3P5-2

Study on improving accuracy in shape estimation of ultrasonic flexible transducer using direct waves

Masayuki Tanabe[1†*], Kosuke Sato[2], Toru Uda[2], and Makiko Kobayashi[1] ([1]Fac. Adv. Sci. Technol., Kumamoto Univ.; [2]NOK Corporation)

1. Introduction

Ultrasound imaging technology is widely applied in the medical field as a non-invasive and real-time diagnostic method. Traditional ultrasound diagnostics primarily employ rigid handheld probes. However, these probes require continuous pressure against the body, making them unsuitable for long-term monitoring. To overcome these limitations, several flexible ultrasound probes that can adapt and effectively adhere to the body surface have been developed.

However, a challenge arises when the element array of the flexible probe deforms, which complicates image reconstruction. When the probe deformation renders the geometry of the element array unclear, accurate beamforming cannot be achieved, resulting in blurred or distorted images. To address this issue, we developed a technique to estimate the geometry of the element array and reconstruct the B-mode images. Recent studies have proposed methods that use deep neural networks to estimate the geometry of an element array from radio frequency (RF) data, enabling real-time monitoring. Our previous research also developed a simple and efficient shape estimation algorithm utilizing the time-of-flight (TOF) of direct waves from the transmitting to receiving elements.

Our initial research was limited to simulations, and overlooked several issues in actual imaging environments. Moreover, the oversimplification of the algorithm may have adversely impacted the estimation results, especially in the presence of reflectors near the body surface. In this study, we evaluate a new method for addressing these issues through experiments using an actual flexible probe.

2. Method

To estimate the shape of the deformed probe, pulse waves are transmitted from multiple elements and received by other elements to calculate the time of flight (TOF) and determine the distances between elements. These distances are then used to estimate the overall configuration of the elements. Heron's formula is applied for structure estimation based on TOF.

This study further proposes a robust shape estimation method that accounts for the deformation of the probe and the arrangement of the elements, ensuring resistance to outliers. The received waveforms undergo detection and logarithmic compression to generate B-mode images. It should be noted that, unlike conventional B-mode images, these images represent the horizontal axis as element numbers and the vertical axis as time (depth), rather than the physical structure of the target object.

Next, a curve is extracted from the direct wave, and interpolation is performed to correct the TOF of each element. When the TOF significantly differs from that of other elements, interpolation is expected to effectively reduce the error. Although the least squares method is commonly used for correction, the modified Thompson-τ method is employed to exclude large outliers and perform interpolation to suppress substantial errors. Specifically, the mean and standard deviation of the errors between the TOF dataset and the approximate curve are calculated, and data points exceeding the critical value are considered outliers and excluded, followed by recalculation of the approximate curve.

3. Result

Figure 1 shows an example of the direct wave received by each element, specifically the RF waveform transmitted from channel 1 and received by channel 32 when the probe was bent to a curvature of 30 mm. The red solid line indicates the theoretical TOF calculated based on the distance between channels 1 and 32. **Figure 2** shows a B-mode image where the horizontal axis corresponds to the receiving element number and the vertical axis corresponds to time. In Figs. 1 and 2, echoes other than the direct wave can be observed. These may be due to reflected longitudinal waves that underwent multiple reflections within the jig, or reflected waves that were mode-converted into shear waves. Since these echoes can potentially lead to incorrect TOF calculations for the direct wave, it is desirable to remove them before estimating the TOF.

Figure 3 illustrates the results of curve fitting using the modified Thompson-τ method, limited to a curvature range of 25 mm to 45 mm. The red line represents the theoretical values, while the green dashed line indicates the estimated results with the proposed method.

E-mail: †*mtanabe@cs.kumamoto-u.ac.jp

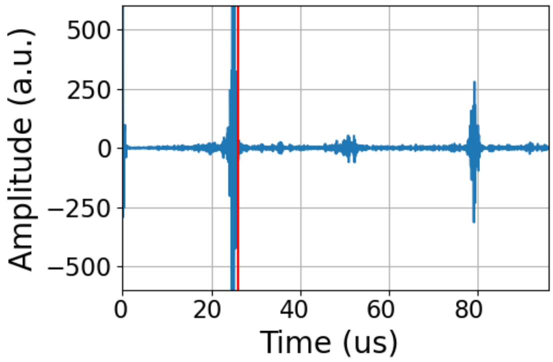

Fig. 1. RF signal from ch. 1 to ch. 32.

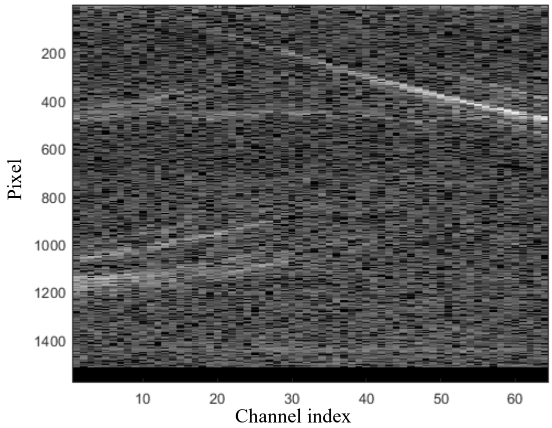

Fig. 2. B-mode image constructed using RF signals from ch. 1 transmission with 30 mm curvature.

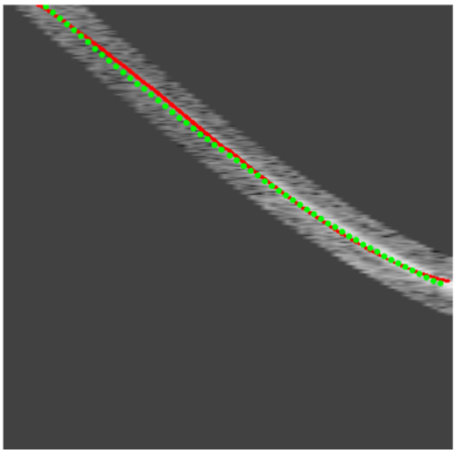

Fig. 3. Estimated curved line with proposed method.

Shape estimation was performed using the estimated TOF values. The estimated shape results are shown in **Fig. 4**. The red lines represent the true values, the blue points represent the conventional method, and the green points represent the proposed method. Using the conventional method, correct

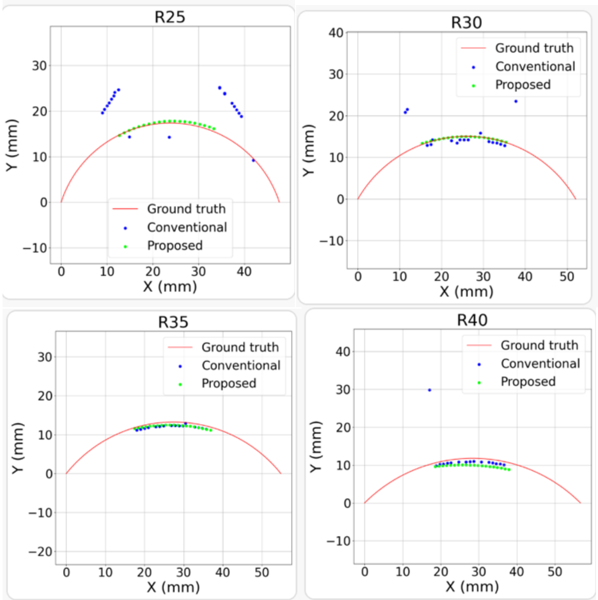

Fig. 4. Estimated probe shapes with curvatures of (a) 25 mm, (b) 30 mm, (c) 35 mm, and (d) 40 mm.

coordinates could not be obtained for most elements at a curvature of 25 mm. In contrast, the newly proposed method, which utilizes an approximate curve based on the B-mode image, was able to estimate values closer to the correct coordinates.

4. Discussion

In this study, we used a flexible ultrasonic array probe to acquire direct waves while varying the curvature, and validated an algorithm for shape estimation based on these waves. Experimental results showed that our newly proposed method significantly reduced errors compared to the conventional approach. This improvement is attributed to the mechanism that excludes TOF outliers caused by echoes other than the direct wave. The method effectively approximates curves from the B-mode image of the direct wave, based on the premise that the distance between adjacent elements remains unchanged even when the probe is deformed.

In the future, we plan to quantitatively evaluate the errors and explore more robust estimation methods.

References

1) M. Tanabe, K. Sato, T. Uda and M. Makiko, Jpn. J. Appl. Phys. **62**, SJ1034 (2023).
2) M. Sada and M. Tanabe, Jpn. J. Appl. Phys. **59**, SKKE25 (2020).
3) S. Matsuoka, M. Tanabe, K. Sato, T, Uda, and M. Kobayashi, Proc. 44th Symp. Ultrasonic Electronics, 2023, 3P5-18.