Tomb of a Sultan: A VR Digital Heritage Approach

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***Abstract*— This project presents the development of a room-scale Virtual Reality (VR) cultural heritage experience, a transmedia storytelling approach for showing museology VR content in a public setting. "Tomb of a Sultan: A VR Digital Heritage Approach" features the 19th century tomb of Sultan Hussein Shah as a three dimensional model reproduced using photogrammetry from the actual heritage site in Malacca. Room-scale VR experience has been made possible with the introduction of sensor-based head mount displays (HMD). However, the user experience and criteria for hyper-realistic VR in the cultural heritage context requires further study in terms of method and apparatus. In this paper we describe a prototype system, a user evaluation study and directions for future work.**

Keywords—digital heritage, virtual reality, augmented reality, user experience, case study, human computer interaction

I. Introduction

Virtual Reality (VR) can be referred to as computer-simulated immersive experience. It replicates virtual environments that resemble the physical presence of real-world places or reconstructed locations to allow for user interaction. In the context of cultural heritage, the demand of precision and detail of target artefacts is key to the success of digital content preservation strategies. As expressed by Ivan Sutherland [1] in 1965, "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal".

This paper describes a case study in the use of VR to create a digital heritage prototype. The development of this project, based on the tomb of Sultan Hussein Shah, involved visiting the heritage site in Malacca and access to resources related to the subject matter. A number of mixed-reality elements are experimented with in the prototype, these include virtual hands interaction, wind/mist, dynamic weather and sky configuration, ambisonic audio, room-scale locomotion, and a photogrammetry enhanced environment. These elements combine in an effort to explore the possibilities for hyper-realistic digital heritage representation.

II. Background

This project builds on previous work in the areas of virtual reality (VR), augmented reality (AR) and cultural heritage. A number of initiatives have explored using digital approaches in heritage studies, preservation and experience [5][7][9][10]. For instance, Frasca et al. [2] and Ciurea et al. [3] have revealed how AR can improve the public exposure of cultural heritage content. Sarah et al [8] has demonstrated the approach of using AR and VR for preserving and providing user experience of the Mogao Caves at Dunhuang. Such work is a practical example questioning how heritage sites can be preserved with high fidelity scanned data, to allow public users to re-experienced and be transported to the site in an exhibition setting. Doing so contributes not only to the preservation of the tangible qualities and information of heritage sites, but also encourages the public to gain awareness of heritage preservation issues via edutainment strategies.

In relation to the main subject of this project, Sultan Hussin Shah (1776-1835) was best remembered for signing two treaties with Britain which culminated in the founding of modern Singapore; during which he was given recognition as "Sultan Hussein Muadzam Shah, Raja of Johor" [6]. In the context of preserving the physical data set of the cultural heritage site, the VR prototype of this project involved photogrammetry scanning of the tomb in Malacca, and a reconstructed scene with a forest landscape of the tomb area. The main focus and contribution of this project is to explore VR elements and usability factors that allow for a realistic digital reproduction of this heritage site.

III. APPROACH

In this section, we present an early prototype of the digital heritage VR based on the subject matter of the "Tomb of a Sultan". This prototype works with room-scale-enabled head mount displays (HMD) and workstation with high calibre graphic processing unit (GPU). In this regard, the configuration works in a confined and controlled exhibition setting where users or participants could have a guided VR experience with proper introduction and safety briefing. Fig. 1 shows an example of user experience during a demonstration.

Fig. 1. User experience during demonstration of the prototype.

Being viewed as a case study [4], the configuration of the VR experience developed for this prototype comprises a number of considerations and design factors. Fig. 2 shows a number of elements in the design process with a goal to improve the sense of realism of the virtual environment. As one might expect, these elements map to the real-world environment. The challenge is how we integrate and address these areas as components within the VR experience, and consider their relevance in the context of this example of digital heritage prototyping.

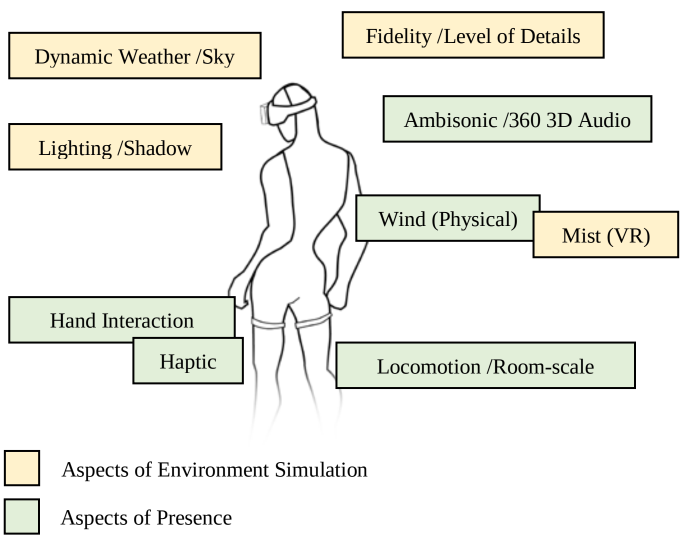

Fig. 2. Consideration and design factors of digital heritage VR.

In this study, and common for digital heritage VR more generally, its level of fidelity was a key factor for success. This was especially relevant as the data sets for the main artifacts were digitally obtained and required transposition into the virtual experiential domain. The following considers a number of aspects which enhance the realism of virtual scene reconstruction.

A. Environment Simulation

Environment simulation is fundamental in managing a VR scene. Users tend to expect to experience virtual scenes with levels of detail comparable to the real-world. This is difficult to achieve with low computing power configuration. However, recent availability of GPU and HMD allows creators to author scenes with higher fidelity both visually and aurally. Photogrammetry is one of the ways to mimic the quality of the appearance of objects scanned from the real-world. It is a computational photography technique which allows creators to combine multiple photographs of an object obtained from the real-world and reprocess it into a 3D digital representation.

In this study, photogrammetry was applied in two areas in the pursuit of greater detail and perceptual fidelity:

- The main artefact of the digital heritage context (i.e. the tomb)
- Environmental elements such as stones, tree trunk, ground texture

Photogrammetry provides visual content with a greater level of detail (LOD), however it only works on VR configurations with sufficient computing capacity – both during the authoring process and final VR experience. From the perspective of creating a scene full of visual details, Fig. 3 shows photo-realistic stones and ground texture, mixed with artificial plants (wind motion enabled). Fig. 4 shows the scanned artefact placed in the virtual environment. In addition to scene and artefacts prepared by photogrammetry, dynamic shadow and weather/sky allows visual sensation such as flare from the sun, fog/mist, and casted shadow of moving foliage affected by virtual wind.

Fig. 3. Photogrammetry-based virtual environment.

Fig. 4. Photogrammetry-based artefact representation.

B. *Presense*

Presence, is a high-end goal for VR. More study is required to explore this aspect where it involves a complicated set of elements which co-relates with personal experience consistent with the real-world environments. In this prototype, a pair of virtual hands (mid fidelity) is included, see Fig 5. Users interact with objects in the virtual environment (e.g. picking up books, plants, readable materials) using the controller while seeing their virtual hands carry out the activity. With the HMD (early prototype using HTC Vive, latter with Windows Mixed Reality HMD Samsung Odyssey), basic room-scale locomotion is permitted where users are encouraged to move around the scene freely (physically able to walk within a confined space). This is done with the help of base station sensors (HTC Vive) and/or inside-out tracking (WMR).

Fig. 5. Controller with virtual hands and interaction with objects.

In the prototype, we experimented with fog/mist in the virtual environment matched to wind-blown from a physical fan. The intention was to create a physical perception of a windy forest atmosphere, enhanced with visual effects such as “leaves dropping”. 3D audio or ambisonic audio is another essential aspect in the construction of a sense of presence. In this regard, audio was an important means for users to separate their experience from the physical world of the exhibition setting (noise from the crowd, food steps of visitors and other asynchronous elements).

IV. User Experience

A pilot study is currently being conducted to evaluate the usability of the prototype. For this, we are acquiring feedback from about 18 subjects (age from 21 - 43 years old, SD = 7.02). Convenient sampling is used, where subjects are approached based on their convenient accessibility to the researcher of this project. The procedure is as follows: The experiment conductor will explain the process and provide a complete demonstration. Each participant is expected to complete the tasks in less than five minutes. We will use a within-subject experimental design. Participants will be requested to experience the content twice in two conditions, in random order. The first condition (C1) allows users to view the VR environment of Sultan’s Tomb with a pair of VR-enabled hands (Fig. 6 (a)), with which they will pick up a bunch of flowers from a pedestal and place them on the tomb. The second condition (C2) will be the same except a pair of controllers, resembling those from Windows Mixed Reality headset (WMR), will be seen. The virtual environment is experienced using Samsung Odyssey WMR with room-scale locomotion-enabled, allowing users to walk around freely in a 2m x 2m setting. After running the experiment, participants will be invited to offer feedback on how easy it was to use the system. This was done by collecting qualitative feedback in response to the questions shown in table 1. Answers are captured on a Likert scale of 1 to 7 in which 1 was “strongly disagree” and 7 “strongly agree”. Our key interest is to understand the perceived ease-of-use and usefulness of the prototype by the participants, and if there is any difference for working with a pair of VR hands and digital controller as shown in Fig. 6 comparisons. However, we do acknowledge the limitation of the low fidelity VR hands used in this study, options of different fidelity and male/female version shall we explored in future study.

Fig. 6. (a) VR hands and, (b) Generic WMR controller in virtual view.

TABLE I. Survey Questions

Q1	I found it easy to use
Q2	I found it natural to use
Q3	I found it useful
Q4	I found it physically challenging
Q5	I found it mentally challenging
Q6	I found the content immersive
Q7	I found convenient to control or reach the objects in the scene

Fig. 7 shows the average results of the condition 1 using a pair of virtual hands (C1) and condition 2 using a pair of virtual controllers (C2) survey questions. A Wilcoxon Signed Rank Test was used to analyse the results to check for significant difference between the results of the C1 and C2.

Q1, using a two-tailed test we found that participants felt that the virtual hands is significant easier to use than the virtual controllers, $Z = -3.29$, $p = 0.00096$. For Q2, users found virtual hands significantly natural to use than virtual controllers, with $Z = -3.51$, $p = 0.00044$. There was significant difference between conditions in terms of how reliable participants felt each condition was (Q3), $Z = -3.52$, $p = 0.00044$, virtual hands are more useful than virtual controllers for user experience. In terms of the physical challenge, participants felt that C2 are significant in physically challenging (Q4) than the C1, $Z = -3.06$, $p = 0.00222$. Next, C2 was felt to be more mentally challenging (Q5) than C1, $Z = -2.93$, $p = 0.00338$. In Q6, users experienced VR content being more immersive in C1, $Z = -2.69$, $p = 0.00714$. Finally, C1 was viewed as a condition being more easy to control or interact with objects in VR environment (Q7) than C2, $Z = -3.41$ $p = 0.00064$. Overall, these results show that the experience of seeing and using a pair of virtual hands (C1) are better than virtual controllers (C2). The results are shown in fig 7.

In addition to the survey, we asked participants for their comments. On the positive side, users said they liked how the "*..I feel so realistic with hands..*", "*I think hands gives me better impression of controlling my own hands in the VR*" and "*I wish I can pick up more things or interact with different objects in the environment*". However, users also said that "*The hands are good, it looks like male's hands to me. Can there be any options for different gender, or even for kids?*", and "*Visual quality looks good to me, but the quality of hands can be improved...*".

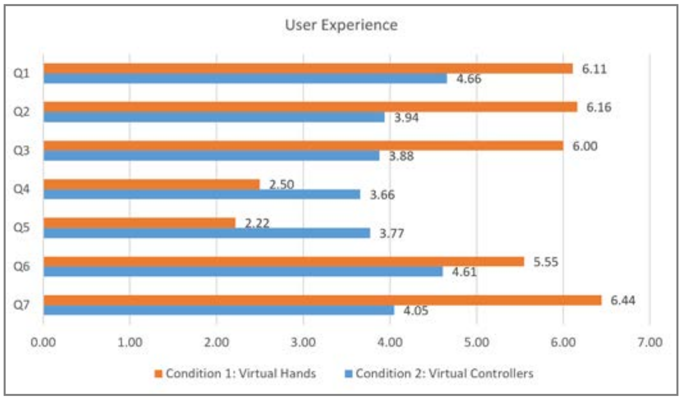

Fig. 7. User experience of virtual hands and virtual controllers in VR.

In addition, some users provided ideas for improvements:

- Some users would like to explore greater space in VR. This implies some users are curious about what is beyond the areas they are confined within the prototype. A quieter and exclusive space is preferred where crowded exhibition space may degrade the experience.
- The quality of 3D scanning of the artefact could be increased to the level of reading the text carving on the stone. This may involve using different techniques of photogrammetry or 3D data acquisition for providing fact-simile level of details.
- A mobile/lighter version of this can be made available for public distribution as a "bring home experience".

V. Discussion

The development of this prototype provides insights, examples of best practice and suggestions for managing VR in digital heritage projects. Most users felt having a pair of virtual hands to be more compelling. However, a number of users expressed that a higher fidelity rendering of the virtual hands was desirable. Some users suggested that having "full arm virtual hands" might enhance the sense of presence.

We also learned that managing and mimicking organic elements of nature is highly challenging. Particularly, achieving realistic foliage such as wind-blown trees/leaves is currently a difficulty. Continual changes to 6DoF positioning and user perspective caused a highly undesirable visual experience of seeing "jittering or pixelated plants". For now, we are experimenting with solutions to overcome this, using "anti-aliasing" seems to lessen the problem when viewing a virtual scene with foliage such as a forest. We also anticipate challenges such as managing VR performance issue (frame per second rate of 3D graphics, resolutions, compressions of organic textures) in developing organic environments such as a forest as well as other cultural sites.

VI. Implication

This project focuses on the development of an engaging VR digital heritage experience for an exhibition space. The system runs on high-calibre hardware using room-scale tracking, and so is suitable for controlled exhibition settings. Users felt that the system was easy and natural to use, and the use of VR hands enhanced their experience and level of engagement. Participants also made several good suggestions for improving the system. In the future the system could be adapted to various scenarios and public showcases, such as for museums, tourism expos, education fairs, and more. However, there are still various obstacles and design issues that need to be solved. For example, in an ideal situation, a wireless HMD room-scale experience should greatly enhance the freedom of movement and experience of users. In the future, we would like to further improve our efforts in designing VR content for different museology and exhibition settings. We hope to explore ways to improve VR experience such as using hybrid approaches that combine 3D environment, HDR spherical panorama content, and ambisonic audio.

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