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● *Original Contribution*

HYBRID ALGORITHM FOR ELASTOGRAPHY TO VISUALIZE BOTH SOLID AND FLUID-FILLED LESIONS

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Abstract—We propose a novel strain estimation technique that can produce reliable strain images of both solid and fluid-filled lesions. In our method, a kernel-based correlation coefficient technique and a speckle tracking-based strain estimation technique are combined into a single algorithm. The elegance of our algorithm is that fluid-filled lesions are first automatically identified by three selection criteria, and strain in those parts is estimated using the kernel-based correlation coefficient technique. Strain where fluid-filled lesions have not been detected is estimated using a speckle tracking-based algorithm, and then these two estimates are merged to form the final image. Any speckle tracking algorithm can be used in our proposed technique; however, we used a modified version of the direct average spectral strain estimation technique to describe our algorithm. We modified the direct average spectral strain estimation algorithm to track smaller strain variation and to facilitate strain calculation from multiple frames. We describe the performance of our proposed hybrid algorithm using *in vivo* patient data. Both the solid and fluid-filled lesions are clearly visible in the strain images produced by our proposed approach and are of better quality in terms of contrast-to-noise ratio and border sharpness than the strain images generated by other reported techniques. We also validate the performance of our proposed multiframe technique using experimental phantom data and *in vivo* patient data. The results reveal that the quality of the strain image can be improved using the multiframe technique compared with its dual-frame counterpart. (E-mail: khasan@eee.buet.ac.bd) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Elastography, Strain imaging, Weighted nearest neighbors, Spectral strain estimation, Correlation coefficient, Fluid-filled lesions, Solid lesions.**

INTRODUCTION

Elastography is an imaging technique developed over the past two decades for imaging tissue elasticity or strain that offers new insights into tissue diagnosis (Samani et al. 2007). In this non-invasive imaging technique, ultrasound echo signals are obtained before and after applying gentle external pressure on the surface, typically with the ultrasound transducer. The internal tissue strain distribution caused by the applied external pressure can be estimated by tracking speckle movement from the pre- and post-compression radiofrequency (RF) echo signals in the time (Alam et al. 1998; Hussain et al. 2012), frequency (Alam et al. 2004; Hasan et al. 2012) or phase domain (Ara et al. 2013; Pesavento et al. 1999). Elastography has been reported to have great potential in improving the detection and/or characterization of breast and prostate tumors (Garra et al. 1997; Céspedes et al. 1993; Ophir et al. 1991, 1996), vascular plaques (de Korte and van der Steen 2002) and liver cirrhosis (Friedrich-Rust et al. 2007). However, recent studies trying to detect and characterize cysts with elastography have had limited and sometimes conflicting results (Booi et al. 2007). Because cysts are filled with fluid, they contain insufficient speckle for the speckle tracking algorithms to reliably track speckle motion between pre- and post-compression RF echo frames (Booi et al. 2007). As a result, cysts can have a variety of appearances in elastogram (Garra et al. 1997; Hall et al. 2003), depending on the ultrasound scanner used, percentage compression and pre-compression and type of signal processing (Booi et al. 2007). This observation is valid not only for cysts, but also for other fluid-filled lesions that do not contain sufficient speckle.

In Nightingale et al. (1999), ultrasonically induced acoustic streaming was used to differentiate cysts from

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solid lesions. Also, it has been proposed that correlation coefficient-based imaging derived from elastography be used to differentiate cyst from solid masses in Booi et al. (2007, 2008). As signal in the fluid-filled lesions is composed mainly of random noises, reverberation, side lobes and clutter (Booi et al. 2007), the correlation coefficient between the pre- and post-compression RF echo signals inside the cyst will be significantly lower than that in the surrounding tissue. Therefore, a technique to estimate strain from correlation coefficients can be adopted to visualize fluid-filled lesions in the strain image.

A study on estimating tissue strain from signal decorrelation using the correlation coefficient has been published (Varghese and Ophir 1996). Here, tissue strain is directly computed by taking the peak value of the correlation coefficient between the pre- and post-compression RF echo frames. However, it has been pointed out that the estimate of strain obtained from the correlation coefficient is a biased estimate and that it is not possible to estimate the true value of strain using the correlation coefficient technique. As a result, it is not possible to obtain a high-quality strain image with the correlation coefficient technique.

The problem faced here is that the correlation coefficient-based strain estimation technique (Varghese and Ophir 1996) is the only way to produce reliable strain images of fluid-filled lesions. But for solid masses, speckle tracking-based algorithms (*e.g.*, Hasan et al. 2012; Hussain et al. 2012) will produce better defined and less noisy strain images than the correlation coefficient-based technique. Until now, to the best of our knowledge, no algorithm has been published that can effectively visualize both solid and fluid-filled lesions. We propose a novel technique that combines an enhanced correlation coefficient-based strain estimation technique and a speckle tracking-based strain estimation technique into a single algorithm to visualize both solid and fluid-filled lesions. In our proposed technique, the fluid filled lesion is first automatically identified and then strain in that part is estimated with the enhanced correlation coefficient-based technique and strain in the rest of the region is estimated with the speckle tracking-based algorithm. The strain estimates from these two techniques are merged to form the final strain image. If no fluid-filled lesion is detected, then strain is estimated with the speckle tracking-based algorithm alone. Any speckle tracking algorithm can be used in our proposed technique; however, we describe our technique using a modified version of the direct average spectral strain estimation (DASSE) algorithm (Hasan et al. 2012).

The performance of our proposed hybrid algorithm is evaluated using *in vivo* data and compared with that of the correlation coefficient-based and speckle tracking-based strain estimation algorithms.

Symbols and acronyms used in this paper are listed in Table 1.

METHODS

The *in vivo* breast data and experimental phantom data used in this study were acquired at the Medical Center of Bangladesh University of Engineering and Technology (BUET) Dhaka, Bangladesh. The study was approved by the institutional review board and conducted with prior informed consent from the patients. Thirty-five patients with six different diagnoses (25 cysts, 1 galactocele, 4 fibroadenomas, 2 carcinomas, 2 abscesses and 1 malignant tumor with necrosis) were selected for this study. These patients had come to the BUET Medical Center for free-hand elastography. Ages ranged from 19 to 57 y (mean $\pm$ standard deviation: 37.05 $\pm$ 8.77 y). Diagnoses were confirmed by fine-needle aspiration cytology and/or histopathology.

The experimental phantom used was an 18 $\times$ 12 $\times$ 9.5-cm CIRS (Norfolk, VA, USA) tissue-mimicking phantom comprising a 13.6-mm-diameter spherical inclusion in a homogeneous background. The Young's moduli of the background and lesion were 17 and 75 kPa, respectively. The attenuation coefficients of the background and lesion were 0.68 and 0.73 dB/cm/MHz, respectively and the scatterers were 38–60 μm in diameter.

The quasi-static free-hand elastographic data (both *in vivo* breast data and experimental phantom data) were acquired using a SonixTOUCH Research

Table 1. Symbols and acronyms

Symbol	Definition
L_v	Interwindow shift between two consecutive radiofrequency echo segments
L_i	Length of radiofrequency echo segments
L_a, L_l	Nearest-neighbor factors in the axial and lateral directions, respectively
N_c	Number of scan lines in an ultrasound frame
AM2-D	2-D analytical minimization
s_{avg}	Estimated applied strain
CCSE	Conventional correlation coefficient-based strain estimation
K-CCSE	Kernel-based strain estimation from correlation coefficient
DASSE	Direct average spectral strain estimation
M-DASSE	Modified direct average spectral strain estimation
DASE	Direct average strain estimation
s_{corre}	Estimate of strain from K-CCSE technique
s_{MN}	Estimate of strain from M-DASSE algorithm
ν	Poisson's ratio
NCC	Normalized cross-correlation
SSD	Sum squared difference
DSR	Differential strain ratio
RF	Radiofrequency
SNR	Signal-to-noise ratio
CNR	Contrast-to-noise ratio