第 28 回日本バーチャルリアリティ学会大会論文集（2023 年 9 月）

Experiential VR System for Visualization and Enhanced Understanding of a Statue of Prince Shotoku

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概要： 本研究では，「聖徳太子童形立像」の理解支援のため，体験型インタラクションを含めた VR システムを開発した．HMD を被って VR 空間に没入し，手のジェスチャにより仏像の制作過程を体験しながら像内を探索できる．本システムは，博物館において仏像の観覧と同時に体験してもらうことを想定し，VR 未経験者でも操作しやすく，VR 酔いを起こしにくいインタフェースについて検討した．本システムを博物館で二日間展示し，来館者のアンケートによりシステムの操作性および VR を用いた展示支援の有用性を考察した．

キーワード：3D フォトグラメトリ，博物館展示支援, VR，聖徳太子像

1. Introduction

Advancements in VR and 3D model generation technologies have led to instances where museum exhibits can be observed from various angles [1]. Unfortunately, existing museum archives generally focus on the exterior appearance of exhibits. In contrast, the production of Buddhist statues involves the fusion of an artisan's intricate techniques and artistry, hidden treasures are sometimes incorporated into the interior of the statues. By directly examining these internal structures, one gains a deeper understanding of the complexities of the production process and the significance possessed by such statues. However, digitizing internal structures poses challenges: time-consuming and labor-intensive; specialized inspection methods; difficult presentation.

In this study, we used photogrammetry and CG production individually to digitize both the interior and exterior of Buddhist statues. We also developed a VR system and demonstrated it alongside the actual object to help museum visitors deepen their understanding of such internal structures.

Research has integrated museum exhibits with VR. Shibasaki et al. [2] developed a pointing system that allows museum and art gallery visitors to gain viewing experiences based on their individual interests using VR content and a large screen. In this study, our system allows users to observe the interior and exterior of a Buddhist statue through gestures with a head-mounted display (HMD) without special controllers.

Kobayashi et al. [3] created an experiential media system that expresses shrine-worship culture in terms of divine messengers, deities, and rituals using video projection that integrates elements of traditional Japanese picture scrolls with physical movements and object recognition. In this study, we introduced an experiential interaction that deepens the understanding of the techniques used in the creation of Buddhist statues, providing a sense of immersion to users through VR devices.

When developing this system, we addressed the physical strain that occurs when users must directly look up from inside the statue. Leo [4] proposed a new rotational method that addresses the issues of full-body rotation and large head movements required in 360 degree video. In this study, we adjusted the camera angle in advance to reduce the physical strain caused by vertical observation.

This paper provides a detailed explanation of our developed system, its operation in the museum, and the evaluation results.

2. Overview

This study focused on a statue called Standing Prince Shōtoku in His Youth, which is housed at Kōshō-ji in Hiroshima. Prince Shotoku was a politician during Japan's Asuka period who greatly contributed to the spread of Buddhism. We made a surface model of the statue using photogrammetry and crafted a 3D CG model of its interior with reference to images captured by a fiberscope. These interior and exterior datasets served as the basis for the development of VR content.

The aim of this study is to make the statue's internal structure

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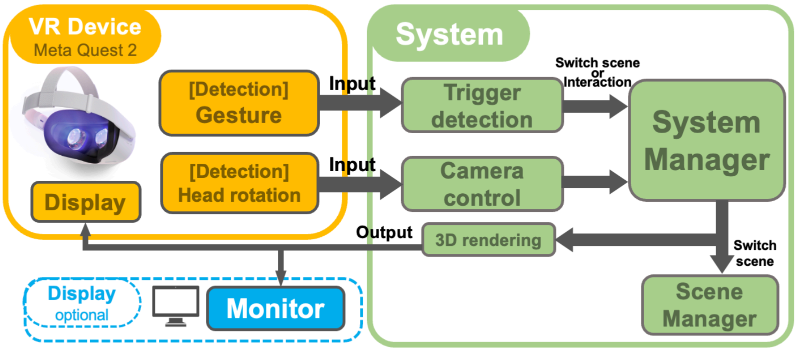

Fig. 1 System configuration

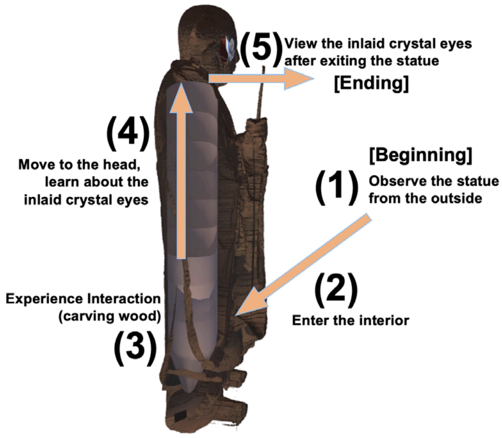

Fig. 2 Scene composition

comprehensible to museum visitors of all ages by emphasizing the importance of intuitive operations. As such, gesture recognition was chosen as the system's input methodology instead of conventional controllers. The progression of content scenes is regulated by a folded-hands gesture, facilitating an understanding of Buddhist statues and culture.

Considering the broad age range of visitors and the reality that the majority of our participants are novel HMD users, enhancements reduced the quantity of explanatory text. We also aimed to alleviate the physical burden on the participants. Furthermore, we introduced an experiential interaction to promote a more profound comprehension of the statue's internal construction process.

3. Development of VR System

3.1 System configuration

Our system’s configuration is shown in Fig. 1. Meta Quest 2 was used as the HMD; its built-in hand-tracking function is also utilized. The HMD’s sensors detected a user's hands and reflected them in the hand model in the virtual world. The rotation angles of a user's head is simultaneously detected by the HMD and reflected in the viewport of the visible virtual world. Gesture recognition controlled the content scenes. Once these processes are completed, the system renders and shows the results on its HMD display. An external display can be output, allowing other visitors to see the user's field of view.

The content advances from scene (1) to scene (5). After the actions in each scene have been completed, a transition to the next scene can be triggered by the folded-hands gesture.

The specific tasks conducted in each scene are shown in Fig. 2. When the content starts, the user enters scene (1). Here a life-sized Buddha statue rotates in front of the user, and after the folded-hands gesture, the user moves to scene (2), where the Buddha statue gradually grows, and the user enters its interior and lands at its feet. Here users are invited to observe carving traces.

In scene (3), the participant holds a chisel with which she can virtually carve a plank for an interactive experience that deepens her understanding of the internal structure and the production techniques of Buddha statues.

Combining scenes (4) and (5) deepens the participants’ understanding of the statue's internal structure. In scene (4), they move from the Buddha statue’s feet to its head. After reaching the head, they are invited to observe and learn about the structure of the inlaid crystal eyes from the inside. To reduce the physical strain caused by looking straight up, the viewing angle in the VR space is adjusted. In scene (5), the user viewpoint moves from inside the Buddha statue to outside of it so that they can observe the inlaid crystal eyes from the outside. Based on prior time measurements, experiencing the entire system from beginning to end takes approximately two and a half minutes.

3.2 User input and interaction

3.2.1 Recognition of folded-hands gesture

We used the hand-tracking feature of Meta Quest 2. Its hand-tracking-capture area is shown in Fig. 3 (a). The hand-tracking results are directly reflected in the hand model within the VR content. This allows the movements of user hands to be conveyed to the hand model in VR in real time, enabling a more immersive experience. In addition, small cubic blocks are attached to the palm portion of both hand models. These blocks serve as triggers when a user executes specific actions. The system identifies the moment when the two blocks collide as a folded-hand gesture (Fig. 3 (b)).

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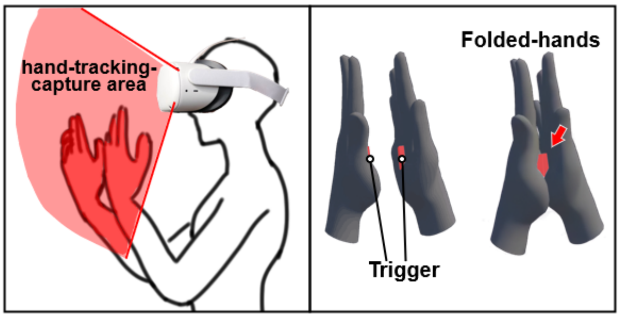
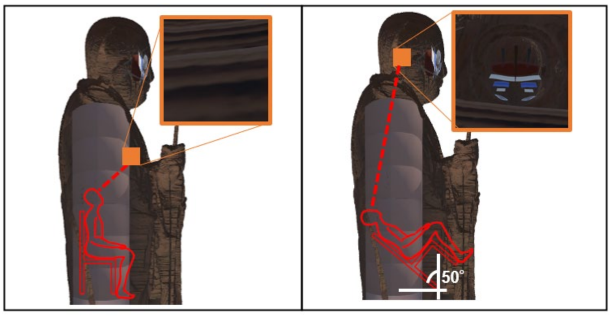


(a) Hand-tracking-capture area (b) Determination of folded-hands

Fig. 3 Identifying folded-hands gesture



(a) Before adjusting angle (b) After adjusting angle

Fig. 5 Comparison before and after angle adjustment

3.2.2 Experiential interaction: carving wood

To gain a better understanding of the carving techniques used in Buddhist statues, we introduced an interaction where users can actually experience a carving method and a technique with a chisel. This experiential interaction starts by examining the carving marks inside the Buddha statue. A chisel and wooden plank are placed in front of the participant (Fig. 4, left). When the participant touches the chisel, its CG model is synchronized with the position of the model of the participant's hand. When this chisel's tip touches the wooden plank, the participant visually experiences a plank being carved (Fig. 4, right).

Fig. 4 Experiential interaction: carving wood

3.3 Viewing angle adjustment

In this system, users enter the interior of the Buddha statue and must inevitably look up while inside or moving from the feet toward its head (scene (4)). Unfortunately, looking straight up imposes a significant physical strain, a problem we addressed by slightly tilting the camera angle up just before moving toward the head. This approach is expected to alleviate the physical burden on participants caused by looking up (Fig. 5). After a trial and error process, this viewpoint angle was ultimately set at 50 degrees.

4. Exhibition and Evaluation at Museum

4.1 Exhibition at museum

This system was displayed for two days, specifically on the 26th and 28th of May, 2023, at Ryukoku Museum [5] in a special exhibition titled 'Shin Buddhism and Prince Shōtoku'. The exhibition setting is depicted in Fig. 6. These devices were positioned next to the area where the actual Prince Shōtoku statue was displayed. We prepared two sets of VR terminals and swivel chairs to allow two visitors to experience it simultaneously during the exhibition. One VR terminal was connected to a monitor so that others could also experience the user perspective.

Fig. 6 Museum exhibition

4.2 Evaluation

Our survey asked the participants to evaluate the system's operation, their experience with the system, and its duration on a five-point scale; VR sickness was graded on a four-point scale. The survey results are shown in Figs. 7 and 8. An overwhelming majority (almost 90%) felt that their understanding of the statue’s internal structure and the overall exhibit was deepened by their VR content experience (Fig. 7).

As shown in Fig. 7, On the other hand, 94% of the participants managed to make the folded-hands gesture; 6% failed to do so. Perhaps they made the gesture outside the hand-tracking detection range. Although 72% engaged with the interactive experience without any problems, only 56% were satisfied with their experiences. A lack of physical feedback or resistance when

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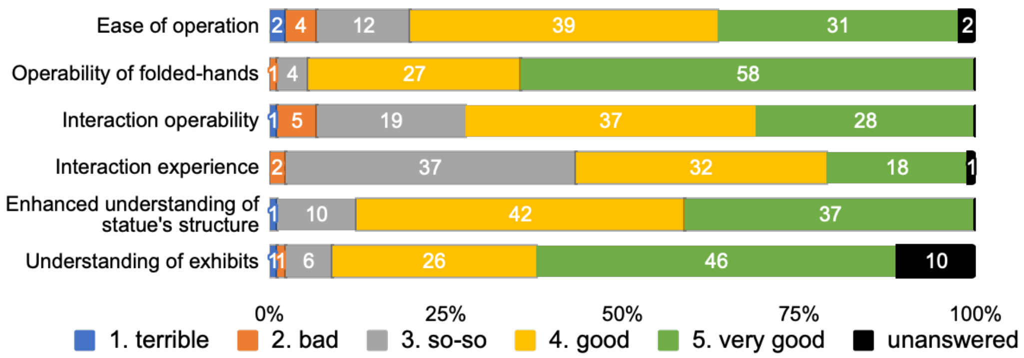

Fig. 7 Evaluation related to operation experience

"carving the wood" in the virtual reality environment may have created discomfort in participants during the carving operation.

As shown in Fig. 8, regarding the experience's duration, the target length was around two and a half minutes, referencing the average duration of other digital exhibits in the museum. However, the survey revealed that 42% of the respondents preferred a longer duration. Additionally, even though a large proportion of the participants was elderly, only 7% experienced VR sickness. This small percentage suggests that extending the experience is feasible.

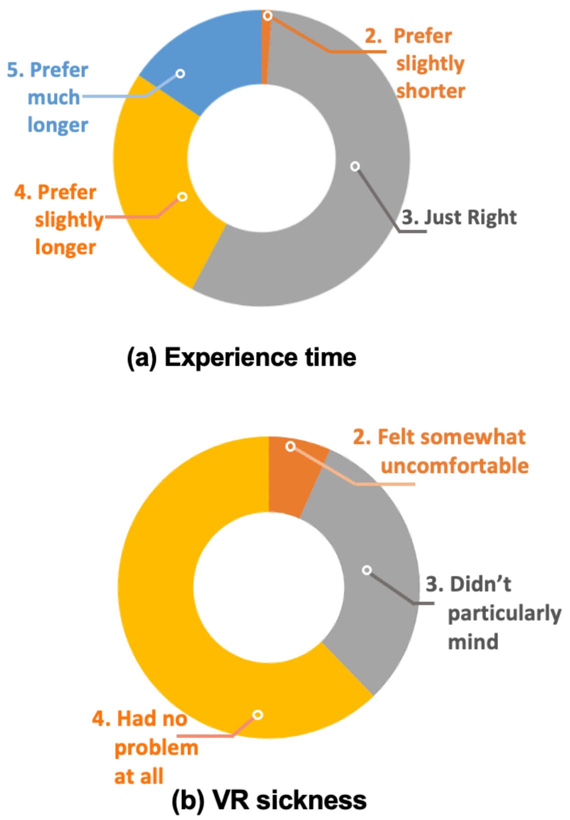

Fig. 8 Evaluation of experience time and VR sickness (No respondent assigned the lowest rating of "1".)

5. Conclusion

We digitized the exterior and interior of a Buddhist statue with an easy-to-understand operation method (folded hands) and provided experiential interactions to deepen understanding of its internal structure and production techniques. After integrating these elements, we developed exhibition support content using VR technology. Our VR exhibition experience is a promising tool that can deepen users' understanding to provide a more vibrant experience.

However, some users described a lack of realism and some discomfort, mainly attributed to the lack of physical resistance when "carving" using hand tracking. We also addressed VR sickness and fatigue from the usage duration and clarified that most users didn't find their two and a half minute experience to be excessive. Most used the system without issues even for short durations (2.5 minutes). This research demonstrated the feasibility of using VR devices as exhibition support tools for short durations and increased understanding of exhibits.

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