Comparison of Image Haptization Systems for 2D and Depth Images with Local Deformation

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Abstract—Image haptization systems for 2D images and depth images with local deformation have been proposed, and from the experiments they have been proved effective in improvement of image contents perception and user interests. However, a comparison between the two kinds of systems has not been done. This paper compares the depth image haptization system with the 2D image haptization system based on a user questionnaire.

Keywords—haptization; image haptization; comparison; depth image

I. INTRODUCTION

Haptic technology has been widely researched and used in various interactive systems. Among these interactive systems, we are concerned about image haptization systems. Recently, we have proposed image haptization systems for 2D images and depth images [1] [2]. In those systems, user can interact with the images through a haptic device and feel various haptic properties such as texture or depth of the images. In order to improve the user experience, we proposed local deformation.

As shown in Fig. 1, the haptic device used in the proposed system is SPIDAR-GCC. SPIDAR-GCC (Space Interface Device for Artificial Reality – type GCC) is a tension based haptic device developed by Sato laboratory, Tokyo Institute of Technology. By connecting it to a personal computer with the AHS controller, SPIDAR–GCC could provide a high definition force feedback sensation [3] [4].

II. IMAGE HAPTIZATION SYSTEMS

A. 2D image haptization system with local deformation

Fig. 2 shows the system overview of the proposed system.

The image is mapped on a floor of 3D virtual environment, which is same as the OpenGL coordinate system. The system accepts the user input through the haptic device. When the pointer is moving in the free space, there is no contact between the pointer and the floor. Hence, no force is generated. When the pointer collides with the floor as shown in Fig.3, the feedback force is generated and calculated.

Figure 1. SPIDAR GCC

Figure 2. System overview of 2D image haptization system

Figure 3. Pressing the floor
The reacting force is calculated with the color information of the corresponding pixel and generated through the haptic device. As a result, user can feel the texture of the object based on color information.

To generate the feedback force of SPIDAR-G, two haptic parameters, \( K \) and \( B \) have introduced as in (1). \( K \) represents the virtual stiffness of the material based on the soft-hard emotional effect of the color. \( B \) represents the virtual damping of the material based on the dynamic-passive emotional effects of the color. Here \( C_{F}(x,y), C_{G}(x,y), C_{B}(x,y) \) represent the red, green and blue value of a pixel at \((x, y)\).

\[
K = \varphi_{r}(C_{F}(x,y), C_{G}(x,y), C_{B}(x,y)) \\
B = \varphi_{g}(C_{F}(x,y), C_{G}(x,y), C_{B}(x,y))
\]  

(1)

The feedback force has calculated using the penalty method as shown in (2)

\[
F = K \cdot s + B \cdot \nu
\]  

(2)

Here \( s \) represents the y-displacement from the plane of the image and \( \nu \) represents the velocity.

Along with the haptization rendering, deformation is also rendered when the user is pressing the floor. A distortion is applied to area with the center of \( Q \), the corresponding pixel of the current position of the pointer. As shown in Fig. 4, the effective radius and pinch amount is in proportion to the penetration depth. The two parameters, radius \( r \) and pinch amount \( a \) are determined by the penetration depth and the virtual stiffness as shown in (3).

\[
r = \varphi_{r}(K, s) \\
a = \varphi_{g}(K, s)
\]  

(3)

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**B. 3D image haptization system with local deformation**

Fig. 2 shows the system overview of the proposed system.

Depth images have been used in interactive systems more frequently in recent years. A depth image is a grayscale image of which every pixel stores the height. Obviously we can know that the height is ranged from 0 to 255. Usually a smaller value means a lower height, however reversed cases also exist. Fig. 6 gives an example of depth image.

In order to make the depth image tangible, we need to build a triangle polygon mesh from the image data. First of all we need to transform the 2D coordinates to 3D coordinates. For each pixel in the image, we use the image coordinates as the \( x, z \) coordinates and use the height as the \( y \) coordinate in the 3D coordinate system.

After the coordinate transform we build a triangle polygon mesh from the depth image. As shown in Fig. 7, for each four vertices, we have two triangles by adding a diagonal.

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**Figure 5.** System overview of 3D image haptization system

**Figure 6.** Depth image

**Figure 7.** Triangle polygon mesh extraction
A proxy graph algorithm [5] is used to calculate the contact force when pointer collides with the polygon mesh. The proxy graph algorithm always updates the position of the proxy to the endpoint of the haptic device. When the goal is in a free space, proxy is updated directly to the position of goal. When the haptic endpoint penetrates into the polygon mesh, the proxy is updated to the nearest vertex to the goal on the polygon mesh.

We assume that there is a virtual spring connected between the proxy and the endpoint of the haptic device (Fig. 8). Thus the contact force $F$ can be calculated with (4). In this equation, $K$ is the virtual stiffness of the polygon mesh which could be pre-defined by user. $P$ is the position of the proxy and $G$ is the position of the goal which is also known as the endpoint of the haptic device.

$$F = K \cdot s + B \cdot v$$

$$s = P - G$$

Deformation rendering is performed by applying a displacement to the neighbor vertices of the contact vertex. A simulated situation is demonstrated in Fig. 9. Neighbor vertices are defined as the vertices which are within a distance of max value $d_{\text{max}}$. The distance between vertices is the number of edges on the shortest path between the two vertices as shown in Fig. 10.

The displacement $D$ of distance $d$ can be calculated with (5). In this equation, $P$ is the proxy and $G$ is the goal, $\delta(d)$ is a function of distance $d$ which satisfies $0 \leq \delta(d) \leq 1$.

$$D(d) = \delta(d)(P - G)$$

The algorithm is a breadth first search which could visit all the neighbor vertices of the contact vertex by the increasing order of distance. Fig. 11 and 12 is an example of the local deformation.

III. EXPERIMENTAL EVALUATION

In order to compare the 2D and depth image haptization systems, we carried out an experiment with user questionnaire. The questionnaire includes evaluation of the haptization quality, improvement of the contents perception and deformation effects with five-level scores from 1 to 5. Every subject is required to evaluate the two systems with both haptization and deformation enabled and marks the questionnaire sheet after the experiment. The demo set up of the 2D image haptization system and the depth image haptization system are shown in Fig. 13 and Fig. 14. Those two systems enables different kinds of haptization effects, that is texture of the object based on...
color information for 2D images and 3D shape of the object for depth images. The result of the evaluation is shown in Fig. 15. From the results we found that image haptization system for depth images has better haptization quality, deformation effects and user experience than image haptization system for 2D images.

**IV. CONCLUSION**

This paper compares the two image haptization systems for 2D images and depth images. The haptization of 2D image has used the color haptic parameter mapping and the penalty method to render the haptic feedback. Local deformation was applied by using an image distortion to the local area of the pointer.

The depth image haptization system, a triangle polygon mesh is extracted and built from the depth image for the haptic rendering. Revised proxy graph algorithm is used to calculate the contact force between the contents and the user’s finger. Local deformation is applied by moving the corresponding vertices towards the vector of proxy and endpoint.

From the experimental evaluation we found that image haptization system for depth images has better haptization quality, deformation effects and user experience than image haptization system for 2D images.

**REFERENCES**


