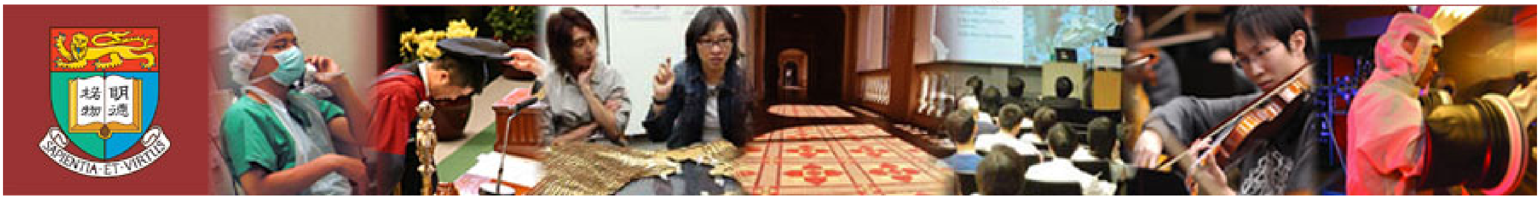

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Author(s)	Guo, Y; Lee, W
Citation	The 2014 IEEE International Ultrasonics Symposium (IUS 2014), Chicago, IL., 3-6 September 2014. In IEEE International Ultrasonics Symposium Proceedings, 2014, p. 1316-1319
Issued Date	2014
URL	http://hdl.handle.net/10722/210421
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10.1109/ULTSYM.2014.0325

On the Feasibility of Speckle Reduction in Echocardiography Using Strain Compounding

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***Abstract*—Strain compounding has been previously developed as an approach to reducing speckle noise. The technique is based on speckle de-correlation induced by different strain levels applied on the medium and has been demonstrated feasible in the human superficial soft tissues under external quasi-static compression. In this study, the efficacy of strain compounding in echocardiography was investigated. A temporal gate in a cardiac cycle was first defined, with the middle echocardiographic frame selected as the reference image. The in-plane motion of the temporally gated images was then estimated and used for image correction with respect to the reference frame. Finally, the spatially matched images were averaged to form a speckle reduced image. Not only did the prerequisite deformation stem from the natural contraction of the heart, but the computational efficiency could also remain by simply using the strain estimates yielded from cardiac strain imaging, which has become a commonly used tool in the clinic. Ultrasonic images of a normal human heart over six cardiac cycles were acquired by a commercial ultrasound imaging system at a frame rate of 70 fps in the apical four-chamber, long-axis and short-axis views. The results show approximately 7.9%, 8.4%, and 11.3% improvements in the signal-to-noise ratio (SNR) of the septal wall segment of the strain-compounded images in the apical four-chamber and long-axis views, respectively. Comparable performance of strain compounding to that of a well-established method, Speckle Reducing Anisotropic Diffusion (SRAD), was also observed.**

Keywords—decorrelation; deformation; speckle reduction; strain; compounding; echocardiography

I. Introduction

Speckle is a characteristic granular structure in ultrasonic images [1]. It results from the coherent interference of the scatterers within the sample volume and does not reflect the underlying structures. As an inherent artifact, speckle appears as brightness variations, degrades image quality, and complicates the identification of low-contrast objects in ultrasonic images and reliable clinical diagnosis.

Several compounding techniques, including spatial compounding [2], frequency compounding [3] and strain compounding [4], have been developed for speckle noise reduction. The standard compounding technique is based on the assumption that the ensemble average of the speckle images is equivalent to the incoherent average of the images without speckle. Thus, the speckle variations can be cancelled by averaging the de-correlated images of the same object. In spatial compounding, one-dimensional (1D) array probe is divided into several sub-arrays. Each sub-array acquires the image of the same object independently. The de-correlation of the acquired images is induced from different geometric relationships between the imaging sources and the scatterers. However, this technique sacrifices the lateral resolution due to the reduced size of the imaging aperture. In frequency compounding, the frequency pass-band of an input pulse is divided into several sub-bands. Due to the reduced bandwidth, this technique sacrifices the axial resolution.

In 2002, Li and Chen proposed a new method named as strain compounding [4], which requires partially correlated images of the object under different strain conditions. External applied force deforms the scanning object and introduces the required speckle de-correlation in compounding. This approach has been demonstrated in simulations, a gelatin-based phantom, and human tissues, such as thyroid and breast, with enhancement in contrast-to-noise ratio (CNR) [5]. Improvement in automatic contour extraction of ultrasonic breast imaging has also been demonstrated to explore the potential application of strain compounding in Computer Aided Diagnosis (CAD) [6].

The major limitation of strain compounding is the prerequisite large strain level, which is higher than the typical values (0.8% ~ 1.3%) used in ultrasound strain imaging [7]. According to a simulation study [4], the application of 20% strain was preferred to result in significant speckle reduction. In a previous in vivo study [5], 16% strain in the human thyroid and 9% strain in the human breast were shown effective in speckle reduction. This requirement limited the clinical application of strain compounding to the superficial soft tissues on which a large external compression was applied.

In this study, the feasibility of strain compounding on echocardiography was studied given that the natural contraction of the heart provides the pre-requisite large deformation and that the motion correction step in strain compounding could directly access the displacements estimated in cardiac strain imaging, which is now widely performed in the clinic, without greatly decreasing the computational efficiency. Strain compounding was demonstrated on a series of echocardiographic images in a clinical setting. The variation of the speckle reduced image quality over the entire cardiac cycle was investigated.

II. METHODS

A. Conventional strain compounding

The general steps involved in conventional strain compounding on superficial soft tissues include: 1) the application of external quasi-static deformation on the object; 2) estimation of the in-plane motion; 3) correction of the in-plane motion; and 4) in-coherent compounding of the corrected ultrasound images. Under the externally applied deformation, three-dimensional (3D) motion is induced. The scatterers within one sample volume will be re-distributed due to different 3D motion patterns of the scatterers. Some of the scatterers may also move into or out of the sample volume. As speckle is generated by the coherent interference of scatterers within the sample volume, the re-distribution of the scatterers de-correlates the speckle signals. The in-plane motion correction step also introduces speckle signal de-correlation because it changes the sample volume geometry [8]. Out-of-plane motion is left uncorrected in strain compounding and contributes to speckle de-correlation.

Accurate in-plane motion estimation requires high correlation between two images to be compared. On the other hand, speckle reduction relies on high signal de-correlation. To tackle this trade-off, multiple incremental compressions were implemented [4]. Small increments between two consecutive ultrasound images ensured high correlation for accurate in-plane motion estimation and correction. Accumulating the motion estimated from each small increment permitted reliable large motion correction. The strain between the un-deformed and lastly deformed images might be deemed sufficient for significant signal de-correlation. The speckle could thus be reduced effectively by correction of these low-correlated images, followed by the compounding of the corrected ones.

To reduce the estimation error, additional processing is required. Multiple pixels may be assigned to the same position due to the estimation error or the change in the sample volume, i.e., single pixel being expanded to multiple ones or vice versa. The un-corrected out-of-plane motion may also reduce the accuracy of motion estimation, leading to poor pixel correction. In [5], bi-linear interpolation was implemented to improve the in-plane motion estimation and correction. When multiple pixels were corrected to the same position, only the pixel with the highest correlation-coefficient was corrected. The displacements of other pixels would be left un-determined. These displacements would be calculated based on bilinear interpolation from the determined displacements. As the motion may be non-integer, bi-linear interpolation was also performed on corrected images to fill in the empty positions.

B. Strain compounding in echocardiography

In our study, the in-plane motion on echocardiographic images was estimated by standard 2D speckle tracking [9]. The matching block was 32 pixels by 32 pixels, and the search region was also 32 pixels by 32 pixels in all cases. The temporal gate size *K*, which was the number of images to be compounded, was seven. The 4th image was selected as the reference frame. All the other images within the temporal gate were corrected with respect to the reference one.

Because it was not possible to control the compression increment in echocardiography as in thyroid and breast imaging, a larger percentage of pixels than that reported in [5] was left un-determined and required to be bi-linearly interpolated. The displacements of approximately 20% of total pixels were reconstructed from bi-linear interpolation in this study.

A signal-to-noise ratio (SNR) was used as a quantitative measure of the ultrasound image quality. It is defined as

$$SNR = \frac{\mu}{\sigma}$$

where μ is the mean brightness value in the region-of-interest (ROI), and σ is the standard deviation in the ROI.

C. Echocardiographic image acquisitions

A commercial imaging system (GE, Vivid E9, Waukesha, WI, USA) quipped with a phased array probe (6S-D) was used to acquire B-mode images of a normal human heart in the apical four-chamber, long-axis and short-axis views. Each set of echocardiographic images was comprised of six cardiac cycles with ECG gating. The frame rate was 70 fps, while the heart rate was 66 ± 2 bps. The human subject study protocol was approved by the Institutional Review Board of The University of Hong Kong/Hospital Authority.

III. RESULTS

Fig. 1 shows the original and compounded images in the apical four-chamber, long-axis and short-axis views at end diastole, end systole and early diastole. The septum was manually traced as the ROI indicated by the red solid curve. It is noted that the speckle in the myocardial walls was reduced in the compounded images. The corresponding temporal profiles of SNR improvement and resultant displacements of the ROI during one cardiac cycle with ECG alignment were shown in Fig.2. The resultant displacements were calculated as the average in-plane resultant motion of all the pixels within the ROI. The SNRs of ROI were improved by approximately 7.9%, 8.4%, and 11.3% respectively in the apical four-chamber, long-axis and short-axis views while variations of SNR improvement were also noted over the entire cardiac cycle. A comparison of the speckle reduction performance between strain compounding and the Speckle Reducing Anisotropic Diffusion (SRAD) [10], which is a well-established speckle reduction method, was shown in Table 1. The SNR improvements by strain compounding and SRAD were quantified from two repeated measurements of three cardiac cycles in the apical four-chamber view. The resultant SNR improvements in percentage show that strain compounding could perform comparably as SRAD.

Table 1. Resultant SNR improvement of strain compounding and SRAD

	Strain compounding	SRAD
SNR improvement (%)	7.89 ± 2.67	9.11 ± 1.92

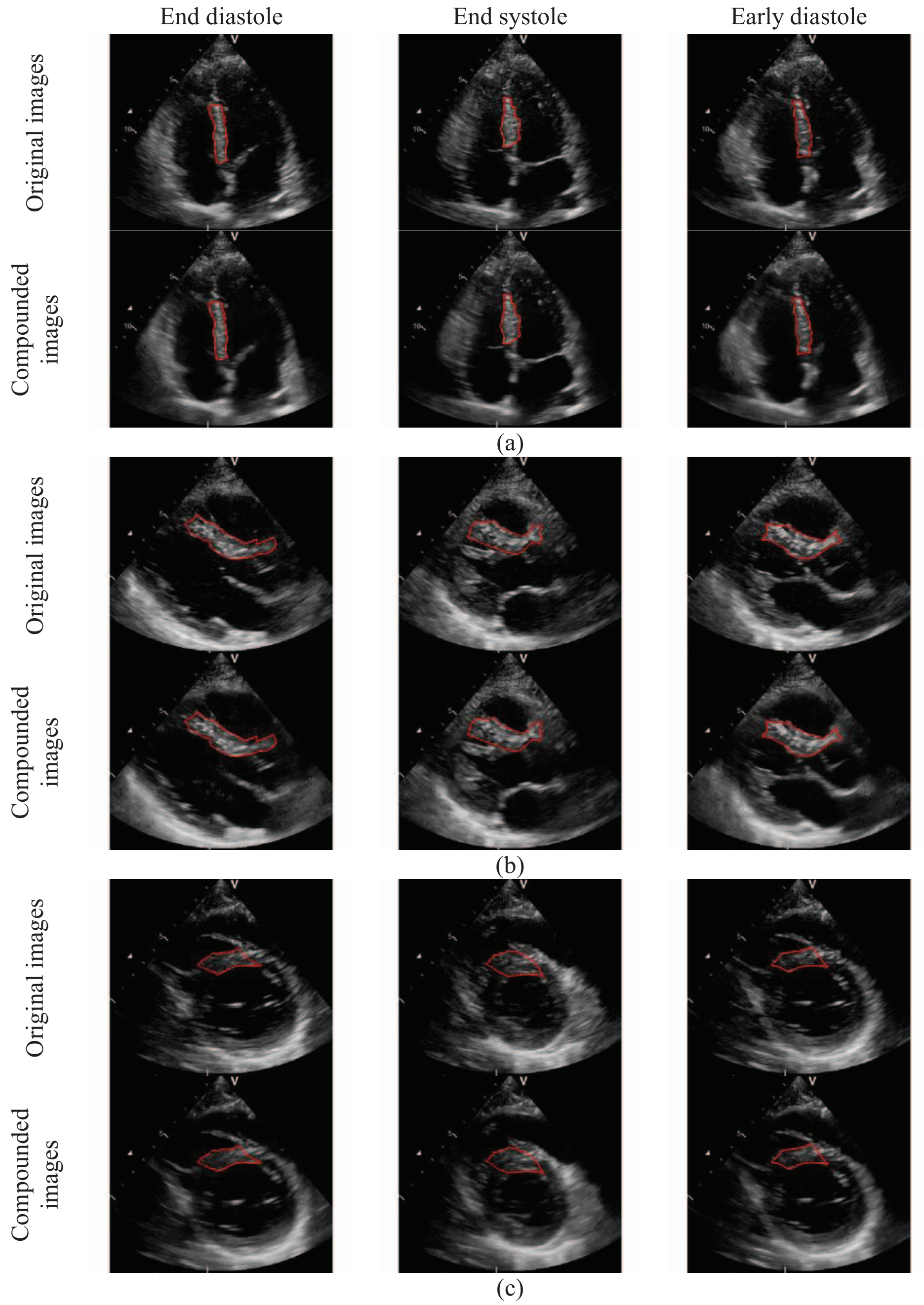

Fig. 1. The original and compounded images in the (a) apical four-chamber view, (b) long-axis view, and (c) short-axis view at end diastole, end systole, and early diastole. The septum is traced as indicated by the red curves.

IV. Discussion and Conclusion

The feasibility of strain compounding in echocardiography was demonstrated in this study. Speckle reduction in the myocardial walls was observed. Unlike the conventional paradigm, where externally applied deformation was performed, the natural deformation of the heart was utilized in strain compounding for echocardiography.

The improvement of SNR over the entire cardiac cycle was not constant under the same temporal gate length. More significant speckle reduction was found to occur during larger resultant displacements. A potential problem of using a single value temporal gate size K over the entire cardiac cycle is that a low K value may be inappropriate for strain compounding to achieve significant speckle reduction when the natural deformation of the heart is small.

Another observation from our findings is that the peak of SNR improvement is not aligned with the peak of resultant displacement. This might be because the resultant displacement did not faithfully reflect the heart deformation. Large resultant

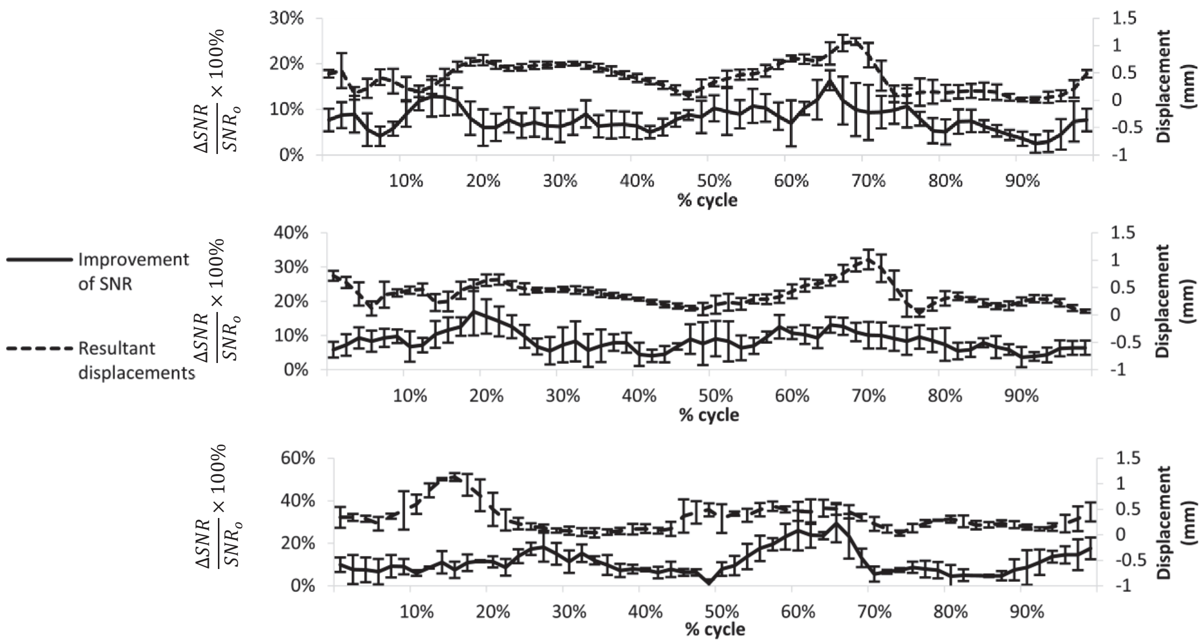

Fig. 2. The solid lines indicate the signal-to-noise ratio (SNR) improvements in percentage in the apical four-chamber view (top row), long-axis view (middle row) and short-axis view (bottom row). The dashed lines indicate the average resultant displacements. SNR_o indicates the SNR of ROI on the original images.

displacement may come from simple translation, which does not cause deformation-generated speckle de-correlation. In this case, strain should be a more indicative parameter to describe the deformation level and predict the performance of speckle reduction in strain compounding.

The trade-off between accurate in-plane motion estimation and significant speckle reduction exists in echocardiography. The employment of a high frame-rate ultrasound imaging sequence might facilitate reliable myocardial strain estimation without sacrificing the image quality compared to the multi-focus imaging method.

V. Acknowledgements

This work is supported by the Research Grants Council of Hong Kong (HKU 739413E). We thank Dr. K-H, Yiu, Dr. J-H Liu and Dr. Y Chen for images acquisitions.

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