REDUCTION OF THE DECORRELATION EFFECT DUE TO TISSUE LATERAL DISPLACEMENT BY 2-D SPATIAL COMPREHENSIVE CORRELATION IN ELASTOGRAPHY

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Abstract- **The cross-correlation based ultrasonic elastography is limited for application due to distortion of the echo waveform by tissue lateral deformation during axial compression. To reduce this kind of decorrelation effect, a time-efficient method called 2-D Spatial Comprehensive Correlation algorithm is proposed in this article. The basic idea of this method is to combine spatial adjacent cross-correlation functions as a comprehensive time shift estimator. Simulation model based on finite element analysis is applied to evaluate the method proposed in this work. Results indicate that this method can reduce the decorrelation effect of tissue lateral displacement with less increase of computation.**

Key Words- **Ultrasound, Elastography, Comprehensive correlation.**

I. INTRODUCTION

Elastography, which is a method for imaging the elastic properties of soft tissues using ultrasound echo signal, is under investigation for years. This technique is based on strain reconstruction through time shift which is obtained by applying cross-correlation analysis between corresponding A-scan echo segments pre- and post- tissue compression. The estimated strain is as follows [1],

$$S(i) = \frac{\Delta t(i) - \Delta t(i-1)}{2dz / c} \qquad (1)$$

where $S(i)$ is strain of the target tissue, $\Delta t(i)$ is the time shift of the i-th echo segment pair, dz is the distance between (i-1)th and i-th segments, c is ultrasound speed.

1-D research on elastography is based on the assumption that tissue is deformed uniformly and uniaxially under a quasi-static compression. The scatterers within the ultrasound beam are modeled as points between serial springs in axial direction. In fact, the tissue after quasi-static compression undergoes a complex motion which depends on its elasticity distribution and boundary condition. This motion of scatterers decorrelates the echoes obtained pre- and post-tissue compression in elastography.

The decorrelation effect of complex tissue motion was recognized. Confined compression [2] and lateral tracking method [3] were introduced to reduce this effect. However, confinement may not be easily applied on target which is deep in tissue and the lateral tracking method needs great computation effort.

In this paper, a time-efficient 2-D spatial comprehensive correlation method is proposed to reduce the decorrelation effect of lateral displacement. Simulation results show that this method can reduce the error of estimated axial strain with comparable processing time as that of 1-D method.

II. METHOD

The elastography experiment installation is illustrated in Fig. 1. The tissue is compressed between two flat friction free compressor with an ultrasound array transducer embedded in one of them.

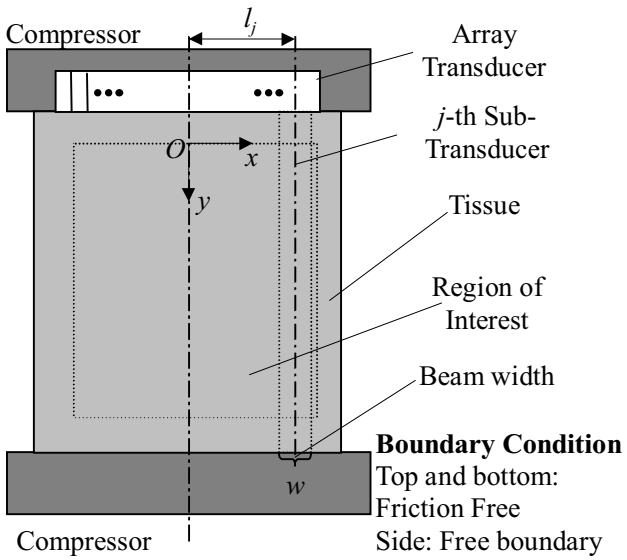

Fig. 1. Elastography experiment setting

In 1-D case, for j-th sub-transducer, the time shift $\Delta t(i)$ in Eq. (1) is determined by locating the maximal peak of the cross-correlation function of echoes obtained before and after

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Abstract

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4

tissue compression. The cross-correlation function is given by

$$R_{12}(t) = \frac{1}{T_i}\int_{T_i} r_1(\tau) r_2(t+\tau) d\tau \tag{2}$$

where T_i is the length of i-th tracing echo segment, r_1, r_2 are echoes obtained pre- and post-compression

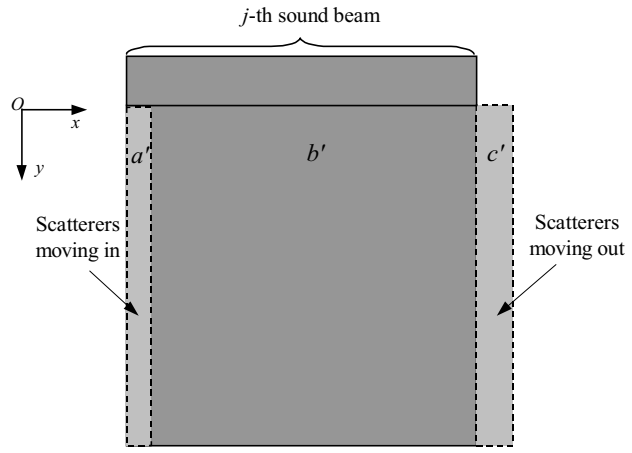


Fig. 2. Sketch of scatterers lateral motion for homogeneous tissue after compression.

The scatterer's moving states for homogeneous tissue is shown in Fig 2. Thus, the pre- and post-compression echoes are given by

$$r_1(t) = s_{jc}(t) + s_{jb}(t) \tag{3}$$

$$r_2(t) = s'_{jb}(t) + s'_{ja}(t) \tag{4}$$

where $s_{jk}(t)$, $k=b,\ c$ are the scattering signal from the scatterers in the regions of $b,\ c$ which are corresponding to compressed regions $b',\ c'$ before compression, respectively. $s'_{jk}(t)$, $k=a,\ b$ are the scattering signal from compressed region $a',\ b'$ (shown in Fig. 2). Thus, the cross-correlation function of Eq. (2) can be expressed as follows

$$R_{12}(t) = \frac{1}{T_i}\int_{T_i} r_1(\tau) r_2(\tau+t) d\tau$$

$$= \frac{1}{T_i}\left[\int_{T_i} s_{jb}(\tau) s'_{jb}(\tau+t) d\tau + \int_{T_i} s_{jb}(\tau) s'_{ja}(\tau+t) d\tau \right.$$

$$\left. + \int_{T_i} s_{jc}(\tau) s'_{jb}(\tau+t) d\tau + \int_{T_i} s_{jc}(\tau) s'_{ja}(\tau+t) d\tau \right] \tag{5}$$

The first term in Eq. (5) is the cross-correlation of echoes from the scatterers remain in the beam-width after compression. The maximal peak location of this term can be regarded as the estimate of the tissue displacement. The other three terms in Eq. (5) are the cross-correlation functions include echoes from scatterers which move in and out of the beam-width and indicate the influence of the tissue lateral displacement. These three terms can be regarded as random noise which decorrelates the first term. Thus, if we combine the lateral adjacent cross-correlation functions, the decorrelation effect of tissue lateral displacement may be reduced.

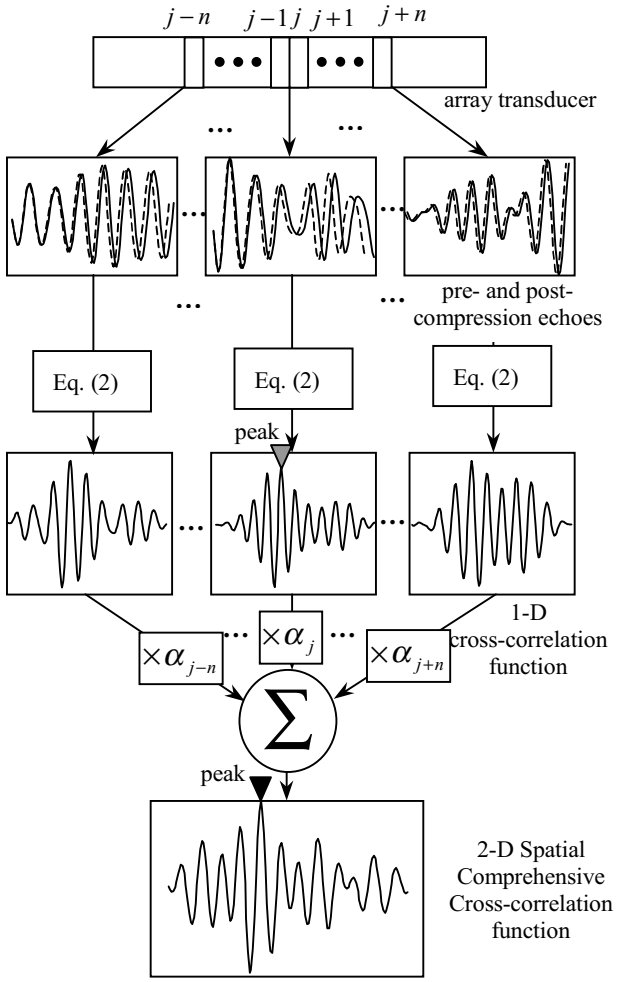


Fig. 3. The sketch of the 2-D Spatial Comprehensive Correlation algorithm. The solid lines in the echo waveform of each ultrasound beam represent the echoes obtained before tissue compression at same axial position and the dash lines represent the corresponding echoes after compression. The 1-D cross-correlation function of each echo pairs obtained from Eq. (2) is multiplied by the weight coefficient α and combined into 2-D cross-correlation function. The maximal peaks of 1-D and 2-D cross-correlation function are marked by a gray triangle and a black triangle, respectively.

2-D Spatial Comprehensive Correlation method is to apply combination of lateral adjacent 1-D cross-correlation functions as the substitute of central ultrasound beam's cross-correlation function as illustrated in Fig. 3. The 2-D comprehensive cross-correlation function corresponding to *j*th ultrasound beam can be obtained by

$$R_j'(t) = \sum_{i=j-n}^{j+n} \alpha_i R_i(t) \qquad \sum_{i=j-n}^{j+n} \alpha_i = 1 \qquad (6)$$

where $R_i(t)$ represents the cross-correlation function of the pre- and post-compression echoes corresponding to *i*th ultrasound beam from Eq. (2), α is the weight coefficient, *n* is the comprehensive coefficient which define the cross-correlation function associated with that of *j*th ultrasound beam. If *n*=0, Eq. (6) turns to be the form of Eq. (2). It means that the definition of 2-D Spatial Comprehensive Correlation method includes that of 1-D cross-correlation method. It must be noted that the 2-D spatial comprehensive correlation method does not filter estimated strain, but filters the correlation function to obtain the comprehensive correlation function peak location.

III. Results And Disscussion

The simulated echoes are obtained by modeling an array transducer with central frequency 3.5MHz and bandwidth 1MHz. The beam-width is 2mm and separated by 0.4mm. The scatterers are uniformly distributed in the medium with the density 16mm^2. The scatterers' diameters which are positive proportional to the scattering strength have a Gaussian distribution with an average of 0.05 mm and a standard deviation of 0.01mm. The speed of sound *c* in the medium is taken to be constant at 1540m/s and the sampling rate of ultrasonic echoes is taken as 40 MHz.

Uniform elastic medium models and hard circular lesion models are studied. The ROI is 40mm×60mm and the Young's modulus of inclusion is set to be two times of that of surrounding tissue and the Poisson's Ratio are the same of 0.495 since the tissue is incompressible in general. The diameter of lesion is set to be 10mm.

The location of the scatterers after compression is computed by commercial available Finite Element Analysis (FEA) software (Mentat Version 3.3, MARC Analysis Research Corporation, USA) as plane strain states.

The multi-scale elastography procedure presented in previous work [4] with optimal tracing segment length was applied to reconstruct the simulated strain field using the 2-D Spatial Comprehensive Correlation method.

Fig 4 illustrates the SNR_e (Mean to Standard Deviation ratio of reconstructed strain) for 30 homogeneous tissue models. The result shows that with the increase *n*, the estimated axial strain is close to ideal strain.

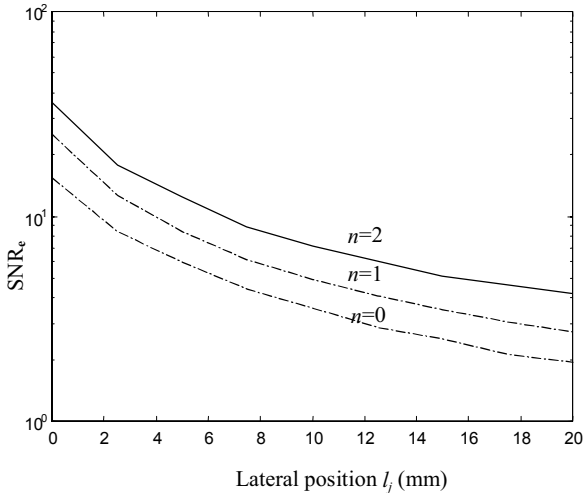
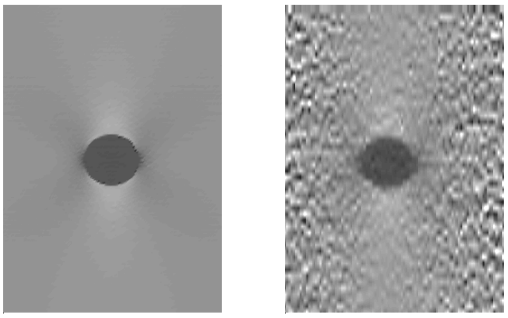


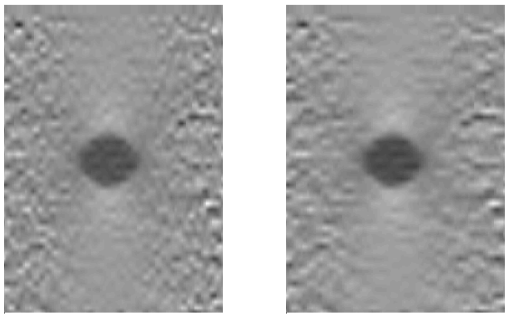
Fig. 4. SNR_e of homogeneous tissue models of 2-D method. Tracing segment length is 3mm with 70% overlap. The compression ratio is 0.5%.

Fig. 5. shows the result of reconstructed strain images for hard circular lesion model. Fig. 5 (a) is the axial strain image of FEA calculation with 0.5% axial compression. Fig. 5 (b) (c) and (d) are the strain profiles reconstructed by 2-D method with comprehensive coefficient *n*=0 (which becomes 1-D case), 1, 2, respectively and the weight coefficient α_i equal to each other. These figures illustrate that the strain profile reconstructed using echoes from the edge of transducer was distorted by the lateral displacement of tissue. The distortion of reconstructed strain was decreased and the decorrelation effect of tissue lateral displacement was reduced by the 2-D method with increasing *n*.

Since the combination of 1-D cross-correlation function is a summation procedure, the computation effort is comparable with 1-D case. As shown in Fig 5. the trade off for reduction of decorrelation effect by tissue lateral displacement is the sharpness decrease of lesion's edge. However, with the increase of SNR_e, the sharpness decrease is acceptable.



(a) (b)



(c) (d)

Fig. 5. Axial strain profiles for lesion model. Tracing segment length is 3mm with 70% overlap. The compression ratio is 0.5%. (a) is the strain image of FEA calculation. (b) (c) and (d) are the strain profile reconstructed by 2-D method with comprehensive coefficient n=0 (which becomes 1-D method), 1, 2, respectively and the weight coefficient α_i are equal to each other.

IV. Conclusion

In this paper, a 2-D Spatial Comprehensive Correlation algorithm is proposed to reduce the elastogram errors by tissue lateral displacement. Simulation results demonstrated that 2-D method can be applied to reduce decorrelation of lateral displacement with less increase of computation effort.

Acknowledgement

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