A Palm-Worn Haptic Display for Bimanual Operations in Virtual Environments

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Abstract. We propose a wearable haptic display that indicates the pressure and vibration on the palm for bimanual operations in virtual reality environments. This system aims to provide the touch and stroke sensations of virtual objects or virtual creatures. We constructed a prototype device that can reproduce vertical and shearing forces on the palm and evaluate the capability of the proposed method to recognize the existence of a virtual object in one-handed and two-handed operations.

Keywords: Haptic Display, Bimanual Operation, Virtual Reality.

1 Introduction

Recently, immersive display systems for virtual reality applications, such as CAVE [1] and TWISTER [2], have been researched and developed. These display systems can provide highly immersive virtual environments that enable us to experience not only with wide view but also with active behaviors such as gaze and gestures. In the walk-through mixed reality environment, by using a see-through HMD (Head-Mounted Display) such as TOWNWEAR [3], we can view virtual objects in the real world and walk around. In these systems, the haptic interface should be bimanual and wearable so as to provide natural haptic feedback to enhance the existence of the virtual objects and improve their operability without disturbing the motion and behavior of the users [4]. There are several wearable haptic displays that can be used in immersive projection environments, such as CyberTouch [5] and HapticGEAR [6].

On the other hand, some researches have been done from other perspectives in these years. Inaba and Fujita [7] have showed that simple constrictive pressures on the fingers resemble a grip sensation, and Nakamura et al. [8] have demonstrated that an ungrounded device can indicate the internal force of an object. These researches have been aimed at realizing the practical use of human perceptual characteristics and perceptual illusions in the design of haptic devices so as to retain the reality of the haptic sensation, while downsizing the device. We have also proposed a wearable haptic display to present the mass [9] and internal dynamics [10] of virtual objects; the device employs dual motors and generates vertical and shearing forces on the

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fingerpads. Our inference that the tactile sensation on the fingerpads can alternate the proprioceptive sensation on arm suggests that wearable haptic displays of virtual reality or mixed reality systems can be more compact and indicate more realistic sensations.

In this paper, we propose a palm-worn haptic display that indicates a tactile sensation on the palm by using a simple method. By using the device, users can touch virtual objects without any disturbance in their motion and gestures, as shown in figure 1.

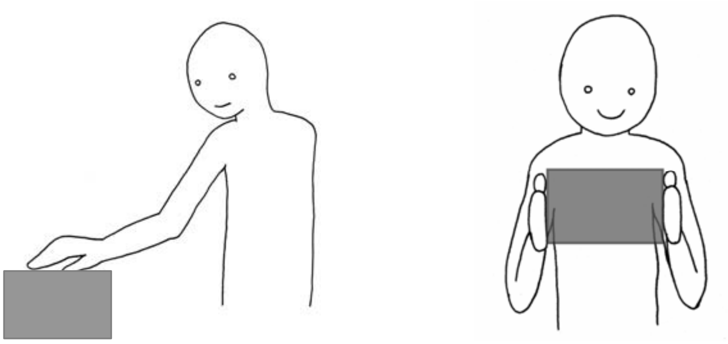

Fig. 1. Conceptual drawing of haptic interaction by using the proposed palm-worn haptic display. The users are touching or holding a virtual object.

2 Prototype Device

In our previous research [11], we proposed a simple method for reproducing vertical and shearing forces; the method employed dual motors and a belt. The forces on the fingerpads could indicate reliable grasping sensations, even when there were no proprioceptive sensations on the wrist and arm. In this study, we attempted to apply this method to the palm, as shown in figure 2, and constructed a prototype device by using two motors (Maxon Moter Corp., RE 10, 1.5 W, great ratio = 1:16), as shown in figure 3.

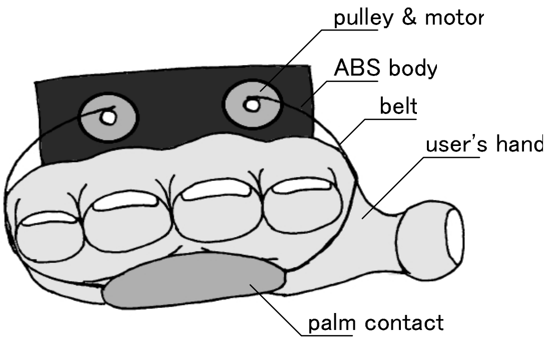

Fig. 2. Conceptual drawing of the proposed method

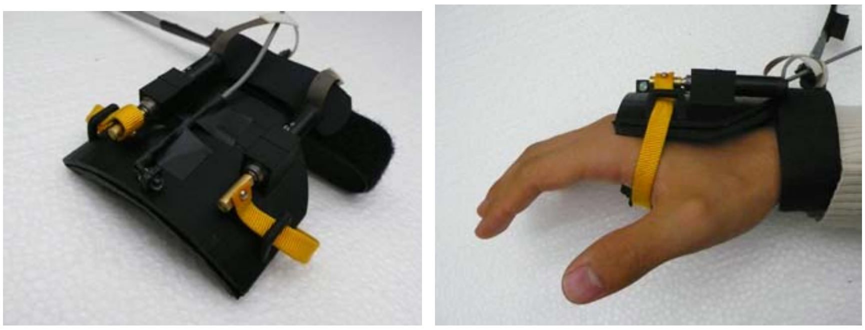

Fig. 3. Constructed prototype device

3 Experiments

3.1 Single-Handed Recognition of Virtual Wall

In this experiment, we evaluated the recognition accuracy of the proposed device in indicating a virtual wall. Figure 4 shows the experimental setup for this experiment. One infrared LED was attached to the device and the position of the hand was measured by using an infrared camera. Appearance of the experiment is shown in Figure 5. We used Wii Remote (Nintendo Co. Ltd., 2006) as a Bluetooth infrared camera. Position sensing was performed at a resolution of 0.5 mm and a frequency of 200 Hz. Five male subjects (aged 21–25) were asked to wear the haptic display on the right hand, and they were blindfolded with an eye mask. White noise was provided to both ears to mask the sound of the motors. They placed their right arm on the armrest and could move their arm right and left. A virtual wall was positioned on the left side of the hand randomly at a distance of 50 mm to 140 mm in the direction of the x-coordinate.

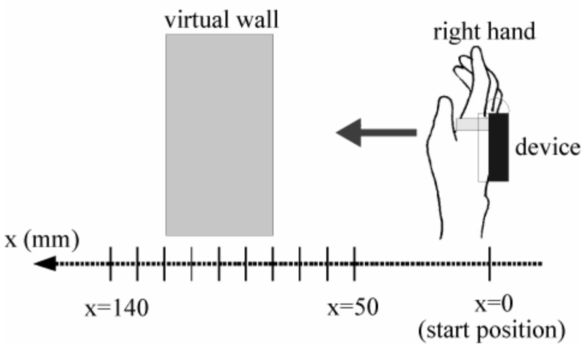

Fig. 4. Coordinate setting of the experiment

When reproducing the force on the palm, we attempted to study two haptic feedback conditions. Under a pressure-only condition, the vertical force on the palm increased in direct proportion to the overshoot of the hand position from the position of the virtual wall. Under an impact-pressure condition, a 30-ms vertical force was reproduced as the impact force, in addition to the pressure, at the instant when the wall was touched. The subjects moved their right hand from x = 0 toward the left and stopped when they felt that they were pressing against the wall tightly. The subjects were allowed to grope for the virtual wall twice in one trial. Twenty trials were performed for each condition and each subject.

Figure 6 shows the average and standard deviation of the difference between the recognized position and the position at which the virtual wall was set for each condition and subject. It shows that the haptic feedback of the impact force is effective in improving the accuracy of recognition of the position.

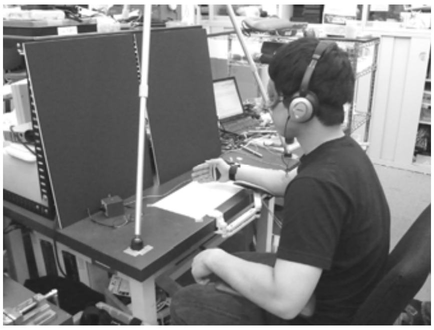

Fig. 5. Experimental setup

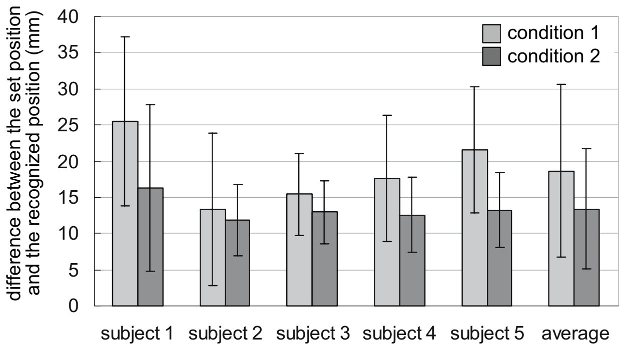

Fig. 6. Result of the experiment on single-handed recognition of virtual wall

3.2 Two-Handed Recognition of Virtual Solid

In this experiment, we evaluated the accuracy of the proposed device in indicating a virtual solid. The experimental setup was the same as that in the former experiment. The subjects wore the devices on both their hands; they were blindfolded with an eye mask and white noise was provided to their ears. Five male subjects (aged 21–25) were asked to spread their hands to shoulder width. A virtual solid with a specific width was virtually set between the right and left hands. The subjects then closed their hands slowly and the distance between the two hands was measured in real-time. When the distance was equal to the width of the virtual solid, the vertical forces with impulse (discussed in section 3.1) were displayed on both hands. The subjects stopped closing their hands when they perceived that they were definitely holding something. The width of the virtual solid was set randomly from 190 mm to 280 mm. Forty trials were performed for each subject.

Figure 7 shows the average and standard deviation of the recognized width of the virtual solid for each of the widths set.

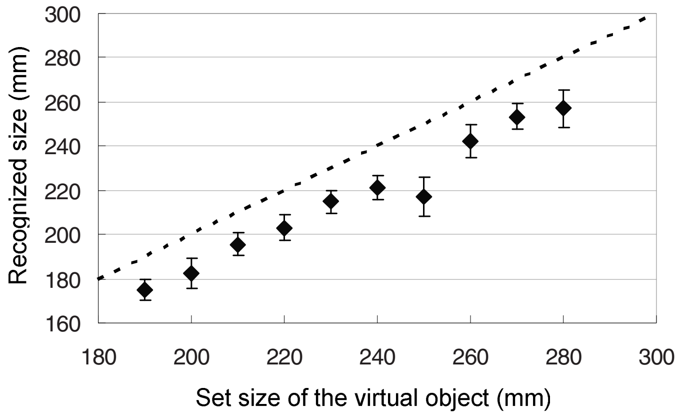

Fig. 7. Result of the experiment of two-handed recognition of virtual solid. The dotted line shows the desired value where the recognized size is equal to the set size.

3.3 Discussions

Comparing the standard deviations of the recognized size in two experiments, it is shown that the standard deviation in two-handed recognition has an inclination to be smaller than that in single-handed recognition. This result assumes that the recognition of the object was performed based on not only the haptic feedback but also the postural sense of arms in bimanual operations.

In these experiments, the subjects stated that they felt that they touched or held something like a tennis ball, not like a wall or a box. It is considered that this perception occurred due to the lack of a haptic sensation on the fingers. When we hold something with both hands, the palms are pushed, and the fingers are free, it implies that a fist-sized object is being held. The combination of the haptic sensations on the palm and fingers is required to represent various-sized objects.

4 Conclusions and Future Work

In this paper, we have suggested that the method of reproducing vertical and shearing forces by using dual motors and a belt is effective for not only the fingers but also the palm. We have confirmed the availability of the wearable haptic display that indicates the pressure and vibration on the palm. This system can reproduce the sensation of touching or holding an object in bimanual operations in virtual reality environments.

So far, we have evaluated only the effectiveness of a vertical force on the palm. The shearing force is considered to cause a stroke sensation. The combination of the touch and stroke sensations would improve the recognition of virtual objects. The multimodal combination with visual sensation in bimanual operations in virtual environments should also be studied.

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