Abstract – A high frame rate imaging method where a limited diffraction beam is used in transmission and received echo signals are processed with both temporal and spatial fast Fourier transforms to reconstruct images has been developed previously. However, this method has a limitation that objects to be imaged are illuminated only within the projection of transducer aperture. To reconstruct images of a large field of view at a large distance, multiple transmissions are required to illuminate the entire objects and thus image frame rate may be reduced.

To overcome such a limitation, in this paper, diverging beams that can illuminate a larger area in one transmission are used while the same temporal and spatial fast Fourier transforms as in the high frame rate imaging method are used to reconstruct images.

Results show that images reconstructed with diverging beams of a diverging angle up to 15 degrees in transmission have a reasonable image quality as compared to that of images reconstructed with a limited diffraction beam in transmission (in theory, limited diffraction beams have 0 degree diverging angle).

Keywords - High frame rate, Beam steering, Fourier transform

I. INTRODUCTION

A high frame rate imaging method has been studied previously [1-5]. In this method, a limited diffraction beam [6]-[19] is used in transmission and received echo signals are processed with both temporal and spatial fast Fourier transforms to reconstruct images of high computation efficiency. Because limited diffraction beams are collimated (has 0 degree diverging angle in theory) and thus objects to be imaged are illuminated only within a projection of the aperture of transducer, multiple transmissions are required to reconstruct an image of a large field of view at a large distance, lowering image frame rate.

In this paper, diverging beams are used in transmission to illuminate a larger area of objects with fewer transmissions to increase image frame rate. Although a method has been developed in the Fourier domain previously to reconstruct images with diverging beam transmissions, it requires a large amount of computation because the fast Fourier transform cannot be readily used in the method [5]. To reduce computation and increase image field of view, diverging beams are used in transmissions and the received echo signals are processed with the fast Fourier transformations in the same way as they are in the high frame rate imaging method.

II. EXPERIMENT

To show the efficacy of the method in which diverging beams are used in transmissions and fast temporal and spatial Fourier transforms are used to reconstruct images, experiments were carried out. In the experiments, a home-made high frame rate imaging system [4] and a 2.5-MHz, 19.2-mm aperture, and 128-element broadband Acuson (Acuson, Mountain View, CA, USA) phased array transducer (Fig. 1) were used to obtain RF echo data. A commercial ATS539 tissue-mimicking phantom (ATS, Connecticut, USA) (Fig. 2) was used as a test object. Images reconstructed have a +/-45 degree field of view at 120-mm and 165-mm depths, respectively. The images were obtained with 11 transmissions at an image frame rate of 486 frames/second for the 120-mm depth. Steered plane wave (a special type of limited diffraction beam) and diverging beams of diverging angles of 0, 3, 6, 9, 12, and 15-degrees that were produced with virtual sources were used in transmissions, and images were reconstructed with both the temporal and spatial fast Fourier transforms used in the high frame rate imaging method [1].

Figure 1. A 2.5 MHz central frequency and 128-element Acuson (Acuson, Mountain View, CA, USA) phased array transducer used in the experiment.
III. RESULTS

Results show that the quality of images reconstructed with diverging beams of 3, 6, 9, 12, and 15 degrees with an imaging depth of 120 mm (Figs. 3-7) is similar to that of image reconstructed with limited diffraction beam (steered plane wave) transmissions (Fig. 8).

Figure 2. A cross-section of an ATS539 tissue-mimicking phantom showing the imaging areas of 120 mm and 165 mm depths with +/-45 degree field of view for the experiments.

Figure 3. Image (+/-45 viewing angle and 120 mm depth) reconstructed with a diverging beam of a diverging angle of 3 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 4. Image reconstructed with a diverging beam with diverging angle of 6 degrees and the same temporal and spatial fast Fourier transformation method as in the high frame rate imaging method [4].

Figure 5. Image (+/-45 viewing angle and 120 mm depth) reconstructed with a diverging beam of a diverging angle of 9 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 6. Image (+/-45 viewing angle and 120 mm depth) reconstructed with a diverging beam of a diverging angle of 12 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].
Figure 7. Image (+/-45 viewing angle and 120 mm depth) reconstructed with a diverging beam of a diverging angle of 15 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 8. Image (+/-45 viewing angle and 120 mm depth) reconstructed with a limited diffraction beam (steered plane wave of 0 degree diverging angle) in transmissions and temporal and spatial fast Fourier transformations for received echo signals [4].

Figs. 9-14 are obtained under the same conditions as those of Figs. 3-8, respectively, except that the image depth is increased from 120 mm to 165 mm.

Figure 9. Image (+/-45 viewing angle and 165 mm depth) reconstructed with a diverging beam of a diverging angle of 3 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 10. Image (+/-45 viewing angle and 165 mm depth) reconstructed with a diverging beam of a diverging angle of 6 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 11. Image (+/-45 viewing angle and 165 mm depth) reconstructed with a diverging beam of a diverging angle of 9 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].

Figure 12. Image (+/-45 viewing angle and 165 mm depth) reconstructed with a diverging beam of a diverging angle of 12 degrees in transmissions and the same temporal and spatial fast Fourier transformation method for received echo signals as is in the high frame rate imaging method [4].
Although the high frame rate imaging method introduced in [1]-[4] was developed based on transmissions with limited diffraction beams, the experiments show that the method can also be used with a diverging beam transmission of a diverging angle up to 15 degrees without substantially reducing image quality. This is significant because it allows the high frame rate imaging method to be used with diverging beams to reconstruct images of a large area at a deep depth without reducing image frame rate, which is particularly useful for cardiac imaging where the sizes of available acoustic windows are small while the viewing angle required is large.

IV. CONCLUSION

REFERENCES


