Haptopus : HMD with Built-in Pressure Sense Presentation Device by Suction Stimulus

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Abstract. With the surging popularity of VR systems using HMD, many efforts have been made to improve the user experience by providing tactile information to the fingertips. However, there are a few problems with the current system, such as difficulty attaching and detaching the devices and hindrances to free finger movement. To resolve these issues, we developed “Haptopus,” which embeds a suction tactile display in the HMD and presents tactile sensations of the finger to the face. In this work, we investigated whether the suction stimulus is perceived as a suction or pressure sensation and found that the two sensations can be switched by changing the suction pressure.

Keywords: Haptopus, Suction stimulus, Haptics HMD, Virtual Reality.

1 Introduction

With the spread of low-cost head-mounted displays (HMDs), there has been much interest in combining visual information with tactile information for a more immersive virtual reality (VR) experience. While several studies have made great strides in wearable tactile presentation [1], the current wearable-type devices are facing various practical issues, such as difficulty in attaching and detaching, and mutual interference between devices when worn on multiple fingers.

To address these issues, methods have been proposed to present the tactile sense corresponding to fingers and hands in the VR space to other parts of the body. Such tactile presentation to different sites is common in the study of prosthetic hands, where transducers are typically placed on arms and shoulders. A typical example of application to the VR environment is the presentation of the sense of touch received by the hand to the soles of the feet [2].

We feel that one alternative body part for presenting finger tactile sensation is the face. If we can embed a tactile display into an HMD, it would negate the necessary of waring additional haptic devices, thus resolving the above issues.

Many works have explored the inclusion of a tactile-sense-presentation mechanism into an HMD [3] [4] [5]. However, most of them did not present pressure sensations considered to be good candidate for representing finger pressure without annoyance. In one of rare examples that did—namely, presenting the pressure with an air balloon—there was an innate fixation issue. In fact, as far as we known, most HMD-embedded tactile displays are aimed at presenting environmental information, and no attempts have been made to transfer the tactile sense of the finger to the face with an HMD.

In an earlier work, we proposed an air-suction type HMD-embedded haptic device named Haptopus [6] and demonstrated that it can enhance VR experience. However, one of the downsides is that we used a relatively strong suction pressure, presenting a clear feeling of suction that unsettled some users.

Weak suction can be felt as positive pressure because human mechanoreceptors respond to strain the “energy” of a deformation they cannot distinguish between positive and negative pressure [6]. In the present work, we investigate the type of sensation elicited by the suction presentation to see if suction pressure to the face can present a pressing sensation.

Fig. 1. Overview of Haptopus

2 Haptopus

As stated in the previous section, we developed a tactile presentation method utilizing suction stimulus in an early work [6]. By using suction stimulus, HMD can be attached to the skin relatively easily. Furthermore, although it is not the main scope of this paper, we know that suction of the skin can be interpreted as a positive pressure under certain conditions, since the direction of strain is difficult for mechanoreceptors to encode [7].

Haptopus transfers the tactile sense of the fingertip to the face and presents a pressure sensation by using a compact suction mechanism that can be built in the HMD. This device transfers multiple fingers tactile sense mainly for providing a sense of pressure to the face. With this device, we have confirmed that users can perceive the fingertip tactile information in the VR space as tactile information mapped on the face without wearing the device on the fingertips.

3 Experiment

We investigated whether pressure sensation can be generated by suction stimulus to the face. Preliminary experiments have confirmed that a pressure sensation was felt when suction pressure was weaker than the threshold pressure value which presents clearly suction sensation. Therefore, in this experiment, we first investigated the threshold pressure value for clear suction sensation for each participant and then identified which condition generated pressure perception below that threshold.

3.1 Device

The device used in the experiment is composed of an air suction pump (SC 3701 PML, SHENZHEN SKOOCOM ELECTRONIC), a solenoid valve (SC415GF, SC0526GF, SHENZHEN SKOOCOM ELECTRONIC), and an air pressure sensor (MIS-2503-015V). The pressure is controlled by a microcontroller (ESP - WROOM - 32). An outline of the suction system is shown in Fig. 3. The suction pressure was presented for three seconds and turned off for two seconds, and the maximum suction pressure value was limited to –500 hPa so as not to leave a mark on the skin. The suction port was composed of an acrylic exterior and the skin contact part was composed of a silicone sheet. The diameter was 12 mm, as determined from a preliminary experiment.

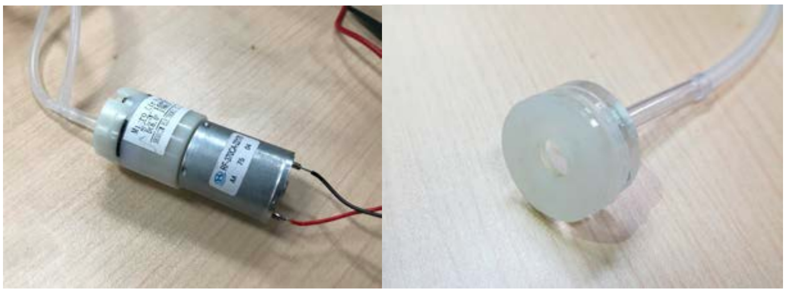

Fig. 2. Suction unit and suction port.

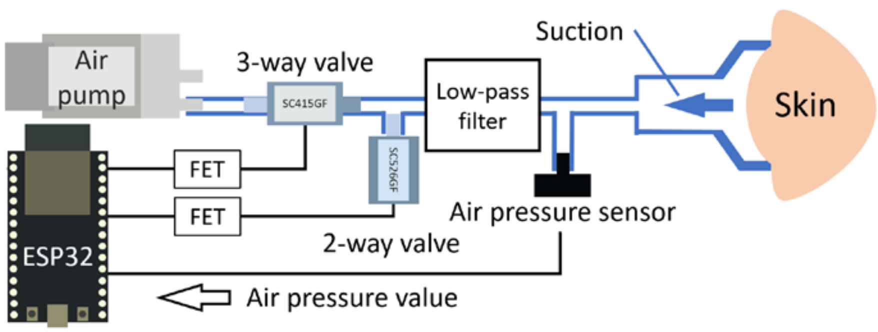

Fig. 3. Outline of suction system.

3.2 Procedure

The threshold air pressure was determined by the method of adjustment. The participants pressed the suction part to the skin with their own hand and adjusted the pressure using a keypad with the other hand. At this time, the threshold was such that the sensation of suction was clearly felt.

After measuring the threshold, we evaluated the quality of stimuli less than the threshold. The air pressure values were ×1/6, ×2/6, ×3/6, ×4/6 and ×5/6 of the threshold. Each stimulation condition was repeated five times, for 25 trials in total per participant in random order. The participants were asked to evaluate the suction strength by magnitude estimation (strength of threshold stimulus set to 10; participants could answer by arbitrary number) and by quality on the 7 point Likert scale (–3: clearly suction, 3: clearly pressing). The comparison stimuli were always presented after the threshold stimulus.

We conducted the above experiment with the suction port located just under the right eye (Fig. 4). This location is a common contact part for HMDs, and Gil et al. confirmed that human can perceive tactile sensation at these points [8]. We recruited five participants (22 to 27 years old, all males). They listened to white noise during the experiment.

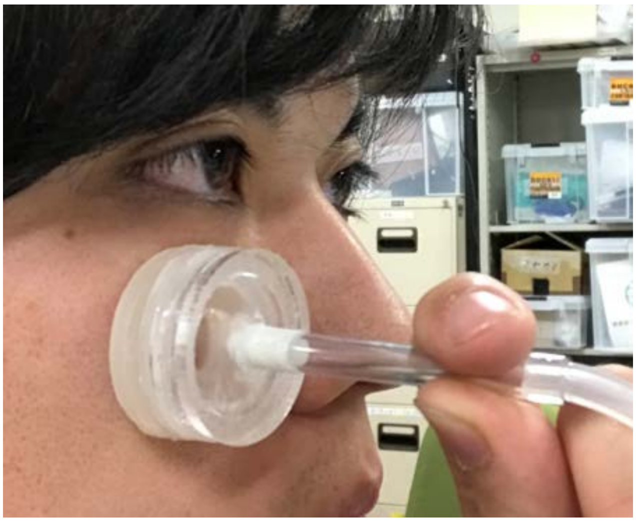

Fig. 4. Suction point

3.3 Results & discussion

The results of the magnitude estimation are shown in Fig. 5. Multiple comparisons by Kruskal-Wallis testing revealed that tactile sensation decreased as air suction pressure value decreased.

The results of sensation quality are shown in Fig. 6. Multiple comparisons by Kruskal-Wallis testing revealed that the 1/6 condition had a significantly more pressure-like sensation than the 5/6 ($p=0.0001$) and 4/6 ($p=0.0001$) conditions. Similarly, the 2/6 condition had a significantly more pressure-like sensation than the 5/6 (p=0.013) and 4/6 (p=0.008) conditions. Next, a comparison with the score 0 (neither pressure nor suction) by Wilcoxon sign rank testing revealed that none of the conditions were significantly different from the score 0.

These results demonstrate that the strength of tactile sensation decreased as air suction pressure value decreased, and the 2/6 or less air pressure condition had a significantly more pressure-like sensation than suction-like sensation.

One participant commented that the feeling of suction was affected by the pressure force of the suction unit. Another said that he felt touching or tapping sensation rather than a pressure sensation.

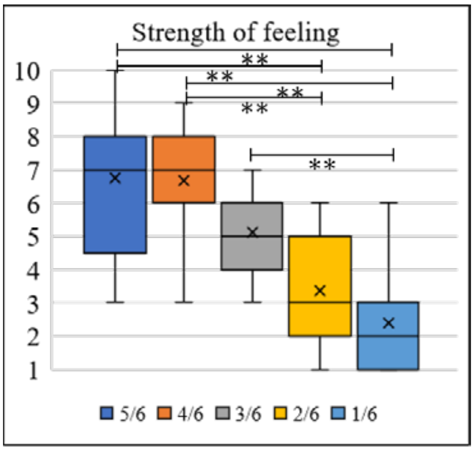

Fig. 5. Results of magnitude estimation (score of strength of threshold stimulate is 10). *: p<0.05, **: p<0.01.

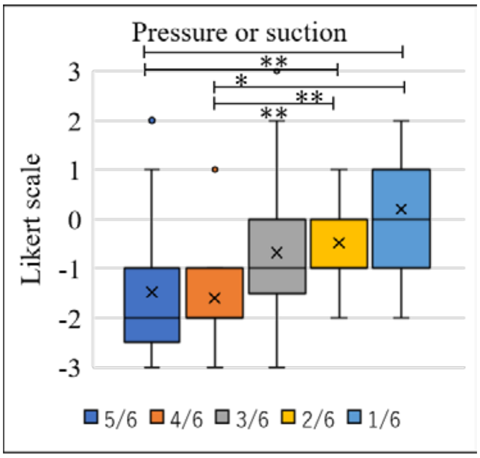

Fig. 6. Results of Likert scale evaluation (–3: clearly suction, 3: clearly pressure). *: p<0.05, **: p<0.01.

4 Conclusion

In this paper, we investigated whether pressure sensation can be elicited by suction stimulation to the face. First, we determined the which threshold suction pressure clearly gave a feeling of suction, and then we presented stimuli smaller than the threshold. Results indicated that the strength of the tactile sense by suction depends on the strength of the air suction value, and participants tended to feel a sensation of pressure rather than suction, especially when the air suction pressure was small.

In our future work, we will add a visual presentation using HMD to strengthen the pressure sensation. On the basis of these results, we will produce a Haptopus that can provide a higher quality VR experience.

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References

[1] C. Pacchierotti, S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward and D. Prattichizzo, "Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives," in *IEEE Trans. Haptics*, 2017.

[2] T. Okano, K. Hiki, K. Hirota, T. Nojima, M. Kitazaki and Y. Ikei, "Development of a Sole Pressure Display," in *AsiaHaptics*, 2016.

[3] V. A. d. J. Oliveira, L. Brayda and L. Nedel, "Designing a Vibrotactile Head-mounted Display for Spatial Awareness in 3D Spaces," in *IEEE Transactions on Visualization and Computer Graphics*, 2017.

[4] Y. Kon, T. Nakamura and H. Kajimoto, "HangerOVER:HMD-Embedded Haptics Display With Hanger Reflex," in *ACM SIGGRAPH 2017 Emerging Technologies*, 2017.

[5] R. L. Peiris, W. Peng, Z. Chen, L. Chan and K. Minamizawa, "ThermoVR: Exploring Integrated Thermal Haptic Feedback with Head Mounted Displays," in *CHI*, 2017.

[6] T. Kameoka, K. Yuki, K. Takuto and K. Hiroyuki, "Haptopus : Transferring the Touch Sense of the Hand to the Face Using Suction Mechanism Embedded in HMD," in *Spatial User Interaction*, BERLIN, GERMANY, 2018. (submitted)

[7] Y. Makino, N. Asamura and H. Shinoda, "Multi Primitive Tactile Display Based on Suction Pressure Control," in *Haptic Symp*, 2004.

[8] H. Gil, H. Son, J. R. Kim and I. Oakley, "Whiskers: Exploring the Use of Ultrasonic Haptic Cues on the Face," in *CHI*, Montreal QC, Canada, 2018.