Accurate Presentation of the Target Range with a 2-D Tactile Stimulator Array for Acoustic Vision Substitute System

Hirofumi Taki, Member, IEEE, Toru Sato, Member, IEEE and Tetsuya Matsuda, Member, IEEE

Abstract—Existing vision substitute systems have insufficient spatial resolution to provide environmental information. To present detailed spatial information, we propose a stimulation method to present the target range accurately using a 2-D tactile stimulator array. A user selects the measurement range and the system presents targets within the range. The user changes the measurement range, and then compares the presented targets in the latter measurement range with that in the former one. The targets, presented in one measurement range and not in the other measurement range, exist between the former and latter ranges. We examine and confirm this method experimentally.

I. INTRODUCTION

Tactile excitation is widely utilized for human machine information transfer. Often, a 2-D stimulator array is used in a vision substitute system [1-6]. 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.

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 [7]. Fig. 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 gathered 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. Kaczmarek et. al. [3] reported that the simultaneous two-point discrimination thresholds of fingertip, forehead, abdomen, and back are 3, 17, 36, and 39 mm, respectively. When the sizes, width × height, of their stimulation areas are respectively 1.5 × 2.1 cm, 12 × 8.5 cm, 22 × 22 cm, and 24 × 24 cm, the numbers of their stimulation points are 48 or 49. Thus the information content transferred to a user has no relation to the stimulation region. 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 one of the lowest two-point discrimination thresholds. Stimulating a region of lower two-point discrimination threshold causes lower power consumption because of lower stimulating power. Since a man-machine interface with lower power consumption can employ smaller stimulating devices, electronics and a lighter battery supply, it is more suitable for a portable instrument. We thus 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 people who lost all their sight as older children or adults, i.e. late totally blind, recognizing target directions is relatively easy.

In this paper we propose a method to transfer the target

Fig. 1. Schematic view of the acoustic vision substitute system.
ranges exactly for the distinction of plural targets at different ranges. A user selects the measurement range and the system proposes targets within the range to the user. The user changes the measurement range, and then compares the presented targets in the latter measurement range with that in the former one. The targets, presented in one measurement range and not in the other measurement range, exist between the two ranges. 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 this method experimentally, and confirm its effectiveness.

In section 2, we propose a method to transfer the target ranges exactly. We then explain the instrument used in the experiment and the content of the experiment. In section 3, we evaluate the experimental results. Finally, conclusions are drawn in section 4.

II. METHODS

A. Voluntary Range Selection

To distinguish multiple targets, we need to present the directions and ranges 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.

Fig. 2 shows a schematic view of targets in the measurement area. Fig. 3 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 [8], 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. Fig. 4 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 sizes and directions of the targets.

Second, the user gives the instruction regarding the measurement range of $d_2$ to the system, and it presents the directions of targets A, B, C, D. Fig. 5 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 sweep of the entire 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.

B. Vibrotactile Stimuli

We examine the voluntary range selection method 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. 6, 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.

Fig. 6. 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.

Fig. 7. An arrangement of stimulators used in this experiment.

In this study, we use a solenoid array as the stimulating device. Each solenoid has a round-topped vibrating rod, as shown in Fig. 8. As shown in [9], the two-point discrimination threshold at the forehead is 0.9 cm to 1.5 cm. 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. Fig. 9 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 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.

Fig. 8. Schema of a solenoid component in the 2-D stimulator array placed on the forehead.

Fig. 9. Stimulus waveform used in this experiment. 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.

C. Participants

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

D. Main Experiment

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. 10. 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.

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 square stimulations of these 20 stimulation sets are presented randomly. In the practical trial participants are informed about the presented 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 [10] to improve the angular resolution of the transfer information.

![Fig. 10. Tactile patterns in the voluntary range selection experiment. Two targets, represented as 4-point square stimulations, are presented one after the other.](image)

III. RESULT

Table 1 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.

![Table 1: The average and the standard deviation of the possibility that the response is correct when a tactile pattern is a 4-point square stimulation.](table)

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>0.958</td>
<td>$4.05 \times 10^{-3}$</td>
</tr>
<tr>
<td>Range</td>
<td>0.979</td>
<td>$1.01 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

With the voluntary range selection method, a user selects the measurement range and targets within the range are presented to the user. The user changes the measurement range, and then compares the presented targets in the latter measurement range with that in the former one. The targets, presented in one measurement range and not in the other measurement range, exist between the former and latter ranges selected. 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 investigate the voluntary range selection method and show that a user can accurately recognize target ranges.

B. Future Works

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 present environmental information more clearly.

REFERENCES


