Quantitative Evaluation of an Illusion of Fingertip Motion

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Abstract

In recent years, touch panels have become widespread as an intuitive means to activate device operations. Because the touch panel has a space over which a finger and a corresponding cursor moves, certain actions become intuitive compared to force input-type devices such as a pointing stick. If we could add an illusory feeling of finger motion with the force input interface, it would become more intuitive. We have found a new haptic illusion of "motion", which occurs when an electrical tactile flow is presented on the fingertip while experiencing a shearing force. We have also investigated occurrence conditions, focusing on the relation between shear force and movement speed of the electrical tactile stimulation. In our study, we investigated directional characteristic focusing on the illusory position of the finger perceived using a new electrocutaneous display mounted on a six-axis force sensor.

Author Keywords

Electrocutaneous display; haptic illusion; slip sensation; input interface

ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User Interfaces - Haptic I/O;

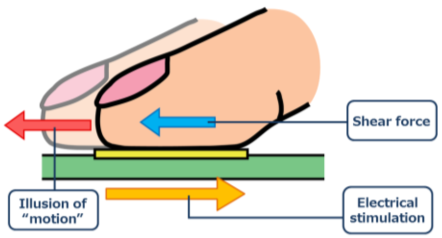

Figure 1. Conceptual image of the illusion

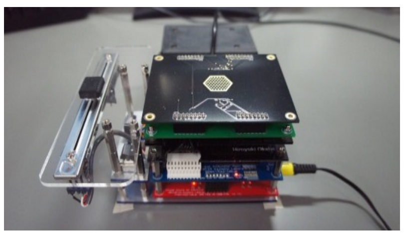

Figure 2. Electrocutaneous display [8]

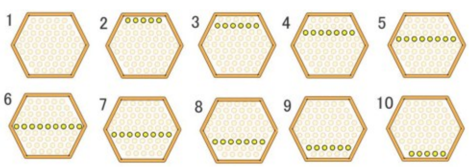

Figure 3. Electrical tactile flow

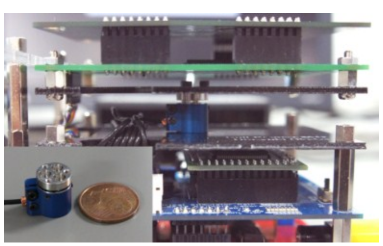

Figure 4. A six-axis sensor

Introduction

Currently, the touch input interfaces such as a touch panel or a touchpad are widely used in PCs or mobile phones. These are position-sensing-input devices, which require a large area for finger activation, with finger and cursor motion being intuitively related. Nevertheless, there are other types of input interface, such as joysticks and pointing sticks that are regarded as force-sensing-input devices. These require relatively small installation areas. Here, with finger force related to cursor motion, our idea is that if we could add a feeling of finger motion without the large input area, the trade-off between intuitiveness and area will be resolved. We focused on our newly found haptic illusion of finger motion [1], which is perceived when a moving cutaneous sensation is applied to a fingertip surface. However, a quantitative evaluation of the illusion has not been conducted. In this paper, we investigate directional characteristics, using a new electrocutaneous display mounted on a six-axis force sensor.

Previous work

Conversion of input methodology

There has been work on converting characteristics of input method. Kurita et al. presented a small touchpad with a fingerprint sensor [2] to produce a motion input device with relatively small installation area. Although micro-movements can be measured, it is subjectively a force input device because the finger barely moves. Harrison et al. equipped a pointing stick under the touch panel to add force inputs [3]. Our concept is to do the opposite by adding a feeling of motion to a force input type device.

Self-motion illusion by cutaneous input

Pasquero and Hayward showed that a cutaneous motion of a pattern presented on a finger augments the feeling of motion, and reduces time in scrolling and selection tasks [4]. In further developments, other research showed that the feeling of self-motion becomes stronger by presenting simultaneously cutaneous motion and proprioceptive sensation, with the latter predominating in perceiving self-motion [5][6][7]. Our finding is one such cross-modal presentation of a proprioceptive and cutaneous sensation that uses tactile flow with an electrocutaneous display and user-explicit force inputs (Figure 1) [1]. In our study, we investigated the illusion quantitatively, focusing on the illusory position of the finger.

Experiment

Experimental system

An electrocutaneous display that we developed was used to present cutaneous sensation on a finger (Figure 2) [8]. The display has 61 electrodes arranged hexagonally. The distance between each electrode is 2.0 mm, and the electrode diameter is 1.0 mm. A moving line pattern is presented (Figure 3). To measure the fingertip force, we used a six-axis force sensor (NITTA Corp., TFS12-10) (Figure 4). This sensor is situated 20 mm under an electrode substrate, and measures shear and vertical force applied to the display. A linear potentiometer was placed next to the electrocutaneous display for participants to gauge illusory finger position.

Experimental conditions

Four participants (2 males including experimenter and 2 females, aged between 21–25 years) took part in the experiment. The moving line pattern was applied to each participant's right index finger using electric pulses with amplitude of 0.0–5.0 mA (adjusted by each

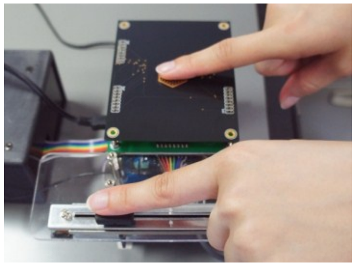

Figure 5. Answer the position of finger

Table 1. Combination of experimental conditions

Total moving distance [mm]		Velocity of the electrical stimulation [mm/sec]			
		-20	-10	+10	+20
Direction and amplitude of shear force	+ High				
	+ Low				
	- Low				
	- High				

Table 2. Experimental results

Total moving distance [mm]		Velocity of the electrical stimulation [mm/sec]			
		-20	-10	+10	+20
Direction and amplitude of shear force	+ High	6.48	6.54	5.09	10.13
	+ Low	6.51	5.01	3.61	8.09
	- Low	-6.51	-6.42	-6.94	-7.38
	- High	-7.84	-5.59	-8.68	-8.64

Table 3. Standard deviations

		Velocity of the electrical stimulation [mm/sec]			
		-20	-10	+10	+20
Direction and amplitude of shear force	+ High	7.51	7.39	5.81	9.19
	+ Low	5.21	6.50	5.80	7.72
	- Low	5.29	5.92	5.24	5.33
	- High	5.87	4.85	6.69	6.89

participant), a pulse width of 0.05 ms, and a pulse frequency of 50 Hz. Participants were also asked to exert designated vertical and horizontal forces. When participants perceived a finger motion, they were asked to slide a potentiometer with their left index finger so that subjectively left and right fingers were at the same location (Figure 5).

We prepared four stimulus conditions that combined two line pattern velocities (10.0 mm/sec, 20.0 mm/sec) and two directions (positive (+), negative (-), positive means fingertip direction). Moreover, we prepared four shear force conditions that combined two amplitudes (Low (0.0-1.0 N), High (1.0-2.0 N)) and two directions (positive (+)/negative (-)). There were four trials for each combination, resulting in 64 (=4×4×4) trials conducted in random order (Table 1).

Experimental procedure

To unify the vertical force during the experiment, the participants were trained to keep the vertical force within the range from 1.0 to 3.0 N by an electronic force balance, assuming a touch-type operation as input interface. During trials, a partition panel covered both fingers and visual cues were eliminated. The participants were asked to keep shear force within a designated range by watching a color bar. Setting a certain constant shear force, the experimenter began presenting electrical stimulations. The position of the slider was recorded for 10.0 seconds from 1.0 to 11.0 seconds after the start of each stimulation.

Results

The results and the standard deviations are listed in Tables 2 and 3. The value of each cell shows the total moving distance of the slider. Positive values (red cells) mean that the finger subjectively moved towards the positive direction. Figures 6 and 7 are graphs of Table 2. The vertical axis gives the total moving distance; and the horizontal axis shows the velocity of the electrical stimulation pattern.

Discussion

The result showed that the direction of the illusory movement always coincides with the direction of the applied shear force; in Fig. 6, all results indicate positive directions, whereas in Fig. 7 all results indicate negative directions. The correlation agrees with previous observations that proprioceptive sensation predominates over cutaneous sensation in the feeling of self-motion. Moreover, the perceived moving distance was affected by the velocity of the electrical stimulation although its relationship seems nonlinear.

In our previous study, we supposed that the direction of the finger shear force and the cutaneous pattern movement must be in the opposite direction to generate a consistent illusion; i.e. when the finger moves, the cutaneous pattern movement must be in the opposite direction to the exerted force. However, even if these cues were not consistent, the illusion persisted and its perceived movement was also by no means small. After the experiment, some participants commented: "In the inconsistency conditions, I had a strange feeling in that my finger was being pushed in the direction of exerted force". That is, there is a possibility of interpreting various cutaneous sensations in accordance with the proprioceptive cue. Random cutaneous sensations might even be effective, although the

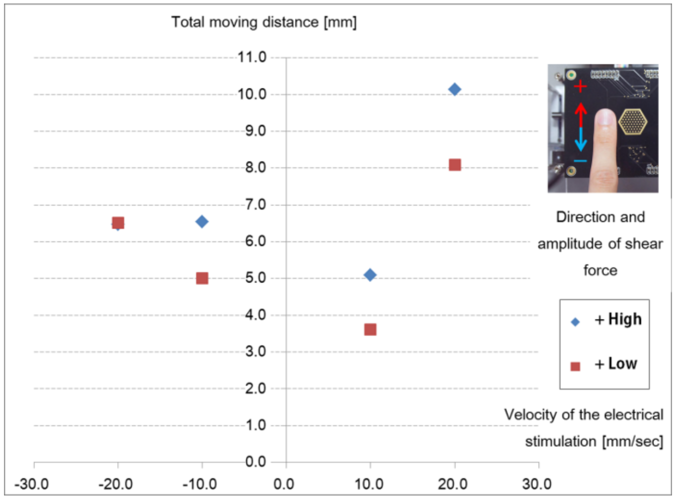

Figure 6. Result of positive shear force

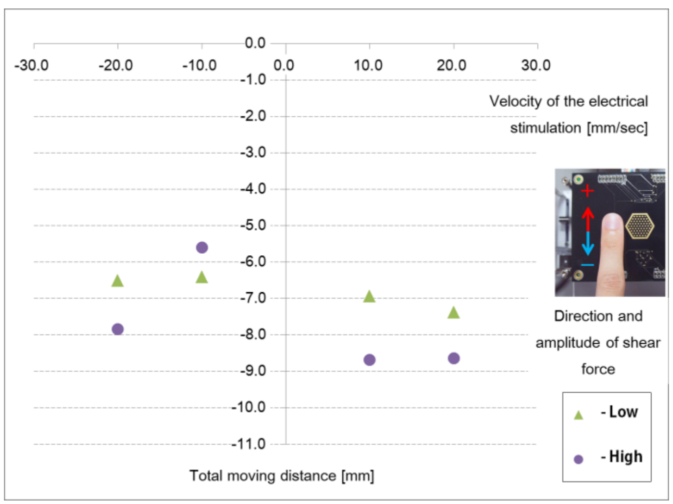

Figure 7. Result of negative shear force

current result seems to support that cutaneous pattern velocity affects the illusion. To verify these possibilities, we will need to make comparison with conditions under random or absence of cutaneous stimulations.

Conclusions and future work

In devising a position sensing input device with small installation area, we employed the haptic illusory finger movement. We conducted an experiment to quantify the effect of force and cutaneous pattern speed on the illusion by measuring the subjective position of finger. The result suggested that the sense of finger motion always occurs in the direction of the applied shear force, whereas movement speed of the cutaneous pattern affects the magnitude of the illusion. Our future work will include an in-depth study of the relationship between proprioceptive and cutaneous cues on the illusion, in particular adding conditions of random and absence of cutaneous stimulations. We will also prototype an input interface and compare with conventional interfaces.

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