A Proposal of Image Haptization System with Local Deformation
（局所变形を伴う画像可触化システムの提案）

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Abstract In this paper, we propose a haptization system that provides users with touch sensations of images. The system consists of a PC, a display, and a haptic device. The image is displayed on the plane in the VR world and can be touched by operating the haptic device. Haptization requires the haptic parameters that can be generated from the color information. The force is then calculated with a spring/damper model and rendered with the haptic device. At the same time as the haptization, the image is distorted locally to simulate the deformation caused by the pressure. Evaluation experiments have shown that the haptization rendering and deformation rendering can increase the interest of the users in the image contents.

Key words: Haptic, Image, Spidar, Local deformation

1. Introduction

In recent years, multimodal interfaces are attracting attention. Among these interfaces, the haptic devices, which could improve perception of information by providing force sensations, are widely used in various fields.

Similar as the definition of visualization, making some data that one cannot directly touch tangible is called haptization. By utilizing haptization techniques people could perceive information more easily and intuitively.

We are proposing an interactive system that enables users to obtain more than visual information from an image by haptization. The system produces the haptic information from the image and allows the users to touch the image with a haptic device.

This paper is mainly organized in six chapters. Chapter 1 briefly introduces the research, explains haptization, and introduces the haptic device. In chapter 2, several related researches that involves haptization are introduced. Chapter 3 mainly describes the design and implementation of the proposed system in two parts, haptization rendering and deformation rendering. Chapter 4 is the evaluation and analysis of the system.

Chapter 5 is the conclusion of this research and in chapter 6 we will discuss the future work.

1.1 Haptization

Haptization has played an important role in highly interactive systems. It is considered helpful with learning and training. This has been studied in interactive educational systems¹². Haptization has also been used for data representation³⁴. Haptization of the images is based on the color information. This will be discussed further in chapter 3.

1.2 SPIDAR

The haptic device used in the proposed system is SPIDAR⁵.

SPIDAR (Space Interface Device for Artificial Reality) (Fig. 1) is a tension based haptic device developed by Sato Laboratory, Tokyo Institute of Technology. By connecting it to the pc with the controller, SPIDAR could provide a high-definition force feedback sensation⁶⁷.

1.3 Research Goal

The goal of this research is to design and implement an image haptization system with local deformation which can motivate the users’ interests of the images.

2. Related Researches

Haptization has been used for interactive education. HaptiChem¹ is an educational system for intermolecular force learning. By haptizing the Van der Waals force according to the distance between two molecules, the system provides the users the attractive and repelling
force by moving one towards another.

INSTILL\textsuperscript{[2]} is an interactive system for word pronunciation training. Along with playing the pronunciation aloud, it emphasizes the stress of the word by displaying a vertical force to the learner. Experiments have shown that this kind of haptic stimulation is helpful for the students to remember the correct pronunciation.

A nail-mounted tactile display for boundary/texture augmentation\textsuperscript{[3]} is proposed in 2007. The device can present tactile sensations of boundaries or textures corresponding to the texture.

3. System Design and Implementation

3.1 System Overview

The proposed system consists of a PC and a haptic device SPIDAR. Fig. 2 shows the architecture of the system.

The VR World acquires the user input (i.e. the position of the grip) through the API of the haptic device. Haptization rendering is continuously calculated and updated to SPIDAR. The deformation rendering is rendered at the same time.

In the following chapters, we will explain the VR World and the design and implementation of haptization rendering and deformation rendering.

3.2 VR World

The VR World is illustrated in Fig. 3. The image is mapped on the floor as texture. A small sphere is displayed to represent the pointer. The pointer indicates the position of the grip of the haptic device. Fig. 4 shows haptization system in use.

3.3 Haptization Rendering

When user presses the image, that is, when the pointer collides with the image, a vertical force is generated to represent the reacting force. The situation is shown in Fig. 5.

1. Generating Haptic Parameters

To generate a force on SPIDAR, two coefficients, virtual stiffness and virtual damping are required. Here we use $K$ for virtual stiffness coefficient and $B$ for virtual damping coefficient. The two parameters are the haptic parameters.

Image haptization is to convert the color information to haptic parameters, for different pixels, the haptic parameters are also different.

However, an image coordinates system is a 2D coor-
coordinates system with the origin lying on the upper left corner. Since the pointer is moving in a 3D space, coordinates transform is necessary to find the corresponding pixel of the current position.

Assume the pointer is at point $P$, and the corresponding point on the image is $Q$, we can get $Q$ from Eq.(1). In this equation, $l_x$ and $l_z$ are the length of the floor plane’s edges which parallel to the $x$-axis and $z$-axis. $RES_x$ and $RES_y$ are the $x$ and $y$ resolutions of the image, also known as the width and height.

\[
\begin{align*}
Q_x &= P_x + \frac{l_x}{2} \cdot RES_x \\
Q_y &= P_z + \frac{l_z}{2} \cdot RES_y
\end{align*}
\]  

Assume that $C(Q_x, Q_y)$ is the pixel on the image at point $Q$, $C_R(Q_x, Q_y)$, $C_G(Q_x, Q_y)$, and $C_B(Q_x, Q_y)$ are the red, green and blue component of the color. As shown in Eq.(2), $K$ and $B$ are functions of $C_R(Q_x, Q_y)$, $C_G(Q_x, Q_y)$, and $C_B(Q_x, Q_y)$. For different images, $\phi_K$ and $\phi_B$ could vary in different mappings.

\[
\begin{align*}
K &= \phi_K(C_R(Q_x, Q_y), C_G(Q_x, Q_y), C_B(Q_x, Q_y)) \\
B &= \phi_B(C_R(Q_x, Q_y), C_G(Q_x, Q_y), C_B(Q_x, Q_y))
\end{align*}
\]  

(2) Haptization Rendering

We use the penalty method to generate the feedback force. With the haptic parameters, the feedback force can be calculated from Eq.(3).

In this equation, $s$ is the $y$-displacement from the plane of the image. $v$ is the velocity.

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

3.4 Deformation Rendering

Without creating a 3D mesh, alternatively we apply a distortion to the small local area around the corresponding pixel to simulate the deformation.

(1) Pinch Distortion

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. The effective radius and pinch amount is in proportion to the penetration depth.

The distortion being used is pinch distortion. Pinch can be compared to applying the image to a soft rubber surface and squeezing the edges or corners. A pinch distortion has two parameters, the effective radius and pinch amount. Pinch amount is a real number of which the absolute value is between 0 and 1. Fig. 6 shows several effects of pinch distortion. If the pinch amount is set to a negative value, it will look as the surface is pushed by a round object up towards the screen from behind the rubber skin. If the pinch amount is set to a positive value, it looks like the surface is pushed down into or dragged from behind, and away from the screen.

Pinch distortion is a common image filter in many image processing software, for instance, the GNU Image Manipulation Program[9].

Pinch distortion with the amount of greater than 0 will lead to a result that looks like being pressed down.
4. Evaluation Experiments

4.1 Experiment

In this experiment, we will evaluate how haptization rendering and deformation rendering affects the interests of the users.

The configuration of the haptization rendering and deformation rendering is as Eqs.(9 - 12). \( K_{\text{max}} \) and \( K_{\text{min}} \) are the max and min value of the virtual stiffness which the haptic device could provide. \( r_{\text{max}} \) and \( r_{\text{min}} \) are the max and min value of the pinch radius and in this experiment we set \( r_{\text{max}} = 5 \) and \( r_{\text{min}} = 0 \). \( a_{\text{max}} \) and \( a_{\text{min}} \) are the max and min value of the pinch amount, we set \( a_{\text{max}} = 1 \) and \( a_{\text{min}} = 0 \). \( C_1, C_2, C_3 \) and \( C_4 \) are constants which are set with experience.

\[
E = \frac{C_R(Q_x, Q_y) + C_G(Q_x, Q_y) + C_D(Q_x, Q_y)}{3}
\]
\[
\phi_K = C_1 E(K_{\text{max}} - K_{\text{min}}) + K_{\text{min}}
\]
\[
\phi_B = C_2
\]
\[
\phi_r = \frac{sC_3}{2\phi_K} (r_{\text{max}} - r_{\text{min}}) + r_{\text{min}}
\]
\[
\phi_a = \frac{sC_4}{2\phi_K} (a_{\text{max}} - a_{\text{min}}) + a_{\text{min}}
\]

The participants are divided into three groups, A, B and C.

For comparison, the three groups will experience the system under different conditions. Participants in group A will experience the system without haptization rendering, while participants in group B will experience the system with haptization rendering. Participants in Group C will experience the system with both haptization rendering and deformation rendering.

We use the experiencing time as an evaluation of a user’s interests to the image contents. The longer a user is experiencing the system, the more he or she is interested in the contents. The experiencing time of each participant will be recorded unwittingly. Experiencing time is unlimited. Each participant can stop until he or she feels like to.

The experiment contains three sub experiments with different categories of contents. The contents are shown in Table 1.
The results are shown in Tables 2–5, the data are demonstrated with a line chart shown in Fig. 8.

4.2 Discussion

From Fig. 8, by comparing each average time of Group A(image only) and Group B(with haptization), we can find that by enabling the haptization rendering, the experiencing time is significantly increasing. By analyzing the statistical significance with students’ t-test, we confirmed that there is significant difference between Group A(image only) and Group B(with haptization). With haptization rendering, participants in Group B could feel different sensations on different part of the image. This extends the experiencing time. Especially in sub experiment figurines, the participants are very interested in touching the area such as hair, face, hands, arms, legs and clothes.

Comparing the average time of Group B(with haptization) and Group C(with haptization and deformation), we can see that although the extended time decreases, the experiencing time of Group C is still longer than that of Group B, however, some participants do not have the same tendency as the other participants. We cannot confirm significant difference between Group B(with haptization) and Group C(with haptization and deformation) with the data in Table 2 and Table 4, which failed the students’ t-test with a threshold of 0.05.

The time difference between each two average experiencing time of Group A(image only) is small. Actually, without haptization rendering or deformation rendering, the participants in Group A are just viewing the photos. Although different people may be interested in different kind of contents, which may influence the experiencing time, the time a user spent on viewing images is short. Except for special situations, one seldom stares at a photo for a long time.

The time difference between each two average experiencing time of Group B(with haptization) is relatively greater. From the chart we can see that the experiencing time of figurines is much longer than the sceneries and snacks, we think this is because the sceneries and snacks photos have less interesting touchable contents, while the figurines photos have more. The time difference is more significant in Group C(with haptization and deformation)’s data. Many participants in...
Group C (with haptization and deformation) are very interested in squeezing the face, the arms and the legs of the figurines, which may explain the average long experiencing time of Group C.

5. Conclusion

We have proposed an interactive image haptization system which enables users to touch the image with a haptic device. The evaluation experiments show that the system will attract the users’ interests to the images, and increase the average experiencing time, however, we did not confirm significant difference between with and without deformation from statistical analysis results. We think this may be due to the not-so-real deformation rendering.

6. Future Work

The system can simply be used for increasing the interests in viewing images. It also has potential uses for virtual shopping, as it can motivate the users’ interests to the products.

However, the haptization rendering and deformation rendering are not perfect. The generation of the haptic parameters and pinch parameters could be improved for better sense of touch and better visual effects. We also want to test the significance between with and without deformation with further experiments.

(References)

8) Hideyuki Ando, Eiouke Kusachi, Junji Watanabe, Nail-mounted tactile display for boundary/texture augmentation, Proceedings of the international conference on Advances in computer entertainment technology, Salzburg, Austria (June 13-15, 2007)