Simulating the Activity of Archaeological Excavation in the Immersive Virtual Reality

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***Abstract*—The popularization of virtual reality brings together educational fields such as science, art, and culture. However, most current cultural education regarding archaeological civilization is based on excavated cultural relics. In this research, we script the process of the Taiwan First Dog being unearthed. Based on this story, we develop a virtual reality application which guides players to experience the process of excavating relics in a virtual world with reconstructed archaeological scenes and various pieces of apparatus. In addition, we also provide non-contact haptic feedback devices and well-arranged guidance to improve the immersive experience.**

Keywords*—*virtual reality, excavation visual effect, multimodal tactile feedback, digital heritage, culture dissemination

I. INTRODUCTION

With the recent advances in hardware performance, virtual reality (VR) technology is becoming more popular. Virtual reality applications typically focus on games or entertainment. However, this technique has been applied to all major fields with diversified content as well. In terms of digital heritage, VR technology can be used to reproduce and present existing cultural heritage in the virtual world. In addition, this technology can recover and reveal the destruction of cultural relics. Moreover, it can also be used to reconstruct historical scenes using interactive animation. An immersive experience can leave users with a deep impression and understanding of the meaning of cultural relics or historical events. In comparison to information from a kiosk, virtual reality can provide a more immersive experience and information due to its visual, auditory, and even haptic feedback in the virtual world.

In Taiwan, there are many historical cities and cultural relics. Tainan, located in the southwest coast of Taiwan, is especially rich in cultural relics and prehistorical events such as the Zuojhen Culture of the Paleolithic Age, the Dapenkeng culture of the Neolithic Age, and the Niaosong Culture of the Iron Age. Students generally learn about these cultures from textbooks or films. However, pure text and imagery is usually not enough to spark a student's interest. Therefore, in this paper, we develop an application which allows users to participate in archaeological activities. Via the VR application, users accumulate more archaeological knowledge by experiencing the actual excavation in a simulated world.

In the first scene of our application, the user slowly flies to the Earth from space and returns back in time to the year 2000, the year in which the remains of the Taiwan First Dog were unearthed in Tainan. The user passes through the clouds and lands at the archaeological site in the virtual world. With the guidance of the Professor avatar, the user begins excavating the remains of the Taiwan First Dog in a test pit. To make the experience more interesting, we bring the First Dog back to life with bone-style shading and common dog behavior. By interacting with the First Dog, the user views it as a companion in the virtual world. The First Dog also helps the user to find two other ancient cultural relics: the Jade Arrow and the Cord-Marked Pot. When the user collects all of these relics in the simulated test pit, the user, the Taiwan First Dog, and the Professor avatar are transported back to the last scene: Tainan, 3,000 B.C.

II. RELATED WORKS

As technology progresses, more and more effort has been put into reconstructing cultural heritage. According to a study by Addison [1], the relationship between developing and disseminating virtual heritage can be divided into documentation, representation, and dissemination. First, documentation concerns the collection and digitalization of authentic data. Then, representation concerns how to represent this tangible heritage. Finally, dissemination concerns the utilization of different hardware, software, and technology, depending on what experience is be presented to society.

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Given the current state of technology, the dissemination of cultural heritage is mainly divided into the following three types: (A) flat display, (B) augmented reality (AR), and (C) virtual reality (VR).

A. Flat Display

The flat display is one of the most common multimedia devices for providing an interactive interface to present cultural heritage. A great number of museums use flat-panel displays with kiosks, websites, and tablets to offer additional information about their exhibits.

Johnson [2] delivers historical images of Sydney as a timemap using a kiosk. Wojciechowski [3] builds a system which helps museums hold virtual exhibitions in 3D virtual galleries. The virtual exhibition is visited by entering the related website. In Hsieh's [4] work, users view Chinese art pieces by touching and scrolling directly on the screen. In comparison with traditional mouse clicking, touch screens provide for more intuitive interaction for users to select their target.

B. Augmented Reality

With help of AR technology, it is possible to map the reconstructed virtual heritage onto the real world by use of a head-mounted display (HMD). Taking advantage of the location system provided by these devices can prove useful for site tourism. ARCHEOGUIDE [5], a personalized electronic tour guide rendered on an HMD, augments a virtual temple at an archeological site by tracking the user's position and orientation. In addition to presenting a restoration of the site remains, augmented reality is often used for museum tours. Pedersen [6] uses the TombSeer HMD to implement hand gesture recognition to interact with exhibits at the Royal Ontario Museum.

In addition to head-mounted displays, augmented reality provides other methods for interaction through projection and handheld tablets. Virtual Showcase [7] projects digitally-reconstructed 3D cultural relics without location constraints, and the AR version of Pure Land [8] builds a true-to-life scale architecture of the heritage in museums by exploring artifacts though handheld devices.

C. Virtual Reality

In the past decades, researchers have utilized projectors and displays to construct virtual heritage. ImmersaDesk, the Cave Automatic Virtual Environment (CAVE), and the Advanced Visualization and Interaction Environment (AVIE) are common projection-based methods. ImmersaDesk is a drafting-table format semi-immersive VR workstation, CAVE projects images on the wall of a room-sized cube, and AVIE utilizes real-time 360-degree omnistereo projection with higher user capacity.

Johnson [9] deploys ImmersaDesk applications by using a virtual world to teach science in an elementary school in Chicago. Lutz [10] presents a digital model of DunHuang Cave 428 in a 5-sided CAVE system, while Kenderdine [8] utilizes AVIE to represent DunHuang Cave 220. Although CAVE and AVIE present a full-scale spatial context, the users perceive only a semi-immersive experience in the virtual caves.

In order to simulate telepresence, an immersive head-mounted display can be used with mobile VR and PC-based VR. With a mobile VR device, users can easily access virtual content on websites such as YouTube or Sketchfab. In addition, some scholars have combined head tracking with virtual reality in mobile applications. Wang [11] describes an application that enables the user to view the restoration of Buddha and enhancement of the Middle Binyang Cave.

In terms of usage and promotion, mobile VR offers the advantage of portability so that most users can hold the device in hand. By contrast, PC-based VR not only provides a higher resolution and auditory experience, but also allows the user to move freely in the virtual space. Additionally, the PC's powerful computing performance can even be used to connect with interactive devices to provide tactile feedback. Accordingly, we use PC-based VR to display Taiwanese culture through a head-mounted display so as to provide the user with an immersive experience in the virtual Nankuanli site.

III. SYSTEM OVERVIEW

The system structure is shown in Fig. 1. In the software layer, we use Unity2017 and the SteamVR plugin to develop the interactions, which can be divided into five phases: "Date back to the site Nankuanli", "Excavation of the Taiwan First Dog", "Excavation of the Jade Arrow", "Restoration of the Cord-Marked Pot" and "Back to 3,000 B.C.". We use the HTC VIVE pro as the head-mounted device; we also take advantage of Bluetooth to connect the haptic device, which is hung directly above the user. The device simulates the haptic effects of mist, rain drops, wind, heat, and hot air. For hardware we use an Intel(R) Core i7-8700K CPU @ 3.70GHz, and 64GB of memory. In order to provide a better visual experience and interactive effects during the excavation, we use an NVIDIA GeForce GTX 1080Ti graphics card.

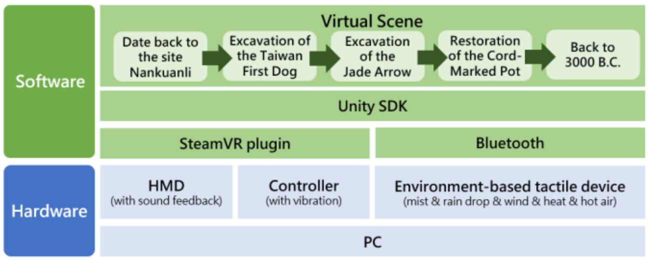

Fig. 1. System overview

A. Virtual Scene and Relics

To design the virtual scene, our team investigated the Nankuanli site and test pit in Southern Taiwan to gain knowledge of the soil properties, the width of the test pit, and the appearance of the excavation at the time. After surveying the related historical documents and discussion with archeologists, we successfully reconstructed an excavation site and all the remains as the 3D models shown in Fig. 2.

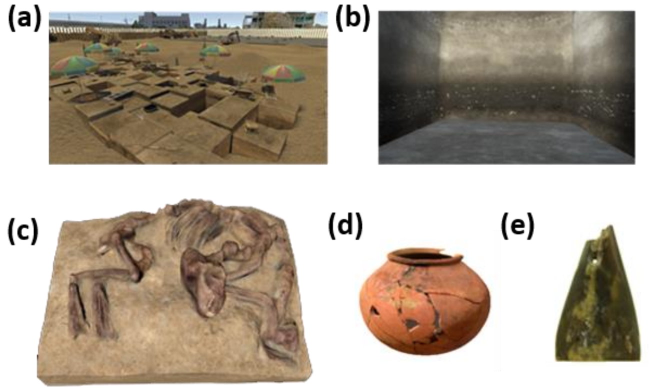

Fig. 2. (a) 3D virtual scene of Nankuanli site. (b) 3D virtual scene of test pit. (c) Faunal remains of Taiwan First Dog. (d) Cord-Marked Pot. (e) Jade Arrow.

B. Design of Archeological Apparatus

Per our discussion with archeologists, three important tools are commonly used for excavation: shovels, brushes, and cameras, as shown in Fig. 3 (a–c). In the virtual Nankuanli site, users use these tools to excavate the test pit filled with soil and stones. Initially, users are asked to dig in the soil until they find the target relic. Then, they use the brush to clean the dust from the surface of the relic, and finally record the finding with the camera.

C. Design of Virtual Companion

In order to enhance the VR presence, we design a living dog and an archeological professor to accompany the user, shown in Fig. 3 (d and e). When the user finishes brushing the faunal remains of the Taiwan First Dog, the remains transform into a living dog and lead the user to the two other relics. Additionally, the archeological professor stands near the user to give assistance and hints on how to manipulate the archeological tools during the process of excavation.

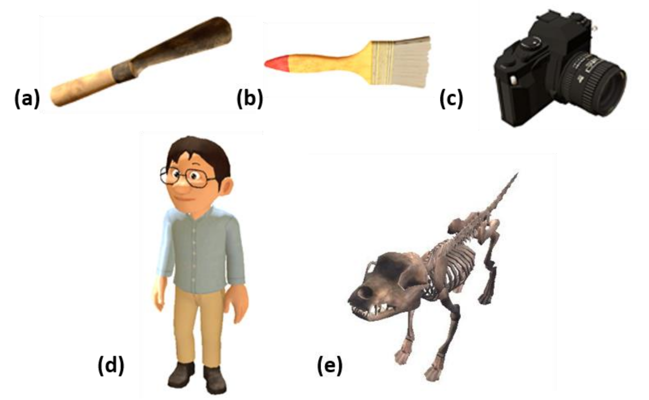

Fig. 3. Archaeological apparatus: (a) Shovel, (b) Brush, (c) Camera. Virtual companions: (d) Archeological Professor avatar, (e) Taiwan First Dog.

D. Visual Effects of Excavation

When creating interactive contents, the visual effect of excavation must be correlated to the user's movement as he/she digs. As shown in Fig. 4, we divide the process of excavation into three phases: initialization, ground deformation and clod generation, and clod fragmentation.

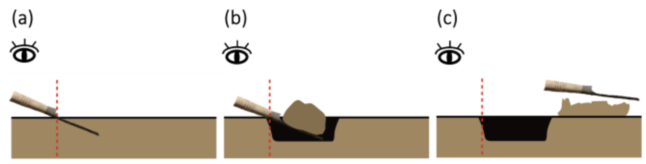

Fig. 4. Three phases of excavation: (a) initializaton, (b) ground deformation and clod generation, and (c) clod fragmentation.

First of all, we initialize the reference points on the shovel and set a height map of the ground; the process starts when the reference points of the shovel intersect with the ground. When the reference points are under the ground, we mark the area of the clod above the shovel and edit the height map of the ground to dig a hole on the ground. In the next phase, we use mathematical methods to find the shape of the clod. Finally, the clod is fragmented into pieces and falls down after the user lifts up the shovel.

1) Initialization

To calculate the correct shape of the hole, we set up two reference points on the endpoint of the shovel to calculate the path when it is under the ground. In addition, we use a 256x256 height map to record the height of the ground. The height map is a gray-scale map in which the color value of 128 indicates the surface of the ground whereas color values below 128 indicate the depth of the point under the ground.

2) Ground Deformation and Clod Generation

In this phase, we focus on calculating the ground deformation and clod generation. When the user lifts up the shovel, the area above it is lifted up simultaneously. When the shovel is higher than the surface level, the system generates a hole on the ground by editing height map of the ground. We project the digging paths onto the ground and updating the uv values of the corresponding points on the height map.

After the user lifts the shovel from the ground, we generate the clod mesh remaining on the shovel by referencing the underground paths of the two reference points and their projections on the ground. To determine the shape of the mesh surface, we generate numerous triangle parts from two neighboring points in one digging path and the closest point of the other in clockwise order, and utilize the function provided by Unity to create the clod.

3) Clod Fragmentation

After the clod has been generated, the system simulates the fragmentation. Once the clod is lifted up to any point higher than the ground surface or has been on the shovel for longer than 50 milliseconds, it breaks into pieces and falls off the shovel to the ground separately.

E. Multimodal tactile feedback

In order to enhance the immersive experience, the system incorporates tactile feedback.

1) Vibration feedback on controller: To simulate the tactile feedback of an excavating motion and simulate the force when digging in the ground in the VR archeology experience, the system sends vibration to the handheld controller in each successful move, including soil excavation, cleaning the soil, and photographing. This makes the VR excavation more realistic.

2) Non-contact tactile feedback: To offer users a more realistic and immersive VR experience, we integrated the AoEs [12], a mid-air haptic feedback device, into our simulation of archaeological excavation, as shown in Fig. 5. With help of this device, users feel the dampness of the test pit and the heat when moving from one test pit to another.

Fig. 5. Haptic feedback using AoEs

Simiar to olfactory fatigue, user's tactile sensing tends to be less sharp when exposed to continuous stimuli. Therefore, if all the excavation in the test pit is presented only with cold modules, the user may feel cold in the beginning, but this sense of coldness will be weakened as the user becomes accustomed to it. Therefore, we utilize a hot module in the system and place a fire hoop in the entry of the tunnels between each test pit. In the system, the entire excavation experience contains haptic feedback of hot and cold in turn (Table I), so the user clearly feels the change in the environment, increasing the sense of immersion.

TABLE I. ENVIRONMENT WITH HAPTIC FEEDBACK

Experience	Environment	Haptic feedback
Fly into the site (covered with clouds)	Windy	Wind
Arrive at the site	Humid	Breeze
Excavate in test pit	Damp	Wind + Mist
Open portal (fire hoop)	Hot	Heat + Hot air
Walk through tunnel	Rapid transit	Strong wind
Fly back to 3,000 B.C.	Rising winds and surging clouds	Strong wind + Mist + Rain drop

IV. DISCUSSION AND FUTURE WORK

In developing the archaeological excavation simulation, designers must take all of the following aspects into consideration: the restoration of archaeological artifacts and activities must be realistic, the gameplay in the player experience must be interactive, and the specified virtual objects must be computable in real time. In the future, to enhance the user experience in the proposed immersive VR system with multiple sensations, we will conduct several user studies to investigate the integrity of the design for the simulation of archaeological excavation.

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REFERENCES

[1] A. C. Addison, "Emerging trends in virtual heritage," IEEE multimedia, vol. 7, no. 2, pp. 22-25, April-June 2000.
[2] I. Johnson, & A. Wilson, "The TimeMap Kiosk: Delivering Historical Images in a Spatio-Temporal Context," British Archaeological Reports International Series 1016, pp. 71-78, 2002.
[3] R. Wojciechowski, K. Walczak, M. White, & W. Cellary, "Building virtual and augmented reality museum exhibitions," Proceedings of the ninth international conference on 3D Web technology, pp. 135-144, April 2004.
[4] C. K. Hsieh, Y. P. Hung, M. Ben-Ezra, & H. F. Hsieh, "Viewing Chinese art on an interactive tabletop," IEEE computer graphics and applications, vol. 33, no. 3, pp. 16-21, May-June 2013.
[5] V. Vlahakis, M. Ioannidis, J. Karigiannis, M. Tsotros, M. Gounaris, D. Stricker, & L. Almeida, "Archeoguide: an augmented reality guide for archaeological sites," IEEE Computer Graphics and Applications, vol. 22, issue 5, pp. 52-60, September-October 2002.
[6] I. Pedersen, N. Gale, P. Mirza-Babaei & S. Reid, "More than Meets the Eye: The Benefits of Augmented Reality and Holographic Displays for Digital Cultural Heritage," Journal on Computing and Cultural Heritage (JOCCH), vol. 10, no. 2, pp. 11:1-11:15. April 2017.
[7] O. Bimber, B. Fröhlich, D. Schmalstieg & L. M. Encarnação, "The Virtual Showcase," IEEE Computer Graphics and Applications, vol. 21, issue 6, pp. 48-55, November-December 2001.
[8] S. Kenderdine, "Pure land: Inhabiting the Mogao Caves at Dunhuan," Curator: The Museum Journal, vol. 56, issue 2, pp. 199–218, April 2013.
[9] A. Johnson, T. Moher, Y. J. Cho, Y. J. Lin, D. Haas & J. Kim, "Augmenting elementary school education with VR," IEEE Computer Graphics and Applications, vol. 22, issue 2, pp. 6-9, May-April 2002.
[10] B. Lutz & M. Weintke, "Virtual Dunhuang art cave: A cave within a CAVE." Computer Graphics Forum, vol. 18, no. 3, pp. 257-264, September 1999.
[11] Z. Wang, X. Jin, D. Shao, R. Li, H. Zha & K. Ikeuchi, "Digital Longmen Project: A Free Walking VR System with Image-Based Restoration," Asian Conference on Computer Vision, pp. 191-206, November 2016.
[12] P. H. Han, C. E. Hsieh, Y. S. Chen, J. C. Hsiao, K. C. Lee, S. F. Ko, K.W. Chen, C. H. Chou & Y. P. Hung, "AoEs: enhancing teleportation experience in immersive environment with mid-air haptics," ACM SIGGRAPH 2017 Emerging Technologies. ACM, no. 3, July 2017.