The Whole Hand Haptic Glove
Using Numerous Linear Resonant Actuators

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***Abstract*— Haptic feedback is crucial for enriching the experience of virtual reality contents. While most haptic devices focused on the fingertip, or some required huge setups, we have developed a simple glove-type master hand that has two features. One is that it uses numerous actuators to cover the whole hand (52 vibrators). The other is that we employed linear resonant actuators to achieve high-speed response. We also developed VR environment that users can touch and feel VR object with the glove. In this paper, we conducted an experiment to verify the significance of the whole hand tactile stimulation and low latency feedback for the identification of contact shape. As a result, whole palm feedback shorten the exploration time and the tendency to improve accuracy was observed. This means whole hand, low latency feedback enhances VR touching experience.**

I. Introduction

In recent years, Virtual Reality (VR) contents are spreading rapidly thanks to the introduction of affordable VR devices. VR head-mounted displays such as Oculus Rift provides 3D, wide field of view image, depth sensors such as Leap Motion and Kinect enables users to input physical action directly. In addition, by using game engines such as Unity and Unreal Engine, everyone can make high-quality VR contents even at no cost. These cost reduction and advancement of devices and developing environments will lead immersive VR contents with physical behavior. However, these devices can't provide haptic feedback. When the user plays VR contents with physical behavior, the lack of haptic feedback harms the immersion in the Virtual Reality.

The device that input position and posture of user's hand is called master hand. As haptic feedback is considered to be essential not only for VR contents but also for improving the performance of tasks such as remote controlling, master hands with haptic feedback have been developed. There are some types of these master hands with haptic feedback. One is "Exoskeleton" type [1][2]. Though this type can provide force feedback, it will take much time to be popular because of its complicated mechanism and cost. In addition, although about 46% of the daily operations cannot be done without just fingertips [3], feedback area of this type is often limited to only fingertips. Another one is "Glove" type [4][5]. Many of these are using Eccentric Rotating Mass (ERM) vibrators for feedback. Although it's possible to present feedback to whole hand by adding vibrators, due to its mechanism ERMs produce high latency. That often force users to move unnaturally or gingerly.

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Therefore, we aimed at the affordable master hand with low latency and enough expressive haptic sensation for VR contents such as games that do not require high precision operation but provides subjective reality.

In this paper, we propose a simple, whole hand and low latency haptic feedback glove using 52 Liner Resonant Actuators (LRAs), and evaluate the impressiveness of whole hand feedback with this glove.

II. Developed System

As shown in Fig.1, the device is a simple "Glove" type haptic device with 52 LRAs (Precision Microdrives, C10-100). While ERM vibrators require the time to start vibrating up to 100ms from the voltage input, the LRAs require only about 10ms. This high response speed of LRA greatly reduces latency of haptic feedback. We attached 52 LRAs all over the glove.

Figure 1. The haptic glove.
We attached 52 LRAs all over the glove for low latency, whole hand haptic feedback.

We also built VR environment to touch virtual object and present touch sensation with the glove (Fig.2). We used game engine Unity, and Leap Motion for hand tracking. When the hand model touches the virtual object, the glove presents vibration stimuli corresponding to the contact site.

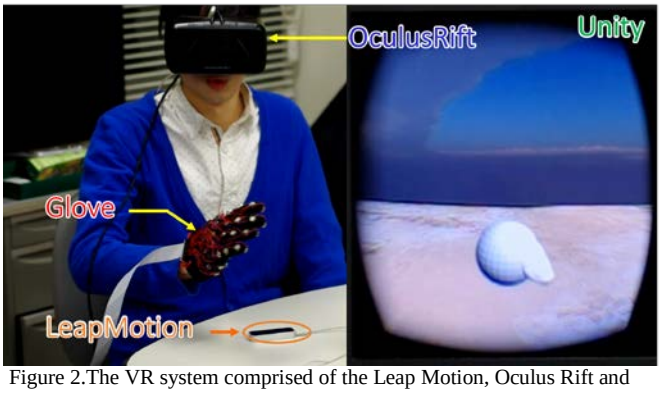

Figure 2.The VR system comprised of the Leap Motion, Oculus Rift and haptic glove. The hand movement is tracked by the Leap Motion and be

reflected in VR environment Unity. The glove presents vibration stimuli corresponding to the contact site.

III. EXPERIMENT

The purpose of the experiment was to assess whether whole hand, low latency haptic feedback by proposed device improved the impressiveness of VR environment. The task of the experiment is discriminating shape of the 3D object from four shapes. We set some conditions based on previous work which evaluates the haptic glove system using ERM vibrators [6]. Although there are 52 vibrators on the glove, the current control unit that we developed only drive up to 48. So we select 48 out of them to drive even under the whole hand condition.

A. Method

The experiment was divided into two phases; the learning phase and the discrimination phase.

In learning phase, participants could see and touch objects freely. They learned features of each objects at this phase. After that, in discrimination phase, they could not see the object but only touch the objects. In this phase, they were presented virtual object individually, then asked to identify the shape of the object as fast and accurately as possible. Presented shapes were cube, cylinder, sphere and cone. The order was randomized and each object was shown 5 times in each conditions. The objects had a maximum of about 20 cm in all three dimensions, and fixed in front of participants.

As shown in Fig.3 and below, there were four conditions of feedback areas.

- Fingertips: 5 LRAs were activated.
- Each phalanges: 14 LRAs were activated.
- Whole palm side: 27 LRAs were activated.
- Whole hand: 48 LRAs were activated.

Figure 3. Feedback areas

The participants are consisted of 5 male and 2 female, aged 23-30, note that one female participant was omitted from the analysis who canceled the experiment because of time exceeding.

B. Results

Fig.4 shows the exploration time. It represents the time that participant required to answer the shapes. There are significant differences between fingertips and palm side, fingertips and phalanges, phalanges and whole hand. This is probably result of the extensive feedback to whole palm made the situation closer to that in the real world. Fig.5 shows the percentage of correct responses. There aren't significant differences but tendency for accuracy to increase with feedback area.

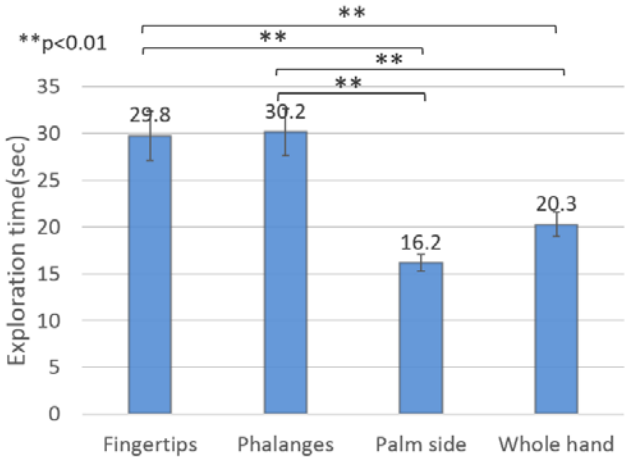

Figure 4. Exploration time

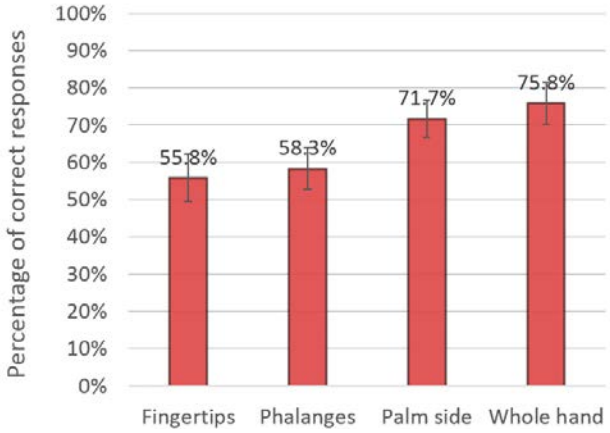

Figure 5. Percentage of correct responses

Contrary to our expectations, the significant improvement of the result by feedback to the back of the hand was not observed. In this experiment, the virtual hand run through the objects. Consequently, in spite of touching object from palm side, the collision detection in back side was generated. This "unnatural" feedback might have confused participants.

Even though, as compare the result with the previous work which uses ERMs [6], exploration time was almost halved to about 20 seconds, and participants could answer more accurately. It indicates that the high speed feedback using LRAs enhance sensation of touching virtual objects.

IV. CONCLUSION

In this paper, we proposed haptic glove using 52 linear resonant actuators as affordable, low latency, expressible haptic display for VR contents and also build a VR environment with Leap Motion and Oculus rift as an application for this glove.

We tested the haptic glove and the VR environment with the identification task of 3D shapes without visual feedback. The result shows that extension of feedback area shorten the exploration time and tendency to improve accuracy. Furthermore, compared with the previous work using ERMs which has low latency, resulted in halved exploration time, more accurate discrimination. From these results, the glove realized affordable master hand for VR contents with low latency and expressive haptic feedback.

Although there are three challenges for the future.

First is reconsider of hand tracking method. Hand recognition by Leap Motion sometimes unstable during the experiment. For faster and accurate input, we are considering to mount gyro sensors, magnetic sensors, and bending sensors.

Second is the investigation of new tactile representation using tactile illusion phenomenon. This glove only provides vibration stimulus, to present force-like feedback without forces, we are considering to use illusion like Pseudo-Haptics which is used in ARAtouch[7].

Third is developing practical applications. We believe that more interactive application such as touching each other with characters in VR world with the device will provide better experience.

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