PAPER

Transfer Information Enhancement with a 2-D Tactile Stimulator Array for an Acoustic Vision Substitute System

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SUMMARY Existing vision substitute systems have insufficient spatial resolution to provide environmental information. To present detailed spatial information, we propose two stimulation methods to enhance transfer information using a 2-D tactile stimulator array. First, stimulators are divided into several groups. Since each stimulator group is activated alternately, the interval of stimulations can be shortened to less than the two-point discrimination threshold. In the case that stimulators are divided into two and four groups, the number of stimulators increases to twice and four times, respectively, that in the case of the two-point discrimination threshold. Further, a user selects the measurement range and the system presents targets within the range. The user acquires spatial information of the entire measurement area by changing the measurement range. This method can accurately present a range of targets. We examine and confirm these methods experimentally.
key words: *vision substitute system, tactile, acoustic, hybrid method, human interface*

1. Introduction

Many researchers have investigated human machine information transfer methods through tactile excitation. Often, a 2-D stimulator array is used in a vision substitute system [1]–[5]. Previous research has been directed to converting visual images to vibrotactile or electrotactile excitation, and thus excitation intensity does not correspond to the range of the target in these methods. For target range detection, a user needs to memorize the shape of the target. Then the user identifies the target and compares the presented information with the memorized shape. Therefore, it is difficult to recognize the location of plural targets with different ranges, because of the difficulty for memory of the plural target shapes and identification of them.

It is expected that early blind have a quite different recognition way of spatial information from late blind, and thus it is difficult to design a vision substitute system for both early and late blind. In recent years Japan rapidly turns into aging society and the occurrence of diabetes increases. Therefore the number of late blind will increase because of senile macular degeneration and diabetic retinopathy. Hence, we direct to a vision substitute system for late totally blind. For acquiring information from visual environments with plural targets, existing vision substitute systems need to improve their angular and range resolutions.

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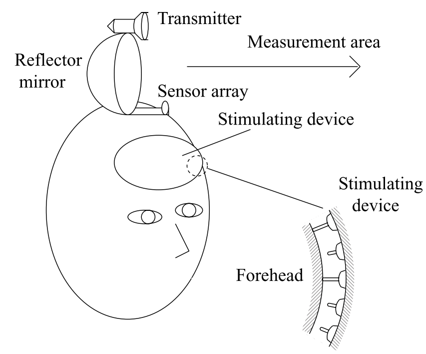

Fig. 1 Schematic view of the acoustic vision substitute system.

The goal of this study is to develop an efficient system for presenting environmental information. To provide environmental information with a portable instrument, we have proposed an acoustic vision substitute system based on a hybrid array-reflector configuration that realizes high time and spatial resolutions with just a modest computational load [6]. Figure 1 shows the schematic view of our vision substitute system in which a broad transmit beam is radiated over the entire measurement area. The reflected echo is first focused by a concave reflector, and then received by the 2-D sensor array. Images are reconstructed from the widely distributed signals received on the array by numerical back projection. With this method, one transmit and receive event can make a 3-D image of the whole measurement area. This system realizes 34 images/s in the case that the measurement range is 5 m.

We propose that spatial information, measured by the acoustic sensor, is presented by a 2-D tactile display placed on the forehead. Auditory sense is one of the most important information for the blind. Mounting a stimulating device on a hand or an arm prevents a user from moving freely. Of all body regions on which we could mount a stimulating instrument without an obstruction, the forehead has a low two-point discrimination threshold and wide stimulating area. Thus we determined the stimulation region should be the forehead. As well, the forward direction of the face corresponds to the center direction of the measurement area. Therefore, for late totally blind, recognizing target directions is relatively easy.

This paper has two purposes. The first is the angular resolution improvement of transfer information to provide sufficient environmental information. The second is to transfer the target ranges exactly for the distinction of plural targets at different ranges. So that each stimulator individually transfers different information, the stimulators in the array are spaced at intervals of the two-point discrimination threshold [7]–[9]. This restricts the number of stimulators that transfer information through a certain area. In this paper we propose two methods to improve angular resolution and transfer target range. The methods employ a 2-D stimulator array having stimulators spaced at intervals of less than the length of the simultaneous two-point discrimination threshold to increase the number of stimulators. Since two stimulators adjoined to each other work with a certain stimulus onset asynchrony (SOA), they can separately transfer different information. Furthermore a user selects the measurement range and the system proposes targets within the range to the user. By selecting from a short range to a long range, the user can acquire spatial information of the entire target area. Since the user knows the measurement range, the range of the targets can be accurately recognized. Here, we investigate these methods experimentally, and confirm their effectiveness.

In Sect. 2, we propose two methods, an alternating stimulation method and a voluntary range selection method. We then explain the instrument used in the experiment and the content of the experiment. In Sect. 3, we evaluate the experimental results. Finally, conclusions are drawn in Sect. 4.

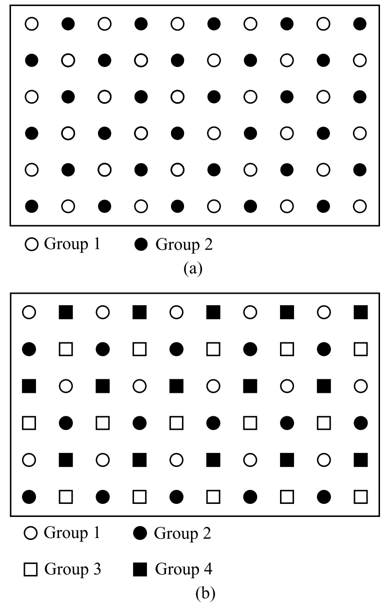

Fig. 2 Division of stimulators that are components of a 2-D array stimulating device placed on the forehead. Stimulators are divided into (a) two and (b) four groups. Stimulators that belong to a group move synchronously and stimulator groups are activated alternately.

2. Methods

2.1 Alternating Stimulation Method

This system uses a 2-D stimulator array as a stimulating device. The stimulator spacing should be more than the two-point discrimination threshold so that each stimulator transfers different information to the user. Since this restricts the number of stimulators constituting a 2-D stimulator array, it is difficult to transfer enough information to a user for the vision substitute system. We propose an alternating stimulation method to gain transfer information by increasing the number of stimulators. In this method stimulators in a 2-D array are divided into several groups. Figure 2 shows examples of the stimulators divided into two and four groups. Stimulators that belong to a group move synchronously and each stimulator group is activated alternately. Stimulators within a group are spaced at intervals of the two-point discrimination threshold. However, the interval of two stimulators that adjoin each other is less than the interval of the two-point discrimination threshold. Since they belong to different groups, there is a SOA between two stimulations. In this case, the two stimulations are perceived individually under the condition that the stimulator spacing is about 1/3 of the two-point discrimination threshold [8]. In the case of the two examples shown in Fig. 2, the intervals of the stimulators adjoining each other are respectively 0.71 and 0.5 of the two-point discrimination threshold. Therefore, if the stimulator spacing of the same group is set to the two-point discrimination threshold, stimulations can individually transfer different information. This means that the number of stimulators can be increased to 2 or 4 times that in a 2-D array spaced at an interval of the two-point discrimination threshold. Thus the spatial information presented in this method is improved to 2 or 4 times that in the simultaneous stimulation one.

2.2 Voluntary Range Selection

To distinguish multiple targets, we need to present the direction and range of targets. The proposed system presents the direction of a target by stimulating the location on the forehead. The subject can then recognize the range of targets as follows.

Figure 3 shows a schematic view of targets in the measurement area. Figure 4 is the projection image of targets to the measurement area. The range of targets A, B is less than d_1, and that of C, D is between d_1 and d_2. Since a target with a shorter range is more important, the target of the shortest range is displayed in the case where plural targets exist in the same direction.

First, a user determines the measurement range of d_1 and gives instructions to the vision substitute system. We suppose the instruction is given by a brain switch [10], a biting force switch, a voice switch, or a kind of contact switch. In future we will examine these various switch types and select the best. The system presents directions of targets A, B by vibrotactile excitation on the forehead. Figure 5 shows stimulating points matched with targets in the case of the measurement range of d_1. From the stimulating position presented by this system, the user can recognize the size and direction of the targets.

Second, the user gives the instruction regarding the

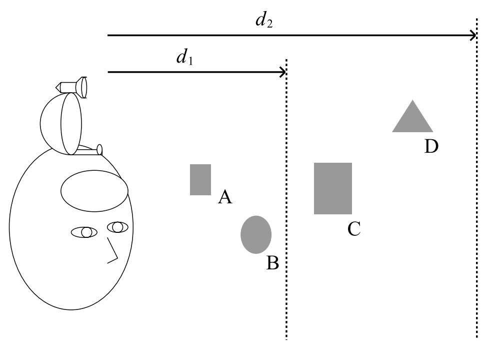

Fig. 3 Schematic view of targets in the measurement area.

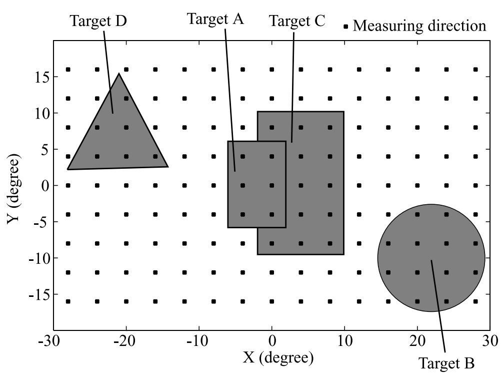

Fig. 4 Directions of targets in the measurement area.

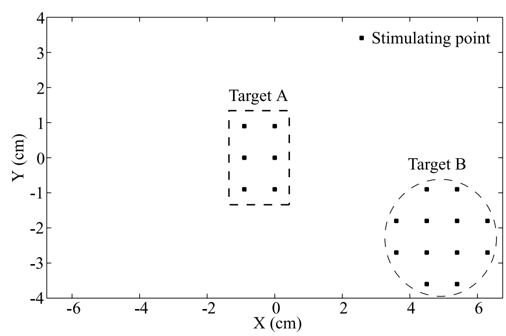

Fig. 5 Stimulating points matched with targets when the measuring range is d_1.

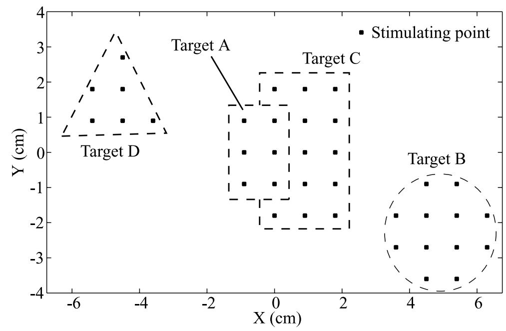

Fig. 6 Stimulating points matched with targets when the measurement range is d_2.

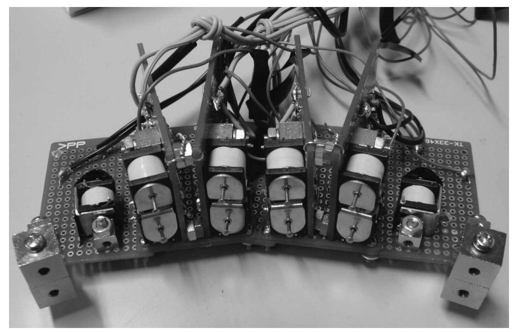

Fig. 7 Solenoid array placed on participants' foreheads. The 2 × 4 solenoids placed at the center of the array are the stimulators. The two solenoids placed at the sides always generate sound and vibration to prevent participants from distinguishing tactile patterns by sound.

measurement range of d_2 to the system, and it presents the directions of targets A, B, C, D. Figure 6 shows stimulating points matched with targets when the measurement range is d_2. From the changes in the information displayed the user recognizes that the range of targets C, D is between d_1 and d_2. By measuring from a short to a long range, the user acquires spatial information of the entire target area.

For identifying objects on a table, there is no need to measure targets with a long range; therefore, a user fixes the measurement range as a short one. Then the interval of each radiation time becomes shorter in the case that a transmitter radiates after the echo from the longest range is received. This allows an improvement in the time resolution. For long range detection, the user can memorize the range of targets from a single detection of the whole measurement area. Then the user can fix the measurement range as a long one, after measuring from the short range to a long one. When the measurement range is 5 m, the time resolution of the system is about 0.03 second, which means that it can deal with pedestrian movement.

2.3 Overview of the Experiment

We examine the alternating stimulation and the voluntary range selection methods experimentally using a 2-D solenoid array consisting of a 2 × 4 arrangement with two dummy solenoids placed at the left and right side of the array, as shown in Fig. 7. The two solenoids placed at both sides always generate sound and vibration, to prevent participants distinguishing tactile patterns by sound. The protuberances, placed at both edges of the array, restrain the stimulation rods from pushing hard against the forehead. When employing the simultaneous stimulation method, the active stimulators work synchronously. When employing the alternating stimulation method, the stimulators in the 2-D array are divided into two groups, as shown in Fig. 8. Each stimulation group is activated alternately. With this proposed stimulation method, a couple of stimulation sets present single spatial information. To correspond the power consumption of the dummy solenoids between the two stimulation methods, the left side dummy solenoid belongs to group 1

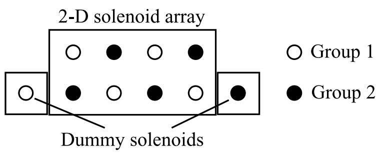

Fig. 8 An arrangement of stimulators divided into two groups when employing the alternating stimulation method.

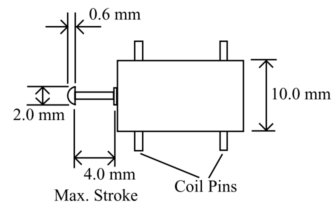

Fig. 9 Schema of a solenoid component in the 2-D stimulator array placed on the forehead.

and the right side to group 2. We first compare the perceived stimulus quality of the alternating stimulation to that of simultaneous stimulation. We then investigate the exactitude of transferring range information of targets using a voluntary range selection method. We suppose that the user gives instructions to the system for a short to a long range. Since the target with a longer range is presented later, the stimulation points increase within a stimulation set.

2.4 Vibrotactile Stimuli

In this study, we use a solenoid array as the stimulating device. Each solenoid has a round-topped vibrating rod, as shown in Fig. 9. As shown in [9], the two-point discrimination threshold at the forehead is 0.9 cm to 1.5 cm. It is assumed from the Loomis' s study [11], that the localization error at the forehead is about 1/4 of the two-point discrimination threshold. Since we assume that the stimulator spacing is about two-point discrimination threshold for transferring information accurately, the tops of the vibrating rods are spaced at intervals of 1.3 cm vertically and 1.5 cm horizontally. A participant places the array on his forehead and responds to the tactile pattern presented by the array. Rectangular pulses are delivered to activate solenoids, which contain two dummy solenoids. The voltage delivered to a solenoid is 3 V. Its pressure, dependent on the stroke of the stimulation rod, is 1 to 2.5 gf.

To provide fine spatial information, it is necessary to stimulate the skin tactile receptors with high spatial resolution. The skin deform threshold of the receptor should be low for the stimulators to have a low power consumption. Since a Meissner' s corpuscle has both high spatial resolution and low skin deform threshold [3], we decided to activate Meissner' s corpuscles. Their most sensitive frequency is 20 to 40 Hz; so we set the stimulating frequency at 30 Hz. Figure 10 shows the waveforms used in this experiment. The interval of pulse onsets is 33.3 ms (pulse repetition rate is 30 Hz) and pulse width is half of the interval. We follow Y. Shimizu [12], and set the duration of the stimulation and SOA at 200 and 800 ms, respectively; that is, the burst onset is separated by 800 ms and each burst contains 6 pulses.

A phantom sensation occurs under certain conditions of SOA, stimulator spacing and stimulation pressure. Such as when two stimulators that adjoin each other can not individually transfer different information. To prevent a phantom sensation, in the alternating stimulation trials we set the SOA and the duration of stimulation as 400 ms and 200 ms, respectively. We also set both types of trials to have the same power consumption as follows.

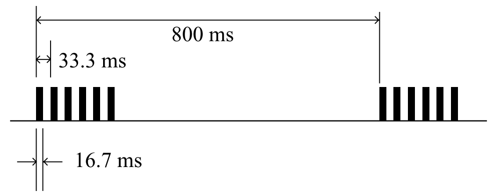

Fig. 10 Stimulus waveform in the simultaneous stimulation trials. Pulse repetition rate is 30 Hz and pulse width is half of the pulse onset interval. Each burst has 6 pulses and burst onset interval is 800 ms.

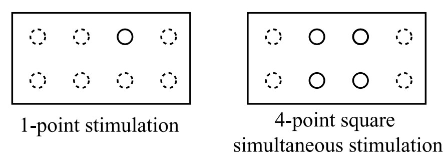

Fig. 11 Tactile patterns in the simultaneous stimulation trials. The 1-point stimulations are presented at one of the 8 positions. The 4-point stimulations are presented simultaneously at one of the three positions; left, middle, and right.

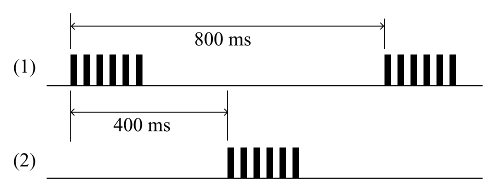

Fig. 12 Stimulus waveform in the alternating stimulation trials. Waveforms (1) and (2) are delivered to the active solenoids of groups 1 and 2, respectively. Stimulus onset asynchrony between the two groups is 400 ms.

In the simultaneous stimulation trials, the waveform in Fig. 10 is delivered to all active solenoids. The tactile patterns used in these trials are 1-point stimulations and 4-point square stimulations, as shown in Fig. 11. The 1-point stimulations are presented at one of the 8 positions. The 4-point stimulations are presented simultaneously at one of three positions; left, middle, and right. In the alternating stimulation trials, the waveforms in Fig. 12-(1) and 12-(2) are delivered to the active solenoids of groups 1 and 2, respectively. The tactile patterns used in these trials are the same as those in the simultaneous trials. Each 4-point square stimulation is presented by two pairs of stimulators that are activated alternately, as shown in Fig. 13. A 1-point stimulation is presented in the same way as that in the simultaneous stimulation trials, except for the activation of the dummy solenoids.

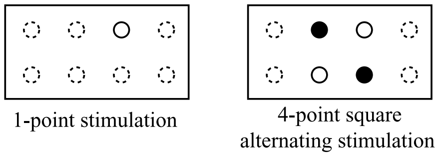

Fig. 13 Tactile patterns in the alternating stimulation trials. The 4-point stimulations consist of two stimulation groups.

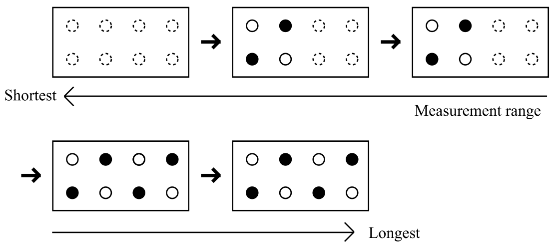

Fig. 14 Tactile patterns in the voluntary range selection trials. Two targets, represented as 4-point square stimulations, are presented one after the other.

In the alternating stimulation method experiment, the presentation time of each pattern is 5 s, which contains 6 bursts of voltage delivered to the solenoids. Since the receptive field of a Meissner' s corpuscle is 12.6 mm^2 [3], the influence of an individual stimulation over an adjacent stimulation point is neglectable. Both trials in this experiment have the same SOA, and therefore there is no difference between any influences from the adaptation in the two trials. This indicates that in the comparison between the simultaneous and alternating stimulation trials it is not necessary to evaluate the influence of the adaptation. The interval between two presentation times is 5 s, and at that time a participant responds to the presented pattern.

In the voluntary range selection method experiment, we assume that the measurement range has 5 phases. Two targets represented as 4-point square stimulations exist at the right and left in different ranges, and a user measures from a short to a long range. Here, these targets are presented one after the other, as shown in Fig. 14. The presentation time for each stimulation set is 25 s, and contains 5 stimulation patterns. In this experiment, we use the alternating stimulation method and set the interval between the two presentation times as 5 s.

2.5 Participants

Six healthy males (21-28 years old) participated in this experiment. Participants provided informed consent and wiped their forehead before the start of the experiment. In the experiments, participants opened their eyes and inserted earplugs. We checked the contact between stimulation rods and the forehead before and after each experiment. All participants underwent the experimental procedures.

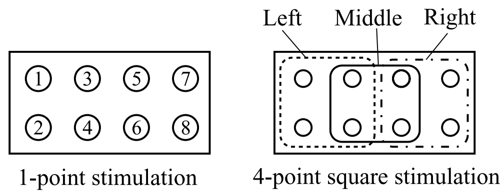

Fig. 15 Solenoid numbers and activated solenoid groups of the 4-point stimulation. A 1-point stimulation is presented by activating one of the eight solenoids. A 4-point stimulation is presented at left, middle, or right position by four activated solenoids. Thus these stimulations are named 1-8, left, middle, and right.

Table 1 Variety of responses in the alternating stimulation method experiment. If a participant perceives a 1-point pattern, he responds with one of the 8 numbers; 1–8. If he perceives a 4-point pattern, he selects one of the three choices; left, middle, or right.

Perception	Response
1-point pattern	1 to 8
4-point pattern	Left, Middle, Right

2.6 Main Experiment

We number the solenoids from 1 to 8, as shown in Fig. 15. A 1-point stimulation is presented by activating one of the eight solenoids. A 4-point stimulation is presented at left, middle, or right position by four activated solenoids, as shown in Fig. 15. We call these stimulations as 1-8, left, middle, and right. A participant responds to the stimulations with the names, as shown in Table 1. If a participant perceives a 1-point pattern, he responds one of the 8 number; 1-8. If he perceives a 4-point pattern, he selects one of the three choices; left, middle, or right.

The alternating stimulation method experiment consists of two practical trials followed by two experimental ones. The first practical trial employs simultaneous stimulations, and the second alternating ones. In the practical trial, the stimulations of 1 to 8, left, middle and right are presented in that order. Participants are informed about the names of the stimulations presented and practice to become accustomed to the stimulations. This practice cycle is presented twice, and then each practical trial consists of 16 1-point stimulations and 6 4-point stimulations. Each experimental trial consists of 12 1-point stimulations and 12 4-point stimulations. The arrangement on the array and the order of these tactile patterns are random. In the experimental trials, participants respond to the stimulations with the names, as shown in Table 1. The first experimental trial employs simultaneous stimulations and the second alternating stimulations, similar to in the practical trials.

The voluntary range selection method experiment consists of one practical trial followed by an experimental one. The practical trial and the experimental one have 8 and 12 stimulation sets, respectively. The two 4-point stimulations of these 20 stimulation sets are presented randomly. Similarly to the alternating stimulation method experiment, in the practical trial participants are informed about the pre-

Table 2 The average and the standard deviation of the possibility that the distance between the position of the stimulation and that of the response is each value when a 1-point stimulation is presented and the pattern of the response is correct. The average is written in the upper line of each cell, and the standard deviation with vinculum in the lower line.

Distance	0	L_0	$\sqrt{2}L_0$	$2\ L_0 \leq$
Simultaneous stimulation	0.437 (0.117)	0.469 (0.173)	0.0787 (0.091)	0.0152 (0.034)
Alternating stimulation	0.518 (0.305)	0.408 (0.278)	0.0602 (0.065)	0.0139 (0.031)

sented patterns and practice to become accustomed to these stimulation patterns. In the experimental trial they respond with the directions and the starting times of two 4-point stimulations. In this experiment we employ the alternating stimulation method.

3. Results

In the alternating stimulation method experiment, a participant responds with the pattern and position of the stimulation. There is a distance between the position of the stimulation and that of the response when the response to the stimulation pattern is correct. We evaluate the possibility that the distance, between the position of the stimulation and that of the response, is a certain distance when a 1-point stimulation is presented and the response being 1-point pattern. We define the possibility as the number of each distance over the total number of the responses being a 1-point pattern. The distance variation is 8 as follows; 0, 1.3, 1.5, 2.0, 2.6, 3.0, 3.9, and 4.2 cm. Therefore we define L_0 as the interval of the stimulation rods, and then classify the 8 distances to 4 grades; 0, L_0, $\sqrt{2}L_0$, and $2L_0$ or over. Table 2 shows the average and the standard deviation of the possibility. The possibility of the distance being 0 or L_0 is almost 1, and the possibility of the distance being $2L_0$ or over is almost nil. This indicates that we can neglect the probability of false positives.

Table 3 shows the definitions of the variables used in the evaluation of the alternating stimulation method. Their values are the numbers of the responses in the experiment. Table 4 shows the average and the standard deviation of the possibilities that the response is correct or not correct when the response is a 4-point pattern. The possibilities for 4-point and 1-point stimulations are defined simply as $a_{22}/(a_{21} + a_{22} + a_{23})$ and $a_{12}/(a_{11} + a_{12} + a_{13})$, respectively. This result shows the effectiveness of the proposed alternating stimulation method for enhancing transfer of information with $p < 0.01$. We introduce the assumption that the possibility follows a normal distribution and use a t-examination.

Furthermore, the interpretation of a no signal response is as follows. Since the false positive probability can be neglected, a bad contact between a stimulator and the forehead causes a no signal response. For future work we need to improve the stimulation instrument to prevent any bad contacts. The probability of a bad contact between a stimulator and the forehead, p_{BC}, satisfies

Table 3 Definition of the variables used in the evaluation of the alternating stimulation method. Their values are the numbers of the sensation responded to in the experiment.

	Response		
	1-point pattern	4-point pattern	No pattern
1-point stimulation	a_{11}	a_{12}	a_{13}
4-point stimulation	a_{21}	a_{22}	a_{23}

Table 4 The average and the standard deviation of the possibilities that the response is correct or not correct when the response is a 4-point pattern, The possibilities for 4-point and 1-point stimulations are defined simply as $a_{22}/(a_{21} + a_{22} + a_{23})$ and $a_{12}/(a_{11} + a_{12} + a_{13})$, respectively.

	The possibility of a 4-point pattern response	
	4-point stimulation	1-point stimulation
Simultaneous stimulation	0.556 (0.190)	0.0278 (0.0393)
Alternating stimulation	0.861 (0.150)	0.0417 (0.0636)

$$p_{BC} = a_{13}/(a_{11} + a_{12} + a_{13}). \quad (1)$$

To revise the possibility that the response is correct when a tactile pattern is a 4-point square stimulation, we treat the result statistically. The number of 4-point square stimulations becoming 1-point stimulations because of a bad contact between stimulators and the forehead, b_1, satisfies

$$b_1 = 4(a_{21} + a_{22} + a_{23})p_{BC}{}^3(1 - p_{BC}). \quad (2)$$

In this interpretation, the possibility that a 4-point square stimulation becomes a no stimulation, $p_{BC}{}^4$, is less than 0.2%. This is consistent with the result that in all experimental trials $a_{23} = 0$. In this interpretation we define the correct response as a 4-point pattern response when a multiple-point stimulation is presented for a 4-point stimulation. The number of multiple-point stimulations presented is given by $a_{21} + a_{22} - b_1$. We remove the superficially correct occasion that the a participant mistakes and responds with a 4-point pattern when a 1-point stimulation is presented because of a bad contact in the case of a 4-point stimulation. The number of occasions that this happens is given by

$$b_2 = b_1 a_{12}/(a_{11} + a_{12}). \quad (3)$$

Therefore the possibilities of a 4-point response when a 4-point stimulation and a 1-point stimulation are presented, p_{44} and p_{14}, satisfy

$$p_{44} = (a_{22} - b_2)/(a_{21} + a_{22} - b_1), \quad (4)$$
$$p_{14} = a_{12}/(a_{11} + a_{12}). \quad (5)$$

Figure 16 shows the average of the possibilities, p_{44} and p_{14}, including the 2 standard deviation error bar. The result shows the effectiveness of the proposed alternating stimulation method for enhancing transfer of information with $p < 0.025$. We also introduce the assumption that the possibility follows a normal distribution and use a t-examination.

In this experiment we can reject cases in which a participant used auditory information caused by bone conduction, as follows. First, SOAs of the vibration sound are fixed at

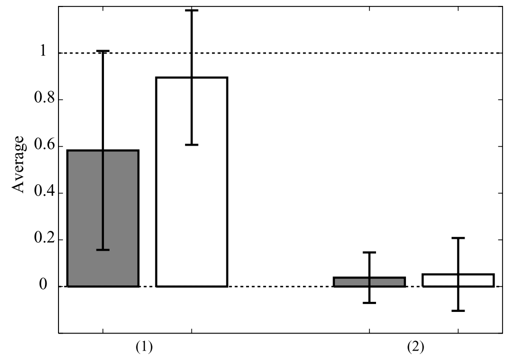

Fig. 16 The average of the possibilities that (1) the response is correct or (2) not correct when the response is a 4-point pattern for the interpretation of the perception of no signal, including the 2 standard deviation error bar. Colored bars are those of the simultaneous stimulation; white bars are of the proposed alternating stimulation.

Table 5 The average and the standard deviation of the possibility that the response is correct when a tactile pattern is a 4-point square stimulation.

	Average	Standard deviation
Direction	0.958	4.05×10^{-3}
Range	0.979	1.01×10^{-3}

800 and 400 ms in the simultaneous and alternating trials, respectively. It is then necessary for a participant to distinguish the intensity of the vibration sound to make the correct response. In the simultaneous trials, 3 or 6 solenoids generate the vibration sound, and then the intensity variation of the sound is generated by 3 solenoids. In the alternating trials, 1, 2 or 3 solenoids generate the vibration sound, and then the maximum variation of the sound is generated by 2 solenoids. This indicates that if a participant utilizes auditory information, the participant distinguishes the two stimulation patterns in the simultaneous stimulation trials more easily than in the alternating stimulation trials. This is contradictory to the results of this experiment. Therefore, we reject the possibility that a participant used auditory information in this experiment.

Table 5 shows the average and the standard deviation of the possibilities that the response is correct in the voluntary range selection method experiment. The possibilities for direction and range are defined respectively as the numbers of the responses where target direction and range are correct over that of all responses. This result shows that range information is almost exactly transferred using the proposed method.

4. Conclusion

For the stimulating device to be utilized in our acoustic vision substitute system, we propose two information transfer methods that use a 2-D stimulator array. In the alternating stimulation method, stimulators are divided into several groups, and each stimulator group is activated alternately. Since two stimulators that adjoin each other belong to different groups, there is a certain SOA between two stimulations. In this case the two stimulations are perceived individually under the condition that the stimulator spacing is about 1/3 of the two-point discrimination threshold. When the stimulators are divided into two and four groups, the intervals of the stimulators adjoining each other are 0.71 and 0.5, respectively, of the two-point discrimination threshold. Therefore if the stimulator spacing of the same group is the two-point discrimination threshold, stimulations can individually transfer different information. This means that the number of stimulators can be increased to 2 or 4 times that in a 2-D array spaced at intervals of the two-point discrimination threshold. Then the spatial information presented in this method is improved to 2 or 4 times that of the simultaneous stimulation method. With the voluntary range selection method, a user selects the measurement range and targets within the range are presented to the user. By selecting from a short to a long range the user acquires spatial information of the entire measurement area. Since the user knows the measurement range, the target ranges can be accurately recognized. We experimentally compare the alternate stimulation and the simultaneous stimulation methods and confirm that the former method is more useful to transfer information to a user. We also experimentally investigate the voluntary range selection method and show that a user can accurately recognize target ranges.

In future work we need to miniaturize this system to make a portable instrument. It will be necessary to reduce power consumption and select proper stimulation devices. To reduce power consumption we need to optimize the duration of the stimulation, SOA, the intensity of the stimulation, and the stimulation waveform. Here, we did not utilize intensity modulation of the stimulation for information presentation. The intensity modulation of stimulation can present other spatial information, such as the echo power from the target. This indicates that this method has the potential to clearly present environmental information.

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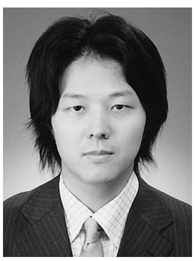

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