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Developing Effective Interfaces for Cultural Heritage 3D Immersive Environments

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Abstract

Although the advantages of the use of 3D Immersive Virtual Environments for the presentation and communication of Cultural Heritage have been demonstrated, the user interfaces and interaction techniques (in software and hardware) that are best suited have not yet been completely identified and deployed. This paper describes research conducted for developing and studying the usability of a historical town 3D Virtual Tour. For this, usability methods combined with head-eyetracking technology were used to explore the suitability of these interfaces. The paper also reflects on issues raised during the design of the testing system for this experience. It is expected the results of this research will contribute towards developing effective interfaces for 3D immersive technologies as well as building a repository of lessons learned from evaluation.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Three-Dimensional Graphics and Realism]: Virtual Reality I.3.6 [Methodology and Techniques]: Interaction Techniques H.5.2 [User Interfaces]: Evaluation/Methodology H.5.2 [User Interfaces]: Interaction Styles

1. Introduction

Although the advantages of the use of 3D Immersive Virtual Environments for the presentation and communication of Cultural Heritage (CH) have been demonstrated, the user interfaces and interaction techniques (in software and hardware) for their use that are best suited to the task have not yet been completely identified and deployed. This issue is critical as these types of applications are used in environments, such as museums and heritage sites, where the physical environment, social and individual setting (visitor, his/her age, knowledge of technology and expectations of the 3D environment) represent a challenge to a technical discipline reliant on more traditional PC based 3D graphic applications (i.e. web applications, computer games).

This paper describes research conducted on the development of suitable interfaces for 3D Immersive Virtual Environments, in particular 3D interactive virtual tours of historical cities. It also describes efforts towards evaluating the acceptability of the interfaces using usability methodologies combined with head tracking technology to explore not only the perceived opinions and responses of users, but also their behaviour. Although these issues have previously been researched within the Human Computer Interaction (HCI) area, it has not been readily applied to the CH field. While there are many lessons which could be easily transferred from this field, the use of 3D immersive environments in museums or heritage sites presents specific challenges. For example, short interaction times, diversity of users' knowledge as well as the relationship between the real artefacts or places and the virtual ones.

The next sections will present the development, technical implementation, evaluation and results of the study, followed by conclusions and future developments in the area. It is expected that this work, although limited in application and results, will add to the repository of lessons learned from evaluation for producing technological experience that can enhance museum visits and visitors' appreciation of the Cultural Heritage of the area.

2. Previous Research

The current Information and Communication Technology (ICT) based presentation trends in museums and heritage sites are challenging computer graphics and other IT professionals to design user-friendly and engaging 3D Immersive

Virtual Environments for CH. This brings particular problems as interfaces and interaction techniques for these applications are not as well defined as, for instance, web-based applications which require and benefit from more standardised software and hardware interfaces, i.e. web browsers on single screens, normally with keyboard and mouse interfaces, or touch panels to the same applications in kiosks.

Previous work on interfaces and interaction techniques for 3D environments has been conducted by [Kje01], [Bow98], [PWBI97]. According to [Kje01], these environments require innovative interaction techniques in order to support the presence of the user inside a virtual world. Interaction is divided into 3 categories in an attempt to match user behaviours in a 3D world to those displayed in the physical world:

- Navigation: refers to all aspects of movement. This includes orientation and movement (moving a user's viewpoint through an environment to look around), moving, and the acquisition of spatial knowledge. This usually happens not physically but virtually, meaning that the user moves or rotates the virtual world while remaining still.
- Acting: involves tasks of selection/picking objects in the virtual environment as well as requesting more information from the system. This task is particularly important, as museums need to create 3D environments which provide the visitor with information about the objects and themes displayed in the exhibition. Acting is typically supported by implementing variations of avatars, virtual hand, pointer techniques or more 'traditional' Graphical User Interface (GUI) elements, such as buttons, labels and text fields.
- Presence: the ability to generate presence is a unique factor that distinguishes an experience using immersive technology from the desktop systems. If the user feels present in the environment, he/she should be able to react to, and more fully experience, all manners of events.

According to [Bow98], the interaction technique describes ways of interacting with a virtual environment using some kind of interaction device(s) and is based on some kind of interaction metaphor. It has been recognised that some interaction techniques change according to the type of immersive display (i.e. panoramic, large scale, CAVE) [Kje01].

Moreover, standard usability engineering and Human-Computer Interaction (HCI) evaluation techniques need to be adapted to 3D immersive environments in order to be able to address the usability problems introduced by these interfaces. Usability work has previously been researched by [SY06], [PWBI97], [SK00], [DSH*00a], [DSH*00b] and [BGH02]. In addition, usability for Interactive virtual environments for Cultural Heritage has been previously researched by [EP06], [CAL*06], [Zar04], [Cha02]. Evaluation techniques previously used involved Formative Evaluation and Post-hoc Usability Questionnaires. Results from these tests indicate that more natural hardware interfaces, such as wands, rather than the traditional mouse, have more potential for interaction within CAVE-like environments. In addition, it has also highlighted the importance of incorporating features common to computers games into CH 3D Immersive Virtual Environments. For example: using artefacts as portals to previous times; using avatars to deliver information; using "highlighted" objects as hyperlinks; and using maps. Although these are individual efforts for evaluation of VR systems there is still a lack of common lessons learned in this area for producing usability guidelines for CH applications.

The next section will describe the approach used in this research to develop and implement a 3D Interactive Virtual Tour after introducing some problems with more traditional approaches.

3. Development and Implementation of 3D Interactive Virtual Tours

It is clear that the historically common approach for creating 3D content is not ideal. This approach has been to create highly detailed, textured models with standard, all-purpose 3D modelling toolkits such as 3D Studio Max or Maya [Aut07]. These models are then exported to an all-purpose rendering engine to interactively explore the virtually reconstructed city. The major problems with this approach are that because the modelling tools are general purpose the system is less able to exploit knowledge of the application domain to simplify the user interactions. In addition, because models are created without exploiting domain knowledge they are more difficult to optimise for real time rendering of complex scenes. To put it another way - the person doing the modelling is very likely to create models which are inefficient to render and the system is less able to optimise these models if it has to assume that the user was creating completely general models.

3.1. Assembling the 3D Virtual Environment

The development of the 3D Virtual Environment exploited technologies for modelling and rendering multi-lingual interactive avatars in populated urban scenes. Hence, it used a combination of generic 3D modelling packages with specialised modelling tools, which exploit knowledge of the types of object being modelled by working in the application domain. For this the Scene Assembler was used to assemble the virtual environment as shown in figure 4. This is an application, developed at the University of East Anglia (UEA), for assembling interactive real time Cultural Heritage environments. It provides tools for creating landscapes, importing buildings modelled in third party applications (i.e Discreet 3D Studio Max and Maya), and avatars with animations that have been created in the ARP Toolkit, another application developed at UEA. The structural information from these modellers gives valuable hints to the renderer to efficiently optimise interactive displays through the use of culling and level-of-detail techniques.

Avatars developed at the UEA were ported into OpenSG [Ope07] (shown in figure 5) and are used to populate the scene and for interaction. In addition, objects of interest in the scene were annotated with meta data that contain hyperlinks so that visitors can explore related websites or other resources during a virtual tour.

In addition to providing fast graphical rendering, which is essential to keep and attract the attention of the user, the system was designed to integrate different modalities in such a way that the interaction appeared as natural and as human-like as possible. For this, the 3D Virtual Environment integrated avatars with gesture representation and natural language understanding, as well as the generation of interesting route paths in the environment. In other words, multi-modality is concerned with the fusion of the input as well as with the fission of the output. In this environment, priority was given to building a mock-up that will allow users with different backgrounds to be part of the full interactive loop (navigation-request-processing-response-navigation) of interaction with a virtual guide. Taking into account contextual (location on the site) information about the user during the interaction provides a first impression of what natural interactive systems can achieve for navigation through Cultural Heritage sites.

The finished scene was exported from the Scene Assembler in the Collada [Col06] format, an emerging 3D file format for interchange between applications. The showcase demonstrator was used for real time rendering of the imported Collada file using the open source scenegraph OpenSG [Ope07], and provides user interfaces for navigation through the scene.

3.2. XVII Century Wolfenbüttel Interactive Virtual Tool

The virtual tour developed recreates Wolfenbüttel as it once stood during the seventeen century. The town sits on the Oker river in Lower Saxony, just a few kilometres south of Braunschweig. Wolfenbüttel became the residence for the dukes of Brunswick in 1432 and in the following three centuries the town was an important centre of the arts. The 3D virtual environment reconstructs the town by using the main buildings from this period, such as the ducal palace, the library and the armoury, as well as a few other areas of interest. The Graphical User Interface (GUI) of the application has different sections (see figure 6). Hence, the interactivity is a combination of navigation and acting actions triggered by GUI elements.

A female virtual avatar populates the environment acting as a tour guide. This was included with the intention of creating a more engaging presentation of the information about the town. Six locations have been selected for the user to visit in the virtual reconstruction. The user navigates from one to another by clicking on labels ‘floating’ in the sky in the "Navigation Panel". Once at a location, the user can look around, rotating the view by using the mouse. Free movement is possible only with keys commonly used in first-person shooter games (i.e. Counter Strike). The ‘floating’ labels have been arranged according to the geographical location of the user in the 3D space. As such, when positioned at any location, the labels for the places to the east/west and north of the current location will appear bigger and clearer, highlighting the fact that to go to another location it is first necessary to pass through the neighbouring locations. The "Location Panel" highlights the name of the location where the user is currently located.

The user can request more information about any of the six locations in town using the following approaches: i) typing a question on the "Free-Type Questions Panel" or ii) ‘pointing&clicking’ on one of the predefined questions in the "Frequently Asked Questions Panel". The user also has access to a webpage when arriving at certain locations.

4. Studying the Acceptability of the 3D Interactive Virtual Tours and its interfaces

The second part of the research aimed to study the suitability of interaction techniques as well as the acceptability of the interfaces of the 3D Interactive Virtual Tour. To support these goals, practical acceptability [Nie93] and usability were evaluated. Practical acceptability includes several factors: support, reliability, compatibility, and usefulness of both software and hardware. This can be measured with usability methodologies, although the social element is difficult to isolate and measure. Hence, it was important to first measure whether the system can achieve a desired goal and then understand the social factors which might affect this process.

The study and analysis of users’ acceptability of the interfaces presented by this application was based on two methodologies: i) *Formative Evaluation* using head tracking technology as well as ii) *Post-hoc Usability Questionnaires* [HH93]. These methodologies are suitable for looking into specific applications (3D Interactive Virtual Tours for Cultural Heritage) with a defined interaction technique and interfaces using representative users.

The testing usually lasted one to one and a half hours and had the following format:

1. Introduction: the host welcomed and explained the different stages of the test.
2. Formative evaluation: which included performing five high level tasks using the software and implementing a ‘Think aloud’ technique. The tasks ranged from open goals such as exploration and discovery of elements in the environment to more structured tasks. The users were using a head tracker during this part of the test which

gave us qualitative and quantitative information of the behaviour of the users towards the environment.
3. Usability questionnaire: based on the ISO 9241/10 standard [Hei98].

A user manual was available, although users were encouraged not to use this help until they really needed it. The observer was also available for help, but tried to intervene as little as possible. The observer's interventions were mainly to avoid the user getting frustrated when they could not achieve one of the tasks or encouraging them to speak their thoughts and opinions of the system interfaces out loud.

4.1. Sample

In total, 12 users tested the application as part of a focus group. The use of a focus group allowed for initial representative results which could potentially feedback into a larger study if such an application was deployed in a museum or heritage site. Although the latter was out of the scope of this research, the expected results are certainly very valuable for such future work.

The sample test involved users with different ages, levels of knowledge in ICT and attitudes towards museums and heritage sites. The highest percentage of the user sample ranged between 27 to 36 years old (see figure 1), while 5 were male and 7 female. Most of the users were university students with an average use of computers in their spare time of 10 to 20 hours per week. Their knowledge of computing ranged from intermediate to advanced (see figure 1), but only 2 had advanced knowledge in computer graphics. From the literature, this is reflective of the audience who would typically attend museums. According to [Ver89] it tends to be those with higher levels of education who visit museums and heritage presentations. The reason is that they have the availability of leisure time which is a determinant factor for people to visit museums.

In addition, three quarters of the sample play or have played computer games within the last 10 years. When compared with research from [Ent06] which shows 69% of American head of households had played computer games, this appears to be reflective of current society. The exposure to computer games definitely influenced the expectations and interaction techniques with which users were familiar. Not surprisingly, [Cha02] hypothesised that including interactive mechanisms used in games in virtual heritage environments will allow for a more culturally immersive learning environment.

From the questionnaires results, it was identified that the majority of users visited museums fairly often as half averaged 2 to 5 visits per year and one quarter averaged more than 6 visits per year. It should be noted that visits to museums were done during travelling, as a high percentage of the answers referred to museums which are not in the local area or even in the UK.

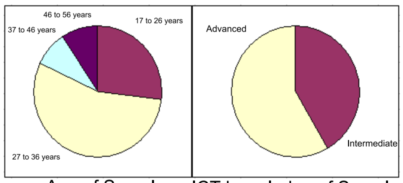

Figure 1: *Sample data on age and knowledge in ICT*

4.2. Observation Technical Equipment

The application was displayed on a single large plasma screen (60" or 1.52m), as this is similar to possible setups that could be adopted by museums and other heritage sites. This is specially the case for small and medium-sized museums which cannot afford the technology and support for bigger hardware systems, such as a CAVE or 180° immersive screens. A mouse/keyboard was used for interaction.

The Polhemus FASTRACK USB™was selected for the head tracking hardware as it provided the ability to track the users head in 3D space as well as the yaw, pitch and roll. figure 2 shows the framework used for the evaluation including:

1. FreeTrack library: interfaces with the Polhemus FASTRACK USB™hardware
2. LibPOR library: calculates the point of regard for the user via the use of a ray tracing algorithm(see figure 3).
3. Axis 213 PTZ network cameras which recorded the overall scene as well as the user's facial and body expressions. The tasks on the screen were recorded using Camstudio ™, which records what is displayed on the screen, including mouse movements and menu selection as well as the voice of the user.
4. ViewPOR: provides a graphic representation of where users have been looking in the 3D environment and the GUI

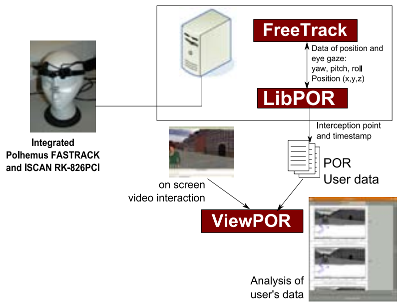

Figure 2: *Framework for head and eye tracking in an immersive environment*

The difficulty of using the head tracking data within this

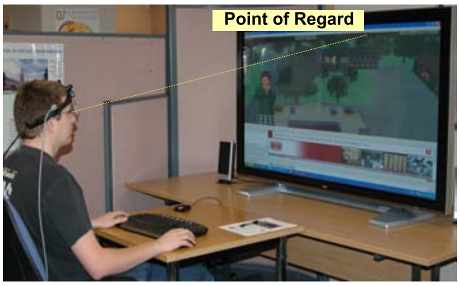

Figure 3: *Head tracking for studying user's view on a single screen*

environment is that each user takes a unique path through the experience. This means average head tracking points or multiple users points cannot be produced at the same time, as it would be when a user is watching a linear experience (i.e. video or pictures), for example. To overcome this problem, the data was clustered into sets around the start of each task. Observing the head data usually involved looking into the actions of the slower and faster subjects to make a comparison. Furthermore, analysis applications are being developed as they are required to aid the observation and analysis of these results.

The head gaze data overlaid with the videos from the user interaction showed: i) the areas which were of interest to the users and ii) the time they took to perform a task, based upon their expectations of the scene. Head gaze tracking works due to the visual acuity of a subject, which is optimal within a 1° - 2° visual angle [YDMHR02]. Although with a scene between 2° and 30°, the eyes can view it by moving independently of the head, fixation on an object will cause the subjects head to move to reduce eye strain. Other research on interactive 3D environments, such as action/adventure computer games, [ENY06] shows similar user's visual patterns backing the results obtained.

5. Discussion of Results

In general, users felt positive that visitors of museums and heritage sites would find this type of 3D Interactive Virtual Tour engaging. This is the case as visitors already have an interest in the subject, want to know more about it, and it provides entertainment value for the user, which can make visiting the museum more fun. In addition, the environment allow the users to explore the virtual space and the information provided with as much detail as required. When evaluating differences in performance of tasks, it was noted that slower users were using a more exploratory approach rather than being unable to use the system. They took their time to see and grasp the environment instead of just trying to extract the information from it, while others focused only on the movement and the text information presented by the environment.

The frame rate was suitable as users navigated the environment without any frame rate delays. Hence, using domain knowledge to model and render the 3D scene is regarded as critical in order to display at an interactive rate, which is something that users actually do not notice unless it is missing. Usability issues, which have already been highlighted in the HCI field, also applied to this environment. Examples included the font size, and the clarity of icons. Moreover, the different modalities that the system exhibited for the interaction to appear as natural as possible were received with mixed opinion by the users. The following paragraphs will discuss these results with more details.

Regarding interaction techniques, the majority of the users initially had difficulty in identifying the interaction mechanisms used by the application. All users took time to get used to the navigation mechanisms. The lack of common navigation techniques within this type of environment could be a contributory factor to this problem. The head tracking data demonstrates that most users focus on the area of the screen where most of the movement is happening. As such, they attempt different actions mainly within this space ignoring the other areas. Typically, users attempted to interact by i) clicking on houses, doors or on the avatar; ii) looking for commands in the applications menu or iii) moving the mouse or the key arrows on the keyboard. None of them actively noticed the fact that most of their interaction techniques have been learned from playing computer games (in their different genres). Regarding the interaction hardware, although it has been demonstrated that wands or haptic devices might be better for CAVE-type environments, this has not been demonstrated for smaller set-ups. Nevertheless, because of their extensive use in games, the mouse might be an option if the correct GUI interfaces are used.

The label based navigation mechanism (using labels for jumping to locations in the 3D environment) was not well received. Using labels with names of places to navigate around the 3D space made it very contradictory and confusing for users. Two thirds of users failed to understand the geographical logic behind the navigation. Most users would have preferred to use an overview/map of the entire environment and a list of all the places where it was possible to navigate to so they can orient themselves easily. Although this fact might be a flaw of the system design, as it has already been highlighted in the literature, the results demonstrate that following simple navigation rules, such as including a map and a list of all places, is enough for navigation.

When users identified that they wished to move from one location to another, the system responded by flying to the destination, which is neither consistent with users real-world experiences or those they gain from the majority of virtual 3D worlds. One user commented that it would have been more natural to walk instead of flying to highlight this fact.

Users also tried to navigate by typing requests into the "Ask a question here" text field. Providing a non restricted space to "Ask", made them think they could type anything including questions, requests, orders to the system (i.e. "go to library", "most important places in town", "map of town", "how do I move", etc.) This highlights the need to inform the users of the restrictions on the information the system can provide at any time and providing help on what they can or cannot do within the environment.

When asked if the 3D virtual environment was an acceptable representation of what the place would have looked like in the seventeenth century, half the users agreed with the statement and the other took a more conservative approach. The users main concerns were that only the exterior of buildings are shown and the apparent artificiality/sterility of the environment. This is in line with the finding that artefacts can act as portals to previous times, as users do not only want to explore the environment but touch or enquire further all the elements of the environment.

When discussing how people engaged with the experience and found it fun, we found a strong link with computer games. One user, who identified the avatar as a representation of herself, saw as a natural interaction to go and ask other characters for the information she was trying to find. She also tried to walk into the building as a natural and enjoyable way to behave in such environment.

The application provided the user with information in a variety of ways (i.e. web pages, question-answer systems). Users tended to get confused regarding the most suitable mechanisms to get an answer to their questions. They felt very comfortable with searching for information in a webpage, as they were familiar with the interaction paradigm. Even when information was in front of their eyes, using other means, they seem not to find it very easily.

Moreover, users were critical about including an avatar. Although including avatars in an immersive environment has been recognised, its purpose and a shared understanding of their role (i.e. tour guide, inhabitant) are imperative. Almost all the women tended to think the avatar was a representation of themselves within the 3D environment rather than a virtual guide which was providing them with help which it was intended to be. Some of them found the avatar to be stressful because her gestures were too realistic and made her looked like if she was bored or confused.

In the user's answers and behaviours there seemed to be a struggle between wanting realism in the scene, but requesting interaction techniques which are not necessarily realistic, most of the time attempting to follow approaches used by 3D games or 3D web based applications. From the test results, it was noted that the interactivity of the virtual environment and its elements is what finally creates the engagement with it.

Finally, it has to be acknowledged that these results are limited, as the sample is narrow, and the system just provides one interaction technique making its comparison with other techniques and other environments difficult at this stage. However, the results provide a contribution to previous studies, highlighting the importance of several issues:

- 3D Interactive virtual tours can be engaging, but their learning time should be kept to a minimum.
- Keep navigation simple by using a map and a list of places the user can visit.
- Using a mouse might be suitable for interaction if the correct GUI interfaces are used.
- The "functionalities" of the environment and the mechanisms for "acting" within the environment should be made clear to the user from the beginning.
- The purpose of the avatar should also be established.
- If the environment includes buildings, objects or any other type of artefacts, users might want to explore these further to find more information. This fact can be taken into account to provide the user with information.

6. Conclusions and Further Work

This paper has presented ongoing research to develop and study the acceptability of interfaces for a 3D Interactive Virtual Tour for CH by potential museums users. The development of this particular 3D environment as well as its interaction techniques has taken an innovative approach based on knowledge domain and objects' meta data, which achieved suitable interaction rates. In addition, a combination of methodologies for evaluating acceptability and usability used by more conventional HCI areas was used.

The results show how the multimodality displayed by the system was received with diverse responses, highlighting a more traditional struggle in the Virtual Reality domain: that of realism against interactivity. Whilst users wanted realism in the scene (i.e. people, building, objects which are realistic) they also wanted interactivity above realism and preferred those interaction techniques which had been learned from previous experiences with 3D environments. Furthermore, lessons should be learned from other more successful immersive environments and their interaction techniques, for example games, as has been previously highlighted, when trying to achieve engaging applications. Perhaps making shorter interaction cycles and better known interaction techniques will help users to enhance their experience in a museum and increase their acceptance of this technology.

Further work in the area of head-eye tracking will involve using gaze data in a 180° video wall to compare the results of both types (head and gaze). Further improvements to the testing framework, based on this experience, are also envisaged so a variety of application for CH can be tested and the results compared. This could potentially contribute to the much needed guidelines for deploying effective interfaces in the CH domain.

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