Tactile information transmission by apparent movement phenomenon using shape-memory alloy device

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ABSTRACT

This paper introduces the development of a tactile device using a shape-memory alloy, and describes the information transmission by the higher psychological perception such as the phantom sensation and the apparent movement of the tactility. The authors paid attention to the characteristic of a shape-memory alloy formed into a thread, which changes its length according to its body temperature, and developed a vibration-generating actuator electrically driven by periodic signals generated by current control circuits, for the tactile information transmission. The size of the actuator is quite compact and the energy consumption is only 20mW. By coupling the actuators as a pair, an information transmission system was constructed for presenting the apparent movement of the tactility, to transmit quite novel sensation to a user. Based on the preliminary experiment, the parameters for the tactile information transmission were examined. Then the information transmission by the device was tested by 10 subjects, and evaluated by questionnaires. The apparent movement was especially well perceived by users as a sensation of a small object running on the skin surface or as being tapped by something, according to the well-determined signals given to the actuators. Several users reported that they perceived a novel rubbing sensation given by the AM, and we further experimented the presentation of the sensation in detail to be used as a sensory-aids tactile display for the handicapped and elderly people.

1. INTRODUCTION

Humans are able to communicate with each other by using not only verbal media but also the five senses such as vision, audition, olfaction and tactility, effectively using their body parts. Information transmitted through non-verbal media directly affects our emotions and feelings, and especially hand gestures and touch feelings play an important role for the emotional human communication. In the face-to-face communication, gestures and touch actions are effectively employed together with the information transmitted through speech and vision, and in the conversation about an actual object, the tactile sensation and haptics help to understand the object intuitively. Human communication is regarded as the information transmission through our body and sensations, and computers have recently been used as an extensive tool for supporting the communications as human-machine interfaces. Especially for supporting disabled and elderly people, computers and intelligent devices are now essential tools in the daily life.

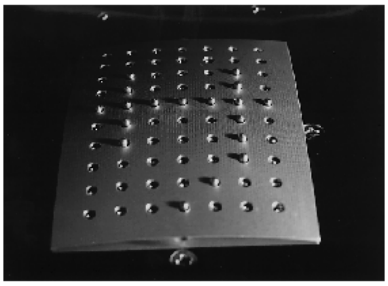
We have so far paid attention to the information transmitted through the gestural actions and the tactile sensation (Moritani et al, 2003), and are now constructing a tactile information transmission system for the presentation and communication of tactility. Tactile displays which employ piezo actuators or solenoid coils have been introduced so far (Asamura et al, 2001; Maeno, 2002; Makino et al, 2004; Moy et al, 2000; Nara et al, 2001), and some of them are commercially available now as shown in Figure 1. Such devices, however, have the problems of the requirement of high-voltage supplies and the large size of the actuators and the device itself. Furthermore, they are designed to display Braille or to present alphabetical letters and the static shape of a 2D/3D object. It is difficult to present touch feeling and tactile sensation such as a moving object and rubbing sensation, due to the restrictions caused by the problems mentioned above. This paper introduces a compact device for the presentation of tactile sensation given by the apparent movement phenomenon and the phantom sensation, by using a shape-memory alloy. A novel tactile information transmission device is developed to be employed for the tactile communication, and is evaluated by questionnaires to be used as a sensory-aids tactile display for the handicapped and elderly people.

2. VIBRATION ACTUATOR FOR TACTILE INFORMATION TRANSMISSION

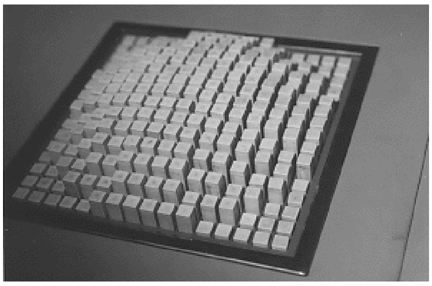
2.1 Shape-memory alloy and its characteristics

A shape-memory alloy (SMA) is employed for the tactility presentation in this study. Shape-memory alloys are the metals which have the shape-memory effect. An alloy has peculiar temperature T_p, and the shape memory effect is observed when the body temperature is cooled to below T_p. In this state, it can be easily deformed, however, the original shape can be recovered by heating the body above the temperature. The effect has been widely applied in different fields such as robotic muscles, medical surgeries, actuators and elastic wires. The SMA also has a unique characteristic to shrink at a certain temperature. Figure 2 shows the schematic figure presenting the relation between the body temperature of SMA and its length. We found a specially-composed SMA whose temperatures T_1 and T_2 are low enough to be touched by human skin.

We also found a novel and interesting effect that, by making the SMA into a string, it accepts a pulse-signal to generate a vibration in accordance with the pulse frequency of the signal. Figure 3 shows a vibration actuator composed with a 5mm-long SMA string with a diameter of 0.05mm. With a weak current given to the alloy, the body temperature rises to the T_2 due to the generated heat inside the body, and it shrinks about 7% of the original length. When the current stops, the body is cooled to below T_1, to recover the original length. In this manner, by giving a pulse signal current with the frequency of several tens or hundreds hertz as presented in Figure 3, a vibration is generated to be perceived by human body as tactile sensation. The actuator has the advantage of its compactness having the diameter 3mm and the thickness 1mm, and the low energy consumption of 20mW with its quick response to generate a vibration.



(a) Vibrator array



(b) Tactile pin array

(c) Piezoelectric actuators

Figure 1. *Examples of tactile displays.*

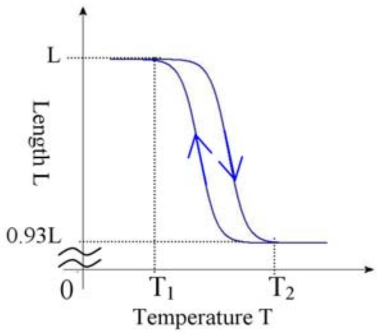


Figure 2. *Temperature characteristics of SMA.*

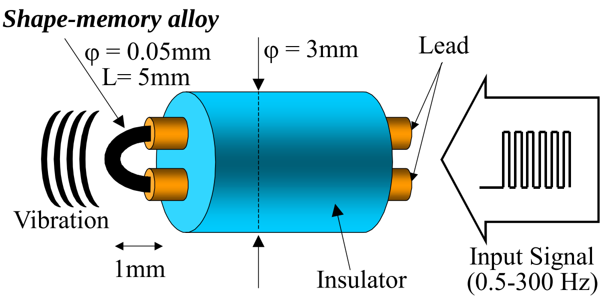
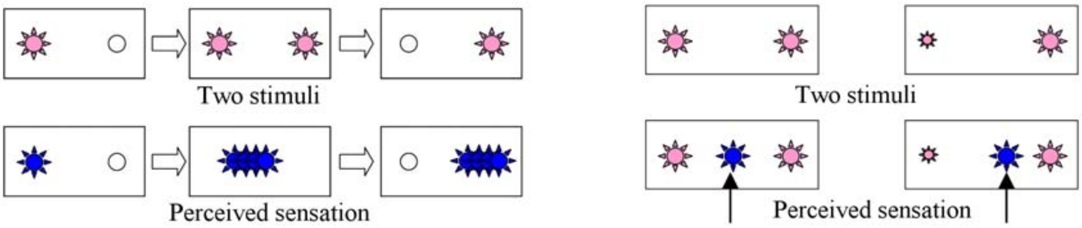


Figure 3. *Vibration Actuator.*

2.2 Higher psychological perception of tactile sensation

In this study, we paid attention to the higher psychological perception of tactile sensation for the transmission of tactile information. The apparent movement (AM) is known as one of the higher psychological perception of human tactile sensation (Bekesy, 1957). When two locations on our skin surface are excited by two mechanical vibratory stimuli with transient time delay, we perceive an illusory sensation which continuously moves from first location to the other, as shown in Figure 4 (*a*). The phantom sensation, on the other hand, is also the higher psychological perception of tactile sensation (Alles, 1970). A variable sensation appears between two locations when they are stimulated simultaneously with arbitrary intensity. If two stimuli have the same intensity, the phantom sensation is perceived in the middle of them. If one stimulus is stronger than the other, the illusory sensation appears at the closer location to the stronger one, according to the strength ratio. Figure 4 (b) shows the schematic figure of the phantom sensation which appears between two mechanical stimuli.



(a) Apparent movement (AM) *(b) Phantom sensation (PS)*

Figure 4. *Higher psychological perception of tactile sensation.*

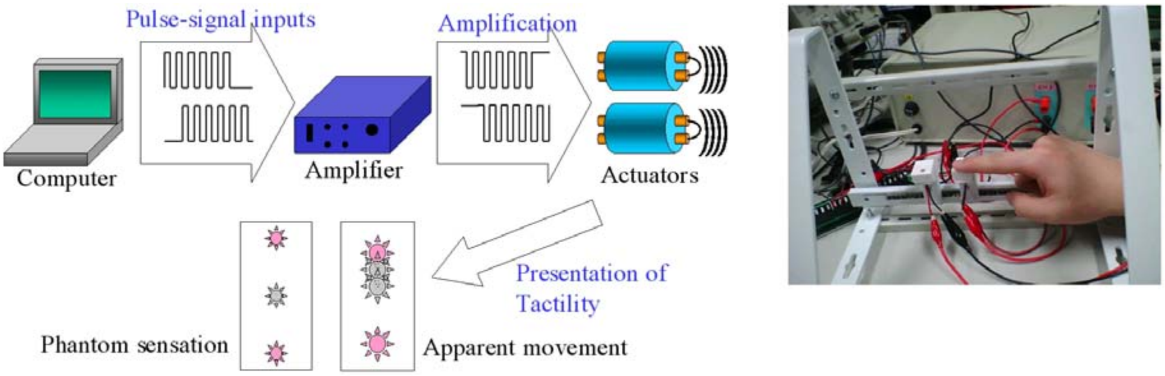


Figure 5. *Tactile information transmission system.*

2.3 Tactile information transmission using SMA actuator

The authors have developed a vibration-generating actuator electrically driven by periodic signals generated by current control circuits, for the tactile information transmission. The vibration actuator employing a SMA formed into a thread is able to provide a mechanical vibratory stimulus on a spot around 1 mm. By coupling two actuators, the PS and the AM are generated by the vibratory sensation on the skin, which are perceived as particular tactile information. Figure 5 shows the configuration of the tactile information transmission system, together with a picture of an experiment to present tactile information to a finger. A pulse-width modulated (PWM) rectangular wave signal with arbitrary frequency, amplitude and duty-ratio is generated in a PC, which is amplified to drive the two actuators. The amplifier was specially designed for driving SMA actuator in variable frequencies and variable voltage amplitude with current control. In this study, the tactile information transmission by the PS and AM were examined, and the tactile sensation by the novel device was evaluated for the development of a tactile display for the handicapped and elderly people.

3. PRELIMINALY EXPERIMENTS FOR TACTILE INFORMATION TRANSMISSION

We first conducted a preliminary experiment to find effective locations on our body for presenting tactile sensation, and also to study the optimal parameters for generating tactile stimuli by the vibration actuator. Two experiments were conducted here, which would reveal

1. the relation between body locations and the parameters of vibratory signal giving to the actuator, and
2. the optimal parameters for generating the AM.

We empirically know that the sensitivity against a mechanical stimulus differs from the location on a skin, for example, a stimulus is perceived as different intensity depending on the location of the skin surface such as palm and the back of a hand, due to the localization of the sensory cells under the skin. Two stimuli with different intensity, on the other hand, might be sensed as the same intensity when they are presented in different location of a hand. To find the relation between stimuli and body locations, the preliminary experiment was required and one subject who had a standard tactile sensitivity was employed.

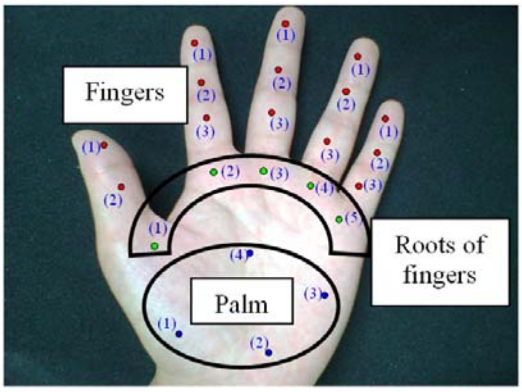


Figure 6. *Locations on palm for stimuli.*

In the experiments throughout the study, the intensity of the sensation was assessed by the scale from 1 to 10, where 10 represents the strongest sensation and 1 represents the weakest or faint to be perceived.

In the experiment 1), one vibration actuator was driven by rectangular waves with different frequencies and voltages using PWM, and the stimuli were presented to different locations on the palm of the subject's dominant hand as shown in Figure 6. By changing the frequency from 1 to 300 Hz, stimuli with the different amplitude 0.3 to 0.7 Volts were given, and the subject answered how strong he felt the tactile sensation.

Table 1. *Results of tactile sensation by the difference of location, frequency and voltage.*

Frequency [Hz]		5			50			200		
Location \ Voltage [V]		0.39	0.46	0.61	0.55	0.61	0.70	0.65	0.70	0.82
Thumb	(1)	2	3	7	3	3	4	0	1	2
	(2)	4	5	8	4	5	7	0	2	4
Index finger	(1)	1	3	5	2	2	4	0	1	3
	(2)	1	3	5	2	2	4	0	1	3
	(3)	2	4	7	2	3	5	1	3	4
Middle finger	(1)	3	4	8	2	3	4	0	0	1
	(2)	1	2	6	2	1	3	1	2	2
	(3)	2	3	7	1	2	4	1	1	1
Ring finger	(1)	2	3	6	2	3	3	1	2	3
	(2)	0	2	4	1	1	1	0	1	1
	(3)	1	3	5	0	2	2	1	2	2
Little finger	(1)	2	3	7	3	4	5	1	2	3
	(2)	1	2	6	1	1	2	1	1	2
	(3)	2	2	6	1	2	4	1	2	2
Roots of fingers	(1)	0	2	5	1	2	2	1	2	2
	(2)	2	3	4	1	5	4	1	2	2
	(3)	3	4	5	3	3	4	2	3	3
	(4)	1	1	6	2	2	1	1	1	2
	(5)	2	3	7	3	4	3	2	2	3
Palm	(1)	2	3	3	1	2	5	1	1	1
	(2)	3	4	6	1	3	6	2	2	3
	(3)	2	5	7	3	5	7	3	3	3
	(4)	0	1	2	0	2	1	1	0	1

Table 1 shows an example of the experimental result. Same numbers represent that the stimuli were perceived as the same strength of the tactile sensation. We found that the 50 Hz vibrations were highly sensitive to the tactility, and the index finger could perceive the vibratory stimuli more sensitive than the other fingers and the palm. The sensitivity of the thumb, middle and little fingers are almost the same, and higher than the ring finger. The middle part of the palm has the lowest sensitivity to the mechanical vibrations. The subject reported that he perceived the stimuli generated by different frequencies as quite different tactile sensations with each other. He felt like the beats of the blood pulse by the stimuli with the lower frequency around 1 to 5 Hz, the vibratory or tapped sensation with the frequencies around 10 to 50 Hz, and the rubbed or gently-touched sensations with the higher frequencies around 50 to 300 Hz.

We paid attention to the tapped and rubbed sensations presented by the vibratory stimuli with the frequency of 50 Hz, and tried to present the AM by using the two actuators. Two signals shown in Figure 7 are given to the actuators, which are pressed against two points of the surface of the skin, and the experiment 2) for the generation of the AM was conducted. Figure 8 shows the 15 points of the stimuli presentations, and two stimuli are presented by two actuators to arise the AM between arbitrarily selected two locations. In this experiment, the transient time delay B [msec] and the amplitude of the signal H [V] shown in Figure 7 are changed, and the subject answered the perception of the AM.

An example of the experimental result is shown in Table 2. The AM appeared with the time delay of 100 to 800 msec and the amplitude of 0.6 to 0.85 volts, on all the locations. Among the conditions, the index and middle fingers have the higher sensitivity to the AM sensation with the time delay of 500 msec. The root of the finger and the center of the palm also have comparatively high sensitivity. When the time delay is smaller than 50 msec, the two stimuli reinforce each other and one phantom tactile image appears in the middle of the two stimuli to work to perceive the phantom sensation.

Based on the two experiments conducted by the subject, the experimental conditions for the AM presentations were established. The frequency 50 Hz and the amplitude 0.75 volts of the input signal for the actuators were set as the basement, and the index and middle fingers and the palm were selected as the AM presentation locations.

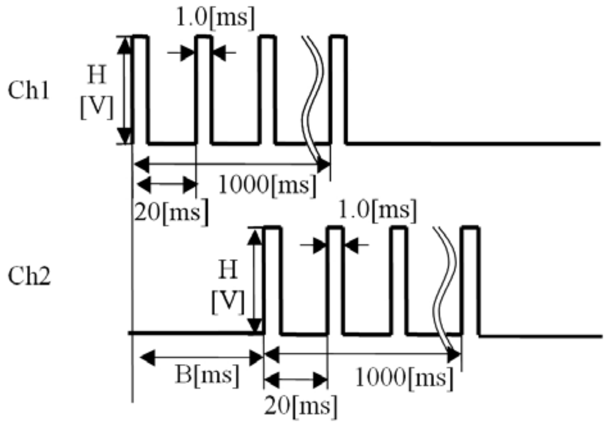


Figure 7. *Signal for AM generation (50Hz).*

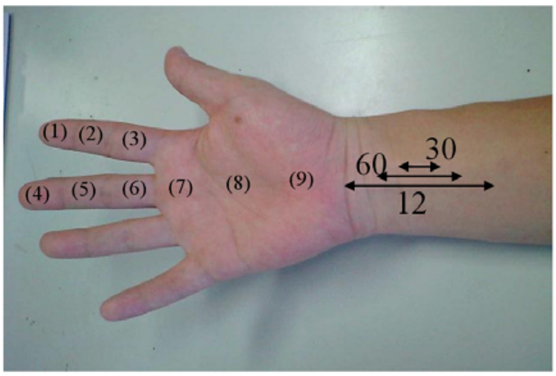


Figure 8. *Presentation points in AM evaluation.*

Table 2. *AM perception by the difference of location, frequency and time delay.*

Time delay [ms]		50			500			1000		
Location \ Voltage [V]		0.70	0.75	0.82	0.70	0.75	0.82	0.70	0.75	0.82
Index finger	(1)−(2)	0	0	1	2	2	3	1	3	2
	(2)−(3)	0	1	1	2	3	3	2	3	2
	(1)−(3)	1	1	0	2	3	4	1	1	1
Palm	(7)−(8)	2	2	2	2	2	2	0	1	0
	(8)−(9)	1	2	1	1	1	2	0	1	1
	(7)−(9)	1	1	1	1	2	1	1	2	1
Wrist	30	1	1	0	1	1	1	1	1	1
	60	1	1	0	1	1	2	2	2	3
	120	0	0	0	0	2	1	1	1	1

4. EXPERIMENTS FOR AM PRESENTATION

4.1 Presentation of the apparent movement

The presentation of the AM sensation given by the actuators was evaluated by 10 subjects, based on the experimental conditions determined by the preliminary experiments. The time delay was fixed to 500 msec, and the explanation of the apparent movement of tactile sensation was given to the subjects in advance. In the experiment, two AM stimuli, which run in two directions, one from the tip to the root of a finger and the other from the root to the tip, were randomly presented to the subjects, and they answered the direction. The trial repeated five times by generating the AM stimuli with various signal parameters, and questionnaires were conducted to the subjects after the experiment.

The result of the experiment is shown in Table 3. The numbers in the table represent the correct answers out of five trials. The AM sensation given by the actuators was perceived perfectly by all the subjects, and the moving direction was recognized 97 %. Several users reported that a rubbed sensation or a small object running across the palm was distinctively perceived by the AM presentation. All the subjects commented that the sensation was quite novel and they could clearly recognize the trajectory of the phantom motion in their hands.

4.2 Evaluation of rubbed sensation

The experiments described above showed that the AM stimuli generated by the vibration actuators were effectively used for the tactile information transmission. Several subjects reported that they felt something rubbing on the finger and the palm, and also they sensed a small virtual object moving on the palm. We also found that this novel sensation was perceived only in particular conditions of the vibration patterns of the actuators. It depends specially on the transient time delay between two vibratory stimuli generated by the actuators. Another experiment was conducted to find the optimal time delay to present the rubbed sensation on a skin.

Table 3. *Result of AM presentation experiment (Number of correct answers out of five trials).*

Location / Subject	Index finger		Middle finger		Palm	
	(1)–(2)	(1)–(3)	(4)–(5)	(4)–(6)	(7)–(8)	Half
A	5	5	5	5	5	5
B	5	5	4	5	5	4
C	4	5	4	5	5	5
D	5	3	4	5	5	5
E	5	5	5	5	5	5
F	5	5	5	5	5	5
G	5	5	5	5	5	4
H	5	5	5	5	5	5
I	5	5	5	5	5	5
J	5	5	5	5	4	5
K	5	5	5	5	5	5

Table 4. *Result of the presentation of rubbing sensation.*

Time delay [ms] / Subject	100	200	300	400	500	600	700	800	900	1000
A	–	–	–	O	O	O	O	–	–	–
B	O	O	O	O	O	O	O	O	–	–
C	O	O	O	O	O	O	O	O	–	–
D	O	O	O	O	O	O	O	O	–	–
E	O	O	O	O	O	O	O	O	–	–

The vibratory stimuli, whose time delay was changed from 100 to 1000 msec, were given to 10 subjects, and they answered whether they could perceive the rubbed sensation. Two locations for the presentation were (1) and (3) of the index finger shown in Figure 8, and the frequency and the amplitude of PWM signal were set to 50 Hz and 0.75 volts, respectively.

Table 4 shows the results of the experiment obtained by the subjects A to E. Almost all the subjects perceived the sensation with the time delay 100 to 700 msec, and they asserted that the moving speed of the sensation changes according to the time delay. With no time delay, phantom sensation appears between two vibratory stimuli, and at 100 msec the sensation instantaneously moves from the one to the other. As the time delay increases, the moving speed decreases, and at around 800 msec, the sensation cannot be perceived. Some subjects claimed that with the delay around 700 and 800, the sensation started moving from the one stimulus, and disappeared in the middle between the two stimuli, and then appeared again to move to the second stimulus. This phenomenon is quite interesting, and should be further examined in the future studies.

With the experiment, we confirmed that the novel sensation was effectively given by the vibration actuators, and the rubbed sensation would be generated with the time delay around 500 msec.

5. TACTILE INFORMATION TRANSMISSION BY VIBRATION ACTUATORS

For the tactile information transmission, we are paying attention to the AM and the rubbed sensation to realize a sensory-aids tactile display for the handicapped and elderly people. By using the phantom sensation, a tactile phantom image appears in any location between two vibratory stimuli. Furthermore, with the apparent movement, one can perceive a sensation moving from one location to the other, under the control of the time delay between two vibratory stimuli. The moving speed can be manipulated by controlling the parameters to drive the actuators.

We designed and constructed a device for the tactile information transmission by arranging 9 actuators two-dimensionally on a flat plate as shown in Figure 9. The device consists of 3 x 3 array of actuators, which are independently driven by nine amplifiers. We held an experiment to present simple letters on a palm by showing the order of writing. This would be realized by employing the AM as shown in Figure 10. By driving the actuators in the order shown by arrows, the letters were successfully perceived and preferably recognized by the subjects. All the subjects also answered that the device presented the letters much clearly than the conventional tactile display which gives a static pattern of a letter.

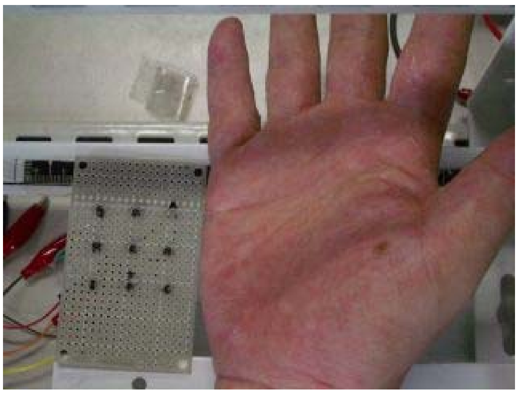


Figure 9. *3 × 3 array of vibration actuators.*

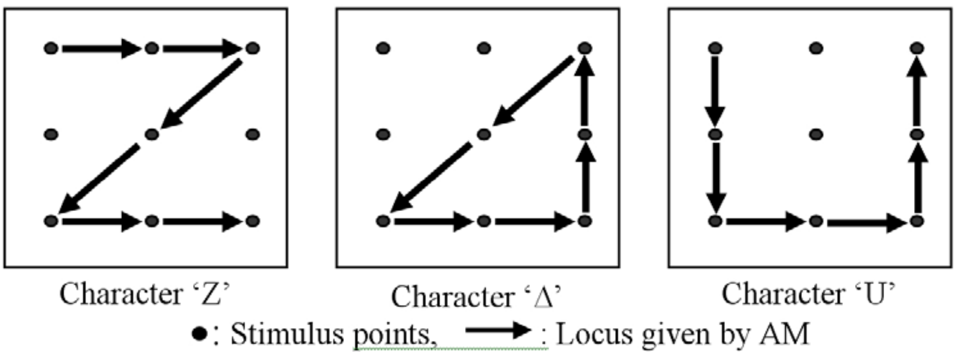


Figure 10. *Presentation of writing motion by AM.*

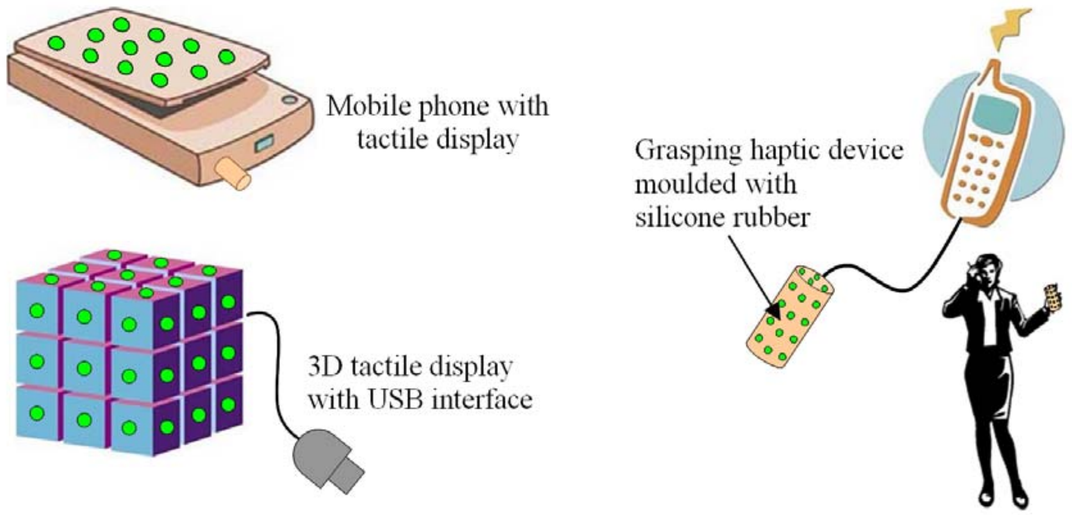


Figure 11. *Ideas for the tactile device.*

6. CONCLUSIONS

This paper introduced a compact device for the presentation of tactile sensation given by the apparent movement phenomenon and the phantom sensation, by using a shape-memory alloy. The vibration-generating actuator electrically driven by PWM rectangular signals had the advantage of its compactness, low energy consumption and quick response, and was effectively used for the presentation of novel tactile information. The device had been developed to be employed for the tactile communication, and was evaluated by questionnaires to be used as a sensory-aids tactile display for the handicapped.

The experiments showed that the device successfully presented the apparent movement and the rubbed sensation, which was preferably accepted by all subjects. Based on the evaluation results, the novel tactile display with the 3 x 3 arrangements of vibration actuators was developed, and was experimentally employed for the alphabetic character presentation on a palm by showing the order of writing. The presentation was also clearly recognized and preferably accepted. The results proved and promised the potential of the actuator using the shape-memory alloy for the tactile information transmission.

The authors are now developing novel tactile devices for the handicapped and elderly people to assist the information presentation and communication employing the tactile and haptic sensation. Figure 11 shows three examples of ideas of the tactile and haptic devices. Owing to the low energy consumption and its thin thickness, the device can be directly installed on an electric circuit board to present tactile information.

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