3P2-12

Self-shape estimation algorithm for a flexible ultrasonic transducer array probe

フレキシブル超音波プローブ使用時の自己形状推定アルゴリズム

Yoshiaki Nakajima[1†], Naoki Tomii[2], Takashi Azuma[2], and Ichiro Sakuma[1] ([1]Graduate School of Engineering, The Univ. of Tokyo,; [2] Center for Disease Biology and Integrative Medicine, Faculty of Medicine, The Univ. of Tokyo)

中島義耀 [1†]，冨井直輝 [2]，東隆 [2] ，佐久間一郎 [1] ([1] 東京大学大学院　工, [2] 東京大学大学院　医, 疾患生命工学センター)

1. Introduction

Ultrasound imaging is widely used in the medical field, because of its non-ionizing radiation, low cost and high temporal resolution. However, the size of an ultrasound probe aperture limits the quality of the reconstructed images especially in deeper area. If the aperture becomes large, reconstructed images will be clearer, however stress of patients caused by the large and solid probe will also increase. A flexible transducer array is one of possible answers to this problem, but the reconstruction algorithm of ultrasound image with a flexible array without any additional sensor to estimate shape of array has not established yet.

This is because position information of each element in the array is essentially required to achieve a focal control in ultrasonic imaging process and we need the way to know the changeable element positions of the flexible array any time.

In this paper, we developed an algorithm which can estimate a 1-D flexible array shape just by echo signal as a first step for making it possible to reconstruct image using a flexible array.

2. Proposed algorithm

In our proposed algorithm, beam image (BI) was used as an evaluation function in the estimation of the array shape. BI is an image representing a transmitted beam profile in the imaging object and the basic idea of BI is derived from HIFU Beam Imaging (HBI) [1)]. BI is obtained by scanning of receive focal points around the transmit focal point. The array shape is estimated based on coarse-to-fine searching. The whole shape is estimated step by step from the partial shape. Radio Frequency data is acquired by the Synthetic aperture [2)] and each transmit and receive focusing is done from that data.

2.1 Evaluation function

Transmit and receive focusing for BI require position information of each element in the array. If the element position information is wrong, an BI would be disturbed because both transmit and receive focus are not done properly. Therefore, the fundamental idea of the proposed algorithm is that we evaluate the quality of BI made by various presumed array shapes information and regard the assumed array shape which has the highest evaluation function score as the real shape. In this study, we set the intensity of the BI at the transmit focal point as an evaluation function.

2.2 Presumed shape function

Various presumed array shapes are defined by (1)

$$f_N(\alpha,\boldsymbol{a_N},\boldsymbol{b_N},\boldsymbol{c_N},\boldsymbol{d_N}) = \boldsymbol{a_N}\alpha + \frac{\boldsymbol{b_N}}{2}(3\alpha^2-1) + \frac{\boldsymbol{c_N}}{2}(5\alpha^3-3\alpha) + \frac{\boldsymbol{d_N}}{8}(35\alpha^4-30\alpha^2+3) - \frac{\boldsymbol{a_N}+\boldsymbol{c_N}}{8}(63\alpha^5-70\alpha^3+15\alpha) + \frac{\boldsymbol{b_N}}{2} - \frac{3\boldsymbol{d_N}}{8}, \quad \alpha \in [-1,1] \qquad (1)$$

In this study, the base of presumed function is Legendre polynomial.

2.3 Coarse-to-fine search

In order to estimate a shape with low calculation cost, searching method should be coarse-to-fine. Even if a whole shape is complex, a partial shape can be regarded as a simpler shape than a whole one. **Fig. 1** shows the way to search. At first, a center partial shape consisting of m elements is estimated. Next, a longer shape consisting n elements (n>m) is estimated using the spline extrapolated shape based on the estimated m elements shape as an initial possible shape for searching. Step by step, a whole shape is estimated.

azuma@fel.t.u-tokyo.ac.jp

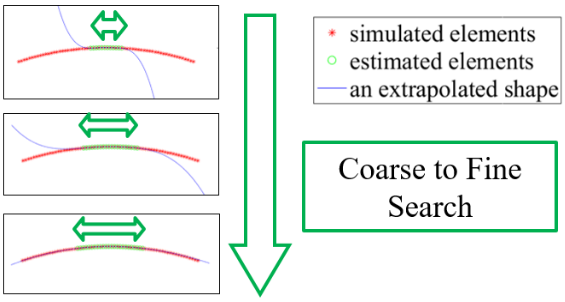

Fig. 1 coarse-to-fine search method.

3. Simulation experiment method

The acquisition procedure of simulated data was controlled by a Matlab program (MathWorks, Inc., Natick, MA, USA). **Fig.2** shows simulated situations. Shape 1 has constant inner 100mm Radius Of Curvature (ROC). Shape 2 is given by (2). Both shapes have 64 elements.

$$f_{shape2}(\alpha) = 0.1410\alpha + 0.2548\alpha^2 - 0.1815\alpha^3 - 0.0894\alpha^4 - 0.0374\alpha^5,\ \alpha \in [-1,1] \quad (2)$$

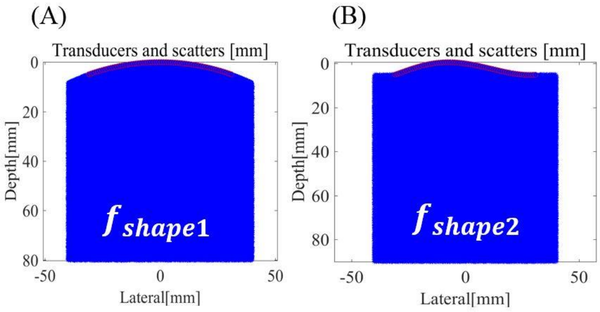

Fig. 2 Simulated situations for each simulated shape. Blue square denotes the scatter region. (A) Simulated shape has constant inner 100mm ROC. (B) Simulated shape is defined by (1)

Each partial estimation is done by Lagarias etal. simplex search algorithm[3].

4. Results and Discussion

Fig. 3 shows the shape difference between simulated and estimated arrays shape. Error is defined as the distance between each element of estimated and that of simulated shape. Shape 1 which has constant 100-mm ROC is estimated in error by less than $^1/_{11.88}$ [λ] as **Fig. 8** (B) shows. As for shape 2, the error of left 48 elements was less than $^1/_{6.7}$ [λ], but that of right 14 elements was not estimated correctly.

This can be caused by the possibility that the searching result was trapped by the local minimum in parameter space. That may be derived from the way to set initial parameter for searching. Every initial parameter is calculated based on the previous estimated shape around center and that results in the difficulties for searching to reach global minimum. To overcome this problem, it might be effective to set initial parameter for searching a long shape taking account of not only a center shape but also an edge shape.

In this paper, we just evaluate the proposed algorithm for homogeneous subject and the proposed algorithm relies on the assumption that the intensity of BI will be the strongest when we use accurate shape information. Thus, the assumption would be suspicious and we would have to use more sophisticated evaluation function when we apply the algorithm for the subjects which have heterogeneous acoustic characteristics.

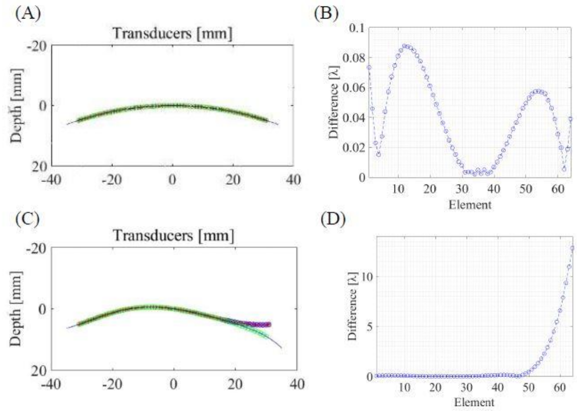

Fig. 3 Two types of simulated flexible array shapes are estimated by proposed algorithm and results are shown. (A)(C) The simulated shape's element position (red dot and blue circle), the estimated shape's element position (green circle), and the extrapolated shape (blue line) are shown. (B)(D) The distance between each simulated element and estimated one

References

1. Matsui, Kazuhiro, et al. "Improving high-intensity focused ultrasound beam imaging via a backscattering suppression algorithm." *Japanese Journal of Applied Physics* **56.5** (2017)
2. Nikolov, Svetoslav, and Jørgen Arendt Jensen. Synthetic aperture tissue and flow ultrasound imaging. Diss. Technical University of DenmarkDanmarks Tekniske Universitet, Department of Information TechnologyInstitut for Informationsteknologi, (2001).
3. Lagarias, J. C., J. A. Reeds, M. H. Wright, and P. E. Wright. "Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions." SIAM Journal of Optimization. Vol. 9, Number 1, (1998), p. 112–147.