The Role of Haptics in Digital Archaeology and Heritage Recording Processes

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***Abstract*—Recently there has been a remarkable increase in the use of multimedia and interactive technologies in heritage and archaeology. Haptics technologies allow the operator to interact with the visual representation using the sense of touch. In this paper, we investigate the role of haptic feedback in exploring archaeological objects. In particular, we explore the following questions: the first question addresses the archaeological value degradation due to multimodal recording (3D visual and haptic modeling) by exploring a real archaeological object against its digital (haptic-visual) representation. The second question examines the added-value of haptic feedback while exploring an archaeological object in the digital world that is never seen in the real world. A thorough evaluation is conducted with eight participants (4 archaeologists and 4 novice users) to evaluate the role of haptic feedback in digital archaeology. Results demonstrated that novice users have rated the similarity between the real artifact and its digital representation much higher than expert users. Additionally, haptic feedback provides additional information that is not accessible otherwise (deteriorating engraving on a gravestone were more readable using haptic exploration). Given how promising haptic feedback is in digital archaeology, our future work will focus on developing highly accurate haptic recording techniques with the goal to preserve cultural heritage and archaeology.**

***Index Terms*—Multimodal digital archaeology, Haptic feedback, Human computer interaction, 3d reconstruction.**

I. Introduction

The usage of different computing technologies for documenting and presenting heritage goes far beyond the creation of a virtual archive; the new methodologies rather provide a flexible and dynamic repository that can be used and navigated for different purposes: research, museums, art, tourism, archives, video games, etc. [1]. By changing the mode of acquiring and documenting data, the new technologies also bring change in the mode of production and representation of heritage. Furthermore, the virtual featuring of heritage could help bridging the artificially institutionalized difference between tangible and intangible heritage, thus allowing for a more holistic understanding of the past [2]. Different memories, stories and images can be combined in the presentation of material culture in order to capture its multiple meanings and significance [3].

Over the past decade there has been significant increase in use of interactive multimedia in archaeology and heritage presentation. A lot of research effort has been made towards heritage preservation using auditory-visual systems [4]. With the increasing availability of haptic and immersive interfaces, virtual reality and haptics are considered a great perspective for heritage preservation and exploration. Haptic technologies in archaeology mainly focus on building tools and interfaces to regenerate, navigate and explore the digital representation of artifacts or heritage sites via the sense of touch. For better engagement and experience, a multimodal system can give users multiple interaction elements such as haptic, visual and aural modalities.

Haptics refers to the sense of touch that can be used for sensing and manipulating objects [5] [6] [7]. Immersive haptic interfaces are usually made up of a virtual reality head mounted display and a pen like stylus. The stylus interface is primarily used to provide force feedback at the hand of the operator [8] [9] [10]. The purpose of this study is to measure similarities in perceiving a real archaeological artifact and its digital representation. Thereby answering questions about to what extent a virtual representation (including visual and haptic properties) may compensate for or replace the experience of original, authentic heritage sites and objects which may be endangered or inaccessible. The aim is to test how the haptic technology can contribute to a multimedia recording in which both tangible and intangible aspects of endangered heritage can be stored and preserved.

The remainder of the paper is structured as follows. Section II contains the related work done towards heritage preservation and use of haptic interfaces in digital archaeology. Experimental design and setup are explained in Section III. Section IV presents the results, along with a discussion about the results. Lastly the conclusion and future work directions are elaborated in Section V.

II. Related Work

Modern 3D scanning is becoming a mature practice for the acquisition of the geometry of objects. However, capturing the physical properties of objects is required to create precise and realistic physical interaction. The need to scan physical properties of objects is highlighted by the emergence of haptic rendering, haptic display technologies, multimodal human computer interaction, and human-robot interaction.

Haptic modeling can be categorized as one of three approaches: physics-based modeling, measurement-based modeling, or vision-based modeling [11]. In the physics-based modeling, interaction forces are governed by physical laws (for instance, pulling on a ribbon will tend to bend rather than twist and stretch it) [12] [13]. Measurement-based haptic modeling uses data captured from real environments to build the haptic models [14] [15]. A pen-like probe, with sensors attached, strokes the surface of the material to measure contact information (forces, position, acceleration, velocity, etc.) [16] [17]. Software algorithms are applied to measure haptic properties based on the captured data [18] [19].

A large number of computer vision and image processing techniques have been investigated with regard to material properties [20] [21]. Vision-based haptic modeling relies on estimating physical properties (such as interaction forces, texture or friction) from visual information acquired via a camera [22]. In this study, we used computer vision to extract surface texture information that we used for haptic rendering. We developed a rotating platform, driven by a servo motor, for uniform and complete scan of the archaeological sample.

The heritage and archeology sectors are experiencing a range of developments in the applications of haptic and virtual representations of objects within museums [23] [24]. The value of touch has thus received nuanced debate within museums studies and has been explored as a related set of sensory concepts. The charisma of objects and the desire of people to touch them were acknowledged by [25].

Recently, contemporary museums are reconsidering their restrictions on the senses and how to revive sensory opportunities for visitors to engage with objects. Initially, the move to touch in museums and gallery has been motivated by the needs of the blind and visually impaired communities. This resulted in the establishment of a significant number of haptic-based museums around the globe, including touchable collections, touch tours, and activities dedicated to physically handling objects.

Haptic technologies offer the chance to physically handle virtual replicas of archaeological objects (particularly rare and/or fragile objects). Furthermore, the haptic system is far more portable and economic to maintain than a large collection of real objects and therefore offers significant outreach potential for public groups. For instance those unable to visit the museum may connect remotely, download the artifacts and use haptic interfaces to physically interact with them. Due to several advantages of incorporating haptic feedback with VR digital archaeology, the goal of this study is to provide evidences about the added value of haptics in digital archeology.

III. Experimental Procedure

A. Experimental Design

In order to evaluate the role of haptic feedback in VR digital representation of archaeological objects, the experiment is divided into two parts. Part I compares the user experience when handling the real artifact using a pen like stylus and the 3D reconstructed artifact using VR and haptic feedback. Figure 1 shows the actual image of the porcelain bowl that is used for the physical examination by the participants. The porcelain bowl is from late 18th-19th century, produced in Jingdezhen, China, made specifically for export to Thailand. The bowl has earlier rivet repairs. Participants are asked to interact with the real porcelain bowl and to gather information about the artifact using sight and touch. During the physical inspection phase, participants are asked to look closely for the physical properties and deformations on the artifacts surface. The participants are also asked to inspect the haptic properties such as texture, stiffness and friction during the physical interaction with the real archaeological object. Participants are then presented with the digital representation while wearing the Oculus Rift display and using the haptic interface to interact with the reconstructed model. Finally, participants are given a questionnaire to complete in order to capture their experience as per the differences between the real artifact and its digital representation.

Fig. 1. Porcelain bowl artifact. (a) Shows the top part of the bowl with texture details (b) Shows the bottom part with visible cracks and other texture details.

Part II of the experiment involves exploring the digital representation of a diminishing gravestone that was reconstructed visually and haptically. None of the participants have experienced the real gravestone. Participants are asked to recognize the handwriting engraved at the front side of the gravestone both visually and haptically. At the end of this part, participants are asked to complete a questionnaire about their experience with the digital representation of the gravestone. The real gravestone object is shown in Figure 2.

B. Data Acquisition and 3D Reconstruction

A data acquisition setup is created to capture a series of images for the 3D reconstruction of the artifacts. The photogrammetry setup involves two separate systems that are linked and synchronized by a central Linux server running on a Raspberry PI zero. The first system is the 360 turntable platform that rotates 12 degrees per 6 seconds to give the

Fig. 2. A snapshot of the real gravestone with engravings in Arabic script on the front side.

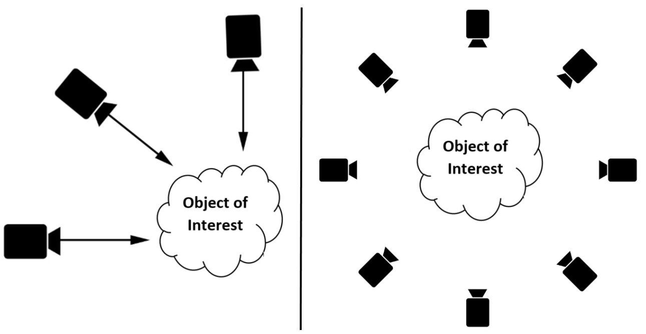

Fig. 3. Recommended camera orientation and angles for photogrammetry process.

camera different orientations of the archaeological object at a fixed tilt. The second system is a Nikon D7000 with a 24mm-120mm f/4 VR G lens camera that is enslaved by the GPhoto2 library to the raspberry PI to take still images at a fixed focus. A python script to control the turntable platform and the camera from a PC is also developed.

The object of interest is focused and then the camera is triggered by the Linux server via USB to take thirty pictures with the object rotating at a pan angle shift of 12 degrees. This process is repeated for three orientations with a displacement of 45 degrees (0 degrees, 45 degrees, and 90 degrees). Figure 3 highlights the recommended camera angles to capture the object for the purpose of photogrammetry [26]. Lighting conditions are kept consistent throughout the visual capture of the artifact via an enclosing tent. The images are then preprocessed in Adobe Lightroom [27] to correct the white balance and calibrate the colors with the ambient lighting. The processed images are then fed into Autodesk Recap Photo software [28] to generate the 3D model. Figure 4 shows the photogrammetry setup developed for the 3D reconstruction of the artifacts.

An initial preprocessing was done on the reconstructed model to bridge any gaps or holes and to remove any unwanted noise generated during reconstruction process. A user may experience unwanted haptic feedback if the acquired model is not preprocessed properly. Figure 5 shows the reconstructed 3D model of porcelain bowl artifact generated through photogrammetry process. Figure 6 shows a snapshot of the reconstructed 3D model for the gravestone using photogrammetry technique.

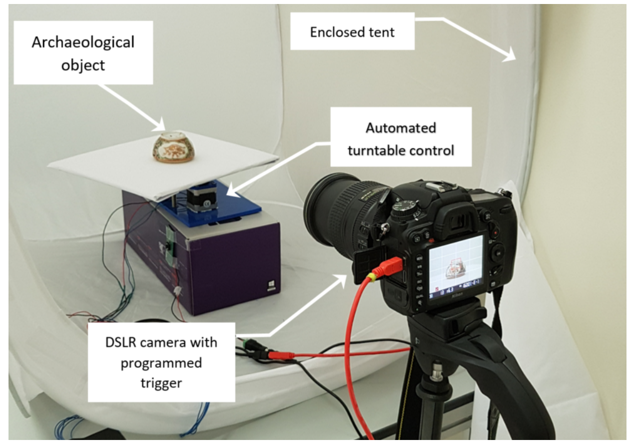

Fig. 4. Photogrammetry Setup with automated turntable control. Camera trigger programmed to capture images automatically at each orientation. Whole setup is enclosed within a tent for consistent lighting conditions.

Fig. 5. Porcelain bowl digital representation (including 3D graphic and haptic models).

Fig. 6. Digital representation of the gravestone object.

C. Software Implementation

The simulation environment is implemented using CHAI3D framework[1]. CHAI3D is an open source C++ framework used for haptic visualization and interactive rendering of force feedback applications. CHAI3D provides extensive force rendering algorithms for sophisticated simulations with integrated haptic capabilities. The CHAI3D framework provides an OpenGL based graphic rendering engine that provides a base for easy rendering of virtual environments and objects via accelerated graphics hardware. CHAI3D also provides a software interface to many commercially available haptic devices.

A haptic model for the digital artifact is created using the CHAI3D haptics framework. Haptic properties are assigned to the reconstructed artifacts (stiffness, static and dynamic friction), so more realistic haptic interactions are rendered with the model. A 3D model of a pen stylus is created and used in the simulation to emulate the physical interaction of the real artifact using the pen stylus. The Geomagic Touch device is utilized in the experiment as the haptic interface. To explore digital archaeological objects using the haptic device, we have implemented a tool cursor as a single haptic point of interaction and finger proxy force rendering algorithm for polygonal objects [29]. The system is complemented by the Oculus Rift VR head mounted display for a visually immersive experience.

D. Study Participants

A total of eight participants (four females) are recruited for this study. Participants are divided into two groups: experts group and novice group. The experts group comprises of four archaeologists (2 females) whereas the novice group is composed of four (4) non-archaeologists (2 females). A written informed consent was collected from all the participants before starting the experimental procedure. As Part II of the study involved the recognition of Arabic handwriting over the gravestone, participants are asked if they can read Arabic script. Three of the participants could recognize Arabic characters.

E. Experimental Setup

The experimental setup consists of the Geomagic Touch device developed by 3D Systems for haptic rendering and the Oculus Rift virtual reality head mounted display for a VR display. The Geomagic Touch device provides six degrees of freedom of motion tracking, three degrees of translational force feedback and has a 1KHz haptic rendering refresh rate. The setup is implemented using an Intel Xeon E5-2630 CPU at 2.6GHz, 32 GB of RAM and an Nvidia GTX 1070 GPU running Windows 10 64 bit operating system. Figure 7 shows a snapshot of the setup used for the experiment.

IV. Results and Discussion

Participants are asked to rate the similarity between the real artifact and its digital representation (visual and haptic) on a 7 point Likert scale from strongly agree (perfectly matching the experience with the real artifact) to strongly disagree. The average rate for how similar the experience of the real artifact compared to its digital representation for all the participants is found to be 71% (standard deviation of 20%). However, the similarity percentage rating for the experts group is found to be 58% (standard deviation of 16%) whereas the novice group rating is 83% (standard deviation of 17%). Figure 8 shows the average similarity scores with the respective standard deviation error for the three groups; experts, novice, and total. This result demonstrates that vision-based haptic modeling would be satisfactory for novice users (such as in an exhibition in a museum). However, using the simulation for academic, research, or professional examination may require more accurate haptic modeling (such as data-driven haptic modeling [19]).

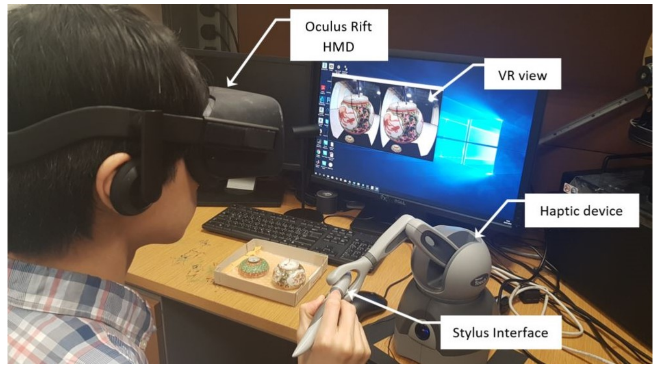

Fig. 7. Experimental setup.

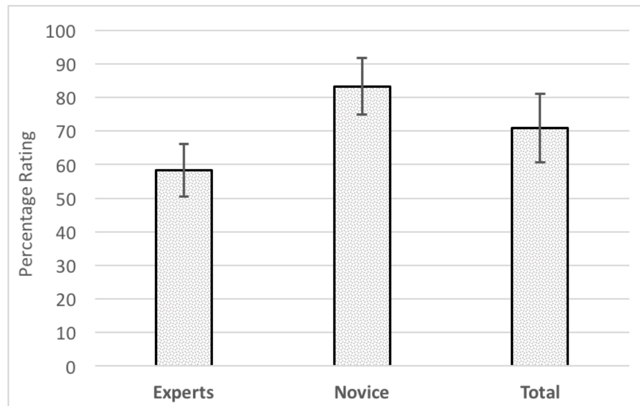

Fig. 8. Equivalency between different participant groups

Participants are also asked to provide a subjective evaluation about the haptic interaction experience and any differences they could gather between the real object and its digital representation.

For Part II of the study, participants are first asked to reproduce the shapes for any recognized Arabic characters on the gravestone using only visual feedback. Participants are then asked to use the haptic device to explore the engravings on the gravestone and to reproduce any haptically recognized characters. Participants are asked to handwrite the recognized

[1]http://www.chai3d.org/

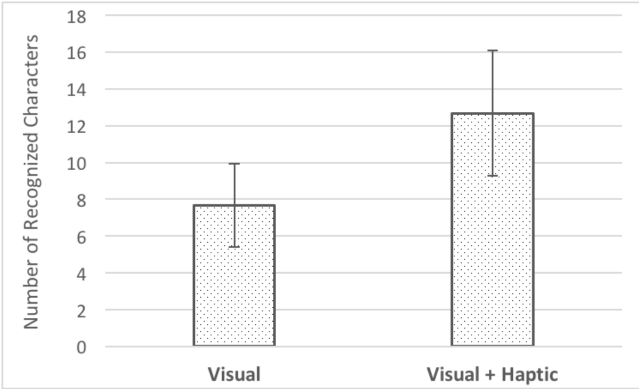

Fig. 9. Number of letters recognized on gravestone visually vs visual and haptic exploration.

characters on a piece of paper for both cases. Results show that on average, participants could recognize around 7.67 characters (standard deviation is 2.25) using visual exploration whereas they could reach an average of 12.67 characters with visual and haptic exploration (as shown in Figure 9). This clearly demonstrates that haptic feedback enhanced the ability of the user to elicit further information about the artifact.

V. CONCLUSION AND FUTURE WORK

This study evaluates the role of haptics in digital archaeology through the use of virtual reality and haptic technologies. Two archaeological objects are modeled, both graphically and haptically, and evaluated with a group of eight participants. Results show that vision-based haptic modeling is sufficient for exploration by novice users (for entertainment in museums). However, more accurate haptic modeling is needed if these digital representations are to be used for education, research or professional archaeological exploration. Furthermore, the interaction with the gravestone demonstrates that the haptic modality can provide improved performance beyond what visual interaction provides (better recognition of the engraved characters when exploring the handwritings haptically). Our future work includes exploring data-driven haptic modeling for capturing more accurately the physical properties (stiffness, texture, and friction) of the archaeological objects. Furthermore, we plan to integrate other feedback from the archaeologists in the simulation (such as providing a scale in the virtual environment to map to the real environment as well as adding an information bar about the presented artifact).

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