Linearized positioning method based on Richardson extrapolation for locating ultrasound beacon attached to catheter

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Background, Motivation and Objective

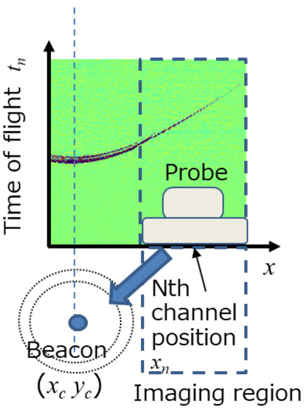
Although ultrasound-guided catheter intervention (UgCI) for peripheral arteries is expected to decrease the radiation dose exposure for X-ray guidance, a critical problem of UgCI is that a continuous ultrasonic monitoring of the tip is needed, which requires additional staff for the operation. A recent study demonstrated an ultrasound-beacon positioning (UBP) system with photoacoustics [1–3], to solve such a monitoring issue. In the UBP system, the ultrasound signal is emitted from the tip and an ultrasound probe outside the body detects the signal. However, it is still difficult to search the tip outside the imaging regions due to the probe's small field of view. The objective of this study is to propose a method to easily detect the tip position outside the imaging region with the UBP system.

Statement of Contribution/Methods

The difficulty in detecting tips outside the imaging region is that nonlinear iterative calculation is needed (Fig. 1-(a)). We propose a linearized positioning method based on Richardson extrapolation (Fig. 1(b)). The accuracy for the proposed method was examined using a tiny PZT beacon with size of 1 mm and center frequency of 6.5 MHz. A research ultrasound scanner (Verasonics with linear probe, L11-5v) measured the known beacon-tip position in a water tank.

Results/Discussion

Fig. 1-(c) shows the result of the experiments, where the tip was set from x= -90 mm to 10 mm, and the origin was at the probe center. The overall averaged error was 0.36 mm, but when the position was more than 70 mm from the center, the averaged error increased since the signal-to-noise ratio (SNR) was close to 1. The results suggest that the accuracy of the proposed method was sufficiently validated for the defined SNR conditions.



(a) Geometry

Relation between ToF of each element and beacon position (nonlinear), where C is the speed of sound

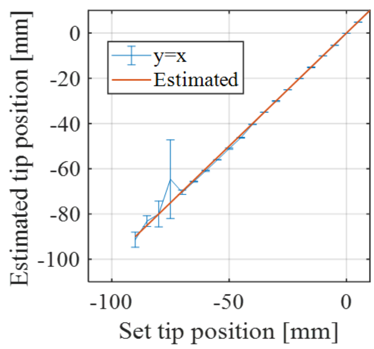
$$C^2(t_n)^2 = (x_n - x_c)^2 + {y_c}^2$$

The beacon position can be calculated by Richardson extrapolation;

$$x_c = \frac{1}{N}\sum_n^N \left(x_n - \frac{C^2}{4\delta x}\left(t_{n+1}^2 - t_{n-1}^2\right) \right)$$

$$y_c = \sqrt{\frac{1}{N}\sum_{n=1}^N C^2(t_n)^2 - (x_n - x_c)^2}$$

(b) Proposed method



(c) Positioning accuracy

Figure. 1 Proposed method schematics

[1] Yan et al., SPIE Medical Imaging, 2018

[2] Tanaka et al., SPIE Photonic WEST, 2019

[3] Allman et al., SPIE Photonic WEST, 2019