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# A Study on Transmission Method for Shape Estimation of Ultrasonic Flexible Probe

# 超音波フレキシブルプローブの形状推定のための多点同時送信方式の検討


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## 1. Introduction

An ultrasonic flexible probe has been developed [1-3]. Because of the flexibility, it is expected to visualize hard areas such as fingers and elbows, as well as soft areas such as the breast and abdomen without bending biological tissue.

When focusing ultrasonic pulses in transmitting and receiving, it is necessary to know the position of each element and determine the delay time for each element [4]. In the previous study, the ultrasonic probe was transmitted from both ends of the probe and received at all elements, and the coordinates of all elements were estimated [5,6]. As a result, it was found that the error of the estimated coordinates became large around the transmitting element.

This study's objective is to reduce the error in the coordinates estimation by increasing the number of the transmitting elements. Numerical simulations are performed, and various transmission methods are discussed.

## 2. Method

In the conventional method [5,6], the elements used for transmission are two elements at each end of the ultrasound probe, each of which is transmitted separately, as shown in **Fig. 1**. Each transmission is received by all elements and the time of flight (TOF) of the direct wave is measured. The distances *a*, *b*, and *c* between the transmitting and receiving elements are then calculated using the TOF and the speed of sound. The speed of sound in the propagating medium is assumed to be constant. Using the calculated distances, the relative coordinates of each element are calculated, and the shape of the ultrasonic probe is obtained as below.

$$y_i = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{a}$$

$$x_i = \sqrt{b^2 - y_i^2}$$

$$s = \frac{a+b+c}{2}$$


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In this study, the number of transmission elements is increased to improve the shape estimation error when the transmitter and receiver elements are in close proximity. As shown in **Fig. 2**, two more elements with sufficient distance from each end of the probe are added. As in the previous study, the coordinates ($x_j$, $y_j$) are calculated using the distances between the elements obtained by the measurements. However, in this study, the coordinates of the transmitting elements are restricted to the range where there is a sufficient distance from the transmitting elements in this study.

$$x_j = \frac{rx_i \pm y_i\sqrt{(x_i^2+y_i^2)\,b^2 - r^2}}{x_i^2+y_i^2}$$

$$y_j = \frac{ry_i \mp x_i\sqrt{(x_i^2+y_i^2)\,b^2 - r^2}}{x_i^2+y_i^2}$$

$$r = \frac{(c^2-b^2)+(x_i^2+y_i^2)}{2}$$

After calculating the coordinates using the direct waves obtained from each transmitting element, the coordinates are averaged for each element to determine the final coordinates. A method of prioritizing the estimates obtained in better combinations according to the distance between the sending and receiving elements will also be investigated in the future.

To evaluate the proposed method, numerical simulations are performed using Onscale (Onscale Inc., USA). The number of elements is 192, the pitch is 212 μm, and the center frequency is 4.625 MHz.

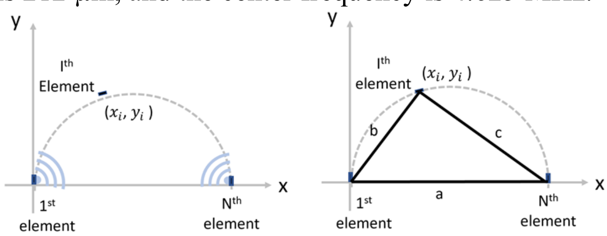


Fig. 1. Schematic diagram of previous transmission method.

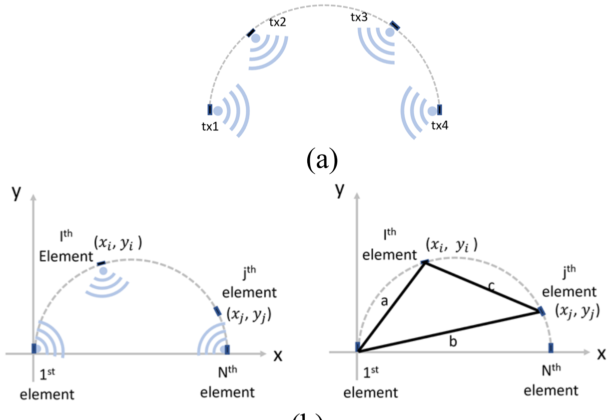


Fig. 2. Schematic diagram of the proposed method. (a) Transmitting elements and (b) estimation scheme.

## 3. Results

The estimated probe shape of the model is shown in **Fig. 3**. The error average between the estimated coordinates and the true value for each element in the previous method was 0.307 mm, while the error average for the proposed method is 0.261 mm. The errors between the estimated coordinates and the true value of each element of two methods are shown in **Fig. 4**.

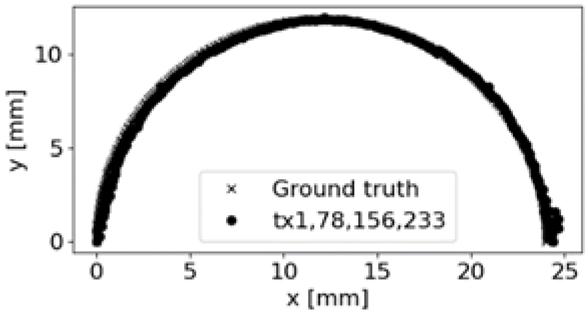


Fig. 3. Estimated probe shape and ground truth.

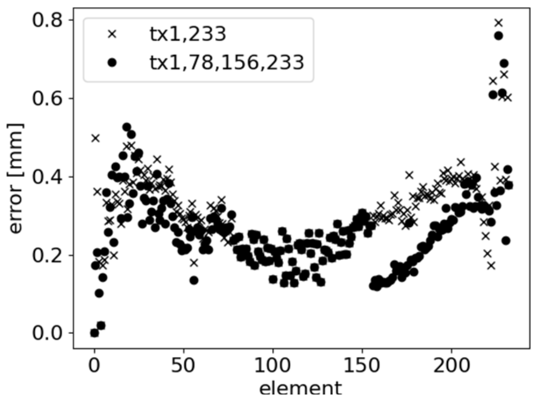


Fig. 4. Errors between estimated element coordinates and true values. Black circles and cross marks indicate errors of the proposed method and previous method, respectively.

## 4. Conclusion

In this study, increasing the number of transmitting elements was proposed to reduce the error. As a result, the error was decreased to 0.261 mm from 0.307 mm on average. As a future work, it is necessary to consider the complex probe shapes.

## Acknowledgment

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