Haptic Telexistence

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1 Executive Summary

"Haptic Telexistence" provides highly realistic haptic interaction among humans and objects located in remote places. We have developed innovative devices and constructed a master-slave system to realize "Haptic Telexistence". Human interaction will be dramatically improved by this concept that perceives us the properties of an object.

2 Project Overview and Vision

Nowadays, we can interact with humans or objects even if they are located in remote places or in virtual environments. In these interactions, we can watch, listen, touch, and move objects. However, the properties of an object are not present in conventional systems. When we communicate or perform a task, a lack of haptic sensation reduces the realism and interactivity. Therefore, there is increasing requirement for haptic technology presently.

"Haptic Telexistence" aims at achieving highly realistic haptic interaction among humans and objects located in remote places. In order to realize this, a slave hand with sufficient mobility and a master hand that can operate the slave hand easily are required. In addition, haptic sensors and displays are needed to perceive the haptic information correctly.

We developed innovative devices and constructed a robot hand master-slave system (Figure 1). Using conventional systems, we can only perceive the stiffness of an object. However, we can also perceive the exact shape of an object by using our system. Further, more natural and dexterous manipulations of an object become possible. This means that complex tasks employing various tools will be simplified. In addition, we can use the master hand as an interface to the virtual world. Therefore, applications such as telesurgery systems and 3D-modeling systems can be realized.

Our ultimate goal is to present all the haptic sensations. Further, our system is capable of presenting more object properties such as texture and temperature. After the ultimate system is realized, we expect a dramatic improvement in the life of human's. For example, not only will we be able to shake hands with people at remote locations but we will be able to feel the warmth of their hands. In the case of internet shopping, we will be able to check the texture of an article before purchase.

We hope that the participants understand the enormous capabilities of haptic technologies from their experience with our system for "Haptic Telexistence".

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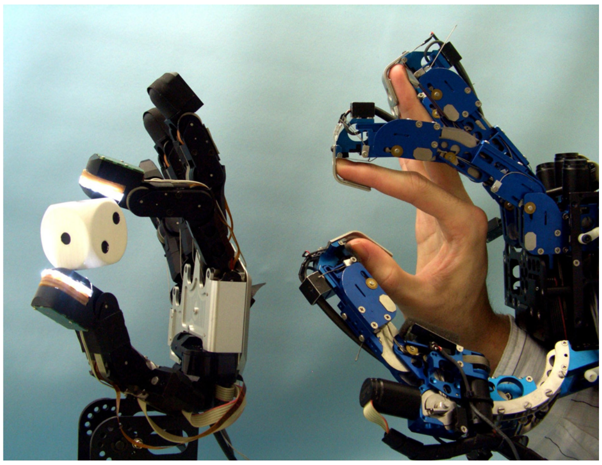

Figure 1: Master-slave system for "Haptic Telexistence."

3 Technical Innovations

Our system consists of four innovative devices, namely, a dexterous slave hand, finger-shaped haptic sensor for the slave hand, exoskeleton encounter-type master hand, and electrotactile display (Figure 2). Each of these devices have more advantages than the corresponding conventional ones. In addition, the integrating them in order to realize "Haptic Telexistence" is also a technical innovation.

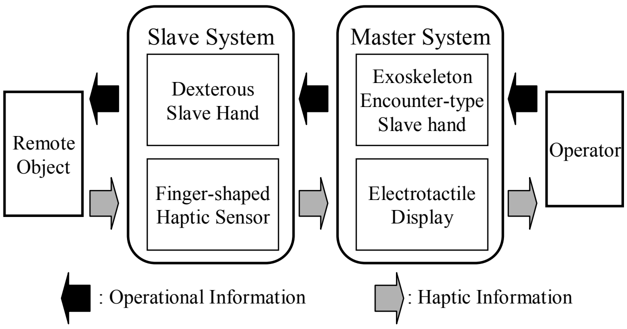

Figure 2: System configuration.

3.1 Dexterous Slave Hand

Natural tele-interaction with remote places is possible only when the slave hand has high mobility and acquires haptic information correctly. Therefore, it is desirable that the salve hand with a haptic sensor has a human-like structure.

Our multi-fingered slave hand has following futures [Hoshino and Kawabuchi 2005]. This hand has a total of 15 degrees of freedom (DOF) — five DOF for the thumb, one for abduction of other fingers, three for the index finger, and two for the remaining fingers. Each fingertip has independent DOF and the index finger and the thumb can be countered. Therefore, a pinching operation by a fingertip is possible. For example, this slave hand can pinch a card (Figure 3).

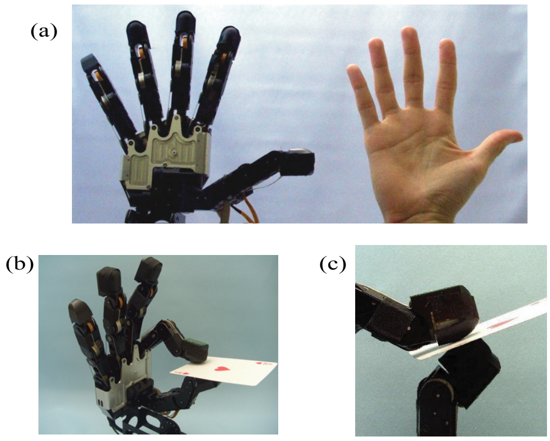

Figure 3: (a) Appearance of the dexterous slave hand.
(b, c) Pinching a card by the fingertips.

3.2 Finger-shaped Haptic Sensor

We developed a finger-shaped haptic sensor using GelForce technology. GelForce is a haptic sensor that measures the distribution of both the magnitude and direction of force [Kamiyama et al. 2004]. This sensor comprises a transparent elastic body, two layers of blue and red markers, and a CCD camera (Figure 4). Because of this simple structure, we were able to minimize the size and realize a high resolution. Now, the finger-shaped GelForce sensor achieves a space resolution of 4.5 mm and a time resolution of 14 ms. These performances can be further improved by developing the camera.

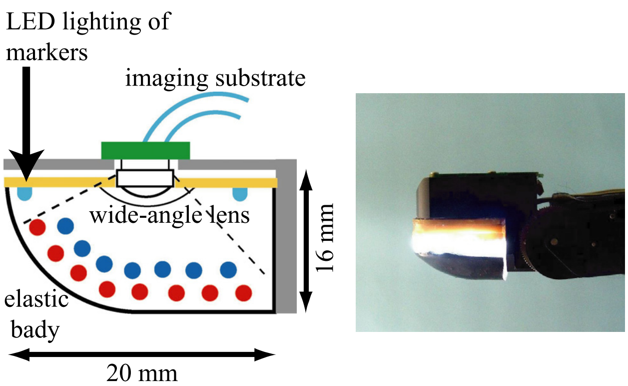

Figure 4: (Left) Structure of the finger-shaped GelForce.
(Right) Finger-shaped GelForce mounted on the fingertip of the dexterous slave hand shown in Figure 3.

3.3 Exoskeleton Encounter-type Master Hand

To operate the slave hand and to present force feedback, we constructed a multi-fingered master hand (Figure 5). This hand has two features [Nakagawara et al. 2005]. One is a compact exoskeleton mechanism called "circuitous joint," which covers a wide workspace of an operator's finger. Another is the encounter-type force feedback. This is realized using the photo reflector and force sensor. They measure the distance between tip of the master finger and that of the operator and the force between them. Using this information, the fingers of this hand is controlled to contact operator's finger only when the slave hand touches an object. This avoids unnecessary contact sensation and enables unconstrained motion of the operator's fingers.

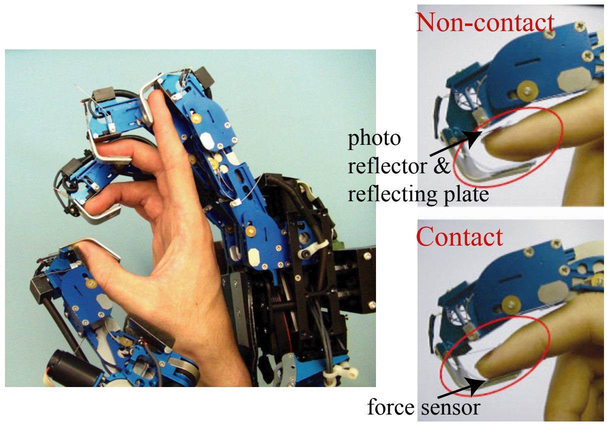

Figure 5: (Left) Exoskeleton encounter-type master hand.
(Right) Encounter-type force feedback.

3.4 Electrotactile Display

Haptic sensation must be presented on the basis of the characteristics of human perception. It can be divided into two types, namely, a kinesthetic (force) sensation and tactile sensation. Therefore, we mounted an electrotactile display [Kajimoto et al. 2004] on the master hand to present both the haptic sensations (Figure 6).

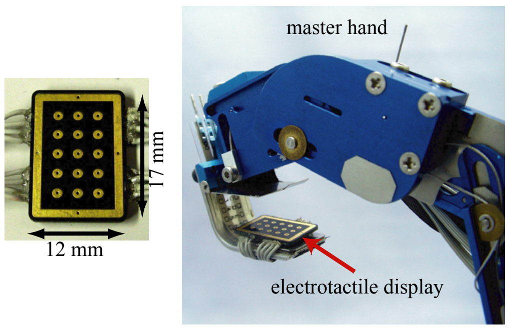

Figure 6: (Left) Electrodes of the electrotactile display.
(Right) Master hand equipped with the electrotactile display.

The electrotactile display is a tactile device that directly activates nerve fibers within the skin surface by an electrical current from the surface electrodes. It can selectively stimulate each type of receptor and produce vibratory and pressure sensations with an arbitrary frequency.

3.5 Realization of “Haptic Telexistence”

By using the above mentioned devices, we constructed a master-slave system for “Haptic Telexistence”.

The master-slave manipulation is realized by bilateral impedance control of the dexterous slave hand and the encounter-type master hand. This control is done from position of the master and slave fingers and force applied to them. The position is calculated from the angles of each finger joints. The force is measured by the finger-shaped GelForce on the slave hand and the force sensor on the master hand. The refresh rate of the control is 1 kHz. Therefore, we can operate it smoothly and perceive sufficient kinesthetic sensation.

When the slave hand touches an object, the finger-shaped GelForce mounted on the slave hand acquires haptic information such as the distribution of the magnitude and direction of force. Then, this information is transmitted to the master system. The electrotactile display presents us with tactile sensation based on this information. Using the force distribution, the electrode stimuli present information on the location. Subsequently, the force magnitude information at each position is presented by the strength of electrostimulus. As a result, we can feel a field, edge, peak, and movement of an object.

By integrating these kinesthetic and tactile sensations, we can perceive the exact shape and stiffness of an object (Figure 7). This enables highly realistic interactions with objects in remote places.

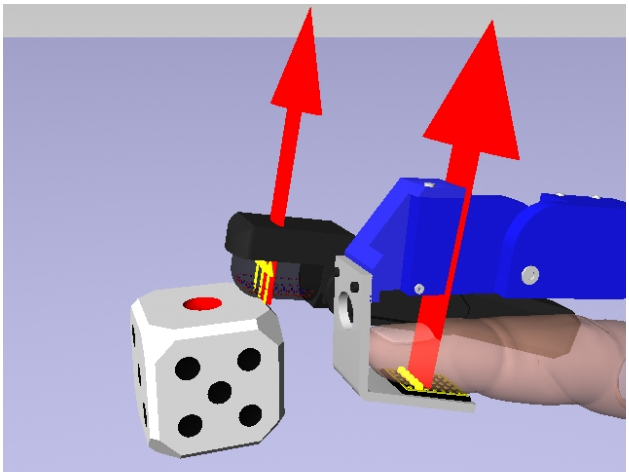

Figure 7: Sensing and presentation of haptic information. When the slave hand touches an edge of a dice, the operator feels a strong force feedback (red arrows) through the master hand. Simultaneously, operator feels linear electrical tactile sensation based on the force distribution (yellow arrows) measured by the finger-shaped GelForce.

4 Context

The necessity of tele-operation technologies originated due to nuclear systems. In the 1940s, the Algona National Laboratory constructed the first master-slave system, which was called “Master-Slave Manipulation.” This technology spread across the world because of a desire to extend a person’s sensing and manipulation capability to remote places.

In the 1980s, an advanced concept of tele-operation originated; telexistence was proposed by Tachi [Tachi and Abe 1982] and telepresence by Minsky [Minsky 1980]. These concepts are named after the technology that enables operators controlling the application to have a real-time sensation of being at a place other than their actual location.

To realize these concepts, a number of types of haptic and robotic devices have been developed [Benali-Khoudja et al. 2002; Bouzit et al. 2002; Lee and Nichols 1999]. Using these devices, the tele-operation systems have been realized [Kwon et al. 1999; Methil et al. 2006]. However, these systems are intended to be applied to only specific tasks and can only present limited haptic information.

We researched both haptic and robotic devices in order to realize “Haptic Telexistence.” For realizing a slave system, we constructed a slave hand that has multi-freedom five fingers. We have also constructed a haptic sensor for the slave hand. First, we developed GelForce that measure the force vector distribution on the surface. We showed it at SIGGRAPH2004 [Kamiyama et al. 2004] (Figure 8. b). By improving this sensor, we realized the finger-shaped haptic sensor for the slave hand.

(a) SmartTouch (SIGGRAPH2003)

(b) GelForce (SIGGRAPH2004)

(c) Forhead Retina System (SIGGRAPH2006)

Figure 8: (a, c) Applications using the electrotactile display. (b) GelForce

Simultaneously, we developed a master system. We constructed the master hand that provides an operator with natural contact sensation and operational feeling. In addition, we developed an electrotactile display to present the natural tactile sensation. As the result of the improvement in the electrotactile display, we showed its applications in the following conferences; SmartTouch in SIGGRAPH2003 [Kajimoto et al. 2003] (Figure 8. a) and Forehead Retina System in SIGGRAPH2006 [Kajimoto et al. 2006] (Figure 8. c). In this study, we mounted this electrotactile display on the master hand and realized highly realistic haptic display.

As a result, practical applications of these devices have become possible. We integrated them and constructed a master-slave system for "Haptic Telexistence." In this system, there are two features that conventional systems don't have. First, the master and slave hands enable us unconstrained operation. In addition, we can perceive an exact touch sensation of an object by the haptic sensor and display. The "Haptic Telexistence" system realizes the remote interaction to have a real-time sensation of being at a place.

5 User Experience

In order to experience "Haptic Telexistence", we will construct a robotic hand master-slave system, as mentioned in the above sections. A participant wears the master hand and controls the slave hand. When the slave hand touches an object, a participant can sense highly realistic haptic sensations. Through the natural interactions with remote objects, the participants can feel like he/she is present in a remote place. In this system, only one participant can experience "Haptic Telexistence." The experience time is approximately 10 min.

In addition, we will construct other master-slave systems for multiple participants to experience "Haptic Telexistence." By taking advantage of the small size of the electrotactile display and GelForce, we will construct two-fingered simple master-slave system. We can construct two or more sets of this system. The experience time of these systems is approximately 5 min. Therefore, we expect that many participants will be able to experience our proposed "Haptic Telexistence" simultaneously.

Credits

This work was supported by associate professor Kajimoto (The Univ. of Electro-Communications) who developed the electrotactile display, Dr. Kamiyama and Nitta corp. who developed GelForce, and Dr. Kawabuchi (the Kawabuchi Mechanical Engineering Laboratory, Inc.) who developed the mechanism of both the slave and master hands.

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