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3D Form Display with Shape Memory Alloy

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Abstract

We propose a new display for presenting 3D forms using a pin-rod matrix. Due to a long range of movement, it is capable of displaying large-scale, dense objects such as human faces or geographical features. In this work, we use a coil-form Shape Memory Alloy (SMA) as a pin-rod actuator. The prototype has a 4×4 pin-rod matrix, with a 120[mm] range of motion (which is longer than previous works), a 12[mm] pin interval and a 1[mm] interval for height accuracy. The pin-rod matrix conveys visual depth information and is designed to be touchable, so our goal is to develop a display that appeals to both the eyes and hands.

Key words: 3D Display, Shape Memory Alloy, Touchable Screen, Tactile Display, Haptics

1. Introduction

Displaying features of real objects in virtual environments has recently attracted considerable research interest in the rapidly developing field of Virtual Reality technology. Many studies have been performed on various aspects of the process, such as acquiring digital shape information of an object with a rangefinder, transmitting the data over a network, and displaying it in a remote location.

By far the most common technique for displaying acquired 3D-information is representing shapes with geometrical primitives, and presenting them visually through computer graphics on a visual display such as a monitor or a projection surface [1].

Another technique that has attracted a great deal of attention is displaying shape attributes through the sense of touch. One example is a haptic display called FEELEX developed by Iwata [2], comprised of an array of linear actuators and a flexible screen. Although this type of display is successful at realizing natural interaction with the bare hand, it is limited in its expressiveness because it is very difficult to construct a pin-rod matrix type shape display with high density and a long pin stroke at the same time.

Some displays use piezoelectric ceramic as an actuator, but they have only a short range of movement so they cannot display large-scale objects. Other displays use a servomotor [2][3] to actuate pin-rods, but the actuator has a relatively large volume so it is difficult to realize a dense pin matrix. Because of these challenges, a pin-rod matrix display with both high density AND long range of movement has not yet been realized.

In this work, we propose a 3D shape display with long stroke pin-rods using as an actuator a coil-form Shape Memory Alloy (SMA), material that can be stretched or deformed from its original shape but would spontaneously return to its original shape when heated. SMAs are able to provide a significant amount of mechanical work due to phase transformation during heating, and have been applied in many different fields to date, such as medicine [4], industry [5], tactile display [2][3][6], daily commodity [7], and so on.

Although there have been a great variety of studies, it is not popular to use SMA as an actuator, possibly because it is very difficult to control this material completely. This difficulty stems from its hysteresis: it doesn’t move instantly after applying heat and needs time to shrink with cooling. This leads to a serious problem with frequency response. Although SMA has apparently been used as an alternative to existing actuators, this approach isn’t very actively pursued; there have been few studies and papers on controlling SMA [4][8][9].

Nevertheless, because of the inherent flexibility and compactness of SMA, it is quite worthwhile to consider its characteristics and potential to be used as a smart actuator. In the next section we discuss the basic characteristics of the shape memory alloy we use, and show some preliminary results from evaluating this actuator. After an overview of the structural components, we report the implementation version of 3D shape display, and examine the position sensor and consider a novel way to obtain positional information. We discuss the basic theory, and show preliminary results. The final section discusses future applications for this type of haptic display that allow us to both see and touch real objects represented in virtual space.

2. Method

2.1 Actuator

The characteristics of the SMA actuator we use, Bio Metal Helix 200 (manufactured by Toki Corporation), are as follows: it can be extended to twice its original length, and ~~it~~ contracts to its original length by heating. A single SMA is very thin (0.85[mm] in diameter), so it is possible to place densely in a pin matrix, while it has enough power to produce a 30[gf] force. We contract the SMA by simply applying an electric current and producing Joule heat.

Fig. 1 shows the results of evaluating an SMA actuator by applying 12[V] under various cooling conditions. SMA contracts rapidly and extends slowly under the no cooling condition. On the other hand, SMA moves relatively little under constant cooling from an electric fan, and doesn’t move at all under soaking with coolant (42-50% ethylene glycol, 18.5℃). The fastest response condition is not cooling when SMA is actuated, and cooling with an electric fan when need be contracted.

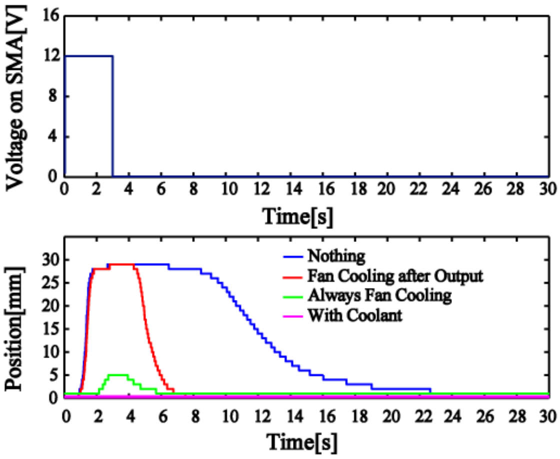


Fig. 1: Evaluating SMA under various conditions

To investigate improvements to the frequency response, we applied a 40V pulse with various frequencies under soaking with coolant, using the experimental system shown in Fig. 2. Fig. 3 shows the frequency response of SMA, suggesting that it is possible to apply high voltage for speeding up the response under appropriate cooling conditions without damaging SMA.

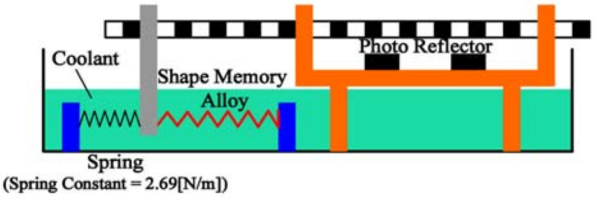


Fig. 2: Experimental System of Frequency Response

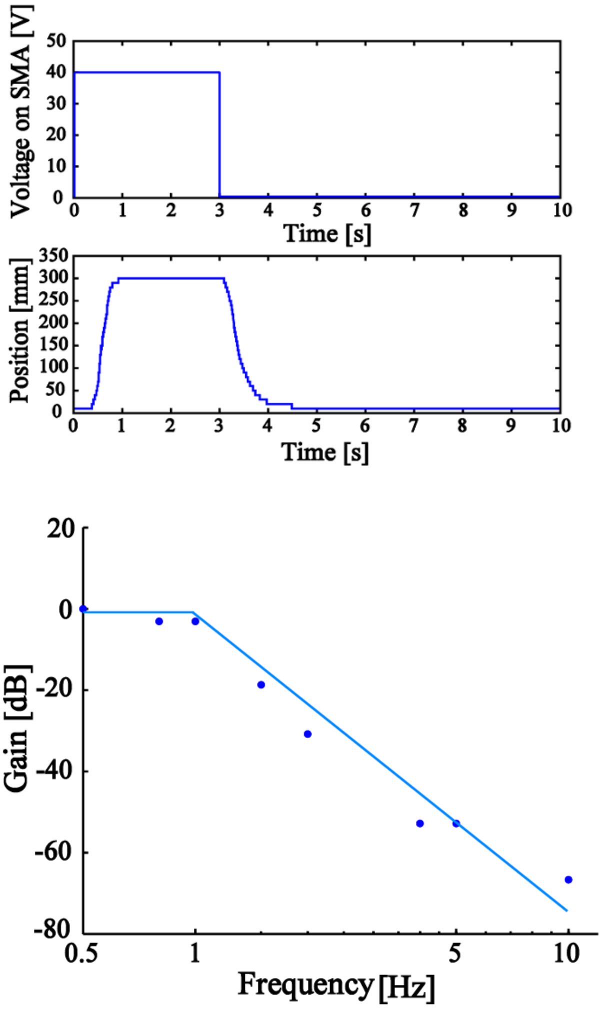


Fig. 3: System Response of Pulse (upper) and Frequency Response of SMA (below) 40[V] input under cooling with coolant, 18. 5℃, and SMA is always pulled with the spring (spring constant *k* = 2.69 [N/m]) according to the expansion from natural length.

The range of motion depends on the SMA length. In the preliminary experiment for a 1[m] rod (42.1[gf]) with SMA (750[mm]), the pin-rod is actuated at 500[mm], and a longer length is possible for larger device units (Fig. 4).

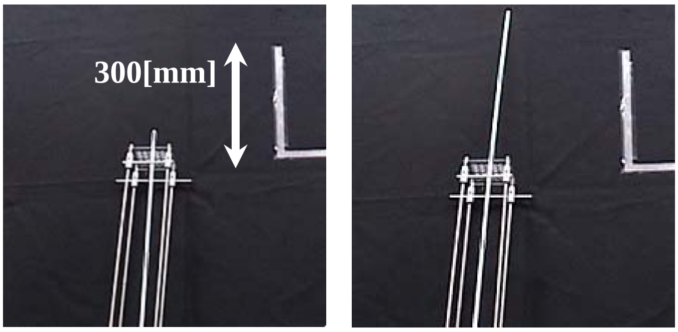


Fig. 4: Range of Motion Experiment

2.2 Position Sensor

Because SMA provides no feedback on its transformed shape, the actuator component becomes an open loop that must be closed by detecting the position of the pin-rods. Each pin-rod requires its own respective position sensor, so each sensor must be small and thin. For this reason, we selected a pair of photo reflectors (SANYO, SPI-315-34, dimensions 4.0×3.4×1.5[mm]) that read black and white stripes printed on the pin-rod itself (Fig. 5). Background noise can be filtered with a slit (1[mm] window width) covering the photo reflectors.

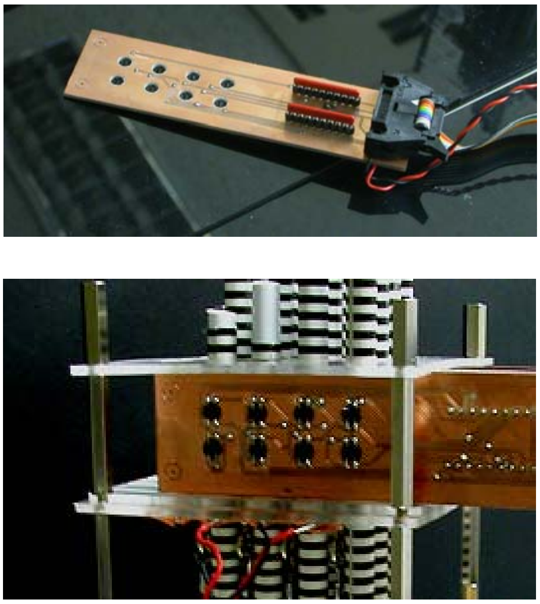


Fig. 5: Position Sensor

3. Implementation

3.1 System Overview

Fig. 6 shows the system block diagram we developed in this study. A PC outputs the PWM signal for driving a FET switch, and adjusts the time-averaged voltage applied to the SMA. Positional information of the pin-rod from the photo reflector is forwarded to the PC, which feeds back a control signal to the pin-rods. Each pin-rod is operated by this driving-measurement system, so it is possible to control an arbitrary number of pin-rods, given sufficient processing power.

Plastic round bars made of ABS resin (diameter: 7[mm]) were used as pin-rods, arranged in a 4×4 matrix. The maximum stroke of the pin-rod is 120[mm] in this prototype. The height of each pin can be controlled to 0.5[mm] intervals, granting the capability to display fine textures.

To extend the SMA for each pin-rod, we use a spring that produces a competitive force, and a cooling fan that cools the SMA at the same time (Fig. 7).

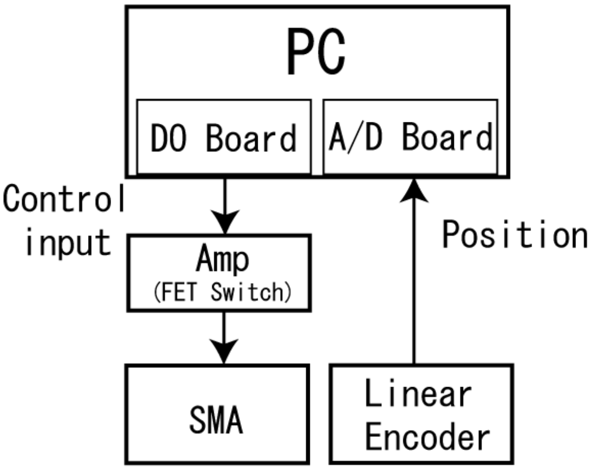


Fig. 6: System Overview

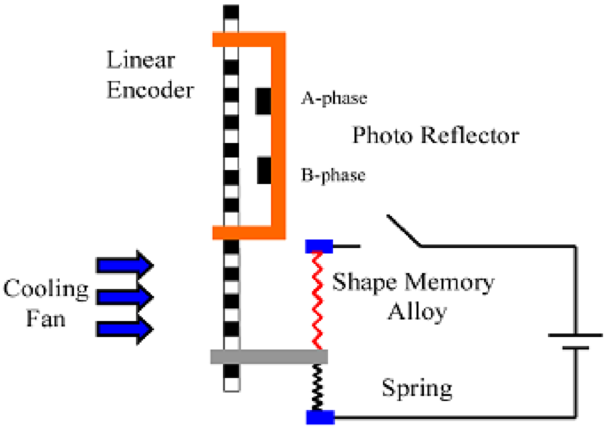


Fig. 7: Mechanical Configuration

3.2 System Evaluation

This display can successfully present arbitrary forms (Fig. 8). The response time for rise and descent is 0.8 sec and 2.0 sec, respectively, under room temperature (22℃) conditions. By forcefully pushing down on each pin by hand, the pin falls temporarily, but upon release it quickly recovers its form. This feature underscores the merit of durability for using SMA in a tactile display.

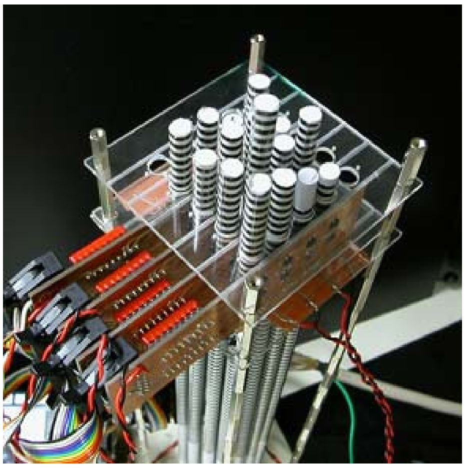
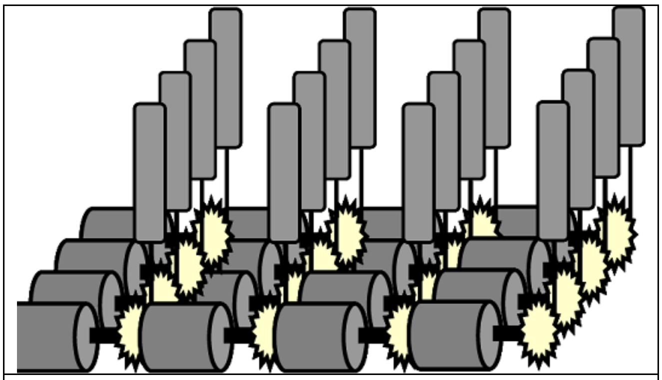


Fig. 8: 4×4 pin-rod matrix prototype

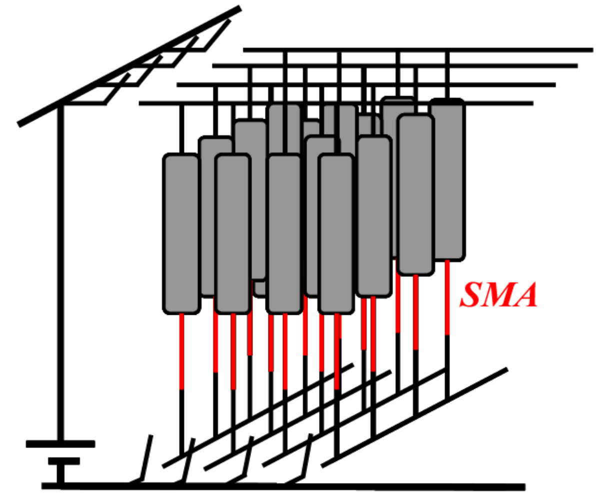
4. Discussion

An important issue that must be addressed in large-scale pin-rod matrix displays is the complexity of the control loop. In methods to actuate a typical $N \times N$ pin-rod matrix such as those driven by servomotors, each pin-rod must be controlled individually, requiring an amount of control information proportional to N^2. Such schemes work perfectly well if the number of pin-rods is small. However, for a high-resolution display with a large value of N, the required information load could quickly hamper the control loop of the system.

To speed up the control of the SMA actuators, we use a scheme that is commonly used in CMOS and LCD displays. Fig. 9 below shows our adopted method, with an N channel FET switch positioned orthogonally at both ends of the pin array. To actuate the SMA for a single pin, each switch needs to be turned on in the corresponding horizontal and vertical channels, as a Boolean AND operation. Arbitrary height maps can be implemented with an active matrix drive algorithm, to be described in a later paper. Because the amount of information required to drive the system is proportional to $2N$, which will be increasingly important as the size of the array increases.



Traditional method: Amount of Information = $N \times N$



The method we adopt: Amount of Information = $2N$

Fig. 9: $N \times N$ Controlling method (Upper) and $2N$ Controlling Method (Below, we adapted)

While the compactness of SMA and the flexibility of the matrix drive scheme provide a decisive advantage in supporting a dense array of pin-rods, the need for position sensors introduces a new technical challenge. This prototype has a pair of photo reflectors for each pin-rod, which was readily constructed for a small number of rods. Naturally, the number of reflectors will increase if we want to add more rods, and the capacity to read the output of photo reflectors will become a more serious bottleneck for larger arrays.

Therefore, we will consider adopting other, more scalable sensor devices for measuring position. The first alternative is using inductance change of a coil by inserting metal rods. Several sensors using ~~the~~ conductance change are already commercially available [10], but we intend to use the spring for extending SMA as a coil. Using springs reduces the complexity of the system and improves pin-rod capacity because it is unnecessary to add another measuring component.

The structural details are illustrated in Fig. 10. This system has two modes: an actuating mode and a sensing mode. In the sensing mode, the Pulse Generator emits a pulse wave, and transmits it through the spring and the SMA. The resulting inductance change creates a wave distortion observed by a voltmeter. The voltmeter is connected to an analog-digital converter, and the PC determines the position based on the change.

We currently use stainless steel and iron rods, although we are still investigating which material is most suitable for this purpose.

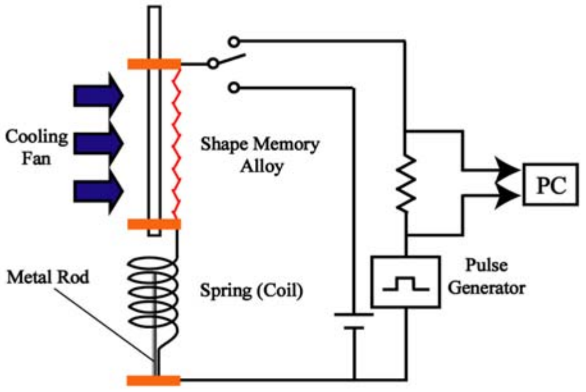


Fig. 10: A Novel System Configuration

5. Future Work

We anticipate applying this device in two ways. One application is a 1m-square large 3D display system (Fig. 11), which creates a rough texture using a pin matrix, and projection technology to visually present an illusionary fine texture. To the authors' knowledge, a 3D display system with this scale, arbitrary shape and fast movement has not yet been achieved. We can use this system as a dynamic street advertisement.

Another potential application is a novel communication interface called "Face Phone". Fig. 12 demonstrates the concept of the system. The device displays dynamic rangefinder data obtained from a human face. Like conventional videoconference technology, the user can hear the other person's voice, and also see his/her face movement. It is one realization of face-to-face telexistence, where the haptic display will convey a heightened sense of presence to help our daily communication with others.

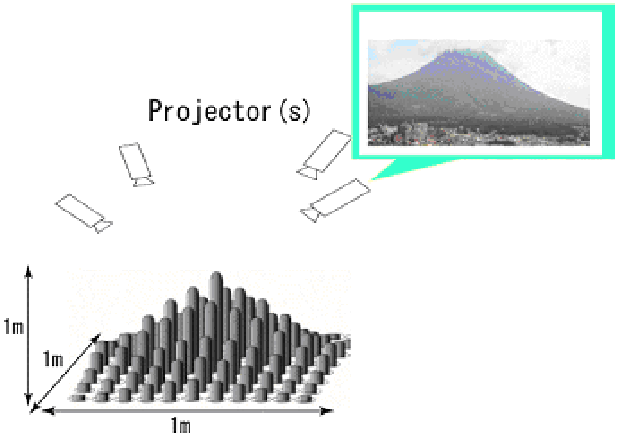


Fig. 11: Concept of 3D Shape Advertisement System

6. Conclusion

We have successfully verified the validity of using a Shape Memory Alloy as an actuator in a 3D form display. Due to the long stroke of the pin-rod array that presents both visual and haptic feedback, it is possible to display almost any kind of shape, even for large objects. Each pin-rod is controlled for height with a height accuracy of 1[mm], so the device can present fine textures. In the implementation device, we used a pair of photo reflectors to obtain positional information of the rods in order to control the SMA actuators. However, due to the imminent engineering challenges for large arrays, we suspect that a measuring method using the inductance change produced by inserting metal rod inside of the coil would be a more scalable approach.

As these issues are resolved, and large-scale 3D form displays with increased density and long pin-rod stroke become more feasible, we anticipate developing communication tools such as a dynamic advertisement system, and a facial expression transmitter. Such innovations promise to enhance the human ability to both see and feel objects represented in virtual space.

Fig. 12: Concept of 3D Face Display

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