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A novel automatic first-arrival picking method for ultrasound sound speed tomography

超音波音速トモグラフィーにおける超音波到達時間推定法の高精度化

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1. Introduction

Ultrasound sound speed tomography (USST) is a promising breast cancer diagnostic technique under investigation[1]. In the same time, our group also considers its potential to guide High Intensity Focused Ultrasound (HIFU) treatment for breast cancer. For both diagnostic and treatment guide, image quality improvement of USST is expected. To ensure high quality USST image, accurate first-arrival picking of sound wave is extremely important.

Most of first-arrival picking techniques have been developed for geophysics to reconstruct internal structure of the earth[2], but two of them are employed for USST: one is classical Cross Correlation method (CC) and another is Akaike Information Criterion method (AIC). CC method calculates cross correlation of sound wave signals for water and object structure to find their time shift. It is robust to random noise but not to object structure complexity. For complex object structure, received wave signal is formed by sound waves from multi paths with different arrival time. The combined sound wave is different to sound wave from homogenous water. Thus, cross correlation between receive wave signals for water and complex structure will decrease as structure complexity increasing. On the other hand, AIC method finds first arrival time by using statistical features difference before and after first arrival time. Comparing to CC method, it is robust to object structure complexity but not to random noise. Therefore, if random noise is heavy, CC method will be better, but if scanning object structure is complex, AIC method will be preferred.

To gain both merits of CC and AIC methods, a combination method, Akaike Information Criterion Neighbor Cross Correlation (AICNCC) method, is proposed for USST first-arrival picking, in this study. The proposed method is more robust to both random noise and structure complexity.

2. Method

The purpose of first-arrival picking method is to calculate travel time difference map (TTDM) for USST reconstruction. TTDM is the difference between travel time maps (TTM) for water and object structure. TTM can be calculated by applying first-arrival picking method to sound wave signals which are obtained by a ring with transducer elements mounted. Each element in the ring acts as an emitter as well as a receiver. All elements receive sound wave when one element emits.

The CC method is always employed to obtain TTDM directly. It calculates the time shift of sound wave signals for water and object structure by finding the maximum cross correlation of them. Strictly speaking, CC method in this application is not first-arrival picking method, since it calculates the time shift of two sound wave singles but not the first arrival time of each one.

The AIC method is proposed for USST reconstruction[3]. It can pick the first rise of sound wave signal and calculate TTMs for both water and object structure, respectively. Then TTDM can be obtained by subtraction. The AIC method assumes there are two locally stationary segments before and after the first-arrival point. Therefore it tries to find first-arrival time k which makes following equation minimum:

$$AIC(k) = k \log \sigma_{1\sim k}^2 + (N-k) \log \sigma_{k+1\sim N}^2 \quad (1)$$

where $\sigma_{1\sim k}^2$ and $\sigma_{k+1\sim N}^2$ are variances of two segments. N is the size of received RF data.

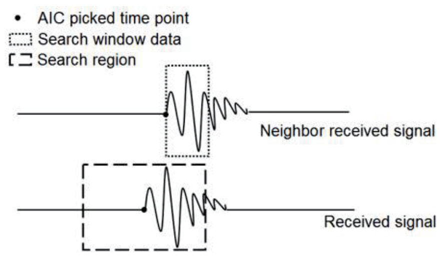

Fig. 1 Schematic of neighbor cross correlation

The proposed AICNCC method combines both AIC and CC methods. And it is roubst to both noise and object structure complexity. There are three steps to calculate TTM by using proposed method. Firstly, AIC method is employed to obtain TTM. Secondly, time shifts between each arrival time and its 8 neighbors in TTM are calculated by using neighbor cross correlation. **Fig. 1** shows the neighbor cross correlation. Search window data in Fig.1 will be employed to find its maximum cross correlation position in search region, thus the time shift between received signal and its neighbor can be calculated. Finally, TTM is updated by:

$$TTM_{AICNCC}(i,j) = TTM_{AIC}(i,j) + \sum_{n=1}^{9} w_n TS_n \quad (2)$$

where i and j denote receiver and emitter number, $TS_{1\sim8}$ are time shifts between received signal and its 8 neighbors. $TS_9 = 0$ and it is for received signal itself. w_n are weights which can be calculated by:

$$w_n = \frac{c_n}{\sum_{i=1}^{9} c_i} \quad (3)$$

where $c_{1\sim8}$ is cross correlation between received signal and its 8 neighbors. $c_9 = 1$ and it is for received signal itself.

3. Results

To evaluate proposed AICNCC method, USST RF data for both simple circle and complex breast sound speed models were simulated by commercial software PZFlex. **Fig. 2** (a) shows the circle model which includes both low and high sound speed circle regions. Fig. 2 (b) shows complex breast model which comes from segmentation of MRI breast image.

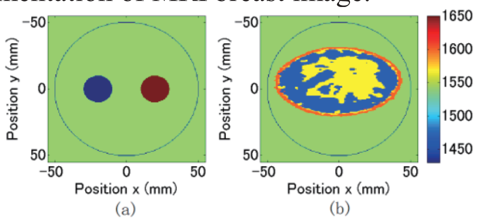

Fig. 2 sound speed models for simulation

Fig. 3 shows calculated TTDMs of simple circle model. For RF data without noise, all of three methods give good TTDMs. However, for RF data with random noise, CC method can keep its performance, AIC method give worst results and proposed method is just affected slightly.

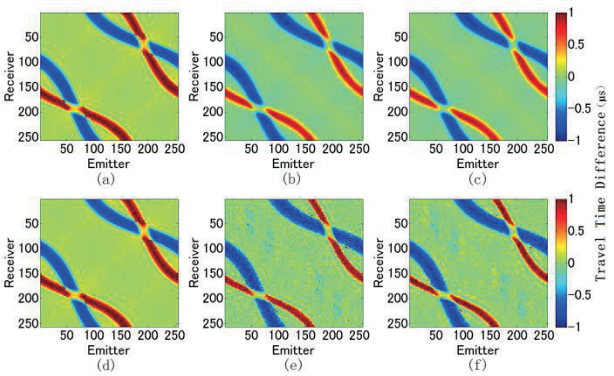

Fig. 3 TTDMs of circle model. (a), (b) and (c) are results of CC, AIC and AICNCC methods, respectively. (d), (e) and (f) are their results for RF data with random noise

Fig. 4 shows the TTDMs for complex breast model. Random noise has similar affect to it for circle model. The difference is that CC method gives worst results for RF data with or without noise, since CC method is not robust to structure complexity.

To quantitatively evaluate accuracy of obtained TTDMs, previous study employed manually picked results to be golden standards. However, it is not just time consuming, but also very subjective. In this study, we obtain golden standard by threshold first picking method from RF data without noise. For simulated noise free data, amplitude is always zero before first-arrival, thus threshold method is considered to be very accurate. **Tab. 1** shows average absolute errors for both circle and breast models.

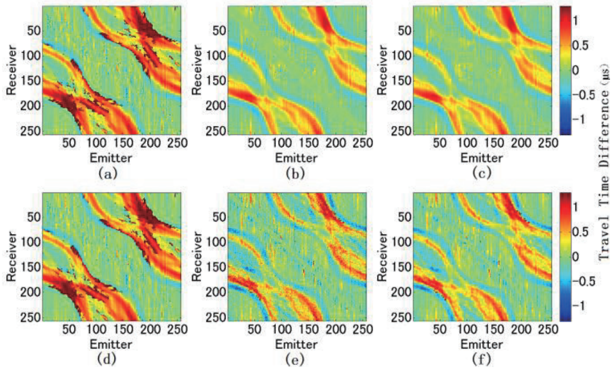

Fig. 4 TTDMs of breast model. (a), (b) and (c) are results of CC, AIC and AICNCC methods, respectively. (d), (e) and (f) are their results for RF data with random noise

Table 1 Average absolute TTDM errors

	Circle Model (ns)		Breast Model (ns)	
	No-noise	Noise	No-noise	Noise
CC	110	110	361	361
AIC	60	129	91	153
AICNCC	52	65	98	103

4. Conclusion

A novel first-arrival picking method (AICNCC) is proposed for USST. It is more robust to random noise than AIC method and to complex structures than CC method.

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