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Two Dimensional Radiation Pressure Tactile Display

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Abstract: We designed a tactile display which produces spatio-temporal pressure patterns on a 2-D plane. The display consists of an octagonal arrangement of ultrasound linear arrays. We conducted simulation studies and confirmed that the intensity at the second peak was satisfactory compared to the other polygonal arrangements and that the pressure patterns can cover 1cm by 1cm area.

Keywords: ultrasound, tactile display, radiation pressure

1. Introduction

One of the difficulties in designing tactile displays is to find appropriate tactile stimuli and their syntheses. For example, electrotactile displays can stimulate different kinds of mechanoreceptors selectively while combining these stimuli to produce realistic tactile feelings is still a difficult challenge[1]. In order to solve this problem, first of all, we should know the relationship between tactile perceptions and actual stress fields on the skin surface by precisely controlling the stress fields. Then we will need a stress field reproduction display for the basic study. We have proposed a tactile display which realizes stress field reproduction using acoustic radiation pressure [2][3]. In previous studies, we developed a prototype tactile display composed of a one-dimensional linear array and confirmed that the prototype display could produce various spatiotemporal patterns of tactile stimuli along an axis on the skin surface.

We are now developing a new tactile display which can create two dimensional patterns of radiation pressure by scanning a focal point of ultrasound. In this paper, we introduce the tactile display and the method to produce a 2-D stress field on the skin surface with acoustic radiation pressure. We carried out simulation studies to discuss the feasibility of the method and the design of the display. In Section 2, the method is described. The feasibility of the method is discussed in Section 3. The implementation of the proposed system is shown in Section 4.

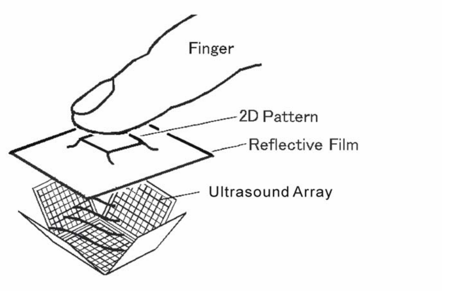

Fig. 1. Concept of the two dimensional scanning tactile display. The display scans the focal point of ultrasound much faster than human tactile perception to create two dimensional patterns of tactile stimuli.

2. Method

It was first shown by Dalecki et al. [4] that radiation pressure can provide sufficient force to produce tactile feeling. One obvious advantage of using ultrasound instead of conventional actuators is that both spatial resolution and temporal bandwidth are easily obtained. The intensity of the radiation pressure is proportional to the energy density of the ultrasound. Therefore if the ultrasound is focused on a point, it provides highly localized force. Though Dalecki controlled temporal intensity of ultrasound, the spatial distribution of radiation pressure did not vary because their aim was to determine the threshold at a single point on the skin.

We have proposed a method to create spatiotemporal patterns of tactile stimuli with the radiation pressure. Lamore et al. [5] found that high-frequency (1000-200Hz) sinusoidal vibrations which were usually imperceptible induced distinct sensations when amplitude modulation was applied. In our method, the focal point is steered on the skin surface at a much higher speed than human tactile perception to create various spatiotemporal patterns of pressure. In our previous studies, we implemented this method with a prototype display. We confirmed that the spatial resolution of the display was 1 mm and the frequency characteristics were quite sufficient, up to 1 kHz, and that the display could produce various spatiotemporal patterns of tactile stimuli along an axis on the skin surface.

Expanding this method, we propose a 2-D scanning tactile display. Fig. 1 shows the basic idea of the 2-D scanning tactile display. Ultrasound from PZT transducers converge to create a focal point. The focal point is steered on a 2-D plane. In order to avoid applying ultrasound directly on the skin, ultrasound reflective film is placed between the medium and the skin. The reflective film is made from polyurethane and silicone rubber, and is very thin and flexible.

It seems easy to expand the method to the 2-D scanning display. However, it is difficult to fabricate a 2-D array which is tiled with small square ultrasound transducers. Instead of using this complicated 2-D array, we propose an octagonal arrangement of linear arrays as shown in Fig. 2. Each linear array is an ordinary linear array except that the

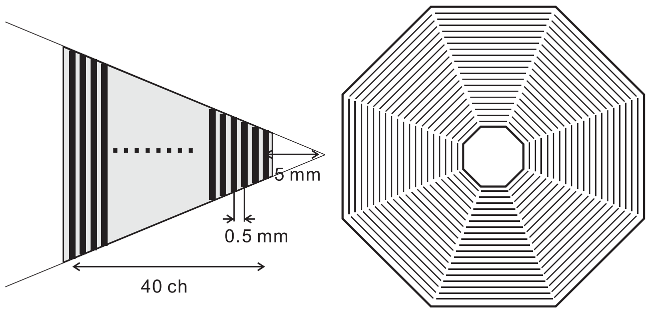

Fig. 2. Octagonal arrangement of eight linear arrays. Left: A schematic drawing of a single linear array. Right: An arrangement of the eight units of linear arrays.

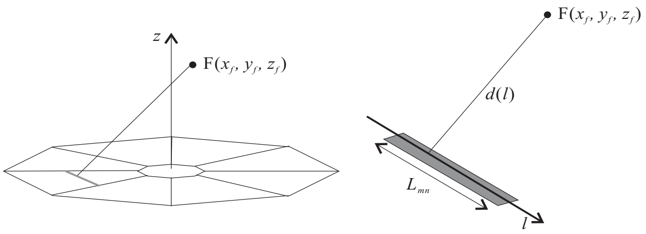

Fig. 3. Parameters in equation (1). Left: A PZT piece on the octagonal arrangement of the linear array components. Right: The *n*th PZT piece on *m*th array component (m = 1,2, … ,8, n = 1,2, … ,40).

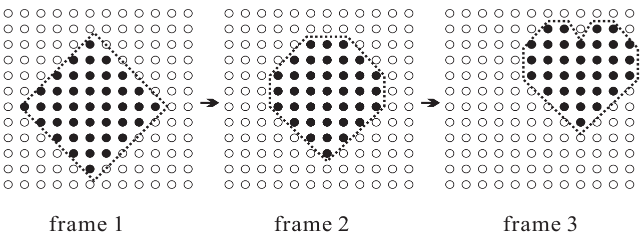

Fig. 4. Method for producing spatio-temporal patterns of tactile stimuli. Several points are selected as stimulation points and the display produces the radiation pressure on the points. The frame rate is 1 kHz.

shape of the radiation surface of each linear array is a trapezoid. Therefore it is easy to fabricate these linear arrays. In addition, compared to the 2-D array, they have fewer channels.

The phase of ultrasound from each transducer was controlled so that it converged at a single focal point. Each PZT piece was recognized as a line source. Depending on the position of the focal point F(x_f, y_f, z_f), the phase of ultrasound from *n*th PZT piece on *m*th array at the focal point was determined as,

$$\varphi_{mn}\left(x_f, y_f, z_f\right) = \arg\left(\int_0^{L_{mn}} e^{j\cdot 2\pi \cdot \frac{d(l)}{\lambda}} dl\right) \qquad (1)$$

where $\varphi_{mn}(x_f, y_f, z_f)$ is the phase, L_{mn} is the length of the piece, λ is the wave length of the ultrasound and $d(l)$ is the distance from a point l on the piece to the focal point (See Fig.3). The *n*th PZT piece on *m*th array was driven so that the phase is delayed by φ_{mn} in order to set the phase at the focal point to 0.

In order to produce spatio-temporal patterns of tactile stimuli, the focal point was scanned over a 2-D plane (See Fig.4). The radiation pressure was exerted on several focal points on the display surface within 1ms. In other words, the total amount of acoustic energy for 1ms was distributed to selected stimulation points. In our previous studies[1], we confirmed that the diameter of the focal point was 1 mm. Therefore 100 points are sufficient for covering 1 cm by 1 cm area. In initializing the system, 128 by 128 coordinate points on the display surface were chosen and the phases $\varphi_{mn}(x_f, y_f, z_f)$ for the 128 by 128 points were calculated and stored in the memory on the driving circuit. The stimulation points were selected from the 128 by 128 points for every 1 ms. Therefore the frame rate of the display was 1 kHz.

3. Simulation results

We verified the feasibility of the octagonal arrangement by simulations. The focal point produced with the octagonal arrangement and other polygonal arrangements were quantitatively compared.

Each piece of PZT was approximately regarded as a gathering of acoustic point sources lined along the piece. A schematic drawing of the linear array is shown in Fig. 2. The focal length was set to 30 mm. The focal point was fixed at the center of the transducers. The simulation results for the octagonal arrangement are shown in Fig. 5. X axis and Y axis represent XY coordinates ranging from -5 mm to 5 mm. Z axis represents the normalized intensity of the radiation pressure. There are second peaks around the focal point. The intensity at the second peaks was 13.1% of that at the focal point. The results for the other polygonal arrangements are shown in Fig. 6 and Fig. 7. Fig. 6 and Fig. 7 show the results for a square arrangement and a dodecagonal arrangement, respectively. Fig. 8 shows the results for the octagonal arrangement with the focal point shifted to (x_f, y_f, z_f) = (5mm, 5mm, 30mm). The shifted focal point was successfully focused on the desired position.

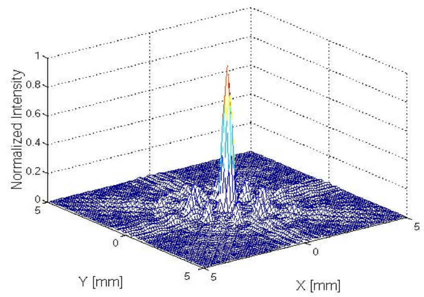

Fig. 5. Simulation results for the octagonal arrangement. X axis and Y axis represent XY coordinates ranging from -5 mm to 5 mm. Z axis represents the normalized intensity of the radiation pressure.

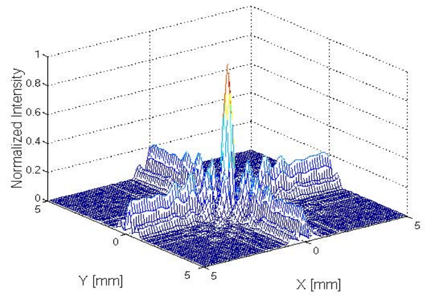

Fig. 6. Simulation results for the square arrangement. X ,Y, and Z axis are the same as Fig. 5. The focal point is surrounded by side lobes.

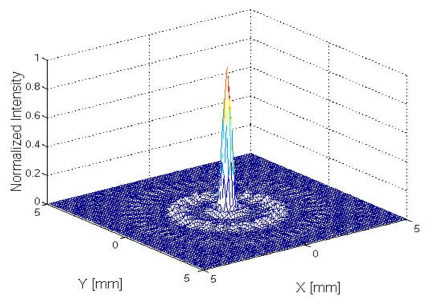

Fig. 7. Simulation results for the dodecagonal arrangement. X, Y, and Z axis are the same as Fig. 5. The intensity at the second peaks is lower than that in Fig. 5.

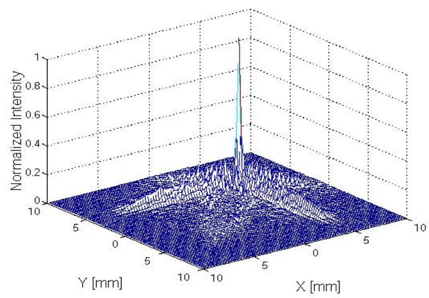

Fig. 8. Simulation results for the octagonal arrangement. Simulation results for the octagonal arrangement. Note that XY coordinates are ranging from -1 mm to 1 mm. Z axis represents the normalized intensity of the radiation pressure. The coordinate of the focal point was (5mm, 5mm, 30mm).

In order to quantitatively compare the octagonal arrangement with other polygonal arrangements, the intensities at the second peak were estimated. The results are shown in Fig. 9. The horizontal axis represents the number of sides of the polygon. The vertical axis represents the intensities at the second peaks. Apparently, as the number of the sides increases, the intensity at the second peak decreases, while the design of the display becomes more complicated. Taking these facts into consideration, we chose the octagonal arrangement of linear arrays as an adequate design for the 2-D scanning tactile display.

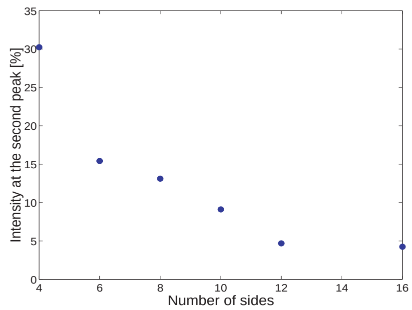

Fig. 9. Intensities at the second peak for polygonal arrangements. The horizontal axis represents the number of sides of the polygon. The vertical axis represents the intensities at the second peaks.

4. System

We are now developing a new system based on the method written in Section 2. The system consists of a PC, a driving circuit and eight linear arrays. Fig. 10 shows a block diagram of the system. Each driving circuit board has a CPLD, a memory, and 40 ch amplifiers. The CPLD includes signal delay circuits implemented with 4-bit counters. The memory holds a look-up table which associates the position of the focal point with the delay time for each channel. When the position of the focal point is given by the PC, the CPLD reads the delay time associating with the position of the focal point from the memory and outputs signals to drive the transducers. In order to produce 100 points within 1 ms, the position of the focal point is given to the CPLD every 10 μs.

The linear array consists of 40 pieces of PZT transducers. We used the linear array transducer (Nihon Denpa Kogyo Co., Ltd.) especially designed for high-power driving using PZT. The power limit is given by the maximum electrical field to maintain polarization of the PZT and the maximum temperature as the Curie temperature. In order to avoid the temperature rising, the PZT pieces were attached on a thermally conductive material. These PZT pieces are arranged at 0.5 mm pitch. The length of the shortest piece and the longest piece are 3.3 mm and 20 mm, respectively. The resonant frequency of the transducers is 3 MHz.

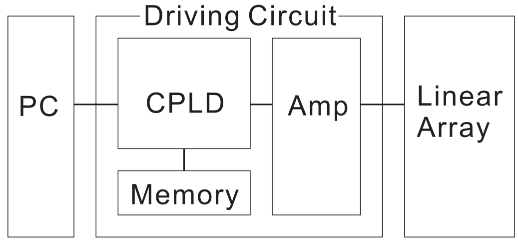

Fig. 10. Block diagram of the system. A driving circuit board includes a CPLD, a memory, and 40 channel amplifiers. The memory is capable of storing 4 bit data for the delay times associating with 128 by 128 coordinates.

Fig. 11. Photograph of the driving circuit board. A driving circuit board includes a CPLD, a memory, and 40 channel amplifiers. Eight driving circuit boards are used for driving 320 PZT transducers.

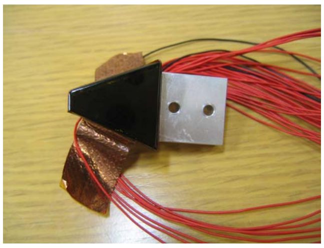

Fig. 12. One of the eight linear arrays. The surface is covered with a water-proof film. 40 pieces of PZT transducers are included in a linear array.

5. Summary

We proposed a new design for the 2-D scanning tactile display with ultrasound linear arrays. The results of the simulation studies validated the feasibility of the proposed octagonal arrangement of linear arrays. We are now working on a new system based on this method.

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