An HMD-Integrated Haptic Device for Force, Friction, and Thermal Sensations of Fingertip

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Abstract. We developed an HMD-integrated haptic device "SPIDAR-Fr," which can present contact and friction sensations to stiff objects. The device consists of two DC motors with a rotary encoder and a brake module attached to the HMD. A ring-shaped device which is the end-effector is attached to a string wound around the shafts. The user attaches the end-effector to the fingertip to obtain haptic experiences for virtual objects. When the user's fingertip comes into contact with a stiff object, the brake module stops the string from being pulled out, causing the string to collide with the fingertip and the reaction force to be perceived. Furthermore, if the finger is moved horizontally in that state, friction will occur between the skin of the fingertip and the fixed string, and the sensation of tracing can be perceived.

In this study, we used a spring-damper model and PWM control of the motors instead of the brake mechanism to enable SPIDAR-Fr to touch stiff and elasto-plastic objects and present its reaction force. In addition, we added a thermal sensation presentation mechanism using a Peltier element to present the warm or cold sensation of the touched object. We named this device "SPIDAR-H&F".

Keywords: Haptics · Force sensation · Friction sensation · Thermal sensation

1 Introduction

1.1 Background and Objectives

In recent years, HMDs have become increasingly high in specifications and low-priced due to their wide utilities by individuals and companies. The application of HMDs to virtual reality systems is limited to the presentation of audio and visual. Even though the controller attached to the HMD has the function of presenting skin sensation feedback by giving vibration [1], it is not possible to reproduce and present the sensation of force or friction. The haptic sensation is attracting attention as a sensory presentation following the advances in the visual and auditory senses. The development of a haptic sensation presentation device for operating directly the haptic sense and feeling the haptic sense using one's fingers are currently active [2–4]. In addition, wearable devices such as HMDs have the advantage of not hindering the user's

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movements, since it is expected that wearable haptic presentation devices will be put into use and commercialized at an early stage.

2 Related Research

2.1 SPIDAR-Fr

SPIDAR-Fr is an HMD-integrated encounter type haptic device that presents force and friction sensation by a braking mechanism using solenoid [5]. We show SPIDAR-Fr in Figs. 1 and 2. SPIDAR-Fr detects the position of the finger using Leap Motion [6], and when the finger touches a virtual object in the virtual space, the brake is activated, stopping the rotation of the motors and the movement of the finger inserted into the end-effector connected with a string. When the finger is slid horizontally while in contact with the object, the finger slides on the string, and the user feels the friction of tracing the object.

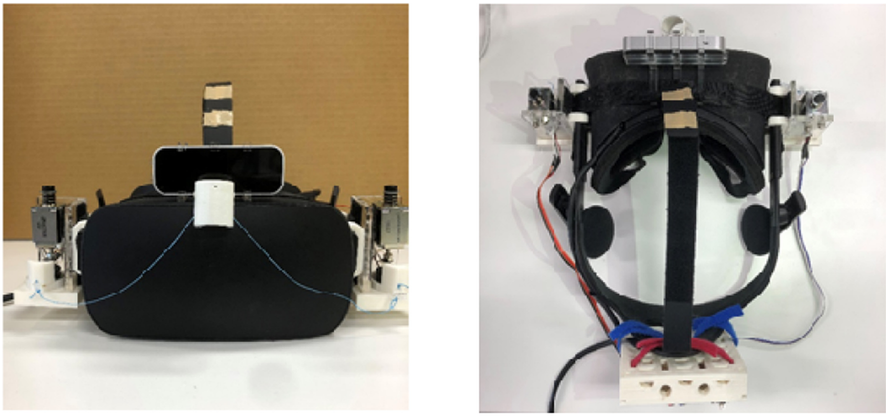


Fig. 1. SPIDAR-Fr

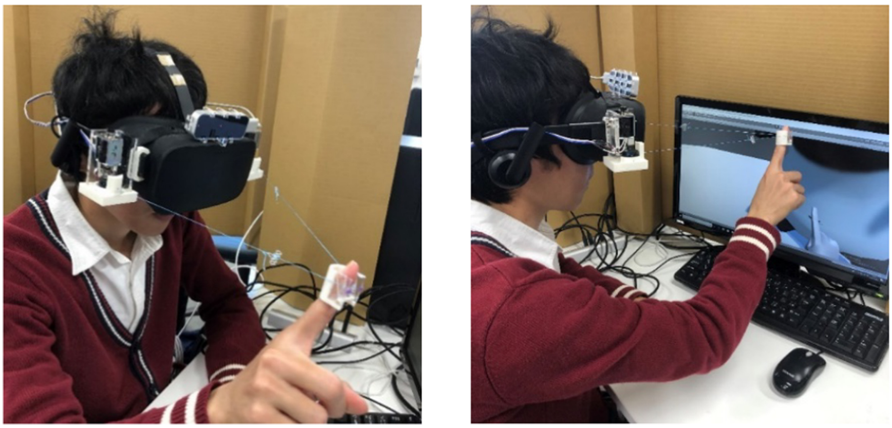


Fig. 2. SPIDAR-Fr in use

3 Proposed Device

3.1 Overview of SPIDAR-H&F

SPIDAR-H&F is an HMD-integrated parallel-wire haptic device that can present a feeling of contact and friction with both stiff and elastoplastic objects by controlling the torque of the motor of SPIDAR-Fr. As shown in Fig. 3, this device consists of five elements: the two brake modules attached to the left and right of the Oculus Rift S [7], the end-effector attached to the string extending from the brake modules, the Leap Motion attached to the front of the HMD, and the controller board attached to the rear. When the user wears the HMD and moves the hand with the end-effector attached to the finger, Leap Motion detects the 3D position of the finger and the hand avatar in the virtual space moves like a real hand. When the user comes into contact with an object, the device presents a different sense of reaction depending on whether the contacted object is a stiff object or an elastoplastic object. When it comes into contact with an elastoplastic object, the device controls the torque of the motor using PWM control to present the reaction force. Furthermore, when it comes into contact with a stiff object, the brake mechanism operates the motor, and the pulley around which the string is wound is fixed to present the reaction force. At this time, when the user moves the finger horizontally, it slides over the fixed string, this mechanism presents a sense of friction as if the user is tracing the virtual object. With these mechanisms, SPIDAR-H&F reacts to the feeling of contact regardless of whether the virtual object in front of the user is a stiff or elastoplastic object and reacts to the feeling of friction in a stiff object. Figure 4 shows the system configuration.

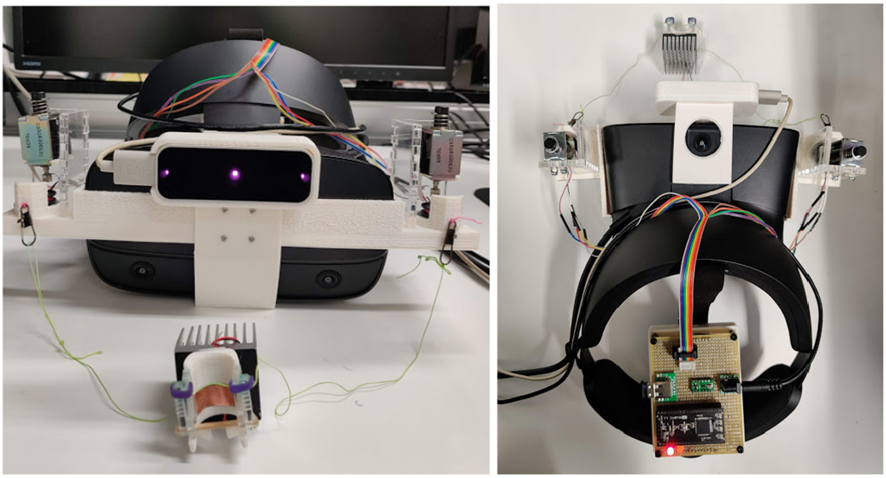


Fig. 3. SPIDAR-H&F

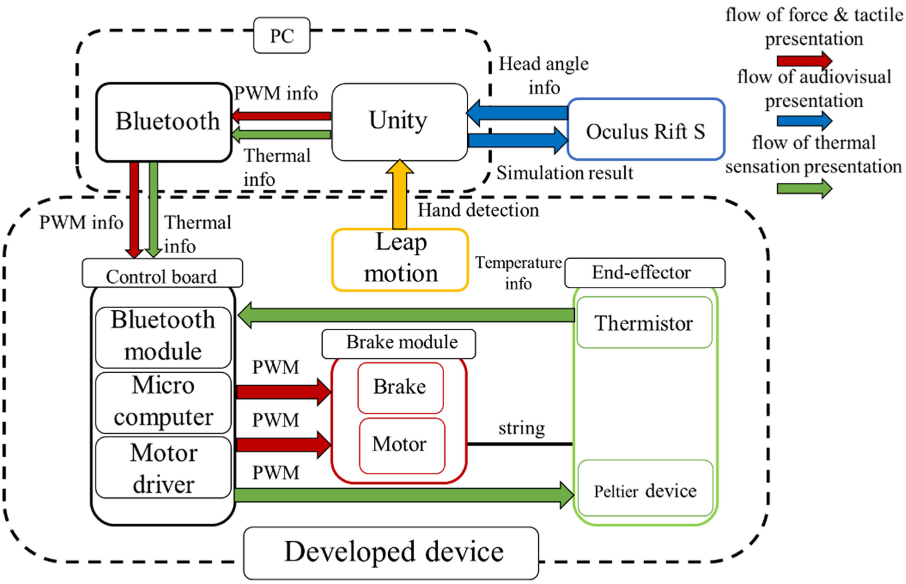


Fig. 4. System configuration

3.2 Components of SPIDAR-H&F

Brake Module. Figure 5 shows the brake module used for force and friction sense presentation. The upper part is a solenoid (Fig. 6, CBS08300120, TAKAHA KIKO Co., Ltd.) [8], and the lower part is a resin motor fixing frame created by a 3D printer. The motor (Fig. 7, RF-300FA-12350, MABUCHI MOTOR Co., Ltd.) [9] is in the frame on the lower side, and the rotating shaft is sticking out the top. A pulley is attached there, and the string is winded up. When the finger pushes an elastoplastic virtual object, the torque of the motor reacts to the spring-damper model and PWM control, and the reaction force is presented. When the finger pushes a stiff virtual object, the iron core of the solenoid presses down on the pulley, stopping the pulley from rotating, and as a result, the user feels a the contact with a stiff object.

End-Effector. We illustrate the end-effector in Fig. 8. The string extending from the motor penetrates the hole on the front of the end-effector and connects to the motor on the opposite side. The user is presented with a sense of force and friction sensation by attaching an end-effector to the fingertip. When the user is not in contact with the virtual object, the string does not come into contact with the belly of the finger due to the tension of the rubber attached to the left and right on the upper side of end-effector (Fig. 8(b)). When the user touches the virtual object, the string touches the finger and

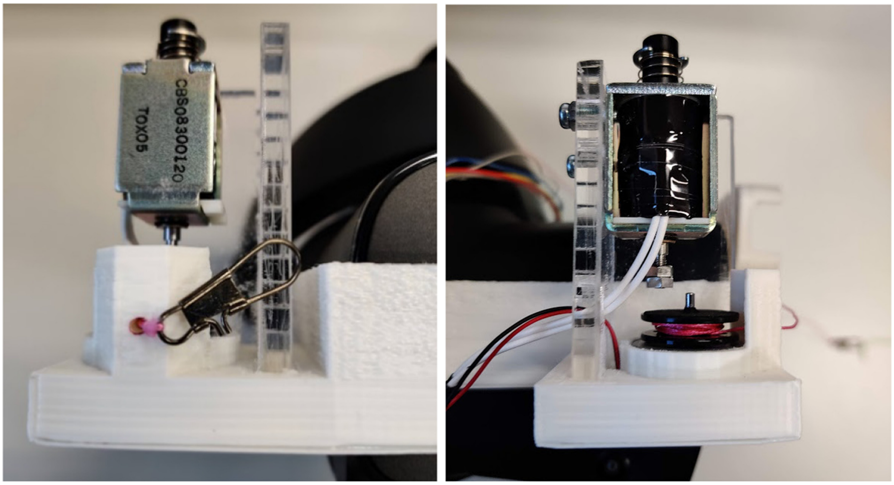


Fig. 5. Brake module

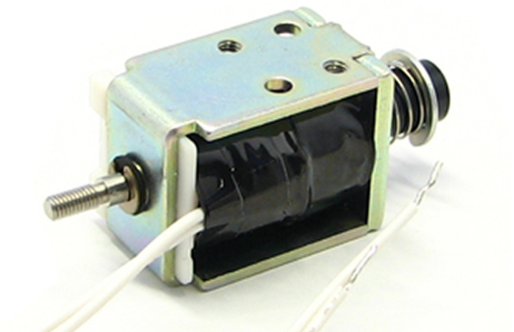
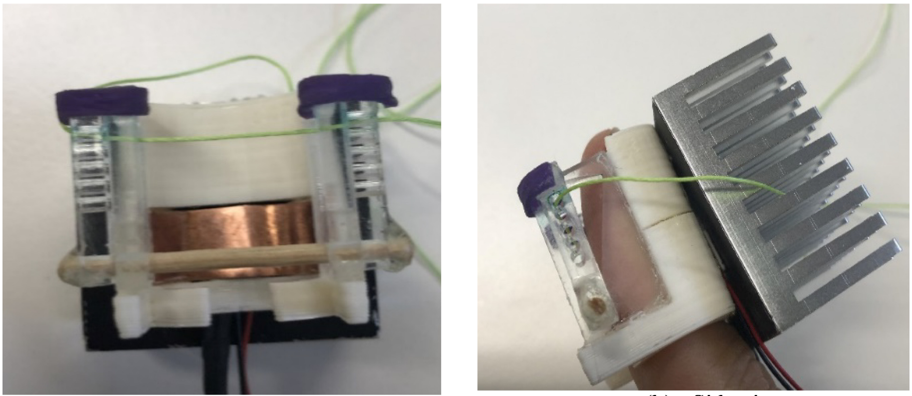


Fig. 6. Solenoid (CBS08300120) [8]

Fig. 7. DC motor (RF-300FA-12350) [9]

presents a feeling of contact. In this state, the user can trace over the fixed string by moving his finger along the string in lateral direction and with a feeling of friction. In addition, a copper plate for thermal sensation presentation is placed so that it touches the skin at the base of the nail, and a small Peltier element (Fig. 9, TES1-1102LT125, Laser Create Corporation) [10] with a heat sink and a thermistor (Fig. 10, 103JT-025, SEMITEC Corporation). [11] for temperature measurement are fixed to the copper plate. When a finger touches a virtual object, the thermal sensations react to the fingertip according to the temperature set for the virtual object.



(a) Front view (b) Side view

Fig. 8. End-effector

Fig. 9. Peltier element (TES1-1102LT125) [10]

Fig. 10. Thermistor (03JT-025) [11].

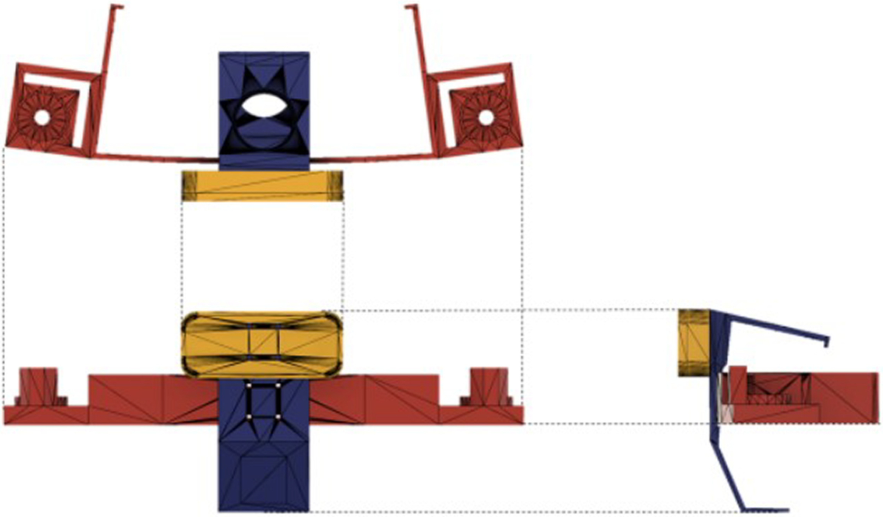


Fig. 11. Three views drawing of the frame

Frame. Figure 11 shows the three-view drawing of the SPIDAR-H&F frame. The frames are all made of resin printed by a 3D printer and consist of three pieces. Red part is a horizontal frame, blue part is a vertical frame, and yellow part is a frame to hold the Leap Motion in place. These frames are fixed together using screws and nuts. The horizontal and vertical frames have claws molded into them such that it can be fixed to the HMD.

Control Circuit Board. The control circuit board shown in Fig. 12 is used for Bluetooth communication with the PC and for controlling the force and thermal sensation presentation. The circuit uses a microcomputer board REWBPIC (Fig. 13, Running Electronics) [12] with PIC24FJ64GB004 [13] to control the motors and the solenoids of the brake modules, the Peltier element of the end-effector, and to read the thermistor thermometer of the end-effector.

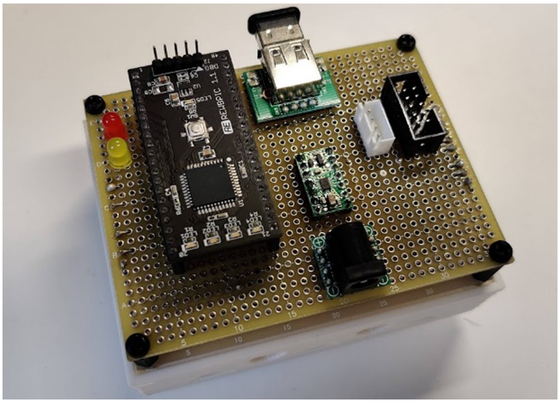


Fig. 12. Control circuit board

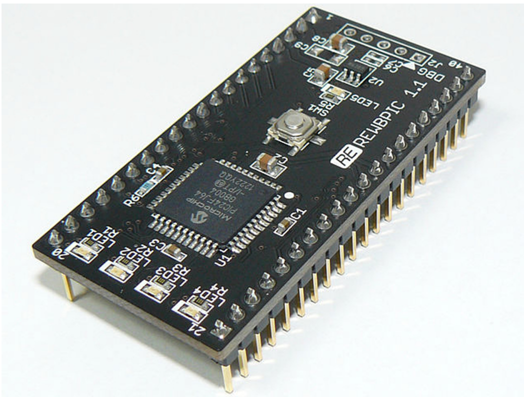


Fig. 13. Microcomputer board REWBPIC [12]

3.3 Specifications of SPIDAR-H&F

The specifications of SPIDAR-H&F is shown in Table 1. The updated frequency of the sensory presentation is around 250 Hz and the weight of the device excluding the HMD is 561 g.

Table 1. Specifications of SPIDAR-H&F

Maximum force (breaking)	11.88N
Maximum force (motor)	0.90N
Usable zone	Depth < 60 cm, 140 × 120°
Update frequency	250 Hz
Weight (excluding the HMD)	561 g
Dimension (break module) $W \times L \times H$	78 mm × 56 mm × 42 mm
Dimension (end-effector) $W \times L \times H$	34 mm × 41 mm × 34 mm

4 Conclusion and Future Work

4.1 Conclusion

In this study, we improved the encounter-type HMD-integrated SPIDAR-Fr developed in the previous study, and developed SPIDAR-H&F, a device that can present force, tactile, and thermal sensations to both stiff and elastoplastic objects. The proposed device consists of an Oculus Rift S, Leap Motion, brake module, end-effector, and control board. Also, we designed and fabricated a control board that control the brake module and the thermal sensation presentation mechanism of the end-effector, and a frame that fix the Leap Motion and brake module to the Oculus Rift S. Finally, we verified and confirmed the final specifications.

4.2 Future Work

We are planning to conduct an evaluation experiment by constructing a virtual workspace with virtual objects that have various stiffness and temperature to check what kind of haptic experiences this device can provide to users.

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