Human Interface and Transmit Frequency Control for The Through-Air Acoustic Real-Time High Resolution Vision Substitute System

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Abstract—Existing vision substitute systems are not useful as navigation system due to the limitation of spatial and time resolution. In this study we propose a transmit control method free from range aliasing for a high resolution acoustic vision substitute systems, which we previously proposed. We also examine a human-machine information transfer method with a vibrotactile stimulator array consisting of 13 × 21 elements. It presents the target area of 30 degree × 60 degree by the sampling interval of 1 degree at the center. The system presents range, direction, and surface topography of targets to the subject.

I. INTRODUCTION

INTENSIVE studies have been made on human-machine information transfer through tactile excitation for vision substitution. A two-dimensional matrix of stimulators can display spatial information to the skin, and previous works have been directed to change visual image to vibrotactile or electrotactile stimulation [1, 2]. In this method intensity of each stimulator corresponds to the light intensity of visual image and does not indicate the range of the target.

Vision substitute system needs high time resolution to present dynamic change of spatial resolution and high spatial resolution to recognize many targets individually. Although various tactile vision substitution systems have been proposed, they are not useful as navigation systems for visually handicapped due to limited spatial and time resolution [3-5].

We proposed a high resolution real-time vision substitute system [6]. In this method we transmit ultrasonic pulse wave and receive the echoes by an element array with a reflector mirror. In this study we further propose a spatial information transfer method to present the range, direction and surface topography of the target through tactile excitation on the forehead, and a technique to control transmit frequency.

II. SUMMARY OF HIGH RESOLUTION VISION SUBSTITUTE SYSTEM

Phased array imagers and digital beam forming imagers have been proposed for high-resolution 3-D imaging system.

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digital beam forming method. With the aid of dictionary look-up algorithm, the image reconstruction based on numerical back projection takes less than 0.1 second, which is sufficiently short for a real-time operation.

III. TRANSMIT FREQUENCY CONTROL

In the previous section, spatial resolution is investigated for the case that transmit frequency is 170 kHz and measuring range is 1 m. The signal to noise ratio of the echo from long distance deteriorates when we radiate pulses of high transmit frequency like 170 kHz due to strong attenuation. In this section we propose a scheme to select the optimum transmit frequency versus range.

Absorption attenuation of the echo power is proportional to $e^{-\alpha_{4}l}$, where $l$ is the target range and $\alpha$ is the absorption coefficient. Fig. 3 shows frequency characteristics of the received echo power versus range. We set the absorption coefficient $\alpha = 1.0 \times 10^{-6} f$ nper/cm, where $f$ is the transmit pulse frequency. Received power is normalized by that of measuring range 1m and transmit pulse frequency 20 kHz. Echo power attenuation of a high frequency pulse is limited at a short range, but significant at a long range. This means that a low frequency pulse should be radiated for a long range detection.

The angular resolution of digital beam forming imager with 2-D circular array is $c/fD$ rad, where $c$ is the propagation velocity of sound and $D$ is the array size. We transmit low frequency pulses for long range detection to increase the echo power and high frequency pulses for short range detection to improve angular resolution.

Repetition of transmit and receive events causes range aliasing. Echo power from another range over that from measuring range is given by

$$P_n = e^{-\frac{4\alpha_{4}l}{n^2}}$$

where $nl$ is the range which causes range aliasing.

We set constant $lf$ to make $P_n$ and $l$ independent of each other by controlling the transmitting frequency. In the case of $lf = 170$ m·kHz, $P_2 = -20.9$ dB and $P_3 = -36.8$ dB. This means the influence of range aliasing is negligible. Fig. 4 shows signal to noise ratio of received echo versus range. Solid line is signal to noise ratio of proposed method, and broken line is that of constant transmit frequency of 170 kHz. Improvement of SNR becomes larger at longer range detection, which increases to 40 dB at the measuring range of 5 m.

IV. SPATIAL INFORMATION TRANSFER BY TACTILE DISPLAY

A. Setting of stimulation points and measuring direction

We assume to stimulate vibrotactile excitation at the location corresponding to the target direction. As the forehead has wide area for stimulation and keen sense of touch, it is suitable for stimulation region. Since the spatial resolution against stimulation at the forehead is about 5mm, we set stimulator pitch 5mm. Fig. 5 shows the alignment of the stimulating points on the forehead in the case of the stimulating area of 6cm long and 10cm wide. The stimulator array consists of $13 \times 21$ elements.

Vision has wide angle of view and high angular resolution at the center. We set the angle of view of the vision substitute system ± 15 degrees in the vertical section, ± 30 degrees in the horizontal section, and the sampling interval of measuring
direction 1 degree at the center. We set measuring directions as follows.

![Fig. 5. Stimulating points on the forehead.](image)

First, we arrange measuring directions on the horizontal and vertical lines at irregular spacing. We set hyperbolas which go through the measuring points on the lines, and we define their intersections as the measuring directions. Fig. 6 shows measuring directions in the target area. The sampling interval of measuring directions on the lines follow quadratic function. Stimulating points on the forehead of Fig. 5 and measuring directions of Fig. 6 correspond one to one.

![Fig. 6. Measuring directions in the target area. Intervals follow quadratic function.](image)

In the case of arranging 21 measuring directions on the horizontal line of ±30 degrees at a regular spacing, the sampling interval is 3 degree. In the proposed layout, the interval is 1 degree at the center and 4 degree at the peripheral directions.

**B. Spatial Information Transfer**

To distinguish multiple targets, we need to present targets’ direction, range and echo power related to their surface topography. The proposed system presents the direction of a target by stimulating location, and their echo power by vibrotactile excitation intensity. The subject can recognize target range as follows.

![Fig. 7. Schematic view of targets in the measuring area. Color depth is related to echo power.](image)

Fig. 7 shows schematic view of targets in the measuring area. Color depth is related to echo power.

![Fig. 8. Targets’ directions in the measuring area. Color depth is related to echo power.](image)

Fig. 8 is the projection image of targets to the measuring area. Neighboring target is displayed in the case of plural targets existing in the same direction. The range of target A, B, C is less than $d_1$, and that of D, E, F is between $d_1$ and $d_2$.

![Fig. 9. Stimulating points matched with targets in the case of measuring distance is $d_1$. Size indicates stimulating pressure related to echo power.](image)

First, the subject determines measuring range of $d_1$ and instruct it to the vision substitute system. We suppose the instruction is given by biting force of a switch. The pulse frequency and interval are made suitable to the range $d_1$ and the system present direction and echo power of target A, B, C by vibrotactile excitation on the forehead. Fig. 9 shows stimulating points matched with targets in the case of measuring range of $d_1$. Size of each symbol indicates the stimulation pressure related to the echo power. The system
presents the echo power by stimulating pressure and the subject can recognize not only the size and direction of targets but also its surface topography.

Second, he/she instructs the system the measuring range of $d_2$, and the system presents the directions and the echo power of target A, B, C, D, E, F. Fig. 10 shows stimulating points matched with targets in the case of measuring range $d_2$.

![Stimulating points matched with targets in the case of measuring distance is $d_2$. Size indicates stimulating pressure related to echo power.](image)

Fig. 10. Stimulating points matched with targets in the case of measuring distance is $d_2$. Size indicates stimulating pressure related to echo power.

From the change of displayed information the subject recognizes the range of target D, E, F is between $d_1$ and $d_2$. He/she can also find the boundary of target B and E (also C and F) from stimulating pressure difference. Targets at shorter range is more important and vision detects only the nearest target in each direction. For safety of subjects and similarity with vision we propose to present the nearest target in the case of plural targets existing in the same direction. By measuring from short range to long range, we get spatial information of the whole target area. The time resolution of the system is about 0.1 second, which can deal with movement of pedestrians.

V. CONCLUSION

For the wide range detection of the acoustic vision substitute system, we proposed a transmit frequency control method. In this method, we transmit low frequency pulses for long range detection to receive sufficient echo power and high frequency pulses for short range detection to improve angular resolution. In the case of product of transmit frequency and measuring range is $f_r = 170 \text{ m}\cdot\text{kHz}$, the effect of range aliasing is reduced to less than -20 dB. We also proposed a human-machine information transfer method to present the target area of $\pm 15$ degrees long and $\pm 30$ degrees wide by the sampling interval of 1 degree at the center. The vibrotactile stimulator array consists of $13 \times 21$ arrangement on the forehead of 6cm $\times$ 10cm size. The subject instructs measuring range to the vision substitute system, and it presents direction and echo power of targets existing within the instructed range. The direction and echo power of the target is presented by stimulating location on the forehead and excitation intensity, respectively. In this method, he/she can distinguish multiple targets of the same range. The time resolution of 0.1 sec per 1 image is sufficiently high for the use of pedestrians.

REFERENCES


