSENSE project uses special see-through glasses with a novel optical see-through display, capable of projecting digital information in the visitor's field of view, as a virtual overlay. The glasses are also equipped with an eye-tracker providing thus the possibility to track the eye movements the user's eye movements which allows gaze estimation [7]. This is an important feature within a CH context since the gaze information can be analyzed, tracked and interpreted so as to index the visual interest of a museum visitor with fidelity and precision. In order to calculate the visitors gaze on an contemplated museum exhibit or artefact, an additional scene camera is attached to the eyeglasses, tracking the objects in the field of view of the visitor and giving the possibility to assign the gaze point of the visitor on the real exhibit. The scene camera also enables hand gesture recognition, which allows the user to interact with the device by simple gestures like pointing or wiping.

Acoustic Sensors: The acoustic environment and its influence on the attention that a visitor may pay to an artwork has been so far scarcely studied. Yet, background noises are common in the museum environment (e.g. people talking, mobiles ringing, crowd, school groups etc). As the acoustic events occurring in the proximity of the visitor can affect and disturb it is important to monitor and understand what is happening around the visitor. For this reason, the ARtSENSE project captures acoustic events and background noise in real-time using a set of omni-directional electret condenser microphones and a multichannel audio data acquisition unit worn by the visitor. The digitalized signals are transferred in real time to the processing unit, which is in charge of applying the signal algorithms. The algorithm can be divided in three stages. First, the presence of any possible acoustic event that has occurred over the noise level is detected. In case that a sound source is detected, the second stage extracts more information about the event and determines the level of disturbance. Finally, the third stage will be used to determine whether \the visitor has turned towards the acoustic event or not. The result of this acoustic processing chain is packed as acoustic event.

Biosensors: The bio signals are used to help determine the change in the interest of a visitor. The purpose here is to explore the potential of physiological sensors (biosensors) so as to provide a covert and quantitative model of the psychological state of the visitor throughout the visit, which is dynamic and may be represented in near-real time. The ARtSENSE deployment focuses mainly on three psychophysiological

measures: (a) heartbeat activity, (b) skin conductance and (c) brainwave activity. One of the greatest challenges is that physiological signals may be influenced by various affective and cognitive processes but also by the physical activity of a visitor. While we are mainly interested in detecting the former, physical activity is a major concern in ambulatory psychophysiological evaluation as the user's posture and level of locomotion will also provoke a physiological change that needs to be taken under consideration prior to providing recoomendations and adapting the content to each visitor This is why in order to remove this effect it is necessary to track the user's movements in order to learn the influence on measuring a visitor's interest.

6 Use Case

Due to lack of space we describe only the use case from one end user partner here. A scenario has been selected by Museo Nacional de Artes Decorativas (MNAD) for the first developments of the project. The selected artwork is a tiled kitchen from late 18th century Valencia (cf. Figure 3). This room is an exceptional piece with rich iconography and representations of figures, animals, tools, etc. In this case, the actual information about the kitchen is really short in comparison with the contents and levels of information related with this item. For that reason, the possibilities that the AR prototype offers will help MNAD providing the visitor different explanations according to his/her interest in different aspects of the scene.. The MNAD proposal is related with the big questions that usually a museum visitor makes: what, by whom, how, why and when. The questions want to connect an object (the kitchen) with its historical period (e.g. economic and social context) trying to give to the visitors a general idea, not only about the object but also, about the related context according to the visitor's interest. In addition, in case the system detects a lack of interest during the delivery of an important educational chunk, the mechanism of adaptation can propose to the visitor an alternative narrative style (e.g. less scholar) or even different available media that clarify and focus on the same message to be revealed. In this way, the content to be revealed is not just suited to predefined visitors' profiles but is based on a continuous monitoring of the reaction of a visitor towards the exhibition and the content delivered through the A^2R guide, thus promising to render the museum visiting experience more exciting and rewarding all by promoting intrinsic and self-motivated learning. For example, if excitement is detected while information about the jewels of the depicted figures is provided, the system can provide more information or even direct the visitor to other -related with this theme- MNAD artifacts. If boredom or fatigue is detected, the system can propose a change in the content, based on the logging of the narratives that has so far been provided and the reactions of the visitor to that. In addition the monitoring of the visitors' gaze on the artifacts provides an invaluable tool for museum professionals, through which a record of the most intriguing museum artifacts or scene details can be progressively revealed. In the long term, this feature could also provide a powerful tool that could be used for the design and set-up of exhibitions or for the evaluation of an artefact's attractive power.

7 Conclusions and Directions for Future Work

ARtSENSE is a project where Cultural Heritage and research institutions have joined efforts to concretize a revolutionary, emerging technology. This novel technology adapts the contents that museum visitors receive according to their psychological state. To estimate this state, the user is monitored by means his psychophysiology, acoustic environment and gaze patterns. The system will suggest to the visitor additional contents or action based on his psychological state. The device will give a personalized visit to the museums or CH institutions. The ARtSENSE device represents a breakthrough in the application of new technologies to CH institutions and creates new communication channels between museum visitors and artworks. The first prototype has been already presented in January 2012 at the French SimeSitem and the first public evaluation sessions with the first prototype are foreseen at the end of 2012.

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