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Speckle Noise Reduction for High-Frame-Rate Imaging

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Abstract **– The high-frame-rate (HFR) imaging method was developed in the 1990s. Recently, this method has found many applications such as supersonic imaging, elasticity imaging, velocity vector imaging, strain and strain rate imaging, cardiac imaging, and functional imaging.**

To increase image field of view and resolutions, the original HFR imaging method was extended using steered plane wave (SPW) or limited-diffraction beam (LDB) of different parameters. In the previous studies, images were reconstructed with a coherent superposition of sub-images obtained with plane waves steered at different angles or with LDB of different parameters. In this paper, instead of the coherent superposition, an incoherent superposition is used to reduce speckle noise of both SPW and LDB imaging.

To evaluate the efficacy of the method, experiments with a home-made HFR imaging system were performed to obtain radio-frequency (RF) echo data from an ATS539 tissue-mimicking phantom. The data were acquired using a 128-element, 2.5-MHz center frequency, broadband, 9.6 mm by 14 mm phased array transducer. Images were reconstructed with the Fourier-based method and have a field of view of 90 degrees.

The results show that the improvements of the SNR of the LDB and the SPW methods are 95.58% and 31.31%, respectively, using incoherent superposition with 91 sub-images (or 91 transmissions). When using 11 sub-images (or 11 transmissions), the improvements are 54.39% and 29.32% for the LDB and SPW methods, respectively. This demonstrates that the incoherent superposition method reduces speckle noise and the LDB method is more effective than the SPW method in terms of the SNR improvement or speckle noise reduction.

Keywords - ***High-Frame-Rate Imaging, Speckle Reduction, Incoherent Superposition, Limited-Diffraction Beams, Steered Plane Wave***

I. INTRODUCTION

Recently, high-frame-rate (HFR) imaging [1]-[6] has found many applications such as fast cardiac imaging [5][7]-[8], elasticity imaging [7][9]-[10], strain and strain rate imaging [8][11], flow velocity vector imaging [12]-[15], and functional imaging [16]. In late 1990s, a HFR imaging method based on Fourier reconstruction was developed using either plane wave or limited-diffraction beam (LDB) [1]-[2].

To increase image resolution and field of view, images obtained with plane waves steered at different angles (steered plane wave or SPW) or obtained with limited-diffraction array beam aperture weightings of different parameters can be coherently superposed [3]-[6]. Although image resolution is improved with the coherent superposition in both SPW and LDB methods, speckle noise of reconstructed images is high, which could mask useful medical diagnosis information.

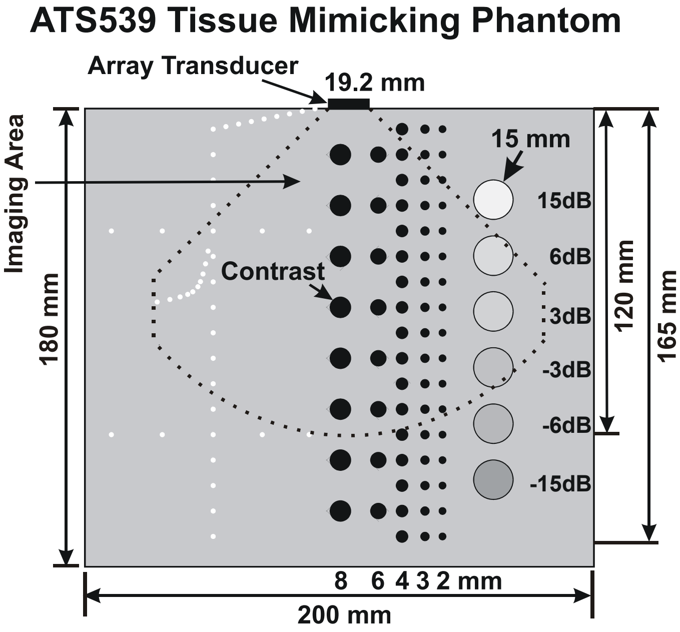

Figure 1. A cross-section of an ATS539 tissue-mimicking phantom showing the imaging areas of 120 mm depth with +/-45 degree field of view for the experiments. (Modified from Fig. 4 of [17].).

II. METHOD

To reduce speckle noise, in this paper, incoherent superposition is used in both SPW and LDB high-frame-rate imaging methods [5]. Images obtained at various steering angles or limited-diffraction aperture weightings are first envelope detected and then superposed to form a final image. 11 and 91 images corresponding to 11 and 91 transmissions (11 and 91 TX), respectively, are used in the superposition for both the SPW and LDB methods. Images superposed are logcompressed to a 50-dB dynamic range for display. The images reconstructed have a width of 153.6 mm and a depth (vertical direction) of 120 mm, with a 90-degree field of view. The Fourier method is used in image reconstruction [1]-[2].

III. EXPERIMENT

To evaluate the efficacy of the speckle reduction method, experiments were performed. During the experiments, a home-made high-frame-rate imaging system was used [5]-[6]. The imaging system has 128 independent transmitters that are capable of transmitting +/-144V arbitrary waveforms and has 128 receive channels. The transducer used has 128 elements and a center frequency of 2.5 MHz. The transducer has a pulse-echo (two-way) bandwidth of about 58% of the center frequency and was excited with about a 1.5-cycle sine wave. The dimension of the transducer aperture is 19.2 mm and the width in elevation is 14 mm. The ATS539 tissue–mimicking phantom in Fig. 1 was used for the experiments [17].

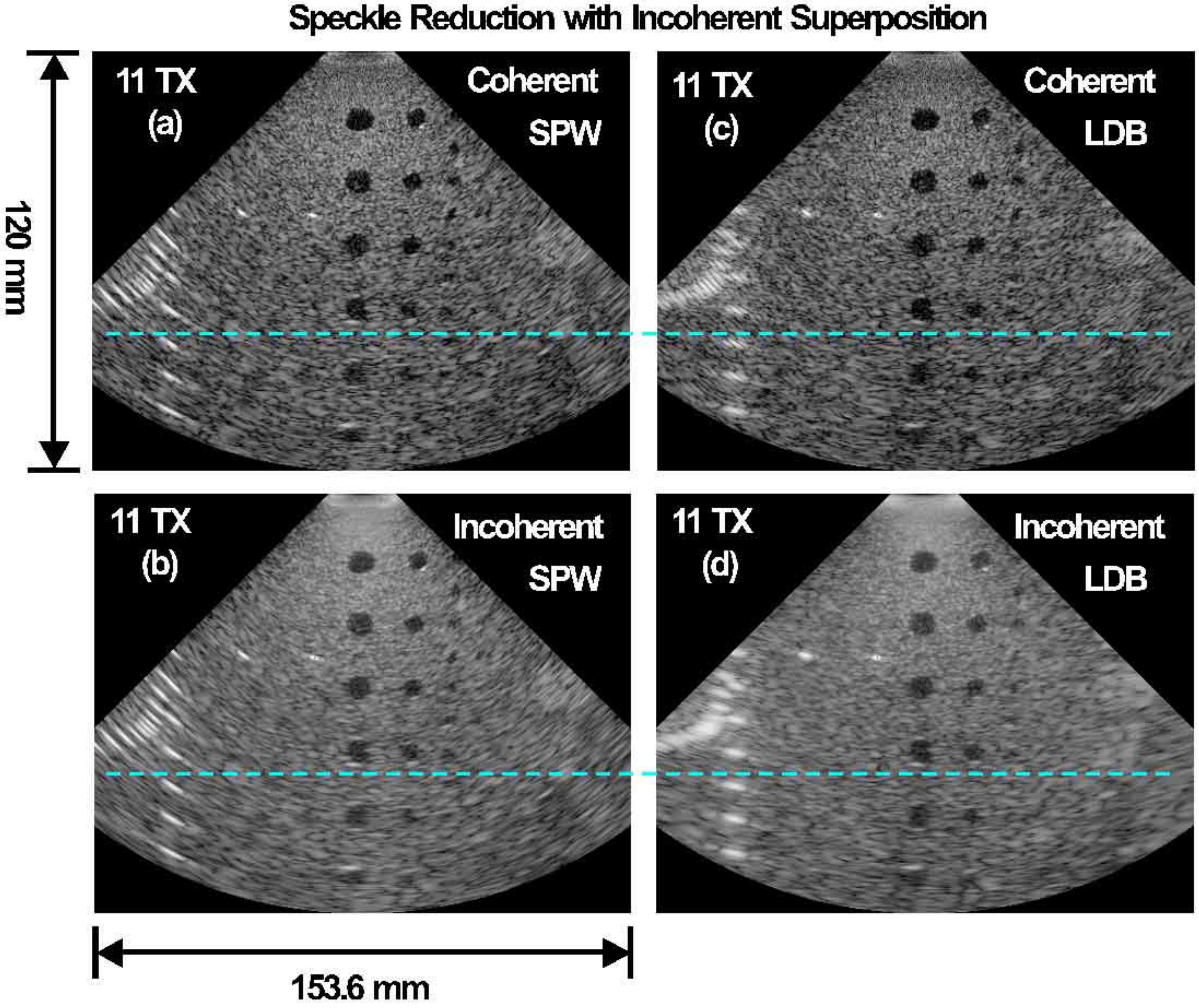

Figure 2. Images obtained with the coherent ((a) and (c)) and incoheren ((b) and (d)) superposition of 11 sub-images (corresponding to 11 transmissions or 11 TX) recontructed with the steered plane wave (SPW) ((a) and (b)) and limited-diffraction-beam (LDB) ((c) and (d)) methods.

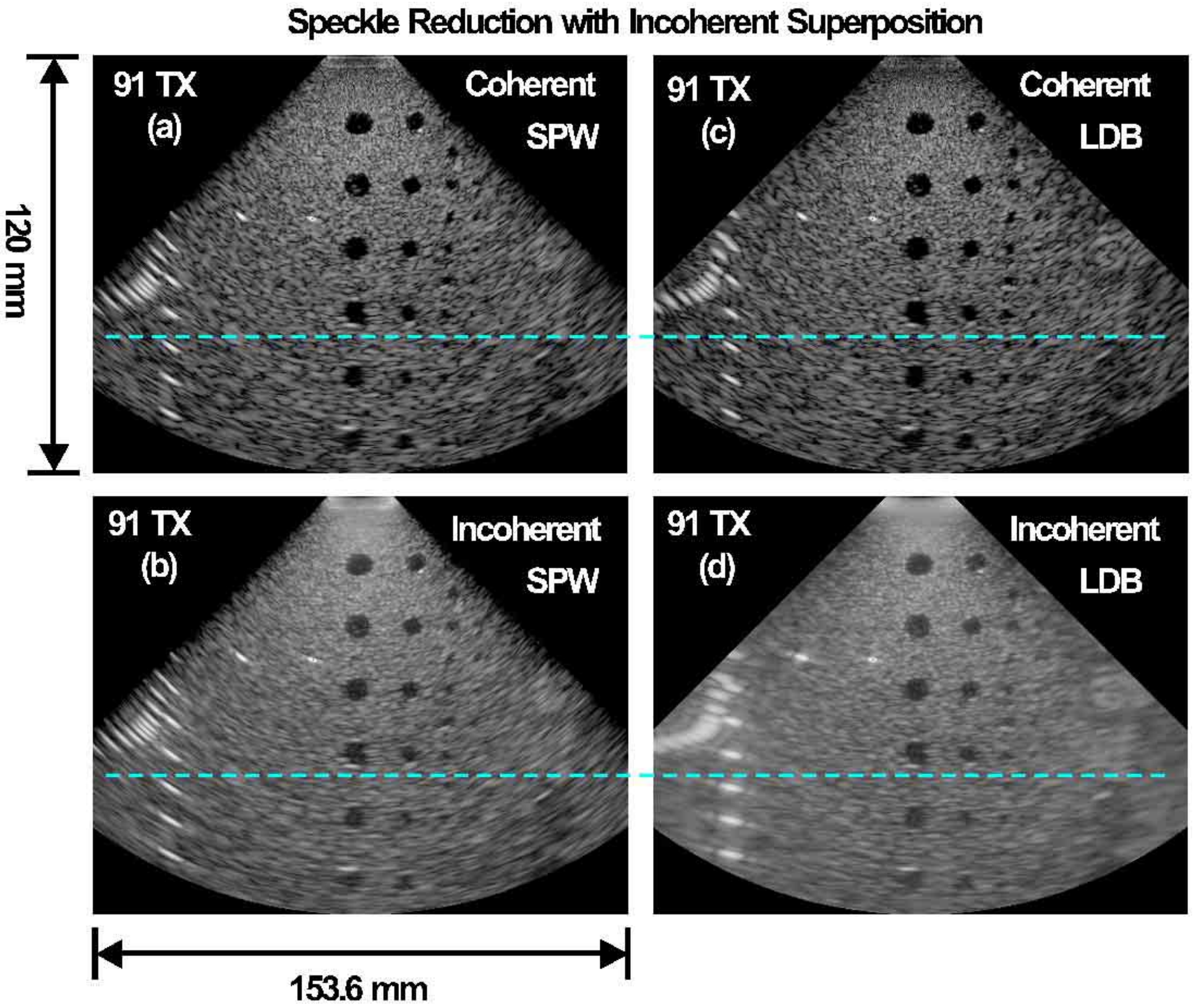

Figure 3. Images obtained with the coherent ((a) and (c)) and incoheren ((b) and (d)) superposition of 91 sub-images (corresponding to 91 transmissions or 91 TX) recontructed with the steered plane wave (SPW) ((a) and (b)) and limited-diffraction-beam (LDB) ((c) and (d)) methods.

IV. RESULTS

With 11 transmissions (or 11 sub-images), images reconstructed with coherent and incoherent superposition are shown in the top (Figs. 2(a) and 2(c)) and bottom (Figs. 2(b) and 2(d)) rows, respectively; and images reconstructed with SPW (Figs. 2(a) and 2(b)) and LDB (Figs. 2(c) and 2(d)) are shown in the left and right columns, respectively. With 91 transmissions (or 91 sub-images), the results are shown in Fig. 3 with the same image layout of (a), (b), (c), and (d) as those in Fig.2.

The signal-to-noise ratios (SNRs) (average of pixel values divided by the standard deviation) calculated along the horizontal dashed lines (cyan color) for 11 transmissions are 39.28 and 45.40, respectively, for SPW and LDB images obtained with the coherent superposition (see Table 1). The calculations were done before the log-compression of images. The SNRs are increased to 50.79 (24.32% improvement) and 70.10 (54.39% improvement), respectively, for SPW and LDB images obtained with the incoherent superposition. For 91 transmissions, the SNRs are 41.33 and 39.22 for SPW and LDB images respectively with the coherent superposition. The SNRs are increased to 54.27 (31.31% improvement) and 76.72 (95.58% improvement), respectively, for SPW and LDB images obtained with the incoherent superposition.

Table 1. Signal-to-noise ratios (SNRs) of images reconstructed with coherent and incoherent superposition of sub-images reconstructed with the steered plane wave (SPW) and limited-diffraction-beam (LDB) methods. Results of both 11 and 91 transmissions (or 11 and 91 sub-images) are shown. The percentages of improvement of the SNRs are in the last row of the table.

SNR	**11 Transmissions**		**91 Transmissions**	
	SPW	**LDB**	**SPW**	**LDB**
Coherent	39.28	45.40	41.33	39.23
Incoherent	50.79	70.10	54.27	76.73
Improve	29.32%	54.39%	31.31%	95.58%

V. DISCUSSION AND CONCLUSION

It is clear from the results that the speckle noise is reduced for both SPW and LDB methods with the incoherent superposition method. However, the LDB method is more effective in speckle noise reduction as compared to the SPW method. With incoherent superposition, the grey scale objects on the lower right of the images are more visible due to reduced speckle noise. This is especially the case for the LDB method.

Despite the reduction of speckle noise, from the results, it is seen that the image resolution is lowered with the incoherent superposition method (see the wire targets of the ATS539 tissue-mimicking phantom in Fig. 2 and Fig. 3), especially, near the edges of the images reconstructed with the LDB method. Also, the image contrast of the cystic targets is lowered with the incoherent superposition. This trade-off between the speckle noise reduction and the decrease of image resolution will be addressed in future studies.

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