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Effect of frequency compound technique on coded excitation and synthetic aperture focusing ultrasound imaging

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ABSTRACT

A combination of coded excitation and synthetic aperture focusing technique enables data collection at a high frame rate and focusing at any depth. The tissue harmonics imaging technique and frequency compound method are well known to improve the quality of the ultrasound image. The tissue harmonics imaging technique is used for improving the resolution and dynamic range, and the frequency compound method is used for speckle reduction. In this study, we examine the effectiveness of the frequency compound method in our imaging system. Odd harmonics are generated by transmitting square carrier waves modulated by Walsh functions, and harmonics signals are extracted from the received echo using bandpass filters. After beamforming, a frequency compound image is constructed by averaging the logarithmically transformed intensities of the fundamental and harmonics signals. As a result, the image shows a smoothed speckle noise. Computer simulation results indicate the speckle reduction ability of the proposed method.

1. INTRODUCTION

In the field of clinical diagnosis, ultrasound devices are widely used to observe the internal structure of the human body. However, ultrasound images contain speckle noise. These artifacts interfere with the detailed observation of the internal structures of the human body.

Split-spectrum processing techniques are used to transmit and receive ultrasound with a wide bandwidth and construct an image by processing multiple images formed by split frequency bands$^{1)}$. Tissue harmonics imaging is one of the methods used to remove artifacts.$^{2\text{-}3)}$ This method is used to reconstruct images formed by harmonics that are generated by nonlinear acoustic properties of human tissue. Akiyama reported that speckle noise can be effectively reduced by averaging logarithmically transformed intensities because the speckle patterns of the images formed by fundamental and harmonics signals are different (the frequency compound method). The frequency compound method and tissue harmonics imaging technique have been used for B-mode ultrasound imaging however, these methods are not used for imaging systems that employ a combination of coded excitation and synthetic aperture focusing technique. The dynamic range can be expected to improve by applying the frequency compound method and tissue harmonics imaging technique to the synthetic aperture focusing technique. We examine the effect of the frequency compound method in the synthesis aperture focusing technique by performing computer simulations.

2. EXPERIMENTAL SECTION

2.1 FREQUENCY COMPOUND METHOD

The tissue harmonics imaging technique is used to reconstruct images formed by harmonics that are generated by nonlinear acoustic properties of human tissue. Speckle noise is reduced without sacrificing resolution by averaging the logarithmically transformed intensities of the fundamental and harmonics signals. Here, we briefly describe the synthetic aperture imaging system used in the examination. This system employs a combination of coded excitation and synthetic aperture focusing technique to form three-dimensional images at a high speed.$^{4\text{-}6)}$ The system drives all the transmitters simultaneously with waveforms modulated using Walsh functions. Both the transmitting and receiving beams are synthesized using the echo received during a single transmission event. Using the imaging system, a 3D image sequence is obtained at a very high frame rate and with a high spatial resolution. However, the dynamic range of the obtained image reduces when the number of the transducers is small. For improving the dynamic range, it is desirable to use information transmitted over a wide frequency band. The harmonics components of the ultrasound echo are used for extending the frequency band.

Figure.1 shows the steps involved in obtaining a frequency compound image. We adopt a filtering method for the extraction of harmonics. The fundamental and harmonics signals are split by passing the received echo through bandpass filters. The fundamental and harmonics images are constructed after beamforming and logarithmically transforming the images reconstructed from each signal. Next, a frequency compound image is constructed by averaging the harmonics images.

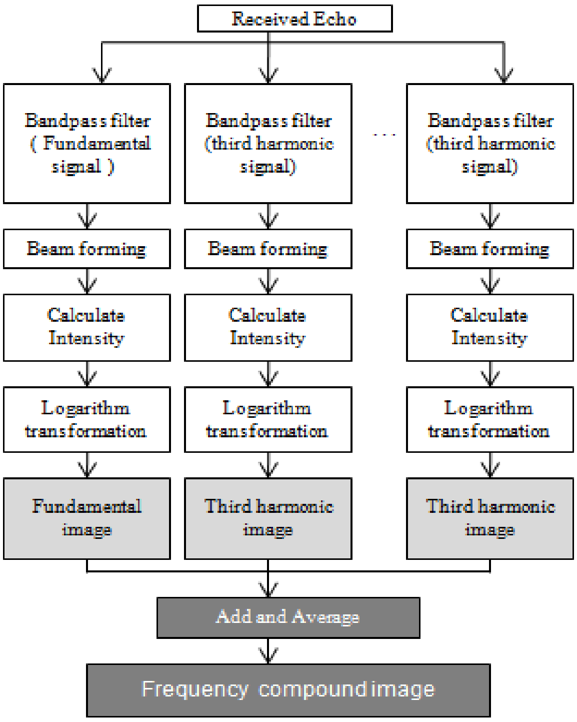


Figure 1. Steps involved in obtaining frequency compound image.

2.2 SIMULATION

We evaluate the effectiveness of the frequency compound method in our imaging system by performing a simple computer simulation.

The system drives all the transmitters simultaneously with modulated waveforms including a large number of harmonics. For performing the simulation, we adopt square carrier waves modulated by Walsh functions as transmitted waveforms. The square carrier waves generate odd harmonics. The transmitted waveforms are given by the following equations.

$$u_j(t)=\sum_{k=0}^{N-1} w_{jk}\, g(t-k\Delta t) \qquad (j=0,1,\ldots,N-1) \qquad (1)$$

$$g(t)=\begin{cases}\operatorname{sgn}\{\sin 2\pi f(t)\} & 0\le t\le \Delta t\\ 0 & \Delta t\le t\end{cases} \qquad (2)$$

where, w_{jk} denotes the (j,k) component of an $N\times N$ Hadamard matrix (N is a power of 2), $g(t)$ is a square pulse burst function of frequency f , and Δt is the clock period of the Walsh functions. The clock period Δt is an integer multiple of the carrier period $1/f$.

Table 1. Details of computer simulation.

Carrier frequency	0.50 [MHz]
Sampling frequency	16.0 [MHz]
Image volume size	50.0 [mm]
Number of pixels (x×y×z)	64 ×64×256
Number of Transmitters	32
Number of receivers	29
Radius of transmitter	2.64 [mm]
Radius of receiver	4.96 [mm]
Object	Spherical cluster (diameter = 30.0 [mm])
Distance from array to object	100 [mm]

A spherical cluster of small reflectors with random reflectance and a diameter of 30 mm is used for the simulation. The image volume size is 50 × 50 × 50 mm^3. The carrier frequency of the transmitted waveforms is 0.50 MHz, and the sampling frequency is 16.0 MHz. The details of the simulation are shown in Table Ⅰ. We use bandpass filters with the following frequency bands to separate the harmonics: 0.25~0.75 MHz for the fundamental, 1.25~1.75 MHz for the third harmonic, 2.25~2.75 MHz for the fifth harmonic, and 3.25~3.75 MHz for the seventh harmonic.

The quality of the images is evaluated by the standard deviation normalized by the mean of the intensity in the object region.

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}\left(\bar{x} - x_i\right)^2 \qquad (3)$$

$$\sigma_a = \frac{\sqrt{s^2}}{\bar{x}} \qquad (4)$$

where n is the number of pixels in the object region and $\bar{x}$ is the mean intensity in the object region.

3. RESULTS AND DISCUSSION

Figure.2 shows the power spectrum of the echo received from the spherical cluster. Figure.3 shows the conventional image obtained using sinusoidal carrier waveforms. Figure.4 shows the fundamental and harmonics images obtained using the bandpass filters. Figure.5 shows the images obtained using the frequency compound method. The images shown in Figs.2~5 are obtained by extracting two-dimensional data from the 3D images. Table Ⅱ shows a comparison of σ_a in the object region.

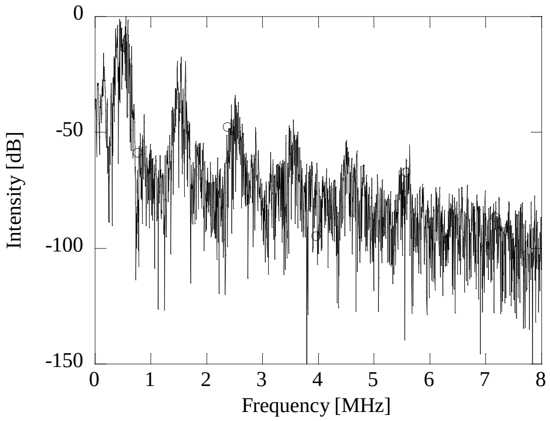


Figure 2. Power spectrum of echo received from spherical cluster.

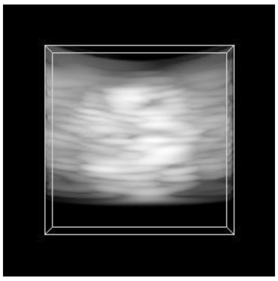


Figure 3. Conventional image obtained using sinusoidal carrier waveforms.

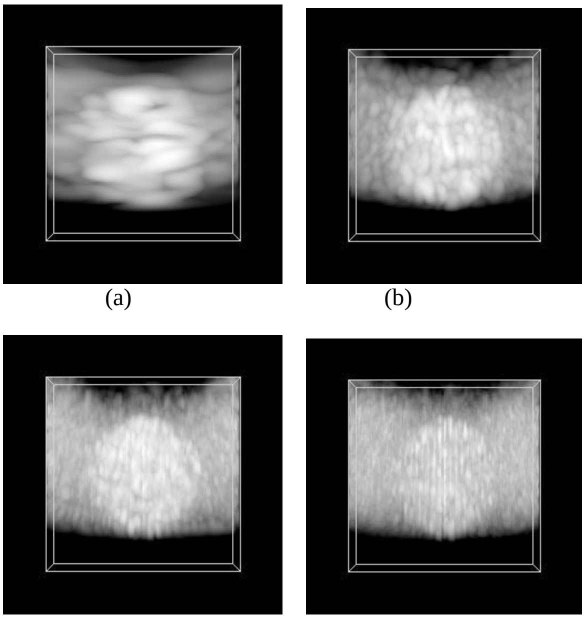
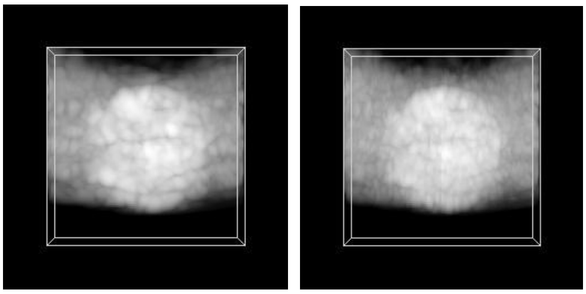


Figure 4. Fundamental and harmonics images obtained using bandpass filters. (a) fundamental image, (b) third harmonics image, (c) fifth harmonics image, (d) seventh harmonics image



(a) (b)

Figure 5. Images obtained using frequency compound method. (a) frequency compound image formed by fundamental and third harmonic images, (b) frequency compound image formed by fundamental, third, and fifth harmonic images

4. CONCLUSION

The simulation results show the speckle reduction ability of the synthetic aperture imaging system that employs the frequency compound method to transmit waveforms containing harmonics. However, the signal to noise ratio reduces for higher-order harmonics. In addition, the frequency compound method is not effective when the available harmonics decrease. Therefore, it is necessary to increase the transducer bandwidth and sampling frequency of the digital-to-analog converter to implement a practical system.

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