Trial for Presenting Braille Words by Vibratory Patterns from Shape-memory Alloy Wires

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Abstract: In this study, we developed a Braille display for presenting words to the blind and visually-impaired people. We have developed a shape-memory alloy (SMA) wire-based actuator that generates micro-vibration when a pulse current is provided. The actuator can present tactile information by utilizing the micro-vibration. The objective of this study is to develop a portable Braille display. We constructed an experimental display consisting of two Braille cells with 12 pins. Each pin is connected with the SMA actuator to generate vibratory stimuli instead of the conventional Braille dots. For the Braille presentation, the actuators in the Braille cells are driven by pulse current with different frequencies and appropriate timing. We found that subjects could recognize Braille characters presented by the display. The effectiveness of the proposed display was verified by users' experiments.

Keywords: SMA wire, Active Braille display, Tactile sensation.

1. Introduction

Humans use five senses, which are vision, audition, touch, gustation and olfaction, to get information from the surrounding environment. Blind and visually-impaired people use speech and touch for communication. For touching, they use Braille to get the information through their fingers. Each Braille character consists of 6 Braille dots (3 dots in columns and 2 dots in rows). Six Braille dots are set as a character and used to represent lexical symbols. Braille is read from left to right by one finger.

In Japan, Braille is called "tenji", which means 'dot characters'. Japanese Braille is written in "hiragana" and "katakana", which are two of the three writing systems in Japan. The third writing system in Japan is "Kanji" (Chinese characters), but kanji is not used in Japanese Braille. In Japanese Braille the upper left corner represents vowels and the lower right corner represents consonants. In this research, our Braille display presents words in hiragana.

There are many studies about suitable actuators for driving Braille pins. A research group from EPFL and ITT had introduced a shape memory polymer membrane to develop a scalable latching assistive haptic display [1]. This research reported the development of a display to present simple graphical non-textual symbols. In particular, they employed a shape memory polymer membrane as an actuator, and used thermal energy to heat the membrane. They controlled the direction of the membrane motion by pneumatic actuation to present and change symbols in a short time. Another example is a dynamic tactile display, which was developed by a research group from the Wyss Institute, Harvard University. They studied the use of electromechanical actuator arrays for its low cost construction[2]. POST-PC research group from South Korea developed a small tactile display by using a small ultrasonic linear motor for presenting Braille and texture[3].

Recently we have developed a shape memory alloy (SMA) wire-based actuator to be used for presenting tactile information by generating micro-vibration. Since the energy consumption of this actuator is very low, it is able to be driven by commercial batteries. Moreover, due to the small size of SMA, it is suitable for constructing a Braille display.

In this study, we propose a Braille display which has the ability to present words in Japanese by using 12 pins representing two Braille characters. From our previous studies, the patterns presenting one Braille character were examined, and the change of vibration frequencies among columns improved the recognition and discrimination of the position of pins under the condition of 50 Hz vibration frequency and 500 ms time delay [4]. Moreover, for the recognition of words, visually-impaired subjects were able to guess words if they did not understand one character in 3 or 4 letters by using one finger [5].

It is interesting to develop effective patterns of presenting Braille information in two Braille cells read by two fingers. The objectives of this study are to investigate the patterns of vibration frequencies and time difference among pins in the Braille display that are suitable for recognizing the Braille information by using two fingers.

2. Concept of Braille display

2.1 Braille Display

A small Braille display is constructed by using SMA wires. The display has 12 Braille dots with 1.5 mm in diameter and 3 mm in height, the distance between dots is 5 mm, as shown in Fig.1. The diameter of a SMA wire is 75 μm, and the length is 4 mm to generate a micro-vibration.

The frequencies of the vibration actuator can be set from 1 to 100 Hz. The vibration of the wire is generated by pulse width-modulated current, and the vibration frequency synchronies with the frequency of the current. In this research, pulse duty ratio is set at 10% because a high duty ratio may cause the overheating of the wire and thus a break the wire. In the case of 100 Hz vibration, it is difficult to feel the sensation of the Braille the dots. Therefore in this study, we examine the

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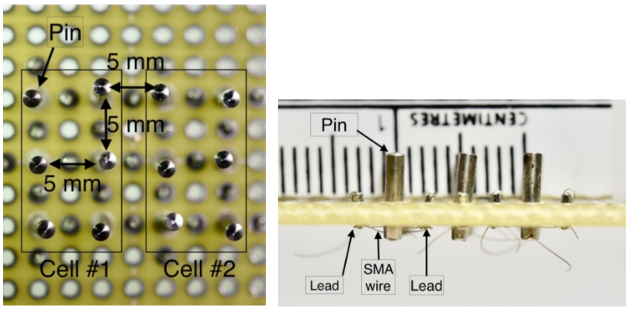


a) top view b) side view

Fig. 1 Braille display with 2 Braille cells.

frequencies from 5 to 50 Hz.

2.2 SMA wires

SMA wires are driven by pulse signal as shown in Fig.2. When the pulse current is in the 'on' state, the temperature of the SMA wire rises up to T_2 and the SMA wire shrinks in its length direction. If pulse current is in its 'off' state, the heat is released to lower the temperature to T_1 and the length returns to its original length, as shown in Fig.3. A copper lead is used in order to hold the SMA wire through soldering, as shown in Fig.4.

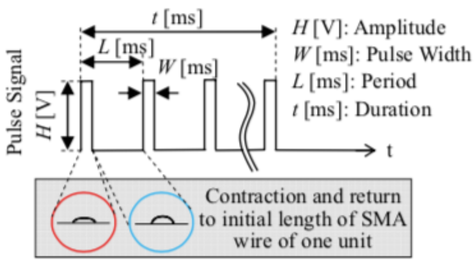


Fig. 2 Pulse signal for driving SMA wire.

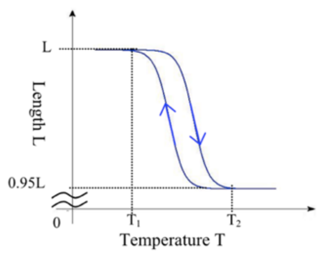


Fig. 3 Temperature Characteristics of SMA wire.

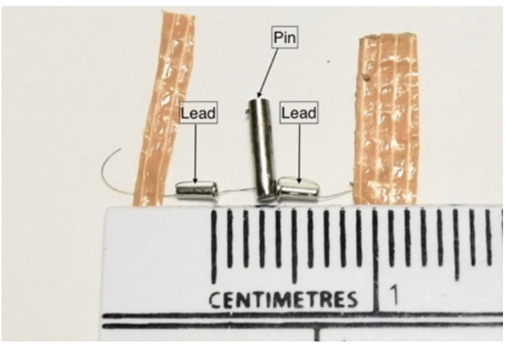


Fig. 4 Structure of SMA and pin.

2.3 System controlling the device

To control the vibration of the pins we use Arduino DUE as a micro-controller as shown in Fig.5. The output current from Arduino is low, therefore a Darlington transistor was employed to amplify the current to 200 mA. Twelve Darlington transistors were used in order to independently drive the 12 pins. Arduino IDE software was used to generate the signals.

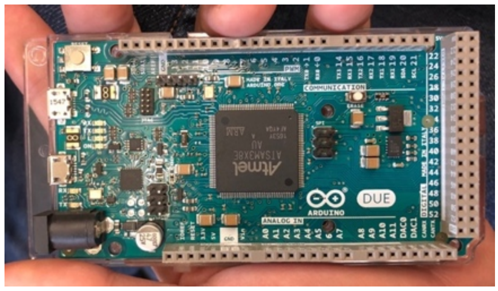


Fig.5 Arduino DUE.

3. Methods to present Braille information

To present Braille information using two Braille cells, different vibration patterns were studied. Six patterns were designed to test the recognition by subjects. According to our previous studies, four different tactile receptors were situated under a skin, and Meissner and Pacinian corpuscles responded well to vibrational stimuli. In this study, we selected vibration frequency from 5 – 50 Hz that is related with the Meissner corpuscles and Ruffini endings. Four vibration frequencies, 5, 10, 25 and 50 Hz were selected to test the response of tactile receptors, and time difference is given among Braille pins.

For the verification of our Braille display, we conducted users' experiments by preparing 6 vibration patterns I – VI. Details of the patterns were presented as follows. In each pattern, 5 different parameters were selected for the comparison.

3.1 Pattern I (P1)

As shown in Fig.6, different frequencies were set to different columns to test the recognition ability. All the pins were driven simultaneously with different frequencies as shown in Table 1. For example, in the pattern P1-5, dots in the first column vibrate with frequency 10 Hz, dots in the second column vibrate with 25 Hz, and the bottom dots vibrate with 50Hz.

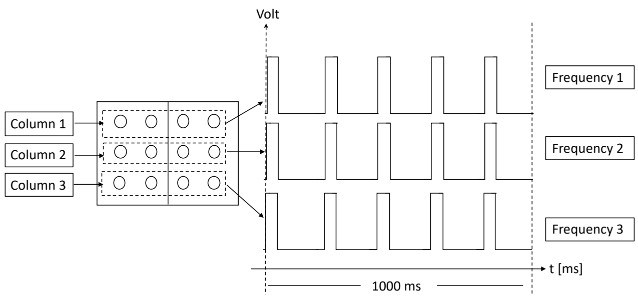


Fig.6 First pattern presenting Braille characters.

Table 1: Patterns with different frequencies.

parameters	Column 1 [Hz]	Column 2 [Hz]	Column 3 [Hz]
P1-1	5	5	5
P1-2	10	5	10
P1-3	10	25	10
P1-4	25	50	10
P1-5	10	25	50

3.2 Pattern II (P2)

In this pattern, as shown in Figure 7, the dots in the cell #1 firstly vibrate for 2 seconds, then the dots in the cell #2 vibrate. The dots in different columns vibrate with different frequencies as shown in Table 2.

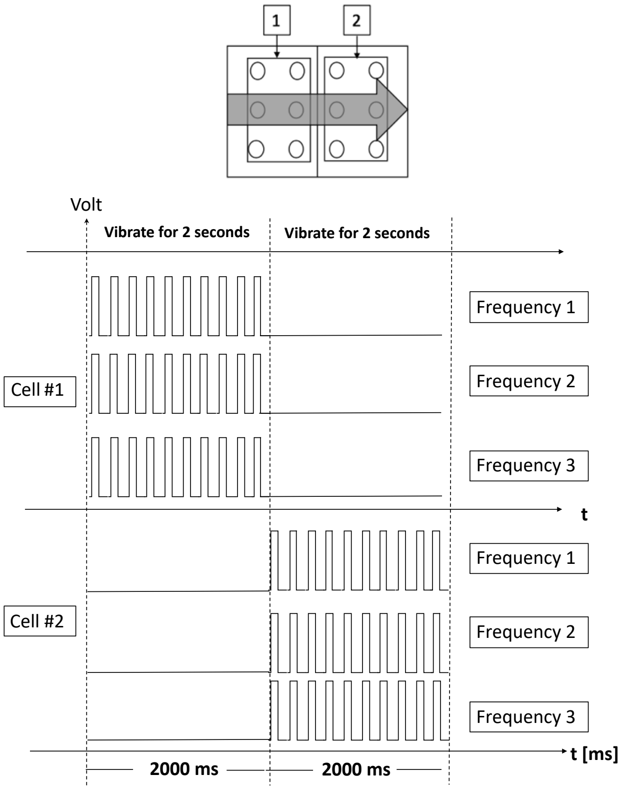


Fig.7 Second pattern presenting Braille characters.

Table 2: Patterns with different frequencies for pattern II.

Parameters	Cell #1			Cell #2		
	Column			Column		
	Upper [Hz]	Middle [Hz]	Bottom [Hz]	Upper [Hz]	Middle [Hz]	Bottom [Hz]
P2-1	5	5	5	5	5	5
P2-2	10	5	10	10	5	10
P2-3	10	25	10	10	25	10
P2-4	25	50	10	25	50	10
P2-5	10	25	50	10	25	50

3.3 Pattern III (P3)

In this pattern, vibration was sequential from the first column to the third column. Time delay was settled among the columns to improve the subjects' perception. The time chart of the sequential presentation is described in Fig.8, and the vibration frequencies given to each column and the time delays among columns are shown in Table 3.

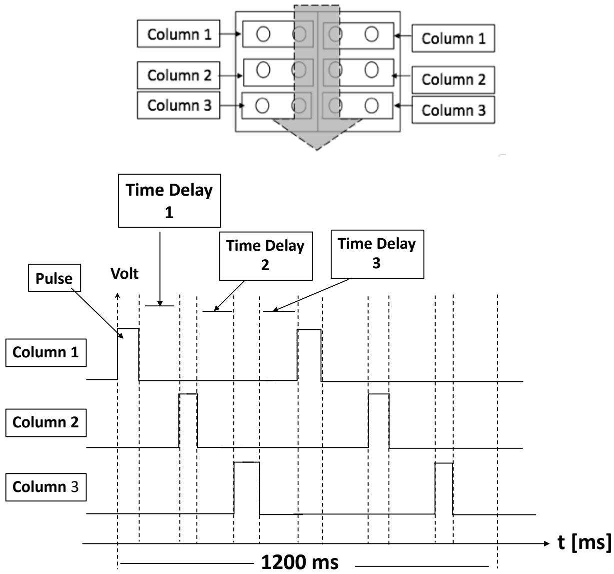


Fig.8 Third pattern presenting Braille characters.

Table 3: Pattern of time delay to vibrate two braille cells at the same time

Parameters	Time Delay among columns [ms]			Frequency of each column [Hz]
	Column 1 and 2	Column 2 and 3	Column 3 and 1	
P3-1	180	180	180	1.60
P3-2	90	180	90	2.50
P3-3	90	36	90	3.50
P3-4	36	18	90	6.25
P3-5	90	36	18	6.25

3.4 Pattern IV (P4)

Sequential presentation was further extended to each cell in this pattern. The presentation starts from the first column of cell #1, then to the second column, and continues to the third column of cell #2 as shown in Figure 9. this time difference is also settled in the pattern as shown in Table 4.

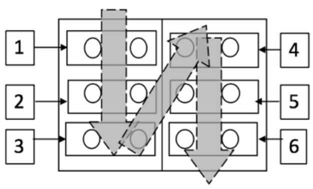


Fig.9. Fourth pattern presenting Braille characters.

Table 4: Pattern of time delay to vibrate six couples.

Parameters	Time delay among columns [ms]			Frequency of each column
	Column 1 and 2, 4 and 5	Column 2 and 3, 5 and 6	Column 3 and 4, 6 and 1	
P4-1	180	180	180	1.60
P4-2	90	180	90	2.50
P4-3	90	36	90	3.50
P4-4	36	18	90	6.25
P4-5	90	36	18	6.25

3.5 Pattern V (P5)

In this pattern, as shown in Fig.10, the dots are vibrated sequentially from the first column to the third column by vibrating each column for 2 seconds. The vibration frequencies of each column are different as shown in Table 5. By presenting the vibratory stimuli periodically in every 2 seconds, we expect to improve the perception of Braille patterns.

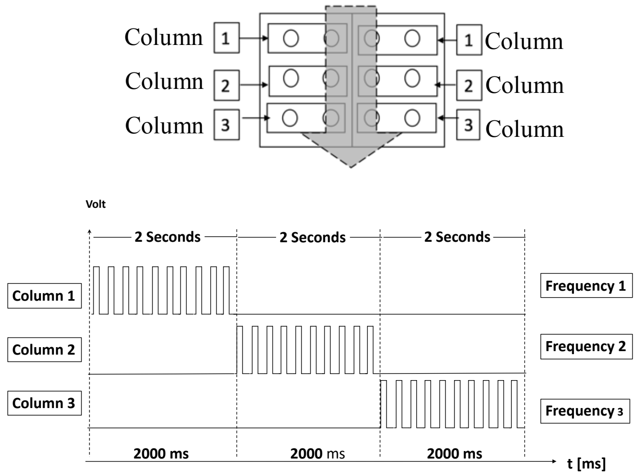


Fig.10 Fifth pattern.

Table 5: Pattern of frequency for pattern V

Parameters	Frequency		
	Column 1 [Hz]	Column 2 [Hz]	Column 3 [Hz]
P5-1	5	5	5
P5-2	10	5	10
P5-3	10	25	10
P5-4	25	50	10
P5-5	10	25	50

3.6 Pattern VI (P6)

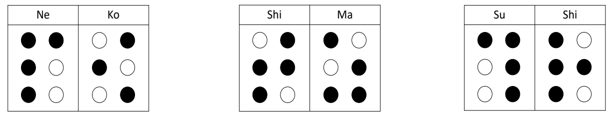
The vibration pattern V was extended by starting from the first column of cell #1 and sequentially continuing to the third column of cell #2, as shown in Fig. 9. Each column was set with different frequencies as shown in Table 6.

Table 6: Pattern of frequency for pattern VI

Parameters	Cell #1			Cell #2		
	Column			Column		
	Upper [Hz]	Middle [Hz]	Bottom [Hz]	Upper [Hz]	Middle [Hz]	Bottom [Hz]
P6-1	5	5	5	5	5	5
P6-2	10	5	10	10	5	10
P6-3	10	25	10	10	25	10
P6-4	25	50	10	25	50	10
P6-5	10	25	50	10	25	50

4. Experiment

Three Braille symbols were used to test the recognition as shown in Fig.11. The first symbol a) was used to test the recognition of patterns I and II, the second symbol b) was used to test the recognition of patterns III and IV, and the last symbol c) was used to test the recognition of patterns V and VI.



a) Symbol for I, II. b) Symbol for III, IV. c) Symbol for V,VI.

Fig.11 Three symbols.

Recognition experiments were conducted by employing 10 able-bodied subjects. We firstly gave instructions to the subjects. No training was conducted before the experiment.

A subject put the index and middle fingers to the cell #1 and cell#2, respectively. We set the time to answer within 40 seconds per one pattern, and each pattern was repeated every 40 seconds. For answering results, we provided an answer sheet to describe answers for the presented Braille. In the experiment, 30 patterns (patterns from I to VI multiplied by 5 different parameters) were randomly presented to the subjects, and they described the answers for each presentation.

For the calculation of the recognition rate, we used only correct answers by considering the number of pins. For example, when a correct answer is pins 1,2,3 and 4, if a subject answers 1 and 2, then the recognition is 50%. In the case that the subject's answer is 1,2,3 and 5, the recognition rate is 0% since the subject confused.

4.1 Results of pattern I and II

Figure 12 shown in recognition results. The best recognition rate was 32.5% from pattern P1-1 by index fingers and 19.99% from pattern P1-3 by middle fingers. For pattern P1-4, it shows comparatively lower recognition. The results show that the vibration with higher frequencies may cause the differently of recognition, when plural pins present vibration stimuli simultaneously.

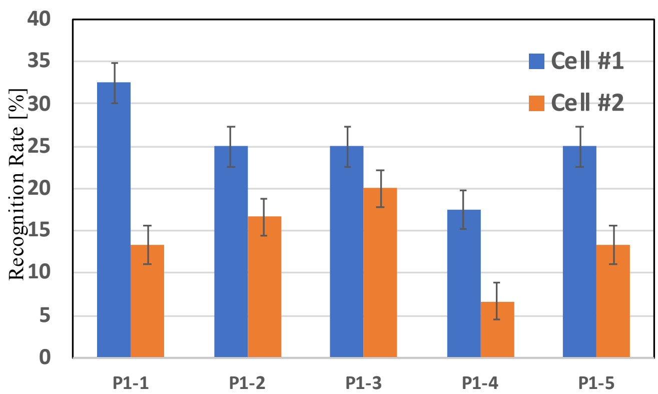


Fig.12 Recognition rate of pattern I.

The result of pattern II is shown in Fig. 13. Recognition rates for index fingers are around 30%, on the other hand the rates for middle fingers are lower around 20%.

From the results of the pattern I and II, we found that the recognition by index fingers performs better than middle fingers, when all the pins vibrate simultaneously.

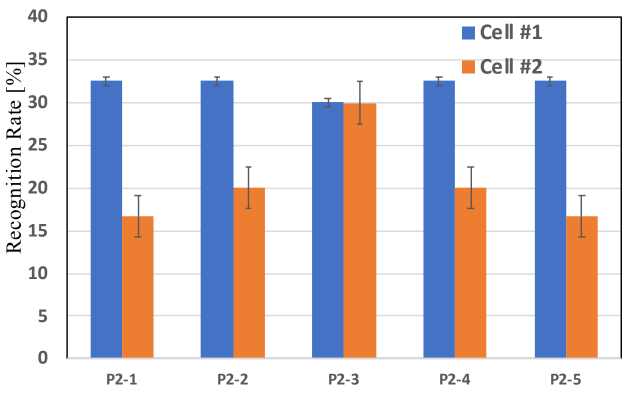


Fig.13 Recognition Rate of pattern II.

4.2 Results of pattern III and IV

Results of the patterns III and IV are presented in Figures 14 and 15. In these presentations, an advantage of index fingers are not found, and the recognition was closely achieved by both fingers. Lower vibrations work better, by comparing with the vibrations with higher frequencies.

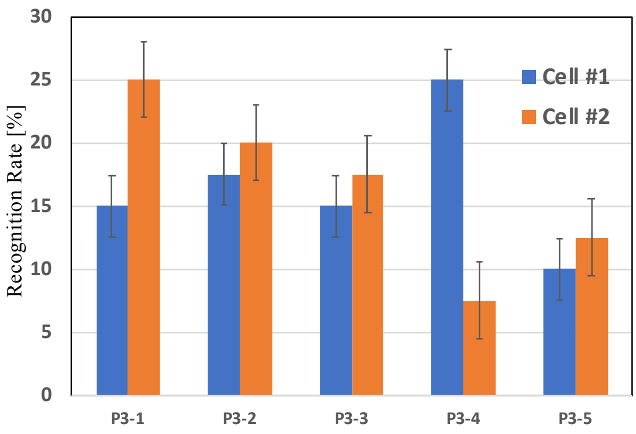


Fig.14 Recognition rate of pattern III.

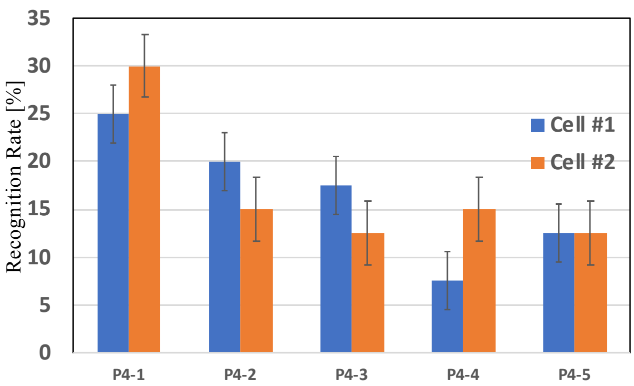


Fig.15 Recognition rate of pattern IV.

4.3 Results of pattern V and VI

Figures 16 and 17 show the results of the patterns V and VI, respectively. Higher recognition rates were obtained by index fingers, comparing with the patterns from I to IV, on the other hand the recognition by middle fingers decreased.

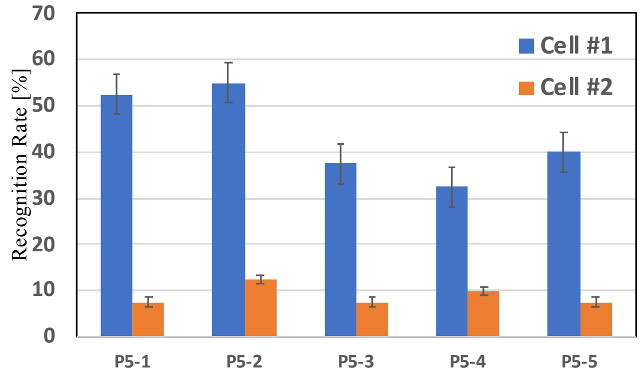


Fig.16 Recognition rate of pattern V.

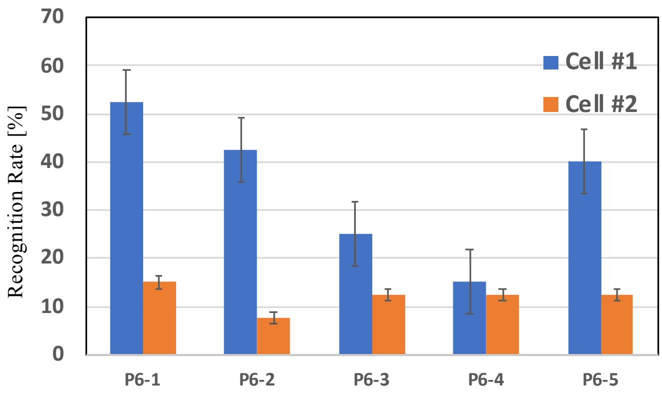


Fig.17 Recognition rate of pattern VI

5. Discussions

According to the results of this experiment, we found that the pattern V and VI have the highest recognition rate for cell #1. Thus, pattern V and VI are suitable to employ for the display using two Braille cells. In case of comparison between cell #1 and cell #2, they have different recognition rates because the results show that the subjects are able to use their index fingers to recognize vibration better than their middle fingers. For the average recognition time, there was no difference for all the patterns. Quicker recognition time is preferable to read sentences in a short time with the active Braille display.

After the experiments, we discussed with the subjects about the recognition, and found some problems due to the distance between an index finger and a middle finger. The design of the device was imperfect to be read by both index and middle fingers at the same time. Some subjects claimed that cell #1 and cell #2 are too close to be read by the two fingers.

6. Conclusions

In this research, we focused on presenting Braille words by using the micro-vibration generated by shape memory alloy wires. We attempted the 6 experiments with different patterns to find the best pattern to present the Braille information with the 2 Braille cells. Eventually, we found that the patterns V and VI demonstrated higher recognition rates to read with an index finger. However, there were problems in the design of the display to read with a middle finger. The imperfectness of the design resulted in the miss-recognition when using a middle finger. To solve this problem, the first and the second cells should be properly located to fit with two fingers on the display. In the future, we will develop a Braille display that is easy for users to recognize characters using two fingers at the same time.

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