A Realtime and Direct-Touch Interaction System for the 3D Cultural Artifact Exhibition

Wataru Wakita[1], Katsuhito Akahane[2], Masaharu Isshiki[3], and Hiromi T. Tanaka[1]

[1] Department of Human and Computer Intelligence, College of Information Science and Engineering, Ritsumeikan University, Kusatsu, Japan
{wakita,hiromi}@cv.ci.ritsumei.ac.jp

[2] Precision and Intelligence Lab, Tokyo Institute of Technology, Yokohama, Japan
kakahane@hi.pi.titech.ac.jp

[3] Department of Electrical and Electronic Engineering and Computer Science, Ehime University, Matsuyama, Japan
isshiki@cs.ehime-u.ac.jp

Abstract. We propose a realtime and direct-touch interaction system for 3D cultural artifact exhibition based on a texture-based haptic rendering technique. In the field of digital archive, it is important to archive and exhibit the cultural artifact at the high-definition. To archive the shape, color and texture of the cultural artifact, it is important to archive and represent not only visual effect but haptic impression. Therefore, multimodal digital archiving, realtime multisensory rendering, and intuitive and immersive exhibition system are necessary. Therefore, we develop a realtime and direct-touch interaction system for the 3D cultural artifact exhibition based on a texture-based haptic rendering technique. In our system, the viewer can directly touch a stereoscopic vision of 3D digital archived cultural artifact with the string-based and scalable haptic interface device "SPIDAR" and vibration motor.

Keywords: Digital Museum, Virtual Reality, Computer Graphics, Haptics.

1 Introduction

We are working on a digital museum project of the "Gion Festival in Kyoto" [1], [2]. The floats in the "Gion Festival in Kyoto" are decorated with various accessories. Therefore, the floats are described as a "Moving Museum". In this digital museum project, in particular, we are working on a digital archiving of the "Gion Festival in Kyoto" by multisensory information such as the visual sense and the haptic sense.

In the field of digital archive, it is important to archive and exhibit the cultural artifact at the high-definition. To archive the shape, color and texture of the cultural artifact, it is important to archive and represent not only visual effect but haptic impression. To exhibit the digital archived 3D model naturally, multisensory digital archiving and interactive, intuitive and immersive exhibition system is necessary.

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Moreover, to reduce the graphic and haptic rendering cost, a realtime rendering is necessary. Generally, to achieve the realtime rendering in graphic process, at least 30-60 Hz update rate is necessary. In haptic process, to represent the soft objects, at least 300 Hz update rate is necessary, and to represent the hard objects, at least 10 kHz update rate is necessary while considering the graphic rendering cost.

Therefore, we develop a realtime and direct-touch interaction system for the 3D cultural artifact exhibition with the string-based and scalable haptic interface device "SPIDAR" [3] and vibration motors.

2 Related Work

Recently, various haptic rendering devices have been developed, and various haptic rendering techniques to touch the virtual object have been proposed. The penalty-based haptic rendering method [4], [5] is a basic approaches to represent the polygon wall, has several problems such as passing through, discontinuous force and vibration. To solve these problems, Zilles *et al.* proposed a constraints-based God-object method [6]. However, their method has the same problems such as passing through, discontinuous force and vibration in haptic rendering for the high-definition virtual object. On the other hand, several texture-based haptic rendering techniques have proposed to represent the asperity of the interior of the polygon according to the 2D image [7], [8], [9], [10]. In our previous work, we proposed a texture-based haptic rendering technique for the pseudo-roughness on the surface of the low-polygon virtual object using height map and normal map, and we developed a material system under haptic rendering for pseudo-roughness on the low-polygon object surface [9]. In this system, a difference of the haptic impression is represented by changing magnitude and/or direction of the reaction force dynamically according to the pixel value of the object surface which mapped the haptic texture which converted surface height, stiffness and friction into the 2D image. Moreover, we have proposed a realtime haptic rendering technique for representation of the high-definition model surface using the low-polygon model, distance map and normal map [10]. In this approach, the reaction force is calculated according to the pixel value of the low polygon model surface which mapped the haptic texture which converted the geometric difference of the high-polygon model and the low-polygon model into the 2D image. However, these techniques are not based on the measurement. To represent the high-definition virtual object, it is necessary to model the virtual object based on the measurement. The same can be said for digital archive. Therefore, in our previous work, we captured the surface structure of the materials in the real world with OGM (Optical Gyro Measuring Machine) and generated the normal map [11] which has surface asperity information. Then we modeled the tactile sense by vibration signals based on normal map, and we developed a haptic rendering system for a 3D noh-cloth model based on the measurement with the string-based haptic interface device SPIDAR and vibration speakers [12].

2.1 Multisensory System of the Cultural Heritage

As related work of the cultural heritage, Christou *et al.* [13] proposed a versatile large-scale multimodal VR system for cultural heritage visualization. Their exhibition system is the Cave-like multimodal system, and their system enables haptic interaction with two haptic arm. On the other hand, Carrozzino *et al.* [14] proposed a large-scale multimodal and immersive VR system. Their exhibition system is the Cave-like multimodal system, and their system enables haptic interaction with exoskeleton haptic arm. These works enables to represent the shape, color, and texture of the cultural artifact with the haptic device. However, these systems are impossible to directly touch to the digital archived model. To exhibit the digital archived 3D model naturally, a direct touchable immersive exhibition system is necessary.

2.2 Direct-Touchable Multisensory System

As related work of the direct-touchable multisensory system, Inami *et al.* [15] and Arsenault *et al.* [16], [17] proposed a system with half mirror and haptic arm device. Vallino *et al.* [18], Bianchi *et al.* [19], and Sandor *et al.* [20], [21] proposed a AR/MR system with HMD and haptic arm device. Brederson *et al.* [22] and Ikits *et al.* [23], [24] proposed a system with 3D projector and haptic arm device. These system enables direct-touch for the graphic models with the haptic arm device. However, it is difficult to touch the large-scale cultural artifact because there is a limitation over the range of arm movement. On the other hand, Yoshida et al. [25] proposed RePro3D with vibration motor and retro-reflective projection technology. However, it is impossible to represent the kinematic sense.

To exhibit the cultural artifact naturally, a direct-touchable exhibition interface corresponding to the size of the cultural artifacts is necessary (see Figure 1). Therefore, in our work, we use the string-based and scalable haptic interface device "SPIDAR" [3] and vibration motors.

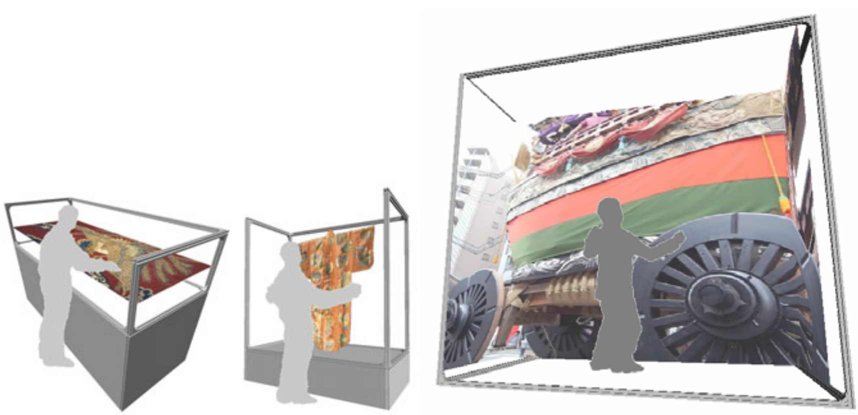

Fig. 1. Direct-touchable multisensory exhibition interface corresponding to the size of the cultural artifacts with scalable haptic interface device SPIDAR

3 Direct-Touchable Multisensory Exhibition System

Figure 2 shows a direct-touch able multisensory exhibition system with SPIDAR. SPIDAR is on top of a screen. SPIDAR has ability to control the 3DOF position and to present the 3DOF forces. A grip part is attached to 4 strings from 4 motors with an encoder. The strings length got from each encoder's data is used to measure the grip's position. The strings tension from each motor is displayed the feedback forces.

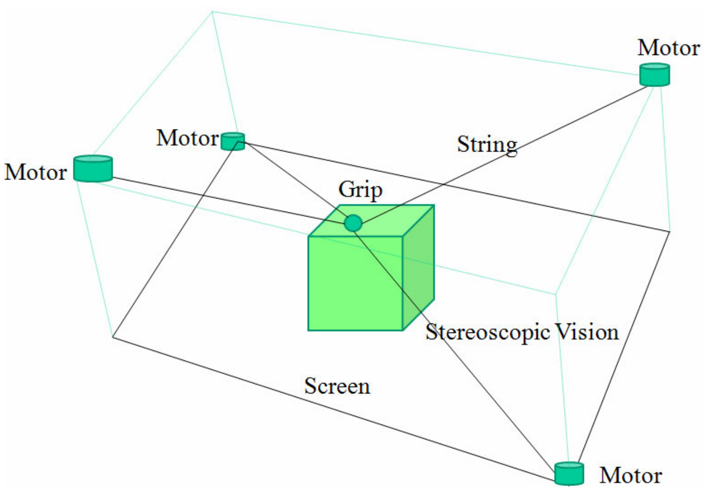

Fig. 2. Direct-touchable multisensory exhibition system with SPIDAR

Users attach the vibration motors on fingers, users can feel kinematic sense and tactile sense moving the fingar tip and tracing the stereoscopic 3D virtual objects on the screen. Reaction force and vibration signal is calculated with the finger's move direction vector and surface asperity of collision point. A vibration signal is converted to voltage by D/A converter.

3.1 Direct-Touch Interaction for the Stereoscopic Vision

To touch the stereoscopic objects naturally with a SPIDAR, a grip position in the device space is required to match the virtual space according to the camera space.

To represent the 3D shape with SPIDAR, firstly, the intersection is detected between the finger tip and 3D model surface on the screen. Secondly, if they are crossed in the intersection detection and have the possibility of contact, the polygon height is changed according to the pixel value of the height map in relation to intersection point and the polygon is replicated [9], [10] (see Figure 3).

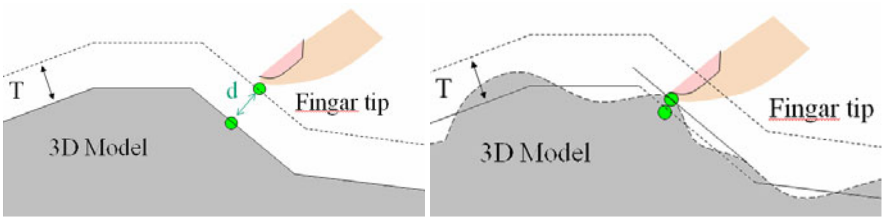

Fig. 3. Direct-touch interaction for the 3D model based on our texture-based haptc rendering technique

Finally, the intersection is detected again between the finger tip and a copy polygon, and the reaction force is calculated according to the penetration depth and the pixel value of the friction map and stiffness map [10]. Our haptic rendering technique is based on a constraint-based God-object method [6].

In our system, we display the vibration signal transform to voltage and input to vibration motors. The signal is calculated by the inner product finger tracing direction and the normal vector in the contact point of normal map.

4 Digital Archive

4.1 Graphic Modeling

We used the laser range scanner "VIVID" for the measurement of the shape, and we used a high-resolution multiband imaging camera for measurement of the color and spectral reflectance.

Figure 4, 5 shows measurement data of the woven cultural artifact "Hirashaji Houou Monyou Shishu" of "Fune-hoko" of "Gion Festival in Kyoto". Figure 4 shows a height image data (height map) that was generated from measured range data by the laser range scanner, and Figure 5 shows a color image data (color map) by the multiband camera.

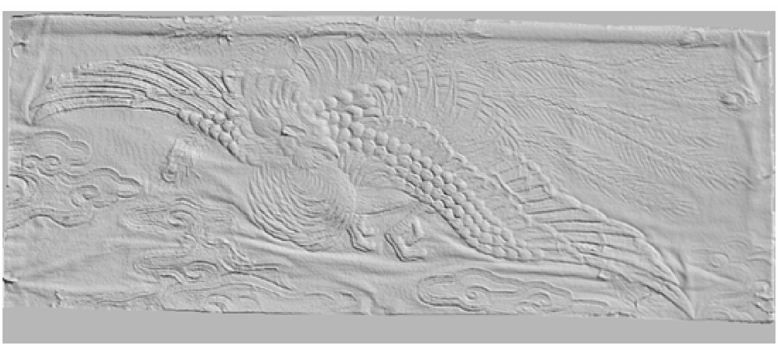

Fig. 4. Measured height image data of the "Hirashaji Houou Monyou Shishu"

Fig. 5. Measured color image data of the "Hirashaji Houou Monyou Shishu"

The measured range data have 612,522 (1193x512) vertices, and measured color image data have 73,300,500 (13650x5370) pixels. To reduce the graphic rendering cost, we reduced a 3D polygon model and we mapped a measured 2D color map to a reduced 3D polygon model (see Figure 6).

Fig. 6. 3D Digital Archived Model of the "Hirashaji Houou Monyou Shishu"

4.2 Haptic Modeling

To reduce the haptic rendering cost, we used our texture-based haptic modeling and rendering technique [26]. Firstly, we created a normal map from height map (see Figure 7).

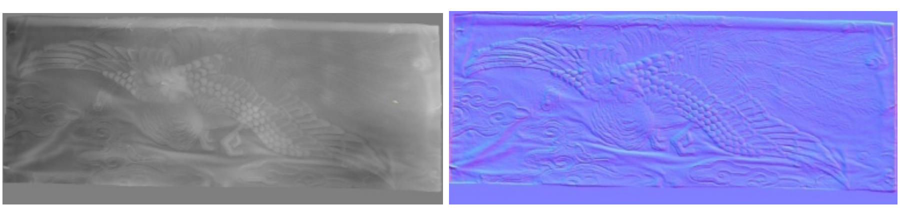

Fig. 7. Height map (*left*) and Normal map(*right*) of the "Hirashaji Houou Monyou Shishu"

This normal map is used to represent the surface gradient, where the RGB values correspond to the XYZ coordinates of the normal vector. The height map is used to represent the surface height, where the surface height is changed according to the grayscale value (white is high and black is low elevation). We mapped these maps to low-polygon model which is used for the haptic rendering, and is not used for the graphic rendering.

5 Results

We developed a direct-touch interaction system for the digital archived 3D cultural artifact exhibition (see Figure 8). Our system is composed of a display system and an 3D application. A display system consists of a graphic part and haptic part. In graphic part, we used a rear projector screen (1000x750 mm) and the stereoscopic projector "DepthQ HD". The stereoscopic vision is projected to the bottom projector screen with a mirror. A haptic part is on top of a projector screen, and at one with a graphic part. In haptic part, we used SPIDAR and vibration motors. We used two 2.33 GHz Intel(R) Xeon(R) CPU E5410, NVIDIA Quadro FX 580 graphics card with 512MB video memory, 16GB RAM, Windows VISTA 64bit, and NVIDIA 3D Vision. The graphic process is 120 Hz update rate, and haptic process is 1 kHz update rate.

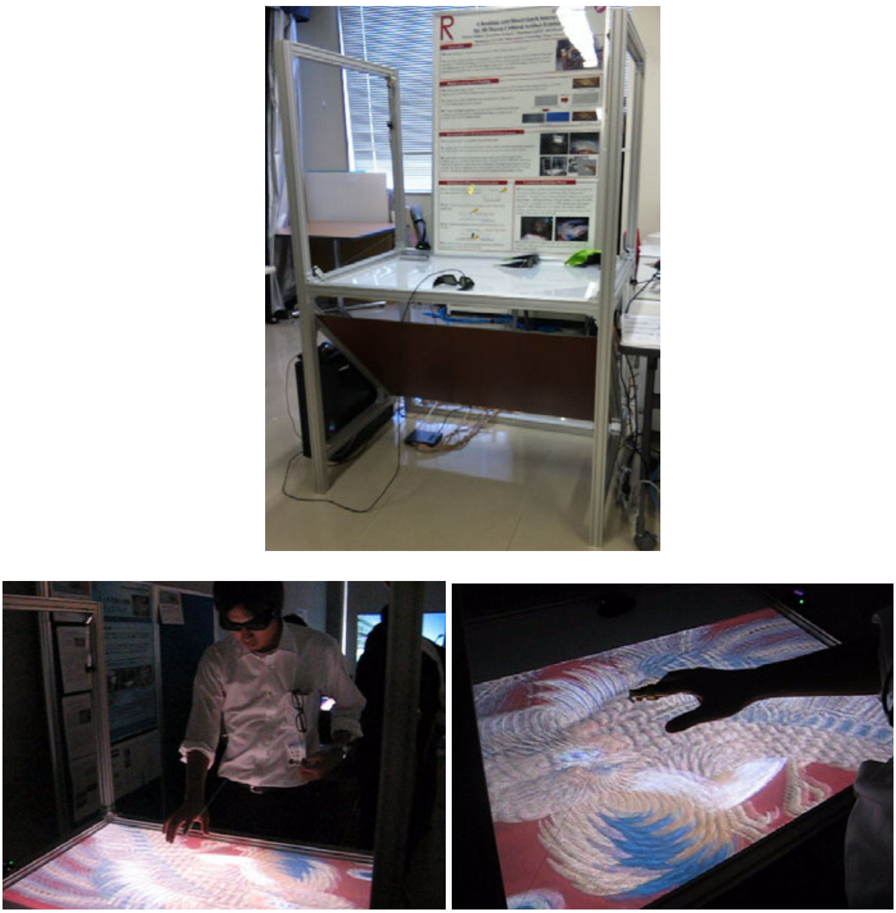

Fig. 8. Realtime and direct-touch interaction system for the digital archived 3D cultural artifact exhibition

6 Conclusion and Future Work

We developed a realtime and direct-touch interaction system for the 3D cultural artifact exhibition with the string-based and scalable haptic interface device "SPIDAR" and vibration motors. Specifically, firstly we archived the cultural artifact "Tenmizuhiki" tapestries "Hirashaji Houou Monyou Shishu" of "Fune-hoko" of "Gion Festival in Kyoto". Secondly, we developed a exhibition system with the stereoscopic projector, SPIDAR and vibration motors based on our texture-based technique. However, in our system, the stiffness properties are not based on the measurement data. Therefore, we plan to measure various materials in the real world.

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