Cross-Field Haptics: Tactile Device Combined with Magnetic and Electrostatic Fields for Push-Pull Haptics

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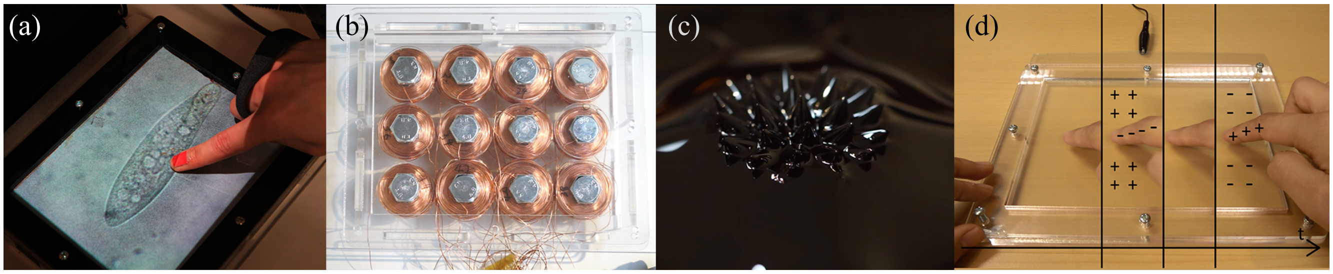

Figure 1: *(a) The user feels the paramecium caudatum sensation from the surface (b) Electromagnet array layer (c) Magnetic fluid layer (d) Conductive electrode layer*

Keywords: Haptics, ferrofluid, electrovibration, cross-field

Concepts: •**Human-centered computing** → **Haptic devices;**

1 Introduction

The representation of texture is a major concern during fabrication and manufacturing in many industries in the real world [Ochiai et al. 2014].

Tactile feedback allows displaying texture and affordance of contacts to users. In conventional studies, interaction using tactile feedback has been actively researched. Most haptic feedback systems currently being studied are categorized into two areas; wearable or non-wearable devices. Tactile feedback using wearable devices often uses force feedback devices, *e.g*., users wear the feedback devices on their arm or fingertips. Wearable devices can provide strong tactile feedback and tactile presentation for any condition. However, it is difficult to implement larger wearable devices to mount on the user. On the other hand, tactile feedback with non-wearable devices mainly utilizes environmental type tactile displays such as magnetic field, electrostatic field, and acoustic fields. Because the user does not necessarily wear the device, the user's load becomes a low-level load.

In present study, we aim to research new material interactions as environmental type tactile display. We aim to develop a new tactile display to express various textures. The proposed system physically deforms and changes the physical force between the finger and the device. To achieve this, we combine magnetic and electrostatic fields. We utilize ferrofluid which is flexible liquid affected by the magnetic field, and electrovibration on a film that covers ferrofluid to generate adsorption force from the electrostatic field to develop this device.

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We compared tactile sensation for single field and multiple fields. Through verification, it was determined that haptic feedback using multiple fields provides a wide range of tactile sensations compared with that using a single field. By combining different types of force (*e.g*., pull and push) simultaneously, the proposed system can display various textures. To the best of our knowledge, this is early study that combines multi-field physical quantities to render haptic textures. The electrostatic and magnetic fields do not influence each other. Further, from the experiment, it was determined that the fields do not influence each other's tactile presentation.

2 Related Works

Ferrofluid is used in the method for tactile presentation used with magnetic field. Ferrofluid is a fluid that changes viscosity as per the given magnetic field. It is possible to express the softness of the object by changing the viscosity of the magnetic fluid and it is also possible to express bumpy through fluid deformation. Linetic [Koh et al. 2013] which use ferrofluid, combined Hall Effect sensing and actuation through electromagnetically-manipulated ferrofluid. In this study, we employ ferrofluid and magnetic field to render "push" haptic feedback.

Adding to a ferrofluid, we present haptic feedback using a technique called electrovibration [Mallinckrodt et al. 1953] as "pull" haptic feedback. Electrovibration creates a rubbery feeling when dragging a dry finger over a conductive surface covered with a thin insulating layer excited with a high voltage signal. TeslaTouch[Bau et al. 2010] uses electrovibration, which adds a signal to an electrode. Am interaction display and a touch display were developed using electrode without a power unit. Electrovibration can provide haptic feedback without using a complicated actuator and device. However, it is necessary to move a finger because tactile presentation is related to the electrostatic force generated between a finger and the surface. Therefore, it is impossible to provide one point haptic feedback such as a button.

This study combines multiple tactile technologies in order to overcome each other's disadvantages and to help improve interaction varieties. Cross-Field Aerial Haptics [Ochiai et al. 2016] generates tactile interface in the air by combining ultrasonic waves and laser plasmas. Cross-field haptics is not a widely studied in haptic areas. To explore thes tactile display areas, we decided to use the electrostatic and magnetic fields simultaneously. The magnetic field generates force to push up and down using ferrofluid. The electro-

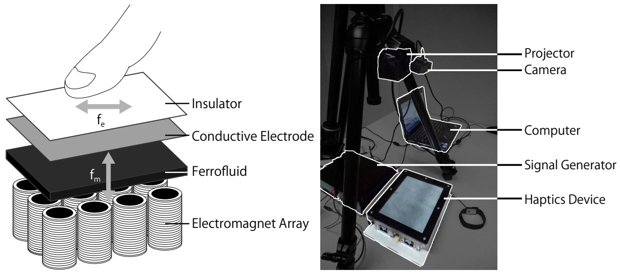

Figure 2: *System Overview; (Left)System layers. fe is Frictional force generated electrovibration and fm is push up and down force generated ferrofluid; (Right) System unit.*

static field generates force to horizontal directions using electrovibration. The top, bottom, right and left directions can be produced by combining the power generated to pull with the power generated to push.

3 Implementation

The device consists of an electromagnet array layer, a ferrofluid layer, and a conductive electrode layer (Figure 2 upper) [Hashizume et al. 2016]. Ferrofluid is a liquid that changes its viscosity in response to a magnetic field.Ferrofluids are prepared by dissolving nanoscale ferromagnetic particles in a solvent such as water or oil and remain strongly magnetic even in a fluid condition. It is well known that ferrofluids form spikes along magnetic field lines when the magnetic surface force exceeds the stabilizing effects of the fluid weight and surface tension. If a magnetic field is provided the viscosity is linearly controllable using a magnetic field. Ferrofluid is controlled using an electromagnet. Further, to ensure that a groove of the magnetic field is not created on the screen, 12 coils (three vertical and four horizontal) are laid on the 12 cm$\times$17 cm screen. In this study we focused on the upward force of ferrofluid. When Viscosity changes, the force pushing up the finger by vibration created by switching the magnetic field in the electromagnet.

The Electrostatic force part uses a conductive electrode. This part of the system provides haptic feedback using electrostatics adhesion. Furthermore, it also provides high-voltage electric vibration to the electrode (Figure 1 (d)). When a body is connected to GND and an electrode is struck, force is generated. Force is generated in the direction where a movement is resisted; therefore, the frictional force is generated. In this study, a transparent conductive film on the electrode, the insulation coating agent (Hayacoat), was applied as the insulating layer. The insulator is pitched by the electrode and the finger, and therefore, electric current does not flow into the human body. Even if it flows into the human body, it is restricted to 0.5 mA electric current, as there are constant current diodes of 0.5 mA on the GND side that is connected to the human body.

Arduino Due and a personal computer are used for the control of a circuit (Figure 2 lower). A finger that attached a marker is tracked with a camera, and the tracking position is used as input. A projector sends the image to a device based on the location of the tracked finger. An electronic signal is sent to the electromagnet and the electrode with a signal generator based on a tracked coordinate.

4 Application

Application to express various textures is possible (Figure 3 (a)(b)). In order to do this, we change the frequency of the signal which adds to electrode and electromagnet. TeslaTouch express texture using friction, our application expresses texture using the force of magnetic fluid in addition to friction.

It is possible to assist GUI operation by using the Push-Pull haptics.

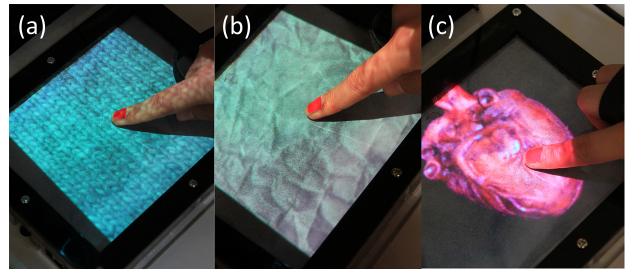

Figure 3: *(a) Wool texture rendering; (b) Paper texture rendering; (c) reproduction of the heart motion*

As an example, it is Drag & Drop which is a basic operation of GUI. Our application produces friction using electrovibration when you are dragging files, icons, and other draggable items. It makes a tactile illusion that is similar to have things in the real world. When things come to destination, we change stickiness of ferrofluid. The user can judge whether it is destination by hardness of the surface. This can become useful guide to operation, and the moving speed to destination is faster.

Cross-field haptics can express the body tissue such as the heart and the liver (Figure 3(c)). In the medical field such as the operations, accurate movement to match the state of the body tissue is essential. The exact behavior is performed easily if the body tissue can be expressed. To reproduce the organs, the texture of the surface, viscosity such as softness, and vibration such as pulsation is a need to express. Surface texture can be expressed in electrovibration, the viscosity and deformation can be expressed using the ferrofluid.

In this study, we developed a method that combines multiple haptics technologies. This method generates multiple direction force (up and down, pull) using the ferrofluid and the electrovibration. We discussed width of the sense of touch presentation spread from an experiment of cross-field haptics. However, there are some problems. Because of vibration by the ferrofluid is big, friction feeling of electrovibration is weak. It is necessary to regulate electricity to add to an electromagnet. In a process of implementation, there are some difficult points including the method to put an insulation film on the electrode and handling of the ferrofluid. It will be necessary to think about simpler method for implementation in future.

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