Interactive representation of virtual object in hand-held box by finger-worn haptic display

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ABSTRACT

To deliver a realistic presence of virtual objects with a simple haptic display in an augmented reality system, we have developed a wearable haptic display to present the sensation of weight and inertial force of the virtual objects. In this study, we developed an augmented reality application for our haptic device that represents the dynamics of the virtual objects inside a real box based on a physical simulation. We implemented the prototype system to represent a virtual ball in a real box, and evaluated the capability of our proposed method.

Keywords: Haptic I/O, interaction techniques, augmented reality

1 INTRODUCTION

In order to identify the contents of a box or a bottle without opening it, one might hold and shake the box or the bottle and recognize the contents by sensing their weight and inertial force. In a virtual reality or augmented reality system, this type of behaviour is required in order to improve the recognition of the virtual objects. Recently, some researchers aimed to deliver the sensation of weight or the internal dynamics of a virtual object by means of wearable haptic devices. A portable haptic device producing a force and a torque [1] illustrated that an ungrounded device was able to represent the internal force. A few devices could in fact shift their spindle in order to deliver the movement of a barycentre [2]. Impact forces and the resulting vibrations among the virtual objects are also important in order to be able to recognize these objects. Yao [3] demonstrated that the rotation and friction generated when moving an object can be reproduced by recording and playing the impact forces and vibrations. In this study, we tried to represent the virtual objects inside a real object with the help of a wearable haptic display developed by the authors [4]. Interactivity among operators and a real-time performance are important in order for the operators perceive a comfortable force feedback according to their movements. Moreover, the shape, mass, volume, hardness and other parameters of the internal objects are required to be easily adjustable. Therefore, we employed a simple physical simulation that calculates the vertical and shearing forces generated on the fingerpads, these forces are then reproduced by our proposed haptic devices and relayed to the operator.

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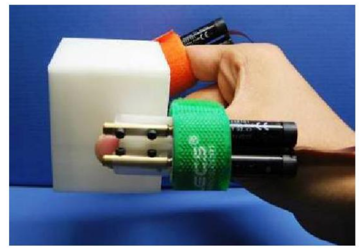

Figure 1. Conceptual picture of our proposed system. By wearing our proposed devices, the user can feel the force feedback of the virtual objects in a real box.

2 METHOD

2.1 Finger-worn haptic display

In our previous research [4], we proposed a simple wearable haptic display that represents the mass of a virtual object. Conventionally, it is believed that it is necessary to reproduce the proprioceptive sensation in order to generate a weight sensation, and thus, a large grounded device is required. However, it was found that the vertical and shearing forces generated due to the deformation of the fingerpads can reproduce reliable weight sensations even when the proprioceptive sensations on the wrist and the arm are absent. Based on this observation, we designed the mechanism of the haptic display, as shown in Figure 2, which has a simple structure comprising dual motors. Based on this mechanism, we implemented the prototype device shown in Figure 1. By wearing our proposed devices on the index finger and the thumb, the operator could perceive the weight and the inertial mass of the virtual object in his/her hand during varied behaviors.

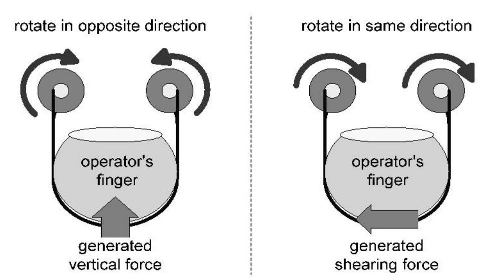

Figure 2. Our proposed method for generating vertical stress (left) and shearing stress (right) on fingerpad.[4]

2.2 Representation of internal virtual object

To reproduce the deformation of the fingerpad when grasping a box with virtual objects inside it, we developed a simulation-based force feedback system using the following method. We used the open dynamics engine (ODE) [5] as a physical simulator.

1) Set the model of the box, the virtual fingers, and the virtual objects in the physical simulator.
2) Fix a three-dimensional accelerometer on the real box.
3) Assign a sign-reversal acceleration to the virtual objects. The virtual objects start moving with this acceleration.
4) Calculate the force vector on the virtual fingers generated due to the inertial mass of the virtual objects.
5) Generate the haptic devices to reproduce the calculated vertical and shearing forces.

3 Experiment

The method of constant stimuli was employed for this experiment wherein three subjects (aged 23–25) were asked to wear the haptic displays on their index finger and thumb and hold a light-weight box. As a standard stimulus, the weight of a specific virtual ball (as shown in Fig. 3-a) was represented by the proposed method for a few seconds. Subsequently, another virtual ball with a random weight (ranging from 1 g to 300 g) was represented as a test stimulus. The subjects could move their arms freely and the inertial mass of the virtual objects were represented in these trials. The subjects then stated whether the weight of the virtual ball in the test stimulus was "heavier" or "not heavier" in comparison to that in the standard stimulus according to a two-alternative forced-choice procedure. The cycle length of the physical simulation was 5 ms (200 Hz), and the cycle length of the motor control was 500 µs (2 KHz).

Figure 4 shows the average rate of "heavier" responses obtained during the trials with a standard stimulus of 50 g. The circles represent the average of all the 16 trials conducted with each subject. The curve indicates the fitted line with a cumulative normal distribution. The solid line indicates the point of subjective equality (PSE), and the dashed lines indicate the 75% difference limen (DL) that was derived from the difference between the PSE and the 75% discrimination threshold. Table 1 presents the 75% DL for each standard stimulus. This result confirmed that our proposed method for reproducing the stresses on the fingerpads provides a clear perception for recognizing the weight and inertial force of the virtual object. The recognition resolution in the 10-g standard stimulus trials was poorer than that in the other trials because the device (45 g on each finger) and the real box (30 g) were constantly placed on the subjects' fingers, and the 10-g standard stimulus on the fingers was insignificant in comparison with these constant weights. It is believed that decreasing the device weight will result in a further dexterous representation of the virtual mass.

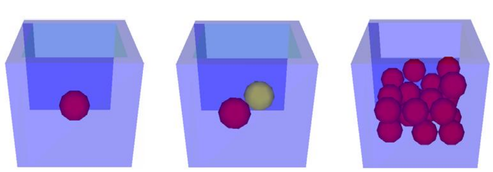

Figure 3. Physical simulation modes: virtual balls in a box

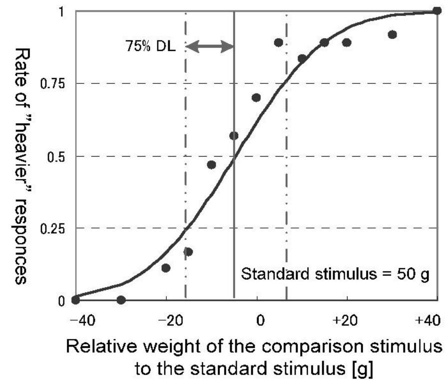

Figure 4. Average rate of "heavier" responses for a 50-g ball as the standard stimulus. The solid line indicates the PSE and the dashed lines indicate the 75% DL

Table 1. 75% DL for four types of standard stimuli in representing a virtual ball in a hand-held real box

standard stimulus	75% DL	
10 gf	4.3 gf	(43.0%)
50 gf	10.7 gf	(21.4%)
100 gf	21.0 gf	(21.0%)
200 gf	58.2 gf	(29.1%)

4 Conclusion & Future work

In this paper, we have proposed a simple simulation-based method to represent the mass of virtual objects inside a real object. Using our proposed finger-worn haptic display, we have interactively developed a haptic feedback system that represents the mass of a virtual ball in a real box. The experiment results indicate that the subjects could recognize the weight of the internal virtual object using this method.

We have also confirmed that more than one internal virtual object, as shown in Fig. 3-bc, can be represented using our proposed method in a technical demonstration [6]. The haptic feedback in this system is so sensitive that the small forces of collisions among the virtual balls can also be recognized. While conventional haptic displays can barely represent such a sensitive sensation, our proposed method can represent more realistic sensations of various internal objects. In future works, we will represent other types of virtual matters such as liquids and animate beings.

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