Haptic Display Glove Capable of Force/Vibration/Temperature

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***Abstract*— Since human skin has tactile receptors for force, vibration, and temperature, if it can be presented, it is considered possible to present various textures based on the theory of haptic primary colors. In this study, we propose a haptic glove that enables the display of the three haptic elements. A haptic glove for one finger was developed by combining a thread drive actuator for force display from tactile to deep sensation and a vibration/temperature display device specialized for tactile presentation. We also showed that it is possible to present multiple softness to the finger. It is capable that combine the proposed haptic device and the vibro-thermal tactile unit to display Haptic Primary Colors. With our system, sensing of the finger is also capable of using a depth-sensing camera.**

***Keywords*— haptic display, haptic primary colors, humanoid robot, telexistence**

I. Introduction

High fidelity tactile presentation improves the reality of the VR experience. Haptic presentation technology is becoming more and more important as audiovisual VR has become widespread and tactile presentation devices are becoming popular. Tactile presentation devices for VR/gaming controller (e.g. Nintendo Switch and Oculus touch) are mainly presenting vibration. However, since human skin has not only vibration but also receptors for force and temperature, presentation of these are necessary for high-fidelity tactile presentation. The most of all game controller may be made of hard plastic, and the soft material cannot be presented as it is. Tactile presentation by pressing the trigger button using above game controllers[1] are capable. But because it is not possible to freely design the hardness. It is difficult to present softness.

The presentation of a soft material such as a blanket or rubber sponge requires presentation of a sense of touch felt in the skin at the moment of touch, and a deep sensation felt in the joints of the fingers. There are some reports[2] [3] that the change in the contact area of the fingerpad is a factor in the presentation of softness. However, those need to cover the fingerpad.

As a haptic presentation device, a method of presenting force with a link mechanism has been proposed. Although a large force can be presented, the mechanism for transmitting force is not one that can be worn by hand, but one that is large and stationary[4][5][6]. A small-sized / scaled presentation device SPIDAR-G6[7] had been proposed by reducing transmission parts such as gears and links by using a large mechanism as a thread drive or separating an actuator from the presentation unit. By using a motor capable of outputting a high torque force, the reduction gear is unnecessary and the force transmission from the motor directly to the pulley is realized by the thread drive. In addition, the SPIDAR motor has back drivability, and it is possible to measure the length of the thread which is tensioned by light force. Since the position of the thread knot can be calculated from the measured thread length, the motor output can be adjusted. The force required for tactile presentation that can be felt on the skin is small at the beginning of presentation. It is necessary to output a large force so as to move the joint gradually. The back drivability enables to serve this purpose. Therefore, we propose a wearable-type force presentation method that presents the force to the fingertip and deep sensation by thread drive. A thread drive system NUIBOT[8] has been proposed which develops SPIDAR and moves a stuffed toy arm. However, a stuffed toy is packed with cotton at a high density, and it is necessary to present a very high output power in order to stretch them. For this reason, a motor with a high gear ratio is used to output a high torque, and the back drivability is small. On the other hand, our proposal is a system which combines the good point of both SPIDAR and NUIBOT. It is not a stationary type but a wearable type haptic presentation system using an actuator consisting of a motor and low gear ratio with back drivability.

A. Haptic Primary Color Theory

Tactile sensation is based on information obtained from human tactile sensors and is a type of human somatosensory sensation. The Haptic Primary Colors (HPCs)[9] is a theory that tactile sensing is composed by elements of tactile stimulus. It is the same as the three elements of light. In the primary colors of light theory, human visual cells accept real-world landscapes as three wavelengths. In the same way, the camera records images in three colors. A real-world landscape is reconstructed using a display that projects the recorded three-primary colors of light. In the HPCs theory, vibration, force, and temperature correspond to tactile sensation receptors and thermal sensation receptors. Tactile receptors that accept mechanical stimulation include Meissner corpuscles, Pacinian corpuscles, Merkel's cell, and Ruffini ending. The vibration detection area curve has an open U or V shape as a whole, and has a minimum threshold of about 0.1 μm in amplitude around the vibration frequency of 250 Hz. Experiments have been conducted to measure the vibration detection area by sinusoidal vibration stimulation ranging from about 1-500 Hz for the measurement of the skin-vibration detection area[10]. As tactile information, it is necessary to measure mechanical vibrations of about 1 kHz stimulus. The force is sensed on muscle, tendon, and joints as a deep sensation. The vibration is like the alternating current component, the force is like the direct current component, thus both vibration and force is needed. The frequent neural firing of temperature receptors at 40 - 45℃ in warm sensation and at about 30℃ in cold sensation. The configuration of haptic presentation based on the haptic primary color principle needs to be a display corresponding to the characteristics of those haptic perception.

II. Wearable Deep Sensory Presentation Device

We designed a wearable deep sensory presentation device [11] that stimulates deep sensation in the finger joints. Fig. 1 shows how a deep sense presentation device is attached to a finger.

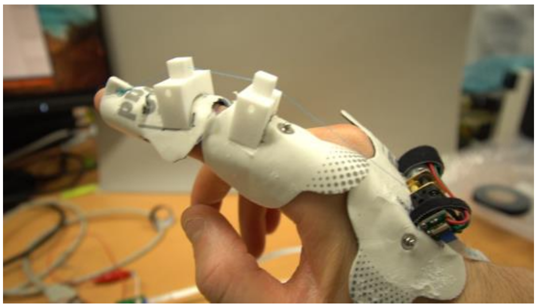

Fig. 1. Wearable deep sensory presentation device.

A. Force presentation mechanism

We describe a haptic device that stimulates deep sensation that we propose. In order to present force, a sticky gel pad was attached to a fingertip. When a thread sewn to the gel pad is drawn by motor force, deform the fingers initially. It stimulates the deep sensation inside the finger joint by an additional further force presented. The gel pad is worn around a finger from the side, top, and the other side. When a thread is pulled, as shown in Fig. 3(b), the finger skin is deformed. When a thread is pulled up, as shown in Fig. 3(b), the skin of the side finger is also pulled up. It gives tension force on the fingerpad. The applied force feels like a virtual force. When the force increases furthermore, beyond the range of skin deformation, the fingertip is pulled up. At this time, deep sensation is stimulated. Thus, continuous force presentation from skin deformation(tactile) to deep sensation(haptic) is enabled.

In order to realize continuous force presentation, the proposed device consists of a gel pad, a thread, thread passing column, DC motor for winding thread. The system configuration diagram is shown in Fig.2.

The gel pad covers both sides of the fingertip and nail of the finger without covering fingerpad (Fig.3). A thread is sewn of the gel pad attached on the fingernail. The other end of thread wound up by a pulley attached to a motor mounted on the back of the hand. In the path to the fingertips, the thread passes through the threading column mounted on the gel pad. The threading column was designed by CAD according to the shape of the finger and printed with nylon material. A small DC motor(Micro Metal Gearmotor HP 6V, gear ratio 10:1, Pololu Robotics & Electronics)[12] with back drivability was used to drive.

B. System Configuration

Fig.4 shows the driver board. In the driver board, PIC32 MM0064 GPL036 was used. It sends a command from the PC via UART (asynchronous serial communication) to control the motor. In response to the command from the PC, the control target is obtained, the sensor information is returned, and the motor is controlled.

Since a magnet is attached to the pulley, the rotation can

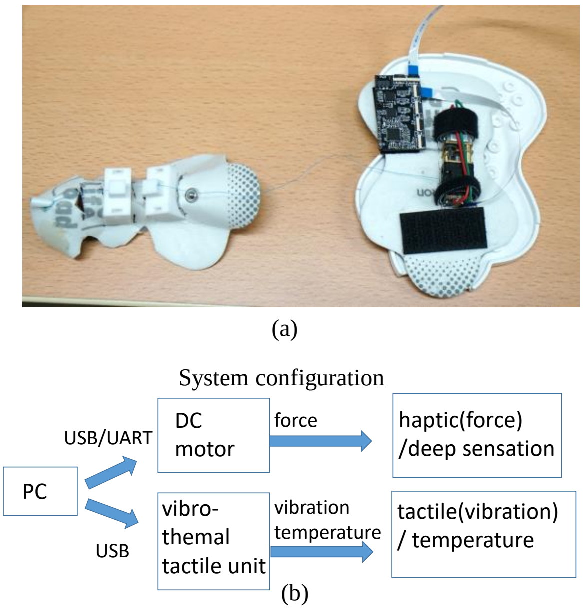

Fig. 2. (a) presentation device overview(including gelpad, thread throughout column, DC motor, driver board) (b)System configuration.

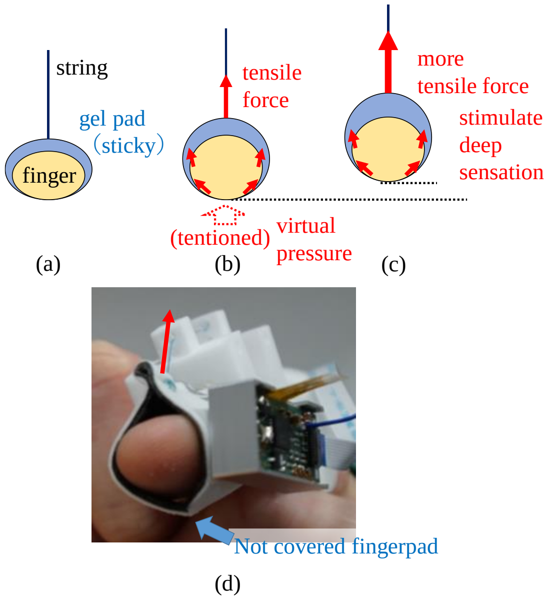

Fig. 3. Mechanism of force presentation. (a) before force presentation, (b)force presented in both side of a finger then the tactile stimulus is presented on fingerpad, (c)deep sensation is stimulated when the pull-up force increased, (d) actual device front view

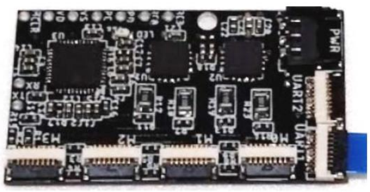

Fig. 4. Driver board (35mm╳20mm╳2.8mm)

be measured. By controlling the rotational speed of the pulley, position control is possible. In addition, the motor driver has a current measurement function and has two DRV8833

(Texas Instruments) that can perform PWM control of up to 10.8V and 1.5A at two circuits. The thread thickness was used No. 0.8 (4.8 kg). Because of the consideration of safety, the force that human fingers can exert is estimated to be about 5 kg.

C. Finger Posture Sensing

Measurement of finger posture is performed by Leap Motion[13]. The proposed haptic device could present texture in a VR simulator when the texture would be prepared. The Fig. 5 shows how Leap Motion is used to sense the bending of a finger while wearing a deep sensation presentation glove. Since the proposed glove does not significantly change the shape of the hand, it does not interfere with the measurement of the finger's posture using such a contactless sensing device and has an affinity with the hand gesture input device.

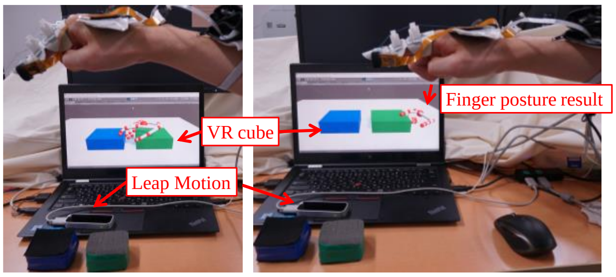

Fig. 5. Interaction with VR simulator could be possible by sensing finger posture by Leap Motion. The user can touch a VR hard rubber sponge (left, blue object) and a urethane sponge (right, green object).

D. Composition of tactile primary colors presentation glove

From the above, by combining the vibration-thermal tactile unit (Fig. 6)[14][15] with a glove (Fig.7) capable of presenting tactile force and deep sensation, it becomes possible to present three haptic primary colors of force, vibration, and temperature. The vibro-thermal tactile unit was developed by JST ACCEL project on "Embodied Media Technology based on Haptic Primary Colors". A compact version of the vibrating actuator (forcereactor ™ AF series) provided by Alps Electronics is embedded inside the device. A Peltier element (KSMH029F KELK Ltd.) [16] is mounted on the top of the device. A haptic presentation corresponding to the tactile primary colors is possible.

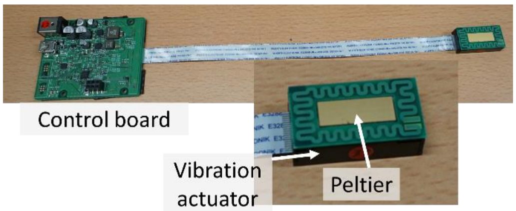

Fig. 6. vibro-thermal tactile unit

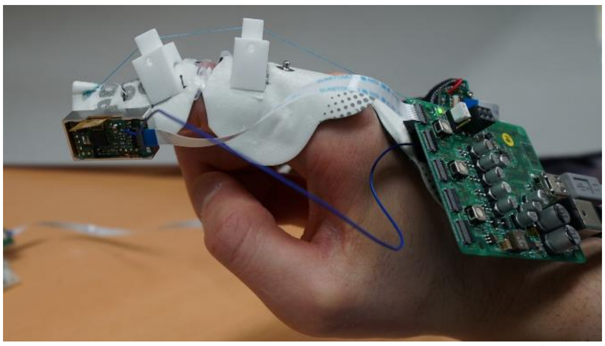

Fig. 7. Interaction with VR simulator is possible by sensing finger posture by Leap Motion

III. EVALUATION

A. Force control

The deep sensation presentation device proposed in this paper is capable of force control and can apply force from weak to strong. The Fig. 8 shows the movement of the finger when presenting a weak force (torque:7u), and a strong force(torque:10u). When a strong force is presented, it can be seen that the finger joints are under force. When a large force was applied (Fig.8 right), the index finger moved in reaction against the presented force. The thumb moved together. Such a reaction has not occurred in the presentation of weak force (Fig. 8 left). As described above, it can be confirmed that the presented force was adjusted by observing the frame-by-frame moving image. The Fig.5 shows an application example to demonstrate two different softness material experience. The blue VR object has three times hardness than the green one. The presentation force is calculated by the spring-damper model when the finger collides on the surface of objects.

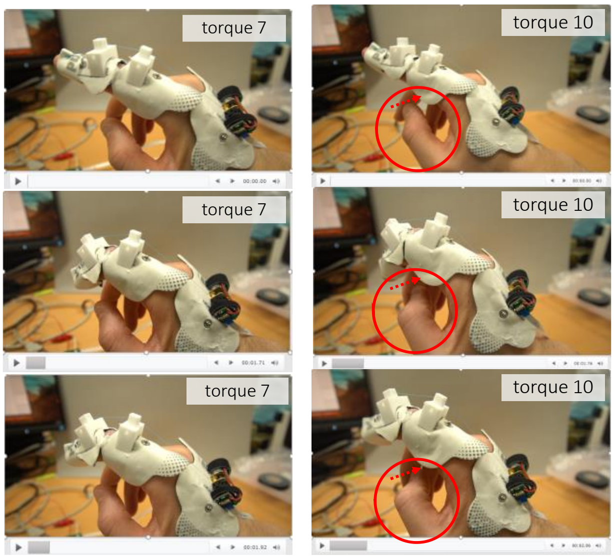

Fig. 8. left: frame-by-frame playback of finger movement when weak force is applied (torque 7), right: when strong force is applied (torque 10)

Comparison with other methods

A tactile display Gravity Grabber(GG)[17] has been proposed capable of presenting pressure and shear forces by locating two DC motors at the fingertips, taking up the belt by the pulley attached to the motor and pressing the belt against the finger pad. The GG is a compact system that can be attached to the finger, as it can provide tactile sensation by tightening the belt round around the fingertips. GG specializes in the presentation of vibration and pressure among haptics. However, GG is not a device aiming to present the deep sensation for the finger joints. In addition, it is not suitable for presentation of softness. It is basically difficult for the belt to present fluctuations in the contact area. Since the belt covers the finger pad. Tajima et al. ［18］ constructed a tactile primary color display by combining a vibro-thermal tactile unit and a tablet, but the vibro-thermal tactile unit was attached to the GG belt. The similar problem was lying that difficult to display softness. In addition, they used thread-driven tablets for presenting deep sensation, but it was a station-type haptic device.

There are studies[19][20] that enable tactile presentation using the array of electrodes on the finger pad. It can present pressure sense (e.g. softness), vibration sense. In addition, there is a proposal[21] which stimulates a deep sensation of finger by myoelectric stimulation to a finger muscle.

Neither method aims at the coexistence of both the tactile presentation to a fingertip and the force presentation to the deep sensation in a finger joint. In addition, the contact area of the finger pad cannot be changed in principle. In our proposed method, tactile presentation is achieved by adjusting the tension on the finger pad by applying a force to the sides of the finger without covering the finger pad. In addition, since the displacement component of force can be presented to deep sensation in the finger joint, it has an advantage in presenting softness. In any case, in addition to the haptic presentation technique, another force presentation method was required for deep sensory presentation. The proposed method is also advantageous in that continuous haptic sensation can be presented from tactile to deep sensation without adding a separate presentation mechanism.

IV. Limitation and Future Work

Acquiring method of the finger posture using a depth camera has an advantage at acquiring a global position for realizing interaction with a VR object. However, the latency occurs because the refresh rate is slow in the current setting. Delay needs to decrease for the vivid haptic presentation. In order to present the low latency tactile, it is considered that it would be better to acquire the length of the thread and feed the force back immediately when the collision to the VR object occurred. This could be a more accurate measurement system to acquire finger posture. The future challenge is to improve the quality of force presentation by combining a depth-sensing camera and a measurement system of finger posture by a thread length.

V. Conclusion

In this article, we have proposed a haptic presentation device that is capable of presenting force from tactile to deep sensation. Compared with the similar tactile presentation method, the conventional system only presented a tactile or deep sensation but the proposed haptic device present continuously from tactile to deep sensation such as finger joint tendon. We also showed that it is possible to present multiple softness to the finger. With our system, sensing of the finger posture is achieved using a depth-sensing camera. It is capable that combine the proposed haptic device and the vibro-thermal tactile unit to display Haptic Primary Colors.

Acknowledgment

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