Design of Cylindrical Whole-hand Haptic Interface using Electrocutaneous Display

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Abstract. Precise manual work is frequently required in remote and virtual environments. Cutaneous feedback to the whole hand is a key element in achieving this goal; however, most haptic I/O systems for the hand only present haptic sensations to the tips of the fingers. I propose to use an electrocutaneous display to construct a whole-hand cutaneous feedback system. The display shape is cylindrical, to allow it to be grasped as a handle, and integrated with kinesthetic display. The prototype contains 1536 (64 × 24) electrodes that work both as stimulators and touch sensors.

Keywords: cylindrical haptic I/O, electrocutaneous display, haptic display, telexistence, virtual reality, whole-hand cutaneous display

1 Introduction

Precise manual work is frequently required in remote and virtual environments, such as in telesurgery and virtual reality training systems. Haptic feedback is a key element in achieving this goal. Numerous haptic displays are currently commercially available, most of which attach “hand tools”, such as handles, pens, knobs, and surgical instruments. They reproduce the behavior of the tools so that the users grasping the tools perceive the appropriate haptic feedback. Although this strategy is practical, it limits the scope to tasks using specific tools.

In contrast, a few haptic displays have tried to use the whole human hand functionalities, by presenting haptic sensation to all five fingers. However, most of these only presented haptic sensation to the tips of the fingers, ignoring the middle and proximal phalanges as well as the palm, which represent important sites for hand-tools manipulation. Furthermore, from the viewpoint of cutaneous sensation, the spatial resolution of these systems is low, due to the size limitation of the embedded cutaneous display.

This project aims to design and implement a haptic display for the whole hand. The strategy is to use an electrocutaneous display for cutaneous sensation, which can be made very thin and flexible, making it possible to fit it to the shape of the hand, and to combine it with a kinesthetic display. This paper mainly discusses the design of the electrocutaneous display element.

1.1 Previous studies

A glove-type motion-capture system or data glove is the simplest whole-hand interface. It achieves motion input, but lacks haptic feedback, and its use in remote and virtual environments is therefore not practical. Cybertouch [1] is a data glove with a vibrator at the tip of each finger. It can present rough cutaneous cues, but as the fingers move freely, precise manual work is still difficult.

Many studies have investigated ways of presenting haptic sensation to each finger. Rutgars Master [2] achieved compact size by arranging the linear actuators on the palm side. HIRO [3] achieved a relatively large workspace by utilizing humanoid fingers as the haptic display. Nakagawara et al. [4] proposed an encounter type finger haptic display for the whole hand, and Sato et al. [5] mounted an electrocutaneous display on the haptic display to present cutaneous sensation.

Although these works achieved natural kinesthetic and cutaneous sensation, most of them only presented sensation on the distal phalanges of the fingers. Because manual tasks that only require the fingertips are quite limited, presentation to the middle and proximal phalanges, as well as the palm, is desirable [6].

Some studies have investigated systems designed to present haptic sensation to the middle phalanx [7] or to the palm [8]. The current proposal represents one such trial.

2 Proposal

2.1 Cylindrical haptic I/O

Idealy, a haptic display for the whole hand needs to present kinesthetic sensation (force and position) and cutaneous sensation. A mechanism able to present kinesthetic sensation generally becomes quite cumbersome, and mounting a cutaneous display on top adds an additional burden to the design.

To solve this problem, Sato et al. proposed the MeisterGRIP [9], which is a cylindrical tactile sensor. The sensor measures the pressure distribution of each finger, and the information is used to control the fingers of a remote robot or virtual avatar. In this case, although there are no moving parts, force-to-motion conversion and visual feedback substitute for kinesthetic sensation. In contrast to a data glove, users receive a repulsive force from the cylinder surface, which acts as an additional kinesthetic and cutaneous cue.

This project adopted this practical approach, with the addition of a cutaneous display on the surface of the cylinder. Because there was no cutaneous display on the MeisterGRIP, it was difficult to present a cutaneous sensation in a passive situation, such as catching a ball. Distributed cutaneous sensation can also present the position of the contact.

2.2 Electrocutaneous display

Even though the mechanism can be simplified using a static cylindrical shape, embedding a cutaneous display remains still a challenging problem because of the limited space available for the driving mechanism. Furthermore, it must be cylindrical in shape, making a mechanical-type cutaneous display difficult to mount.

To overcome this problem, the proposed system uses an electrocutaneous display. The electrocutaneous display is a tactile interface that uses surface electrodes to directly activate sensory nerves under the skin [10-13]. Its merits include small and thin size, low cost, energy efficiency and durability.

Because the end-effector of the electrocutaneous display is just an electrode, it can be made flexible and thin, allowing it to be paved onto the cylindrical surface. Furthermore, the electrocutaneous display can be used as a simple tactile sensor by measuring surface electrical impedance during stimulation [14, 15], which is particularly useful for achieving haptic I/O.

Based on these considerations, I propose a cylindrical electrocutaneous display that will be combined with a kinesthetic display and used for precise manual work in remote and virtual environments (**Fig. 1**).

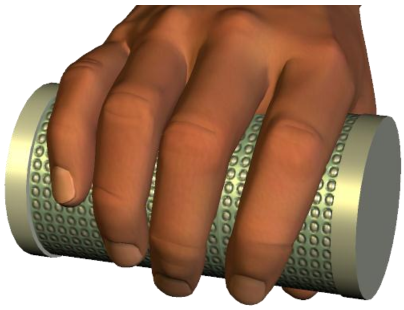

Fig. 1. Image of cylindrical electrocutaneous display.

3 System

3.1 System Structure

Fig. 2 illustrates the system structure [15]. The system used a microprocessor (SH-7144F, Renesas Technology) as a main controller, and included a D/A converter (TLV5619, Texas Instruments, 12 bit, 1 Msps) and an A/D converter (LTC1851, Linear Technology, 12 bit, 1.25 Msps).

The stimulating pulse was generated by the D/A converter and converted to a current pulse by a voltage/current converter, driven by a high-voltage source (350 V). The current pulse passed through a resistor to measure the voltage and current. This means that the system can measure the electrical impedance of each electrode, which can be used for stabilizing sensation and for touch-sensing for the haptic I/O system.

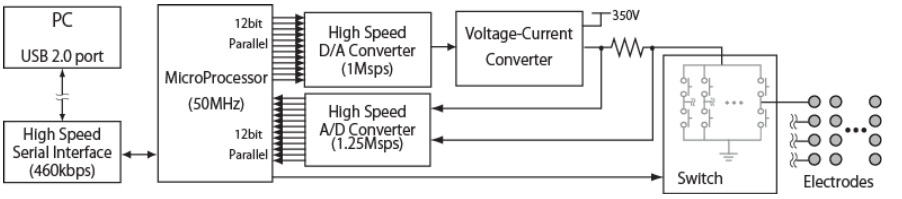

Fig. 2. System structure [15].

A pair of top/bottom switches (HV507, SuperTex) is connected to each electrode. If the top switch is on, the electrode works as an anode, while if the bottom switch is on, it works as a cathode. At any one moment, a single electrode is set as an anode and all the other electrodes work as cathodes. A two-dimensional pattern is produced by scanning. The system only requires a single current source, thus significantly reducing the hardware costs.

3.2 Implementation of the cylindrical electrocutaneous display

The tactile spatial resolution defined as the so-called two-point discrimination threshold is around 1.5 mm at the tip of the finger, 3 mm at the other parts of the finger, and 8 mm on the palm [16]. When we grasp cylinder, the tip of the finger frequently fails to make contact with the cylinder surface, and 3 mm was therefore selected as the required spatial resolution for the electrocutaneous display. Furthermore, the electrodes must be flexible enough to fit to the surface shape of the cylinder.

Fig. 3 shows the flexible electrode unit with 64 (8 × 8) electrodes and one driver integrated circuit that switches the state of the electrodes. A flexible substrate was used so that the electrodes could form a cylindrical surface. The interval and diameter of the electrodes are 3 mm and 2 mm, respectively.

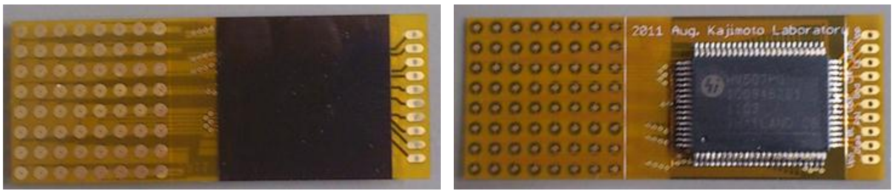

Fig. 3. Flexible electrode unit with 64 electrodes and one driver IC.

Fig. 4 shows the appearance of the electrocutaneous display and the connection of the units. Twenty-four (8 × 3) units were used, containing 1536 (64 × 24) electrodes. The diameter of the cylinder is 61 mm, which is slightly smaller than a beer can and large enough to avoid interference between the thumb and the other fingers. The height of the cylinder is 96 mm, which is large enough to cover the whole hand.

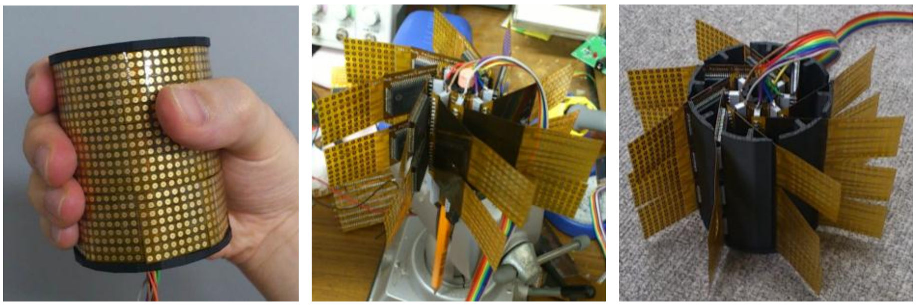

Fig. 4. Cylindrical electrocutaneous display, internal connection and construction.

3.3 Preliminary evaluation

The prototype was tested from two aspects; the presentation of cutaneous sensation, and touch sensing using the impedance measurement of each electrode.

A moving line pattern in the circumferential direction was presented to three participants, all of whom clearly perceived the direction of the motion. The impedance of each electrode was also measured during stimulation, clearly showing the footprint of the fingers (**Fig. 5**).

Fig. 5. Touch sensing by impedance measurement during stimulation.

4 Conclusion

In this paper, haptic feedback to the whole hand was proposed as a means of supporting precise manual tasks required in remote and virtual environments. A cylindrical electrocutaneous display that also works as a touch sensor was constructed.

There are two types of haptic sensations related to hand manipulation; cutaneous and kinesthetic. The main role of the constructed electrocutaneous display was to present cutaneous cues with sufficient spatial resolution. Several reports have suggested supplementation of kinesthetic sensation by illusion, by cutaneous cues [17, 18] and visual cues [19]. Our future work will include the combination of these illusory kinesthetic sensations into our system for kinesthetic presentation of each finger, as well as combination with real kinesthetic sensations by mounting the cylinder at the tip of a commercially available haptic display.

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