# An Interface Composed of a Collection of “Smart Hairs”

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## ABSTRACT

The smart hair is the basic component of the hairlytop interface, which is a visual/haptic interface patterned with smart hair. The hair is composed of shape memory alloy(s), drive circuit(s), and light sensor(s) capable of controlling their bending. The bending of each smart hair is controlled through the intensity of light from below. The high flexibility in its configuration and unique motion enables us to construct various types of interface. In this paper, we describe details about several prototypes of the hairlytop interface. In addition, we also report experimental results from an evaluation of the accuracy in flex-control of the smart hairs.

## Categories and Subject Descriptors

H5.2 [**Information interfaces and presentation**]: User Interfaces – *Interaction styles*

## Keywords

Smart material interface; smart hair; hairlytop interface; shape memory alloy; soft actuator; haptic; surface display.

## 1. INTRODUCTION

A collection of filament-like materials, such as hair and piles of carpets, have enough potential for being a human interface if their shape is controllable. Many animals’ hair is an indicator of emotion; for example, bristled hair often indicates anger. This method of expression is also used by designers of robots[6] and in cartoons and animations to enhance emotional poses. Several studies have been conducted to develop artificial hair that could be used as an effective interface [3][4]. Alternatively, rich carpets could preserve footprints as one walks over them. That shows capability of carpets for being a kind of shape display, if bending of each pile are independently controllable [1][11].

A coating of filamentary materials, the shape of each being controlled independently, would be beneficial in constructing various types of human interfaces. In this paper, we call such materials “smart hairs”. Coverings of smart hairs at various densities could be used as a shape display. In addition, by covering arbitrary-shaped objects with smart hair, these objects would provide a new medium for expressing emotional information. As the fundamental unit in constructing a variety of interfaces, smart hairs should satisfy the followings conditions:

- Fine and lightweight
- Flexibility in configuration
- Real-time control

First, the acceptable size and weight of the smart hairs differs from applications. However, making it finer and lighter should contribute widen applications. For example, when covering an object with the smart hair, the density should directly affects what it looks like. That is the same as real hairs of animals. Therefore, density of smart hairs should be designed easily. On the other hand, higher density of the smart hairs is preferable when developing a shape interface. That is because the density of the smart hair means the resolution of the display. The simple solution about improving the density is to develop finer smart hairs. At the same time, covering a certain area with finer hairs requires more numbers of smart hairs. That extremely increase the weight of the whole system. Then lighter smart hairs are also preferred for ease of use. Second, as a fundamental material, smart hairs should be easily equipped on the surface of arbitrary shape of objects at arbitrary density. The easy equipment also contributes decreasing the load when integrating an enormous number of smart hairs. Then flexibility in integration is necessary. Third, when the number of the smart hairs increased, control delay should become a major problem. If the shape of the each smart hairs is controlled serially one by one, the total control delay will become extremely large. To control all the smart hairs in a real time, some sort of parallel control mechanism is required.

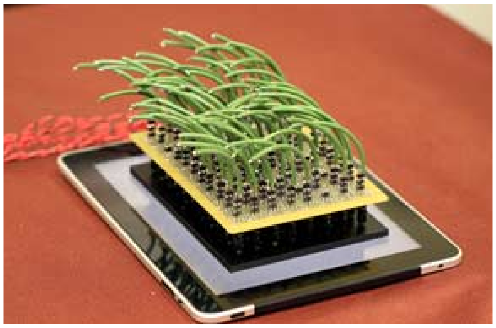

**Figure 1 Prototype of the hairlytop interface**

In this paper, we describe a variety of hairlytop interfaces, which form a collection of newly developed smart hairs that satisfies these conditions [11][12](Figure 1). The smart hair developed is a light-sensitive, flex-controllable hair, which is composed of a soft deformable material, a fine actuator, a drive circuit, and an optical sensor at the bottom of the unit. The actuator of this smart hair is composed of shape memory alloy (SMA) imbedded within a thin

*SMI’13*, December 13, 2013, Sydney, Australia.

http://dx.doi.org/10.1145/2534688.2534692

cylinder of silicone. The current size and weight of the smart hair is less than 6 mm and 1 g, as described in section 3.1.

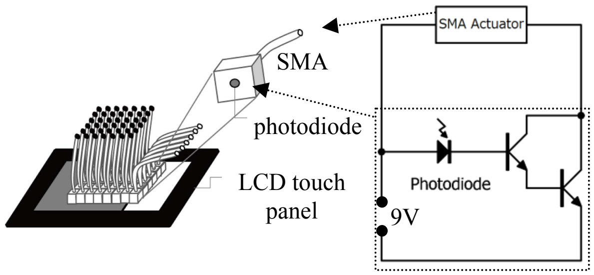

**Figure 2 Conceptual view of the hairlytop interface and its basic drive circuits.**

The drive circuit controls the bending of the silicone tube, according to the light intensity from downward (Figure 2). This kind of control method is known as Display-Based Computing (DBC)[15]. By the virtue of this method, the shape of the all smart hairs are controlled at the same time through the light pattern. Any light pattern source is available such as LCD panel, LEDs, etc. In addition, using DBC enables the smart hairs to eliminate control signal wirings. This could simplify the configuration of each smart hair, which contributes improving the flexibility of integration.

## 2. RELATED WORKS

A collection of soft, filamentary materials is often used for composing various types of interfaces. Nakajima et al. developed a system that is composed of a collection of optical fibers[8]. This system is designed to realize a furry texture surface that affords various interactions such as stroking or clawing. However, it is not equipped with any actuators to move the fibers. “Super cilia skin” is a system composed of arrays of magnet equipped small units[14]. Those units could oscillate in response to a magnetic force. This means, a magnetic source is necessary under the skin, which is not desirable for achieving flexibility in configuration. Minuto et al. developed the “Follow the Grass” system, composed of a collection of bend-controllable artificial blades of grass[7]. This system is a kind of interactive pervasive display that could feature animation by moving their bending sequentially. The size of each unit of the system is larger than the smart hair that we have developed. The most typical, “a collection of soft, filament-like materials”, should appear like the hair and fur of animals. Much research has focused on this aspect. Flagg et al. developed fur interface that could recognize touch gesture[3]. They focus on the context of emotional touch between a person and a furry social robot. However, their fur system was not shape changeable. Furukawa et al. focus on fur as output media[4]. They developed a new fur system that could control its bristling by using vibration motors. Unfortunately, their preliminary results showed that artificial fur does not have bristling effects by vibrations. Then it is necessary to use natural fur for making use of this effect, which is not desirable for developing actual applications.

In the research area of shape interface, hair-like soft actuators are not so common. Many of them are composed of a collection of rigid rods and DC motors [5]. In those systems, rigid rods and motors are tightly configured to the frame, which makes them heavier and less flexibility. Instead of using DC motors, some systems are developed that use SMA as an actuator. Taylor et al. developed a system using 64 SMA as actuators[16]. PopUp! by Nakatani[10] and Lumen by Poupyrev[13] are also making use of SMA as actuator of such shape interface. Using SMA is beneficial for making simpler actuation mechanism comparing to using conventional DC motors. However, using SMA does not have so much contribution for decreasing weight and improving flexibility.

SMA is also used as a soft actuator. Coelho et al. developed a system composed of a collection of flex-controllable SMA-stitched-felt[1]. Two directional movements of the felt provide structural as well as visual and textural quality. Nakayasu et al. developed a system named “plant”, which is an application of their proposed shape memory alloy motion display. The plant is composed of 169 artificial leaves made of SMA to represent rustling of natural leaves [9]. However, those systems also do not have enough flexibility in their configuration. In their system, every unit is tightly configured. Then, it is hard for them to change the density and placement patterns of them.

## 3. PROTOTYPES OF HAIRLYTOP INTERFACES

In this chapter, a variety of hairlytop interfaces are briefly described.

### 3.1 Sparsely arranged type

One of the characteristics of smart hairs is their flexibility in configuration. Each hair can move independently just by supplying power and light signals. Our prototype of this interface is composed of a SMA (BMF75, TOKI Corp.) of 50-mm 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 about 6 mm across in each direction. Figure 3 shows two patterns of arrangements of the hairlytop interface using nine smart hairs. The hairs are arranged 3 cm by 3 cm apart. The maximum bending force of each unit is about 1 gf.

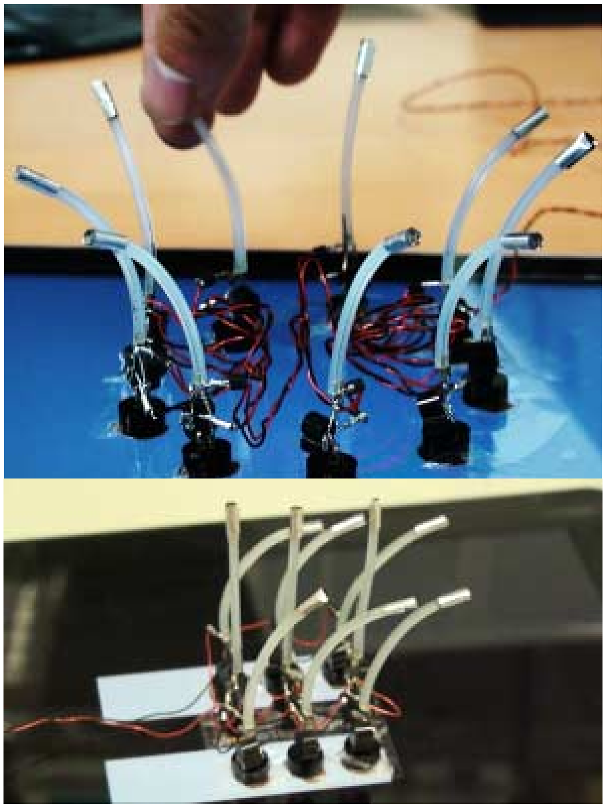

**Figure 3 Sparsely arranged hairlytop interface**

## 3.2 Touch detectable type

When combined with a capacitive touch panel display, the smart hairs are capable of recognizing a touch event. To achieve this, two pieces of electroconductive rubber are used. The rubber pieces are attached to each end of a smart hair (Figure 4), and are connected by wire to each other. When the user touches the top end, the transition of the electrical state is transmitted to the conductive rubber at the other, so that the capacitive touch panel detects a touch event, as shown in Figure 5. A similar detection technique is used in SQUEEZY[18].

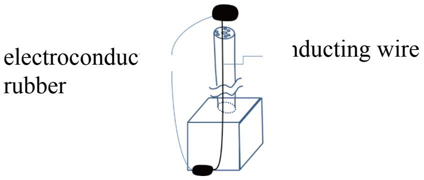

**Figure 4 Schematic diagram of touch detection**

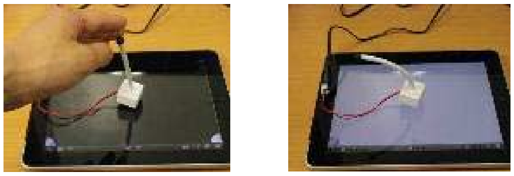

**Figure 5 Detecting a touch event**
**(left: immediately before touch; right: after a touch)**

## 3.3 Multi-directional bendable type

Integrating new functionality into smart hairs that is not present in conventional hairs can also contribute to widening the scope of applications. Thus, we developed new smart hairs that could bend in any direction (see Figure 6). This prototype consists of 9 hairs placed in a 35 mm square, which could bend in any direction. In each of the smart hairs, three SMA actuators located around the circumference of inner silicon tube (Figure 7). Three optical sensors are directly connected to each of the SMA actuators. The amount and direction of the bend of the silicon tube is controlled through the sensors by using circle shaped images(Figure 7).

**Figure 6 Multi-directional type of the hairlytop interface**

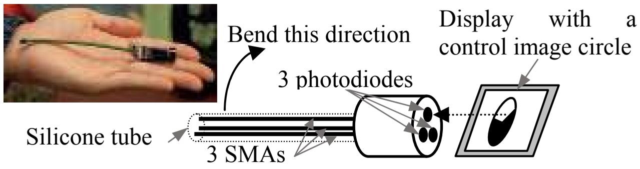

**Figure 7 Schematics of a multi-directional bendable type of smart hair**

## 3.4 Large type

Figure 1 shows a prototype of a large hairlytop interface which is composed of 88 smart hairs arranged in an 11×8 array, and spaced 1.2 cm apart and at 2.5 cm intervals. The DBC method, providing the collective control of all the actuators through images on the display, is enabled without being affected by density and numbers of smart hairs.

# 4. BASIC EVALUATION

In this section, several experimental results and some improvements are described.

## 4.1 Power consumption

The maximum current that is supplied to each SMA of a smart hair rises to 200 mA at 9 V. The power consumed by the interface increases rapidly for large hairlytop interfaces requiring a large number of smart hairs. Reducing the current required is an important problem. For that purpose, the pulse width modulation (PWM) control method is often used. An experimental drive circuit is shown in Figure 8. The power consumption between the previous version of the drive circuits that is used in the prototypes described above and the experimental one was compared. The result (Table 1) shows that the PWM control method succeeded in reducing the power consumption while retaining the same amount of flex.

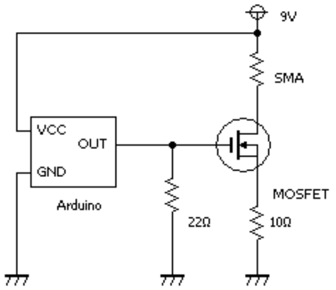

**Figure 8 PWM experience circuit**

**Table 1 Comparing consumption electricity**

| | Continuous current (Former drive circuit) | PWM control (Experimental drive circuit) |
|---|---|---|
| Power consumption | 1.176 W | 0.2942 W |

## 4.2 Deviation in flex

Our prototype of a large hairlytop interface was composed of smart hairs that could bend in only one direction. Observations from the motion of those smart hairs, the deviation of the amount of flex and its direction, seemed to be relatively large. Therefore, two experiments were conducted to evaluate these deviations and the results are described below. In this experiment, the PWM control circuit was used to drive the hair samples.

### *4.2.1 Deviation in the amount of bending*

In evaluating the deviation in the amount of bending, two smart hair samples were measured. The results (Figure 9) showed over a 30-mm difference between the two samples. By a detailed inspection of these smart hairs, it was found that the lengths of the SMA were slightly different. In addition, the connections between the SMA and the drive circuit were not exactly the same. These slight deviations in physical configuration might result in deviations in the amount of bending.

### *4.2.2 Deviation in bending direction*

Smart hairs that were used in the prototype of the large type of the hairlytop interface were designed to bend in only one direction. However, a large deviation in bending direction was observed between each smart hair. To evaluate the deviation, five smart hairs were sampled to measure bending direction. Figure 10 shows the method of measurement for this experiment. Each smart hair is placed at the center of the two protractors set back-to-back. The designed flex direction was set to 0 degree. Then, after flexing the hair, the actual direction was measured. The results (Table 2) show that the bending direction greatly differs from −45° to 40°. Further inspection showed that this deviation came from conditions of implementation between the SMA and the drive circuit. Overall, improvement of the manufacturing process is necessary to improve the flex dependability of smart hairs.

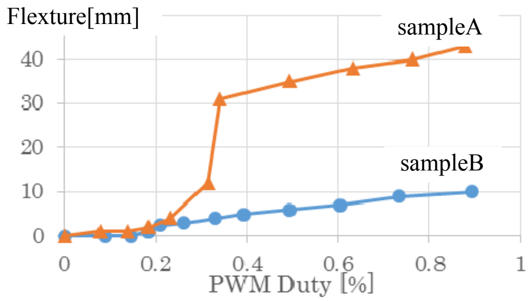

**Figure 9 Deviation in the amount of bending between two samples of smart hairs**

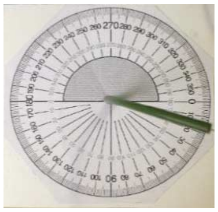

**Figure 10 Experimental setup to measure bending direction.**

**Table 2 Scatter in flexural direction**

| Sample Number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Flexural direction angle [deg] | -7 | 40 | -17 | -11 | -45 |

## 5. CONCLUSION

In this paper, we described the smart hair concept. Various prototypes of hairlytop interfaces based on different types of smart hair are also described. Smart hairs have ample potential for being a fundamental unit that could combine to form various human interfaces. For future work, our research group will continue to develop such interfaces. For example, it is easy for smart hairs to change their appearance. Then, combining a smart hair with real fur will contribute developing more realistic “fur-like” interface. Furthermore, we also considering combining the smart hair with a cluster of optic fibers or small visual displays. That could make the hair as a kind of shape changing visual display[1]. In addition, improvements in manufacturing processes are to be performed.

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