Fabrication and Evaluation of Tactile Stimulator Array Using Stacked PZT

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Abstract: A tactile stimulator array using stacked PZT is fabricated and evaluated in this paper. The purpose of this research is the development of a tactile stimulator to represent the obstacle information for the visually disabled. As a first step of this research, we investigate the physiological characteristics of tactile stimuli and design a tactile stimulator based on the investigated results. Also we evaluated a fabricated tactile stimulator. The prototype of tactile stimulator which has 2×2 tactor elements with 3mm spacing is fabricated using stacked PZT actuator. In order to evaluate the characteristics of this tactile stimulator, physiological experiments are carried out. In the experiment, the threshold of tactile stimulus intensity within a frequency range of 5-500Hz and at various stimulus amplitudes are investigated. According to the obtained experimental result, the input signal of tactile stimulator for the transfer of obstacle information is determined. Also physiological experiments of multi-stimuli recognition such as shift and rotation are carried out.

Keywords: Tactile Display, Tactile Stimulator, PZT Actuator, Physiological Characteristics

1. INTRODUCTION

There are about 200 thousands blind persons in Korean, 400,000 in Japan and 2,000,000 in USA. The acquired cause of disability for the visually disabled persons is over 90%. Also the number of these persons are growing every year due to an aging society. Many of blind persons use the white cane or guide dog. The white cane is a successful and widely used travel aid for the blind. The white cane is inexpensive, lightweight and easy to carry. However, users must be trained in the use of the white cane for a period of over 100 hours. The guide dog is a trained dog for the blind or visually impaired traveler to navigate safely. The guide dog is expensive, difficult to train, and sometimes unfriendly to other pedestrians [1-2]. Therefore, the development of an alternative engineering system is strongly needed. For the visually impaired some engineering system such as artificial retina, guide robot, ETA(Electronic Travel Aid) have been developed, but in the sense of practical use, those research and development are not fully satisfied.

In the case of ETAs such as the Mowat sensor, KASPA, C5 Laser Cane, NavBelt, etc., a fundamental shortcoming with all ETAs based on acoustic feedback is their interference (called “masking”) with sound cues from the environment and reducing the blind person’s ability to hear these essential cues [2-3]. So, this research focus on the tactile feedback for the transfer of obstacle information in ETA. The “C-5 laser Cane” was introduced by Benjamin. It can detect obstacles at head-height, drop-offs in front of the user, and obstacles up to a range of 1.5m or 3.5m ahead of the user [3]. The “NavBelt” was introduced by Shoval. It is based on obstacle avoidance technologies of mobile robots with a portable computer, ultrasonic sensors, and stereophonic headphones attached to the user [2].

The existent tactile stimulators are divided by pneumatic, vibrotactile, electrotactile stimulation etc. The vibrotactile stimulation among tactile stimulators has been studied most such as ultrasound, loudspeaker, ICPF(Ionic Conducting Polymer gel Film), etc [4-8]. However, they are huge and not compact. The pneumatic tactile stimulator was introduced by Sato. The tactile feedback through pneumatic stimulation uses compressed air to press against the skin [4]. The tactile stimulator using ICPF was introduced by Konyo. Combinations of vibratory stimuli of high frequency and low frequency produced complex tactile feels such as the touch of cloth. But this device operated in water or under wet condition [8]. The touch senses of the human are poor at determining absolute quantities but very sensitive to changes [9]. So. We chose the vibrotactile stimulator. This kind of device which generates small displacement is small, compact and light, that is, portable.

The objective of this research is the development of a portable tactile stimulator to display some obstacle information for the visually impaired pedestrian. As a first step of this research, we investigate the physiological characteristics of tactile stimuli and design a tactile stimulator based on the investigated results. Also we evaluate a fabricated tactile stimulator.

This paper present fabrication and evaluation of tactile stimulator array using stacked PZT. The prototype of tactile stimulator(Fig. 1) which has 2×2 tactor elements with 3mm spacing is fabricated using stacked PZT actuator. In order to evaluate the characteristics of this tactile stimulator, physiological experiments are carried out. In the experiment, the threshold of tactile stimulus intensity within a frequency range of 5-500Hz and at various stimulus amplitudes are investigated. Also physiological experiments of multi-stimuli recognition such as shift and rotation are carried out.

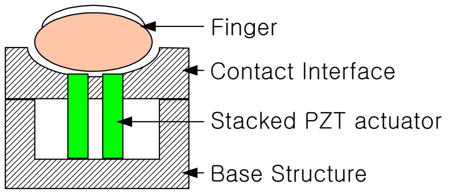


Fig. 1 Schematic diagram of tactile stimulator.

2. PHYSIOLOGICAL CHARACTERISTICS OF TACTILE STIMULI

To be able to design a tactile stimulator understanding of the nerve activities is essential – in particular the present physiological knowledge of the nerves contributing to the sensations must be understood.

Human skin has a number of sense receptors of elementary sensations such as touch, pressure, vibration, pain, temperature, etc. The main elementary sensations given by mechanical stimuli are pressure sense and vibration sense. Mechanoreception is concerned with the detection of mechanical stimuli at the skin and comprises four qualities; the sensations of pressure, touch, vibration, and tickle, detected by a series of nerve endings including Merkel disks, Ruffini endings, Meissner corpuscles, and Pacini corpuscles, each of which have different perception characteristics. Four different kinds of sensors register deformation of the skin caused by contact with external objects. Meissner corpuscles and Merkel disks lie close to the skin surface and have high spatial resolution. In the fingerprint skin of the hand Meissner corpuscles are located between the papillary ridges of the dermis, while the Merkel disks are located at the ends of these ridges. Pacini corpuscles and Ruffini endings are embedded deep in the skin and hence there receptive fields are much broader. In addition, there are free nerve endings with a high threshold which respond to painful and potentially harmful stimuli, such as pricking with a sharp needle. The concerning sensory receptors are shown in Fig. 2 [8-12].

Mechanoreceptive nerve fibers can be categorized by two criteria: the size of their active ares (receptive field), and the speed of their adaptation to static stimuli. Mechanoreceptive nerve fibers with small receptive fields are called type Ⅰ units, while those with large fields are called type Ⅱ. Nerve fibers that respond to static stimuli are called SA (slowly adapting), while those with no static response are called FA or RA (fast or rapidly adapting). Based on morphological observation (receptive field characteristics, adaptive properties of the fibers to stepwise indentation and frequency response to sinusoidal vibration), attempts have been made to associate SA Ⅰ with Merkel disks, SA Ⅱ with Ruffini endings, FA Ⅰ with Meissner corpuscles, and FA Ⅱ with Pacini corpuscles. Merkel disks form 25percent of the receptors in the hand and have a disk-like nerve ending. These receptors respond best to pressure, but can also provide vibration information. These receptors have respond bandwidth in 2-32Hz. Ruffini endings have a fusiform structure and make up approximately 19 percent of the hand receptors. They detect pressure and skin shear as well as thermal changes. These receptors have respond bandwidth in 1-16Hz. Meissner corpuscles represent over 40 percent of the hand tactile receptors. Since they move with the ridges of the skin, these receptors can best detect the movement across the skin and function as velocity detectors. These receptors have respond bandwidth in 8-64Hz. Pacini corpuscles are the largest of the skin corpuscle receptors and represent 13 percent of the hand receptors. They detect light touch as well as vibrations and function as acceleration detectors. These receptors have respond bandwidth in 64-400Hz widely. Also, those respond to very small stimulus displacement(㎛) [9-11]. A tactile stimulator of this research generates various stimuli to Pacini corpuscles.

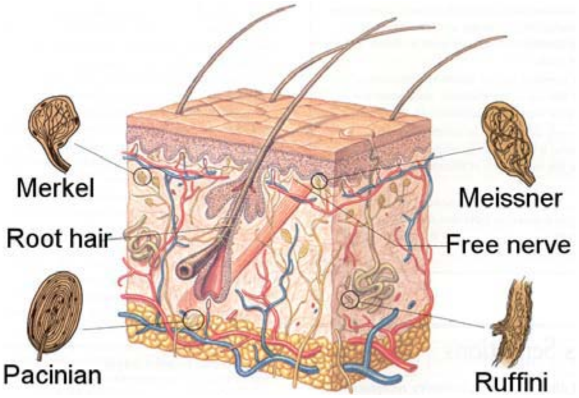


Fig. 2 The cutaneous sensory receptors [12].

3. DESIGN AND FABRICATION OF TACTILE STIMULATOR

The tactile stimulator is designed to stimulate the FA Ⅱ mechanoreceptors (Pacini corpuscles) and consists of a 2×2 array of tactor elements. The tactor elements are spaced 3mm apart. The effective contact area is 63㎟ in a 7mm × 9mm area. An ideal tactile display requires an actuator density of 1 per ㎟, with up to 2mm indentation and 1 N of force per tactor, and a bandwidth > 50H [13].

3.1 Actuator

Stacked PZT actuators are used for the actuator of tactile stimulator. PZT (Lead Zirconate Titanate) is a piezoelectric material. A piezoelectric material makes motion when an electric field is applied between the surface and is oscillated when electrically excited. A stacked PZT actuator (TOKIN-NEC Co., Japan) is shown in Fig. 3 and it's performance is described in Table 1.

Table 1 Performance of the stacked PZT actuator.

	Value	Unit
Displacement (Max. voltage)	9.1±1.5	㎛
Displacement (Operating voltage)	6.1±1.5	㎛
Output force	200	N
Max. input voltage	150	V_{DC}
Operating input voltage	~ 100	V_{DC}
Operating input frequency	~ 40	kHz
Natural frequency	138	kHz

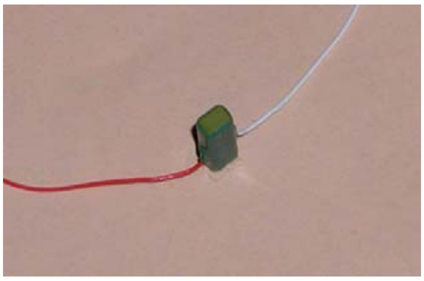
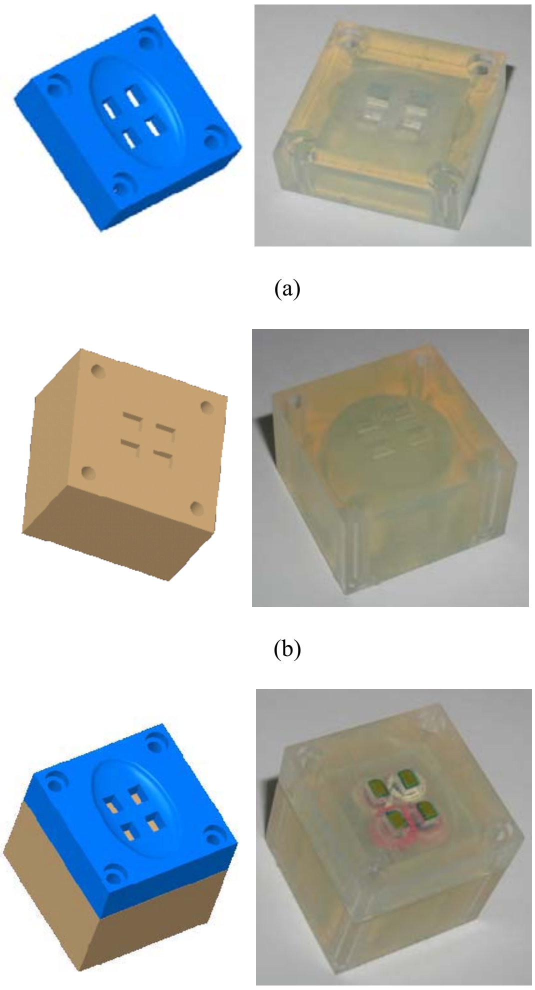


Fig. 3 Stacked PZT actuator (TOKIN-NEC co., Japan).

The dimension of a stacked PZT is 2mm×3mm×10mm (thickness×width×length). We can fabricate a small size, simple structure, and lightweight of tactile stimulator using this stacked PZT actuator. So, it can make portable tactile stimulator to represent the obstacle information for the visually impaired pedestrian.

3.2 Prototype

The prototype of tactile stimulator which has 2×2 tactor elements is fabricated. Fig. 4 shows the fabricated tactile stimulator. The contact interface and the base structure are molded from polypropylene (using rapid prototyping). The dimension of contact interface is 30mm×30mm×10mm. The rounding surface of the contact interface provides constant contact between all the tactors and the finger (Fig. 1). The spacing of 3mm between tactors is kept uniform by the contact interface. The hole of contact surface and the stacked PZT actuator are separated by a 0.5mm gap. It provides the edge sense to finger. The Edge makes more sensitive sensation for vibration stimuli [11]. The dimension of base structure is 30mm×30mm×20mm. The stacked PZT actuators are fixed in 4 holes of base structure using instant adhesive.



(a)

(b)

(c)

Fig. 4 (a) Contact interface (b) Base structure (c) Integrated prototype of tactile stimulator

4. EVALUATION OF TACTILE STIMULATOR

In order to evaluate the characteristics of the tactile stimulator, physiological experiments are carried out. In the experiment, the threshold of tactile stimulus intensity within a frequency 5-500Hz and at various stimulus amplitudes are investigated. According to the obtained experimental result, the appropriate input of tactile stimulator for the transfer of obstacle information is determined. Also physiological experiments of multi-stimuli recognition such as shift and rotation are carried out. The performance of the tactile stimulator is verified in this experiment.

Fig. 5 shows the configuration of the experimental set-up to evaluate the characteristics of the tactile stimulator. The input voltage of sine wave form to the tactile stimulator by LVPZT amplifier(E-663.00) is sensed and processed in the DSP system (dSPACE1103) of personal computer.

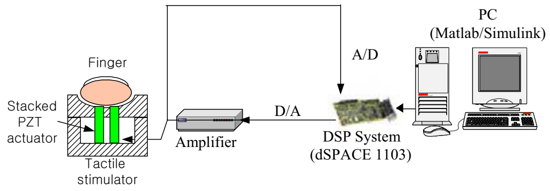


Fig. 5 Configuration of experimental set-up.

4.1 Threshold of tactile stimuli

The first experiment was performed on healthy adults without a previous notice about the subjective of the experiment. So, it prevented the effect of learning. A total of five subjects, one female (age 27) and four males (age 27, 29, 30, and 31) were used. Subjects judged whether they felt the stimulus or not and answered. Thresholds were measured by those answers which were unable to change. The threshold of tactile stimulus intensity within a frequency 5-500Hz and at various stimulus amplitudes was obtained using only one tactor and the result is shown in Fig 6. The results are the averages of five subjects. The error bars signify the standard error of the means.

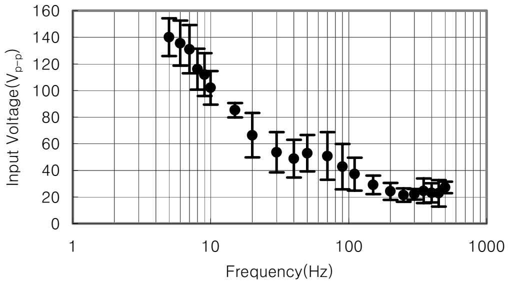


Fig. 6 Threshold of input voltage for stimulus intensity to actuating frequency.

The presented results indicate that vibratory stimuli can be detected at frequencies between 5Hz and 500Hz, the threshold-frequency characteristic being U shaped for high frequencies and partially sloping for the lower ones. The general shape of the characteristic was similar to Bolanowski's one [11]. In generally, human skin is more sensitive to high frequency stimulus than low frequency one in same stimulus intensity (displacement). However, it is not more sensitive to high frequency stimulus over 400Hz. The minimum threshold is about $20V_{p-p}$ (about 1㎛) at 250Hz. But, this minimum threshold can be more low (about 0.1㎛) as reform the tip shape of tactor such as pin shpae.

According to the obtained experimental result (Fig. 6), the appropriate input bandwidth and amplitude of tactile stimulator for the transfer of obstacle information were determined. In the 5Hz-10Hz frequency bandwidth, input voltage more than 100V is needed to feel the stimulus. This voltage is beyond the operating input of the stacked PZT actuator (Table 1). And the input voltage bandwidth of 10-20Hz frequency is narrow to use various amplitude. So some factors, e.g. the possible operating input of the actuator, the threshold for stimulus intensity and previous mentioned restricted condition should be considered for determining the appropriate bandwidth and amplitude of the stimulus actuation. As a result the bandwidth of 30-500Hz and the amplitude of $60\text{-}100V_{p-p}$(over 4㎛) is recommended from the experimental result.

4.2 Recognition of multi-stimuli

The second experiment was performed on healthy adults without a previous notice about the subjective of the experiment also. So, the condition of this experiment is same as the first experiment. The experiment was carried out 5 times each experiment for the finding of stimulated position, shifting, and rotating recognition of multi-stimuli at the determined bandwidth and amplitude of input signal.

The numbering of tactors is shown in Fig. 7. The subjects answered using this numbering. Table 2 shows the correct answer rate by stimulating methods such as (a) recognition of stimulated position, (b) recognition of shift motion, and (c) recognition of rotation motion.

In the experiment for the finding of stimulated position recognition (see Table 2 (a)), subjects answered the stimulated position that is felt by arbitrary one. In the result, comparing 50Hz/100V p-p with 200Hz/100V p-p, the subjects showed high correct answer rate at low frequency bandwidth. On the other hand, the subject confused the finding of correct stimulated position at high frequency bandwidth. So, the correct answer rate is lower at high frequency bandwidth than low frequency one. This result means that tactile sense is more sensitive to the finding of stimulated position in low frequency bandwidth than high frequency one.

In the experiment for recognition of shift motion (see Table 2 (b)), subjects is requested to answer the shifting direction of stimulated position contacting the actuated device. For example, 3 and 4 tactors were vibrating after two tactors which were 1 and 2 tactors. In the result, similar correct answer rates were shown at same amplitude of input signal regardless of frequency bandwidth. This result means that in a simple movement such as shift motion tactile sense does not show different response according to the frequency bandwidth. Also tactile sense does not show different response according to the shifting direction.

In the experiment for rotating recognition (see Table 2 (c)), subjects is requested to answer the rotating direction of stimulated position. For example, clockwise rotation is 1→2→4→3 or 4→3→1→2, that is, starting position is arbitrary. In the result, subjects showed high correct answer rate at high frequency bandwidth. This result means that tactile sense is more sensitive to dynamic movement in high frequency bandwidth than low frequency one. However, rotating direction does not affect the tactile sense. Through the physiological experiment of multi-stimuli, we found that high frequency bandwidth is better to display a dynamic movement than a position and low frequency one is better to display a position than a dynamic movement. Also we found that a direction of movement and a stimulated position do not affect the tactile sense. Therefore, we can use low frequency signals for position information of obstacle and high frequency signals for movement information of obstacle.

In the performance of the fabricated tactile stimulator, the device has reasonable performance when the above mentioned signals are used. However, a high operating input voltage is restricted as 60-100 V_{p-p}. So, we have need of the improvement of the tactile stimulator for same performance at a low input voltage. To make the sharp tip of tactor would be one of the improvement.

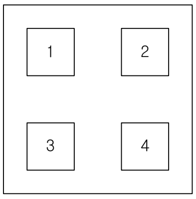


Fig. 7 Numbering of tactors.

Table 2 Correct answer rate by stimulating methods

	Correct answer rate(%)			
	50Hz/ $60V_{p-p}$	50Hz/ $100V_{p-p}$	200Hz/ $60V_{p-p}$	200Hz/ $100V_{p-p}$
1	72	96	88	84
2	64	92	72	84
3	72	92	72	84
4	64	96	80	80

(a) Position

	Correct answer rate(%)			
	50Hz/ $60V_{p-p}$	50Hz/ $100V_{p-p}$	200Hz/ $60V_{p-p}$	200Hz/ $100V_{p-p}$
1,2→3,4	72	88	76	92
3,4→1,2	72	92	72	88
1,3→2,4	72	92	76	96
2,4→1,3	68	96	68	88

(b) Shift motion

	Correct answer rate(%)			
	50Hz/ $60V_{p-p}$	50Hz/ $100V_{p-p}$	200Hz/ $60V_{p-p}$	200Hz/ $100V_{p-p}$
Clockwise	52	76	88	96
Count-clockwise	56	80	92	96

(c) Rotation motion

5. CONCLUSION AND FUTURE WORK

The objective of this research is the development of a portable tactile stimulator to represent the obstacle information for the visually impaired pedestrian. As a first step of this research, we investigated the physiological characteristics of tactile stimuli and fabricated a prototype of tactile stimulator which had 2×2 tactor elements using stacked PZT actuator. The fabricated tactile stimulator was simple and compact. Also, we evaluated the characteristics of stacked PZT actuator. In the physiological experiment, the responses of the subjects to tactile stimuli of a wide range of amplitudes and frequencies were evaluated and the input signal of tactile stimulator for the transfer of obstacle information was determined. The reasonable performance for the recognition of multi-stimuli was verified through the physiological experiment.

As a next step of this research, we will increase the tactors of tactile stimulator such as 2×6 or 10×10 and apply the tactile stimulator to guide vehicle which is developed in our laboratory for the visually impaired. Also we will apply the tactile stimulator to the teleoperation and the virtual reality etc.

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