Haptopus : Transferring the Touch Sense of the Hand to the Face Using Suction Mechanism Embedded in HMD

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ABSTRACT

Along with the spread of VR experiences by HMD, many proposals have been made to improve the experience by providing tactile information to the fingertip, but there are problems such as difficulty in attaching and detaching and hindering free movement of fingers. As a method to solve these issues, we developed Haptopus, which embeds the tactile display in the HMD and presents tactile sense associated with fingers to the face. In this paper, we conducted a preliminary investigation on the best suction pressure and compared with the conventional tactile presentation approaches. As a result, it was confirmed that Haptopus improves the quality of the VR experience.

CCS CONCEPTS

• **Human-centered computing → Haptic devices;**

KEYWORDS

Haptopus, Suction stimulus, Haptics HMD, Virtual Reality

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INTRODUCTION

With the spread of low-cost head-mounted displays (HMDs), many studies have been conducted to combine visual information with tactile information for a more immersive virtual reality (VR) experience. While there were several studies on wearable tactile presentation [1], current wearable-type devices have 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 the other parts of the body. Such tactile presentation to different sites is common in the study of prosthetic hands, typically placing transducers on arms and shoulders.

Applications to the VR environment, presentation of a sense of touch received by the hand to the soles of the feet can be considered as a typical example [2].

We considered that one alternative body part of presenting finger tactile sensation is the face. If we can embed tactile display into an HMD, we do not need to wear additional haptic devices, solving the above issues.

In this paper, we propose an air-suction type HMD-embedded haptic device named Haptopus, describe preliminary investigation on the best suction pressure and show comparative evaluation with the conventional tactile presentation approaches.

RELATED WORK

There were many proposals to include a tactile-sense-presentation mechanism into an HMD.

Oliveira and colleagues developed an HMD with a built-in vibration and verified the effectiveness of direction perception in the VR space. While tactile presentation using vibration can make inexpensive and high quality experiences, constant vibration especially to the head bone might be annoying when continuously using it. Furthermore, it is rather a symbolic expression, since the sensation is limited to vibration [3].

Kon et al. developed an HMD equipped with a balloon pressure presentation mechanism. Although they successfully presented a sense of pressure to the face by using balloon compression, there is a problem of HMD fixation, since the balloon pushes up and moves the HMD itself when presenting [4].

Peiris et al. developed an HMD with built-in thermal sense presentation mechanism using Peltier element, as well as vibration. Thermal sense is an important cue for environmental perception, and they succeeded in giving users the impression of approaching

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to fire or living in a cold place. On the other hand, due to the low spatial resolution of the temperature sensation, the thermal stimulation might not be a good candidate for presenting tactile sensation for each finger to the face [5].

HAPTOPUS

Summarizing the current status of HMD-embedded tactile displays, most of them did not present pressure sensation that is considered to be a good candidate for representing finger pressure without annoyance, and rare example of presenting the pressure with air balloon has an inherent fixation issue. On the other hand, most HMD-embedded tactile displays aimed at presenting environmental information, and as far as the authors know, there was no attempt to transfer the tactile sense of the finger to the face with HMD.

We propose a that utilizes suction stimulus. By using suction stimulus, the fixation of the HMD on the skin is not hindered. Furthermore, although it is not the main scope of this paper, it is known that suction of the skin can be interpreted as a positive pressure in certain conditions, since the direction of strain is hard to be encoded by mechanoreceptors [6].

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

EXPERIMENT 1

We investigated the dynamic range of allowable suction pressure around the eyes. As the sensitivity to suction stimulus is not constant among users, we first measured threshold pressure value for each participant. Then it was increased by fixed factors to see if they felt uncomfortable.

4.1 Suction Unit

Suction unit and suction port is shown in Figure 1. The unit 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 using a microcontroller (ESP - WROOM - 32). Figure 2 shows outline of suction system.

The suction pressure was presented for 1 second and turned off for 1 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 is composed of acrylic exterior and skin contact part of silicone sheet. The diameter is 12 mm, which was determined from a preliminary experiment.

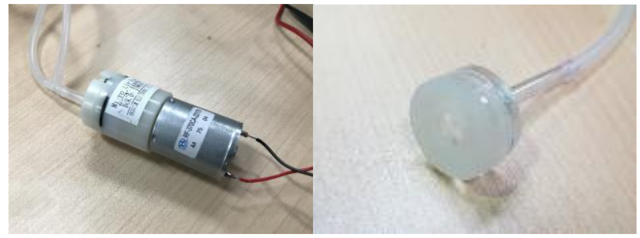

Figure 1: Suction unit & Suction port

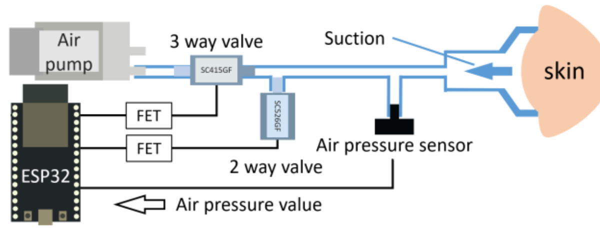

Figure 2: Outline of suction system

4.2 Procedure

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

After measuring the threshold, we evaluated the possible range of stimulation by asking comfort level. The air pressure values were $\times 1$, $\times\sqrt{2}$, $\times 2\sqrt{2}$, $\times 4$, $\times 4\sqrt{2}$ of the threshold, whereas the reference air pressure value was $\times 2$ of the threshold. The participants were asked to evaluate its comfort level by seven point Likert scale (1: not comfortable, 7: comfortable), where 4 was set as the reference stimulus. The comparison stimuli were always presented after reference stimulus.

We conducted the above experiment at under the right eye and over the right eyebrow (Figure 3). These two locations are common contact parts for HMD and Gil et al. confirmed that humans can perceive tactile sensation with these two points [7]. We recruited ten participants (21 to 27 years old, three females and seven males).

Figure 3 Suction point

4.3 Result & discussion

The threshold air pressure values measured under the eyes and over the eyebrows are shown in Table 1. Except for two participants (I and J) out of ten, the threshold value under the eyes were smaller than over the eyebrows. T-test showed significant difference between the two ($p=0.006<0.05$). This is presumably because the perception of the suction stimulus depends on the displacement of the skin and it is assumed that the softness of the skin differs depending on the locations.

The comfort evaluation results are shown in Figure 4 (under eye) and Figure 5 (over eyebrow) as boxplots. The ordinate shows the score by the Likert scale, cross shows average value. As a result of the Kruskal-Wallis test, we found no significant difference between all conditions pairs, and between reference (score 4) and comparison stimulus. That is, we can stably present the suction air pressure to $\times 4\sqrt{2}$ of the threshold. However, large variation among individuals, especially found at $\times 4\sqrt{2}$ of the threshold should be noted. Although we found no significant difference, a trend of an inverted U shape can be noticed, which might mean that at some optimal point, the comfort might be maximized.

We obtained many comments after the experiment, saying that case of smaller values than the threshold, they frequently felt a sense of pressing pressure. There was also a comment about feeling contact or tap besides the feeling of pressure. These comments supported our idea that suction pressure on the face can be interpreted as pressing pressure, which agrees with previous literature [6]. Although we have defined the threshold as a value for which users could explicitly feel "suction" pressure (because stable sensation is required for the next experiment), we must pursue the possibility of presenting the feeling of pressing pressure in our future work.

Table 1 Threshold suction pressure (hPa)

Subject	under eye	over eyebrow
A	-15	-115
B	-35	-50
C	-35	-195
D	-40	-140
E	-45	-205
F	-65	-95
G	-65	-125
H	-75	-125
I	-95	-55
J	-115	-80

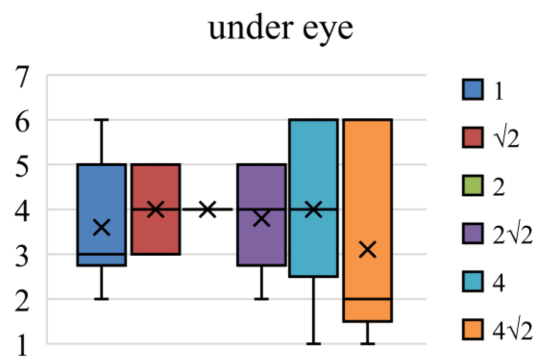

Figure 4 Comfort levels of suction stimulation (under eye)

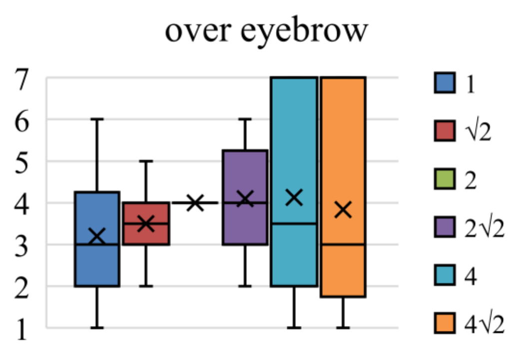

Figure 5 Comfort levels of suction stimulation (over eyebrow)

EXPERIMENT 2

Using the threshold air pressure value confirmed in the previous experiment, we embedded the device inside an HMD and evaluated in VR environment.

5.1 Procedure

We compared the quality of VR experience when using suction stimulus built in HMD (HMD suction), vibration motors built in HMD (HMD vibration), and vibration presentation from controller gripped by palm (palm vibration).

From the result of the previous experiment, we set suction air pressure to be $\times 2$ of the threshold value. The locations of stimulation are the same as the previous experiment (under the right eye and on the right eyebrow), For HMD vibration, two vibration motors (coin type coreless vibration motor; FM 34 F, Tokyo Parts) were attached at the same location as the suction stimulus.

The content of the VR experience was to touch a sphere with 20cm diameter that was floating in the air. The participants experienced the VR content under each tactile condition, and evaluated the experiences. HMD suction, HMD vibration, and palm vibration were all continuously presented while the hand and the sphere contact. We prepared four questions; realism of the ball, quality of the experience, clarity of the boundary of the ball, and clarity of the touch feeling by the hand. Participants answered on a 7-level Likert scale (1 is not good / unclear, 7 is good / clear). At this time, the state without haptic feedback was set as a reference stimulus and its score was set to 4.

The system consisted of a HMD (HTC Vive) and Leapmotion for position measurement of the hand, and each stimulation device (suction system used in Experiment 1, vibration motors, and a Vive controller).

When the collision between the object and fingers were detected in VR space, continuous stimulus was presented. The contact of the index finger was associated with the stimulation over the eyebrow, and that of the thumb was associated with the stimulation under the eye (for HMD suction and HMD vibration). For each trial, the reference stimulus without haptic feedback and each condition stimulus were presented to the participants, and they answered the questions after each trial. We did not limit the time for the experiment. We presented three stimulation conditions to each of eight participants (all male, 21-27 years old). Each stimulation condition was repeated five times, 15 trials in total per participant in random order. Free comments were obtained after the experiment.

5.2 Result & discussion

The result are shown in Figure 6. Comparison with the reference condition (visual presentation only, score 4) by Wilcoxon sign rank test revealed that the HMD vibration stimulus was not significantly different from the reference condition in terms of quality of the experience. All other conditions were significantly better than the reference condition.

Multiple comparison by the Kruskal-Wallis test revealed that the HMD suction was significantly better ($p = 0.009$) than the palm vibration for the realism. Regarding the quality of experience, HMD suction was significantly better than HMD vibration and palm vibration ($p = 0.0001$ and $p = 0.018$). Regarding the boundary, HMD suction and HMD vibration were significantly better than palm vibration ($p=0.0001$ and $p = 0.024$. There was no significant difference between the conditions for the clarity of touch feeling by the hand, even though the palm vibration was the only condition that really presented sensation to the palm.

From these results, it was confirmed that the HMD suction comprehensively improved the realism, quality of experience, and the recognition of the boundary, without losing the feeling of touching by hand. Conventionally proposed HMD vibration was better than palm vibration in terms of recognition of the boundary, but it was also the only condition that gave no significant difference from the reference condition in terms of quality of the experience. It implies that the vibration inside HMD might shake the HMD and degraded the visual experience, and the continuous vibration to the face might be simply uncomfortable. The palm vibration did not show significant disadvantage, but surprisingly to us, it was not better than the HMD suction, even though the content was to touch with the hand. One reason might be that the current task was too simple, just to touch the object.

One commented that the HMD suction gave a feeling of softness. Another commented that compared with HMD vibration, HMD suction strongly gave a feeling of real contact, which both are considered due to the clear pressure sense presentation enabled by suction stimulation.

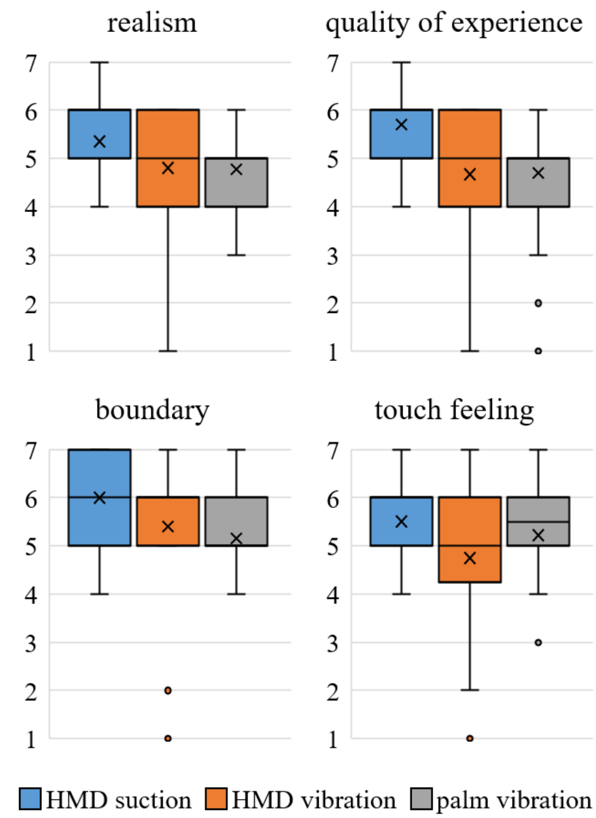

Figure 6 Answer result of the question. (a) realism of the ball, (b) quality of the experience, (c) clarity of the boundary of the ball, (d) clarity of the touch feeling by the hand.

CONCLUSION

In this paper, we developed and evaluated HMD with built-in suction haptic presentation mechanism aimed at realizing an easy to setup and comfortable haptic VR experience. First, we investigated the threshold air pressure that is perceived as suction, and we also investigated allowable dynamic range in terms of discomfort that may be associated with strong suction. The allowable suction pressure was quite large and has large variation among participants.

In the evaluation of tactile presentation during VR experience, we found that the HMD suction stimulus comprehensively improves the quality of the VR experience in comparison with the HMD vibration stimulus and the vibration stimulation by the controller held by the palm.

Our future work includes evaluation of suction stimulus that can be recognized as pressing pressure sense, mapping of suction stimulus points for each finger, and application of Haptopus to various VR and teleoperation scenarios.

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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] Y. Makino, N. Asamura and H. Shinoda, "Multi Primitive Tactile Display Based on Suction Pressure Control," *Proc. 12th IEEE Symp.Haptic Interfaces for Virtual Environment and Teleoperator Systems (Haptic Symp. '04),* pp. 90-96, 2004.

[7] 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.