Haptopus: Haptic VR Experience Using Suction Mechanism Embedded in Head-Mounted Display

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ABSTRACT

With the spread of VR experiences using HMD, many proposals have been made to improve the experiences by providing tactile information to the fingertips. However, there are problems, such as difficulty attaching and detaching the devices and hindrances to free finger movement. To solve these issues, we developed "Haptopus," which embeds a tactile display in the HMD and presents tactile sensations to the face. In this paper, we conducted a preliminary investigation on the best suction pressure and compared Haptopus to conventional tactile presentation approaches. As a result, we confirmed that Haptopus improves the quality of the VR experience.

Author Keywords

Haptopus, suction stimulus, haptics HMD, virtual reality

ACM Classification Keywords

Human-centered computing → Haptic devices; Human-centered computing → Virtual reality;

INTRODUCTION

Low-cost head-mounted displays (HMDs) have recently become widespread and are used in a wide range of applications. With the spread of HMDs, many studies have been conducted to combine visual information with tactile information for a more immersive virtual reality (VR) space. While there were several studies on wearable tactile presentation [1], current wearable-type devices have practical issues, such as difficulty in attaching and detaching the devices and mutual interference between devices when worn on multiple fingers.

To address these issues, methods have been proposed to present 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, and many attempts have been made to place transducers on arms and shoulders.

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For application in VR spaces, a study has been conducted presenting a sense of touch received by a hand to the soles of feet [2].

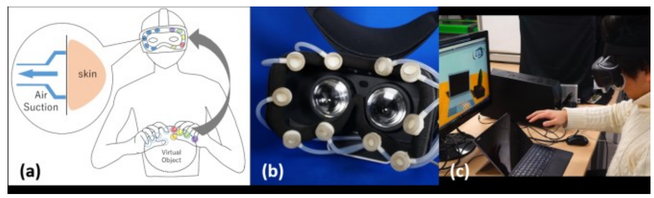

Figure 1 (a) Concept images of Haptopus, (b) Haptopus, and (c) Playing application

We argue that an alternative body part for presenting finger tactile sensations is the face. If we can embed tactile display into an HMD, we do not need to wear additional haptic devices, solving the aforementioned issues. Many proposals have been made to integrate a tactile-sense-presentation mechanism into an HMD—e.g., vibration tactile sense, balloon compression, and temperature presentation. However, the vibrotactile sense needs to convert pressure sensation—which is important tactile information when handling objects—into vibration, which is somewhat annoying when presented continuously. Balloon compression can present a sense of pressure, but when it is embedded in an HMD, the balloon pushes up the HMD and causes alignment issues. Temperature presentation can express environmental conditions, but its low spatial resolution hinders its use in expressing multi-fingered information [3] [4] [5].

Our idea is to use an air-suction mechanism to present a pressure sensation. Although the skin mechanoreceptor responds to the magnitude of the strain energy, it can be felt as being pressed with a certain air pressure suction because the direction of the strain is difficult to perceive [6]. Our system Haptopus transfers the tactile sense of the fingertip to the face and presents pressure sensations using a compact suction mechanism that can be built into the HMD. This device transfers the tactile sense of multiple fingers mainly for pressure sense to the 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 on the fingertips.

HAPTOPUS

Suction unit

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 an outline of the suction system. The suction pressure was presented for 1 second and turned off for 1 second, 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, which was determined from a preliminary experiment.

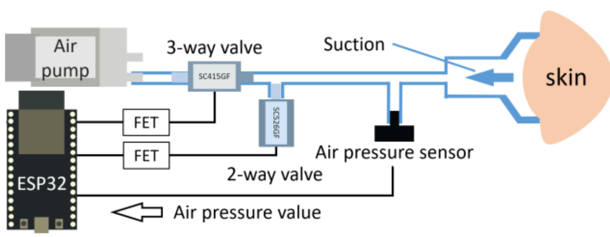

Figure 2 Outline of suction unit

Evaluation Haptopus

We compared the quality of a VR experience when using suction stimulus built into an HMD (HMD suction), vibration motors (coin type coreless vibration motor; FM 34 F, Tokyo Parts) built into an HMD (HMD vibration), and vibration presentation from a controller gripped in a palm (palm vibration). We set the suction air pressure at double the threshold air pressure value. The threshold at which a suction sensation was clearly felt was determined by the method of adjustment before the evaluation experiment. The locations for presenting the stimulation conditions were under the right eye and over the right eyebrow.

The content of the VR experience was touching a sphere 20 cm in 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 were in contact. We prepared four questions, regarding the realism of the ball, the quality of the experience, the clarity of the boundary of the ball, and the 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 an HMD (HTC Vive) and a Leap Motion controller for position measurement of the hand and each stimulation device. 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 the 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.

The results are shown in Figure 3. The HMD suction stimulus comprehensively improves the quality of the VR experience compared to the HMD vibration stimulus and the vibration stimulation by the controller held in a palm.

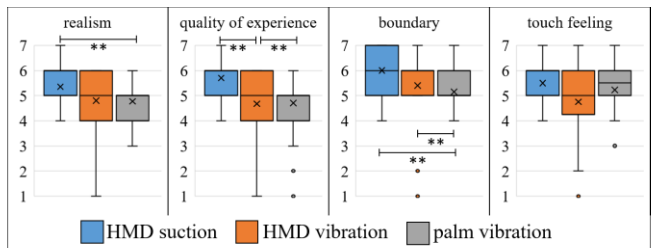

Figure 3 Answer results of the question: (a) realism of the ball, (b) quality of the experience, (c) clarity of the boundary of the ball, (d) clarity of the touch feeling by the hand

APPLICATION

We developed several VR experiences with tactile information using Haptopus. Haptopus can express the sense of fingers touching virtual objects by presenting corresponding suction pressure around the eyes. By applying strong suction, it can present both a simple contact feeling and a pain sensation like a thorn or a needle. It is also possible to express the softness of a contact object by controlling the presentation pressure in accordance with the user's motion. Furthermore, several stimulation points can correspond to multiple degrees-of-freedom for one finger, enabling expression of the force direction; thus, expression of the detailed characteristics of contact objects, such as edges and irregularities, is possible(Figure 4).

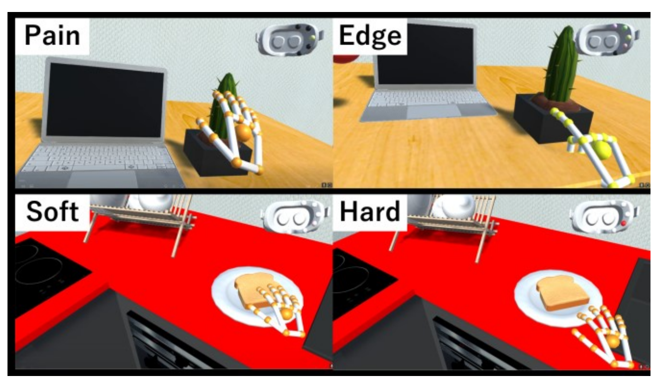

Figure 4 VR applications

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