2P5-18

Self Shape Estimation of Ultrasonic Flexible Probe using Direct Waves Among Elements
素子間の直達波を利用した超音波フレキシブルプローブの形状推定方法の検討

Miki Sada[1‡], Masayuki Tanabe[2] ([1]Grad. Sci. And Tech., Kumamoto Univ., [2]Fac. Adv. Sci. Tech., Kumamoto Univ.)
佐田 実季 [1†]，田邉 将之 [2] ([1]熊本大院　情電, [2]熊本大院　先端科学)

1. Introduction

Ultrasonic flexible probes have been developed for imaging of curved surface materials. One of the application fields is non-destructive testing (NDT). When a piping inspection in nuclear power plants is performed, the flexible probe can be matched to the irregular surface or the shape of components. Therefore, the flexible probe can prevent beam distortions and losses of sensitivity and can improve the inspection performances [1][2].

The flexibility is also useful in the medical field. Some regions such as knee and finger, are hard and curved, therefore the contact area is smaller and the visualized area is smaller. Imaging soft regions using the flexible probe is also helpful because the flexible probe can refrain deformation of human body and the obtained image can be compared with other resources such as computed tomography (CT) and magnetic resonance imaging (MRI).

In ultrasonic inspection using the flexible probe, the information of probe shape is used for reconstruction of the B-mode image. Each element position is necessary to calculate the delay time for beam focusing and steering in transmission and reception. In ultrasonic non-destructive inspection, to solve this problem, the ultrasonic flexible probe has been integrated with two other systems: a mechanical device for pushing the elements along the surface and an instrument for measuring the position profile of the probe [3]. This system was effective but the whole system became complicated and huge. Whereas, the probe shape estimation using echo signals has been also studied [4]. However, further improvement is required.

In this paper, we propose an algorithm for estimating the flexible probe shape which uses the time of flight (TOF) of direct waves obtained by each element. As a first step, we evaluated the proposed algorithm by estimating a concave probe shape using direct waves propagating in a homogeneous medium without any obstacle.

sada@st.cs.kumamoto-u.ac.jp

2. Method

In our proposed algorithm, the element coordinate on the flexible probe is estimated using direct waves. Theoretically, a single element is used for transmission and direct waves are received by all other elements, and two separate emissions are needed to obtain all pairs of TOF. **Figure 1** shows the illustration of the flexible probe and its coordinate. The coordinate of the *i*th element (x_i, y_i) can be obtained as follows

$$y_i = 2\sqrt{s(s-a)(s-b)(s-c)}/max\{a,b,c\} \quad (1)$$

$$s = (a+b+c)/2 \quad (2)$$

$$x_i = \sqrt{c^2 - y_i^2} \quad (3)$$

where a, b, and c are distances between elements as shown in Fig.1 and these can be calculated from the TOFs obtained from corresponding elements. Consequently, the probe shape is estimated by calculating all elements coordinates.

Simulations were conducted using OnScale. **Figure 2** illustrates a simulation model. The ultrasonic flexible probe is concave and includes 23 elements. A Ricker Wavelet pulse wave with the center frequency of 4.625MHz was used for transmission. To obtain all TOFs, two simulations were performed. At first, the ultrasonic wave was transmitted from the 1st element and

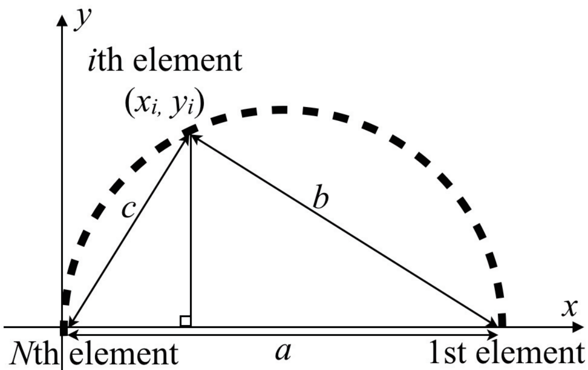

Fig. 1 Piezoelectric element of flexible probe and its coordinate.

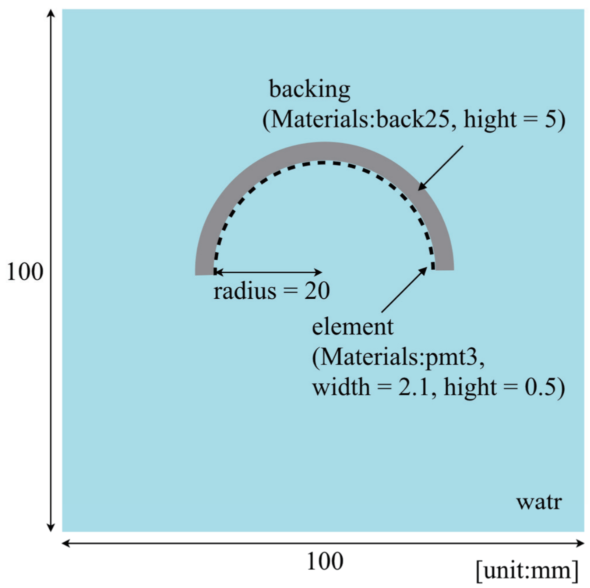

Fig. 2 Simulation model.

received by all other elements. Next, the ultrasonic wave was transmitted from the opposite side (=23th element) and received with the others. In total, 44 echo data were used for estimation. The TOF is calculated by detecting the rise time of the direct wave. The threshold was set to 0.013% of the maximum value of all echoes.

3. Results

The estimated coordinates of elements and these error values are shown in **Figs. 3 and 4**. As shown in the Figs, the curved shape is roughly estimated. However, the coordinates of the 2nd and 22nd elements could not be estimated because the triangle, as shown in Fig. 1, could not be established due to inaccurate measurements of TOF. The average error value was 0.73 mm.

4. Conclusion

In this study, the algorithm using the TOF of direct waves were proposed and evaluated using simulations. As a result, it was shown that shape estimation using direct waves is possible. As future works, inhomogeneous propagation medium, obstacles, and complex shapes including irregularities will be considered.

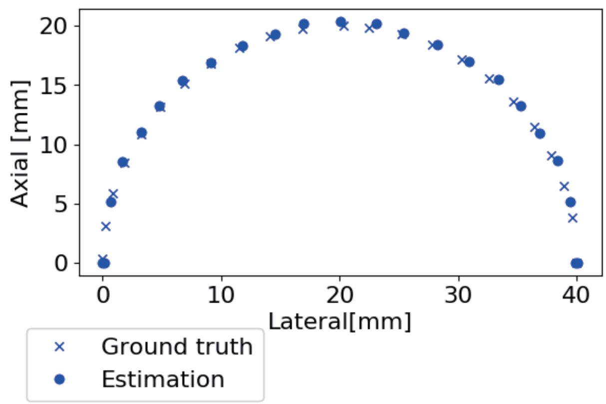

Fig. 3 Estimated results and ground truth.

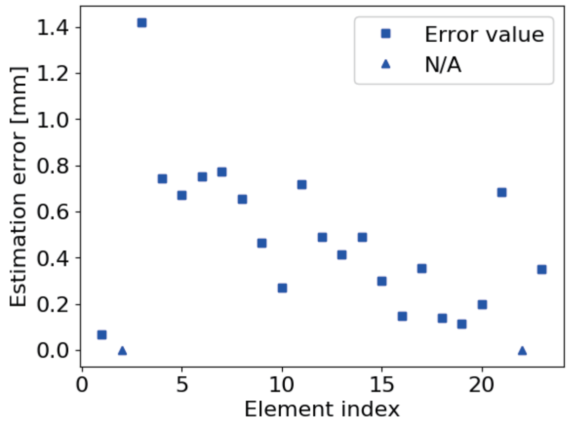

Fig. 4 Error values.

Acknowledgment
This work was supported by JSPS KAKENHI Grant Number JP19K12826.

References

1. O. Casula, C. Poidevin, G. Cattiaux, and P. Dumas: Proc. American Institute of Physics, **820** (2006) 829.
2. TOSHIBA Corporation: E-Journal of Advanced Maintenance, **5** (2013) 1.
3. O. Casula, C. Poidevin, G. Cattiaux, and G. Fleury: Proc. World Conference on Non- Destructive Testing (2004).
4. Y. Nakajima, N. Tomii, T Azuma, and I. Sakuma, Proc. Symposium on Ultrasonic Electronics, **38** (2017) 3P2-12.