Hairlytop interface: an interactive surface display comprised of hair-like soft actuators

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ABSTRACT

There has been much research on interactive surface displays, which are displays that can change the geometric state of their surfaces actively. Most of these displays consist of multiple haptic units, which are composed of pins that actively move up and down. The envelope of these pins mimics the surface shape of an arbitrary object. However, it is difficult to improve the spatial resolution of such displays and to enlarge the display area because of the physical complexity. In this research, we propose the hairlytop interface, which is a collection of hair-like soft actuators composed of shape memory alloy. The proposed interface is capable of improving spatial resolution and can be used in developing larger surface displays. This paper details the hairlytop interface and discusses assumed applications.

KEYWORDS: Surface display, haptic, tabletop, soft actuator, shape memory alloy.

INDEX TERMS: H.5.2 [Information Interfaces and presentation]: User Interfaces—Haptic I/O;

1 INTRODUCTION

An interactive surface display is a haptic display that can change the geometric state of its surface interactively. It is often called a shape display. Such a display consists of many haptic units composed of rigid pins with actuators. Actuators of haptic units are used to move pins upward and downward, so as to mimic the shape of an arbitrary object with the envelope of the pins. In this research area, improving spatial resolution of such display is considered as a big issue. In addition, lack of flexibility for display configuration may also become an issue to be solved.

The above problems strongly relate to the mechanical aspect of haptic units. In much previous research, DC motors have been used as the actuators of haptic units. The rotational motion of them is converted to suitable linear motion by using mechanical gears or links. They are appropriate materials for moving pins with sufficient power and speed. However, it is difficult to reduce the size and weight of such mechanical stuffs while keeping certain durability. To solve these problems, research has focused on using shape memory alloy (SMA) as a small and linear actuator of a haptic unit[2][3]. SMA is capable of to be composed of linear actuator, then mechanical gears are not essential to haptic units. The fact contributes reduce the size and weight of them. Then surface displays with higher spatial resolution have subsequently been developed.

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Despite the above improvement in spatial resolution, a lack of flexibility remains a big issue. Enlarging the display area requires a sufficient number of haptic units to fill the area. All units are fixed to a frame, and there are multiple wires carrying power and carrying signals from each haptic unit to central computers. When expanding the display area of a typical N × N pin matrix shape, the overall task increases in proportion to N^2. For some systems, the complexity of control information has been reduced using switching technology such that it is proportional to 2N[2], while other aspects are remains as problems. Then, it is still difficult to expand the display size in terms of hardware. A greater number of smaller, lighter haptic units are therefore required.

To solve the above problems, we developed the hairlytop interface, which is consists of a collection of SMA based haptic units and light sources with capacitive touch sensors such as a liquid crystal display (LCD) capacitive touch screen. Each haptic unit has light sensitivity and is placed over the light source. SMA on each haptic unit bends according to the light intensity. Then, bending state of all haptic units is controlled by the light pattern, i.e., images on the LCD. In addition, each haptic unit has conductivity then touch event on the haptic unit can be detected through the capacitive sensor under haptic units, i.e., the capacitive touch screen. Overall, hairlytop interface dos not need any wires except for power lines. Control information and touch sensation function are processed by the LCD capacitive touch screen. Just placing sufficient number of haptic units on the screen, hairlytop is able to work as an interactive surface display.

2 RELATED WORKS

Many shape displays have been developed in the field of haptic research area. In the early days, DC motors based displays are often proposed. In 1997, Iwata et al. proposed FEELEX1[1]. The haptic unit of it was composed of a DC motor, an optical encoder, a linear rod and a force sensor. 6 × 6 haptic units are arranged within the 24 cm × 24 cm area. Then they try to improve spatial resolution, they developed FEELEX2[1]. They succeeded in improving the resolution by using piston-crank mechanism instead of linear rods. The resolution of it is 8mm, 23 rods are arranged within 50 mm × 50 mm display area. However, DC motors are bigger than the resolution, then motor housing area of FEELEX2 becomes quite large. That makes them difficult to enlarge display area. PopUp! by Nakatani[2] and Lumen by Poupyrev[3] are making use of SMA as actuator for their haptic units. The characteristic of the PopUp! is its spatial resolution. The resolution of the PopUp! is 5mm, 16 × 16 pins are used. By using SMA as actuator, they succeeded in developing smaller haptic units. The Lumen also making use of SMA as actuator, resolution is about 7 mm, 13 × 13 pins are arranged within 84 mm × 84 mm area. The resolution of the Lumen is slightly lower than the PopUp!. However, the Lumen is capable of displaying simple image on it and touch sensitive, which are functions that the PopUp! does not have. The touch sensitivity is essential for interacting with such displays. Although the haptic units of these two systems are smaller than the FEELEX, they are also difficult to enlarge display area because of complicated hardware configuration.

Matoba et al. proposed ClaytricSurface[4], is a kind of shape display that can change its rigidity dynamically. That is composed of air-sealed bag which is filled with particles, and vacuum pump. The bag have clay-like feel then the user can deform its shape freely. After deforming, let the air out of the bag by using the vacuum pump, the deformed shape is fixed. At the same time, user can feel the transition of rigidity, which is adjusted by the air pressure. Jamming user interface by Follmer et al. works with the almost the same principle[5]. They use oil instead of air to be used with rear projection systems. Both systems have extraordinary higher spatial resolution. In addition, these systems are quite easy to enlarge the display size. However, these systems do not have ability to deform their own shape actively.

For providing geometrical information to user's hand, magnet or electrical is also used. Jansen proposed Mudpad[6], which use magnetorheological (MR) fluid and arrays of electromagnets. A pouch filled with MR fluid covers the electromagnets array. The viscosity of the fluid changes according to the activation of the electromagnets, which brings users a certain tactile feeling. The system actually can display partially differentiated tactile feeling, the resolution depends on the resolution of electromagnets. That is quite difficult for improving the resolution and enlarging the display area. Bau et al. proposed TeslaTouch[7]. They are making use of electrovibration principles[8] to add attractive force between fingers and display. The spatial resolution is quite high and that is easy to enlarge the display area because that does not have any moving parts. However, the attractive force is quite small comparing to the physical force which can be felt when we stroke the surface shape of an arbitrary object.

Raffle et al. proposed a system named Super Cilia Skin[9], which is composed of a matrix of a kind of artificial cilia that are anchored to an elastic membrane. The bottom of each cilia, a magnet is installed. Then slant of each cilia is controlled by the electromagnets under the membrane. This system can display images or physical gestures. However the system is difficult to improve spatial resolution and enlarging the display area because they use electromagnets for their haptic unit. Coelho proposed Sprout I/O[10] which is composed of a matrix of rectangle shaped felt which is SMA stitched. The felt bends by the force generated from the SMA. By controlling bending of each felt, that can generate a certain tactile feeling and visual motion. By using felt as a haptic unit, the system succeeded in reminds us a kind of animal-like feeling. However, it is also difficult for improving spatial resolution and enlarging the display area.

3 System Overview

3.1 Prototype system for feasibility study

Figure 1: is an overview of our hairlytop interface. The hairlytop interface is a collection of soft haptic units made of SMA, a photodiode and electroconductive rubber as shown in Figure 2:. Many soft haptic units are placed on a LCD touch panel. By controlling the bending and restoration of SMA independently, the envelope should be able to mimic an arbitrary shape.

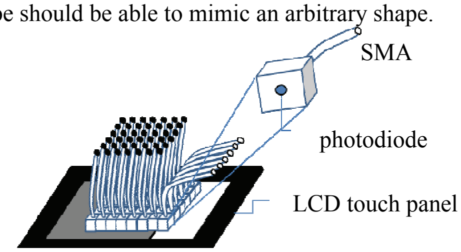

Figure 1: Overview of the hairlytop interface

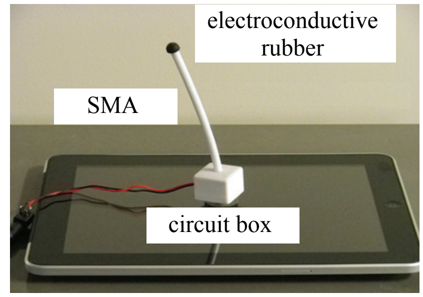

Figure 2: First prototype of a haptic unit for the hairlytop interface

To control the bending status of the SMA, we use an optical signal from the LCD touch panel, which is a known display-based computing method[11]. The photodiode of the haptic unit measures the brightness immediately below to control the current supplied to the SMA. The SMA then bends according to the brightness of the pixel as shown in Figure 3:. In the figure, the LCD panel becomes brighter from (A) to (C), and at the same time, the amount of bend increases from (A) to (C). Figure 4: shows the detailed relationship between the brightness and the amount of bend. Points labeled (A), (B), and (C) in Figure 3: and Figure 4: indicate the same situation. The amount of bend in the figures refers to the vertical displacement of the top of the haptic unit from its original position.

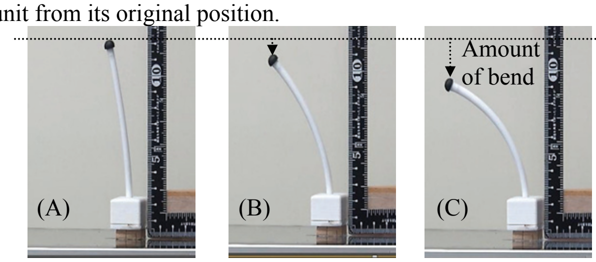

Figure 3: SMA of the haptic unit bends according to the brightness of the LCD panel below

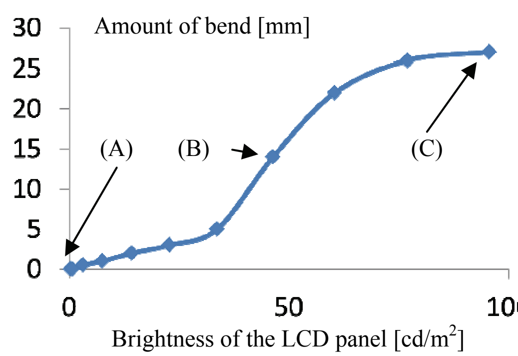

Figure 4: Relationship between brightness and the amount of bend

The haptic unit of the hairlytop interface is capable of recognizing a touch event. We simply use two pieces of electroconductive rubber to make use of the function of capacitive touch panels. The rubber pieces are set on top and underneath each haptic unit (Figure 5:), and are connected to each other. When the user touches the top of the haptic unit, the transition of the electrical state is transmitted to the conductive rubber underneath the unit, so that the capacitive touch panel detects the touch event. Similar detection technique is used in SQUEEZY[12]. Figure 6: shows the touch detection of the haptic unit for the hairlytop interface. The left picture in Figure 6: shows the scene immediately before the unit is touched. The right picture shows the scene immediately after the unit is touched. In this figure, a simple application, which changes image's color from black to white when the LCD panel is touched, is used for showing the touch detection function. Then the user touches the unit, the touch panel detects the event and changes color from black to white. The SMA of the haptic unit then bends according to the brightness of the LCD panel.

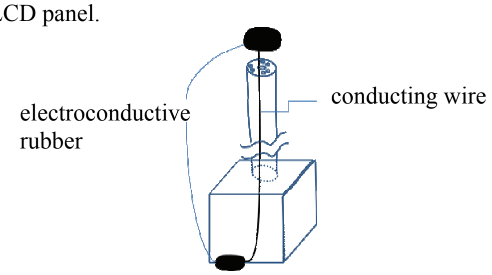

Figure 5: Schematic diagram of the detection method of the touch event

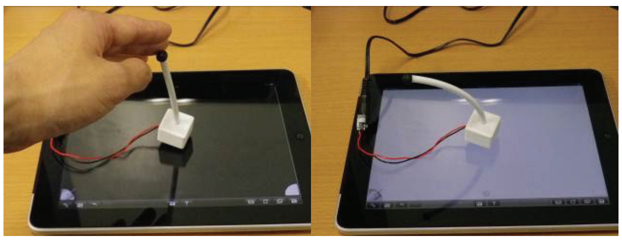

Figure 6: Detecting a touch event (left: immediately before the touch; right: after the touch)

3.2 Development of fine haptic units

To develop an interactive surface display of higher quality, the spatial resolution of haptic units must be improved. However, the size of the current circuit box is about 25 mm along each axis, which is too large for the units to be placed with high density. In this section, we introduce a second prototype of the haptic unit that can be placed with higher density. The overview of the second prototype is shown in Figure 8:. This prototype has SMA (BMF75, TOKI Corp.)of 50 mm in length and a drive circuit with a photodiode (NJL7502L, Japan Radio Co., Ltd.) and two transistors (2SC1815, Toshiba Corp.). The weight of the unit is less than 1 g, and the base is a maximum of about 6 mm in each direction. Using surface mount device should contribute reducing the size of each unit. That should lead to improvement of spatial resolution. Figure 7: shows a prototype system which comprised of 9 fine haptic units. Those units are arranged within 3 cm × 3cm. Maximum bending force of each unit is about 1 gf. Developed haptic units are flexible in their configuration. Figure 1: shows several arrangements of interactive surface displays based on this technology.

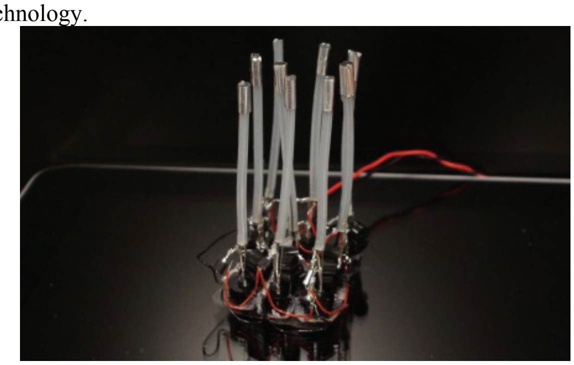

Figure 7: Nine haptic units for the hairlytop interface are arranged in dense format

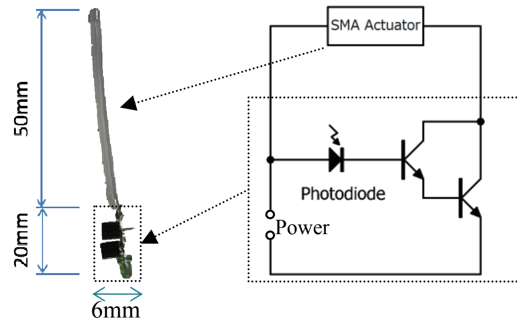

Figure 8: Overview of the second prototype of the haptic unit for the high-density version of the hairlytop interface

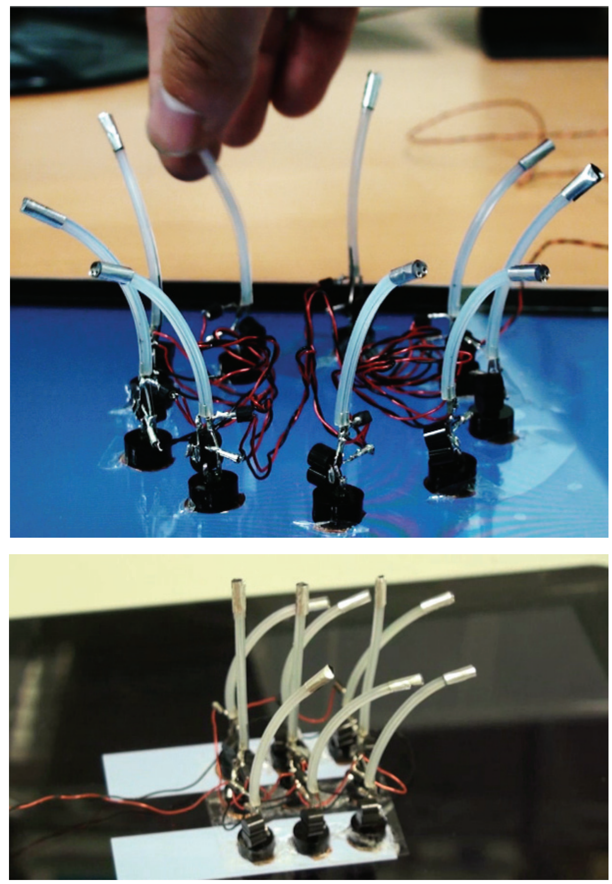

Figure 9: Arrangements of the second prototype of the hairlytop interface (top: haptic units placed in a circle, showing touch sensitivity; bottom: haptic units placed in a square, showing light intensity sensitivity)

To show larger motion, a longer version of haptic unit was constructed (Figure 10:, left). Then refresh rate of this haptic unit is measured. Refresh rate in this system means the bending and restoration speed. Figure 10: (right) shows the transition of the amount of bend when light intensity changes from zero to a maximum (approx. 100 cd/m^2). As shown in the figure, it takes about 3 seconds for haptic units to bend fully. In around 1 second, the unit can bend to 80% of its maximum. Figure 11: shows the recovering transition of the haptic unit. After the unit is fully bent for a while, the light intensity changes from a maximum to zero. The haptic unit can recover 90% from the maximum bending state within 1 second.

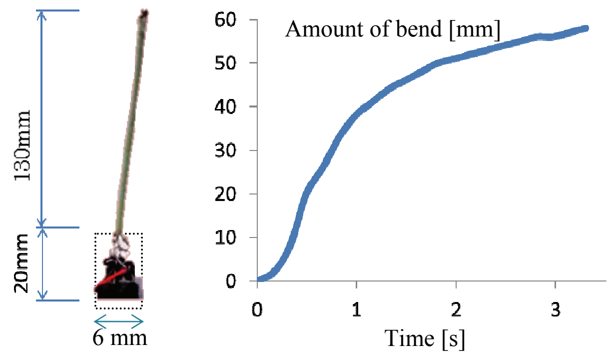

Figure 10: Right: longer version of the haptic unit; left: transition of bending

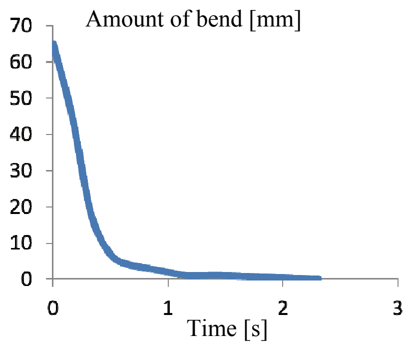

Figure 11: Transition of recovery

4 Discussion

The hairlytop interface is a collection of soft and fine haptic units. Each haptic unit is lightweight and capable of bending according to the light intensity beneath. In addition, it is also capable of detecting a touch event. The structure of each haptic unit is quite simple and fine which should contributes improving spatial resolution of surface displays. Furthermore, developed haptic units are flexible in their configuration. By placing sufficient number of haptic units on a LCD capacitive touch screen and connect them each other to supply power, it can be used as an interactive surface display.

To use the hairlytop interface as a kind of shape displays, more spatial resolution should be required. The basic concept of the hairlytop interface comes from carpets. Carpets can be used as a kind of canvas by stroking on it with fingers. The bending pattern of piles which is formed by the stroke enables us to feel geometrical shape. Then, it can be said that the goal of this research is making a kind of active carpets. Toward the research goal, improvement of the spatial resolution is necessary. In addition, actual amount of bend of each haptic unit should be able to measured, which is not implemented yet. This means, current prototype systems lacks of accuracy in the amount of bending. Therefore, it is required to be equipped with a certain method to measure the amount of bend. It is known that there is a prescribed relationship between electric resistance and displacement of SMA, which is often used to measure the actual length of it[13]. Then in the future, we will apply this method to the hairlytop interface to measure the actual amount of bend of each haptic unit.

The hairlytop interface is composed of a dense, matrix of soft actuators. If it is possible to extremely improve spatial resolution, it should become a real hair-like interface. Hairs and furs are focused as an interface in the affective haptics area[14][15][16][17]. However, most of research related to such fur interface focus on affective aspect of passive furs or on detecting touch event or hand gesture above them. Furukawa et al. proposed fur interface that can control its erection[17]. However they have to use real fur to control it. Furthermore, they can not control erection of each hair. On the contrary, the hairlytop interface can fully control each unit's bend. The current issue is about the spatial resolution, again. The density of hair is ten times as that of carpets. To overcome this, smaller haptic units are required as a matter of course. For further improvement, densely installing passive hair-like units among those active hair-like units is considered. It should be possible to bend passive hair-like units, such as real hair, by bending active ones. Then in the future, the hairlytop interface can be used as a fur-like interface for animal robots to improve emotional communications between human and robots.

5 Conclusion

In this paper, we propose an interactive surface display with a hair-like interface named "Hairlytop Interface". That is a collection of soft haptic units, which composed of SMA, a photodiode and electroconductive rubber. Each haptic unit is light sensitive therefore bending of SMA can be controlled by the light from LCD panel immediately under the units. In addition, by using LCD capacitive touch panel, hairlytop interface capable of detecting touch event. Each haptic unit is lightweight and fine then it is considered to be able to compose a surface display with high density. Furthermore, each haptic unit does not need signal wires to be controlled their bending state because they are controlled by the light from LCD panel. That reduces complexity for composing surface a display system and improves flexibility of hardware configuration. Improvement of spatial resolution and applying this concept to affective haptics research field is our future work.

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