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Estimation of Tissue Harmonic Images using Characteristic of Fundamental Echo as Prior Information

基本波エコーの特性を事前知識とする生体高調波画像の推定

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1. Introduction

Tissue Harmonic Imaging (THI) is used for obtaining high spatial resolution medical ultrasound images[1,2]. THI extracts the harmonic components caused by the nonlinear distortion through the propagation of transmitted ultrasound in tissue, and generates images using them. THI also can generate images of the deeper part of the body, because the harmonic components occur as ultrasound goes forward in the body. THI has also high range resolution because of wide bandwidth compared with the fundamental imaging. Additionally azimuth resolutin is also high, because beam width of the harmonic component is narrower than that of fundamental component. However, amplitude of the second harmonic component is smaller than that of the fundamental component. Additionally, frequency dependent attenuation is severe especially for the harmonic components. These phenomena lower the SNR of the THI.

In this study, we propose a method which improves the SNR of THI with keeping the high resolution of it. In this method, we estimate the power spectrum of the second harmonic component using that of the fundamental component, and use it as prior information to improve the SNR of the second harmonic component. In this paper, we show the effectiveness of the proposed method through *in vitro* experiments.

2. Method

By regarding noise and signals as stochastic process, a filter minimizing mean square error can be applied, which scheme is known as the general Wiener filter. The cost function is defined as follows:

$$E\|\varepsilon\|^2 = E[\{f(x) - \hat{f}(x)\}^2], \qquad (1)$$

where E is the expectation operation with respect to noise and signals, $f(x)$ is an original signal, and $\hat{f}(x)$ is a recovered signal. In this study, to simplify a processing, we assume that the original signal and the noise are weak stationary fields, and hence, the frequency representation of the Wiener filter is given by frequency response is given by:

$$F_B(k) = \frac{F_A^*(k)}{|F_A(k)|^2 + S_{Rn}(k)/S_{Rf}(k)}, \qquad (2)$$

where $F_A(k)$ is a transfer function like as the blurring function, * is a complex conjugate, $S_{Rn}(k)$ is prior information of the power spectrum of the noise, $S_{Rf}(k)$ is also that of the original signal and k means a wave number.

At first, **Eq. 2** is used for the fundamental echo, in which $F_A(k)$ is 1, $S_{Rf}(k)$ is a constant and the ration of $S_{Rf}(k)$ and $S_{Rn}(k)$ is assumed to be known in advance. Subsequently, by stretching $P(k)$, which is the estimate of the power spectrum of the fundamental echo twice with an interpolation, and shifting it to the second harmonic frequency band, we can estimate the prior information of the power spectrum of the second harmonic echo $P'(k)$. Using this estimate $P'(k)$ and Eq. 2, Wiener filter for the second harmonic imaging $F_{THI}(k)$ is defined as follows:

$$F_{THI}(k) = \frac{1}{1 + S_{Rn}(k)/P'(k)}. \qquad (3)$$

The estimated signal $\hat{F}_f(k)$ is obtained by this filter as follow:

$$\hat{F}_f(k) = F_{THI}(k) F_m(k), \qquad (4)$$

where $F_m(k)$ is the Fourier transform of the measured harmonic echo. Consequently by taking the inverse Fourier transform, the spatial representation of the recovered signal is obtained.

3. Experiments

To confirm the effectiveness of the proposed method, *in vitro* experiments are conducted. **Figure 1** describes the experimental circumstance. Agar with a stainless steel block and graphite particles is located in a water tank. The signal is transmitted

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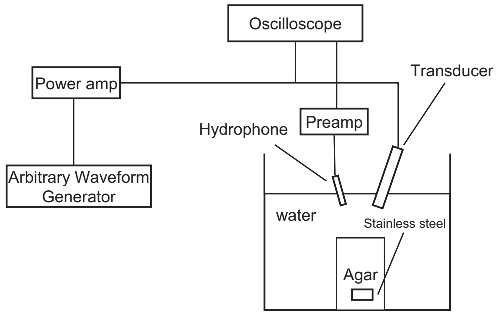

Fig. 1 Experimental circumstance.

toward the stainless steel block by the transducer, and the echo signal is received by the hydrophone. The proposed THI method is performed as an off-line signal processing. We can consider that images simply generated using the second harmonic echoes extracted by band-pass filtering are conventional. Hence, we compare the proposed THI image with the conventional one. The transmitted signal is 5 MHz of the center frequency, 4 MHz of the bandwidth, 1 μs of the pulse width, and the Hanning weighted. An example of the transmitted signal is shown in **Fig. 2**.

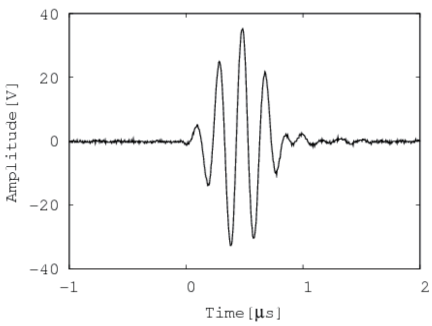

Fig. 2 Example of transmitted signal.

4. Results and discussion

Figure 3 shows the received echo signal, and **Fig. 4** shows the amplitude of the spectrum of it. The envelope of the estimated second harmonic signal by the proposed method(solid line) and that of the simply extracted harmonic signal (broken line) are shown in **Fig. 5**. To examine the proposed method in detail, the unit of the vertical axis is set as decibel in Fig. 5. This figure indicates that the noise level of proposed signal is 5 – 10 dB lower

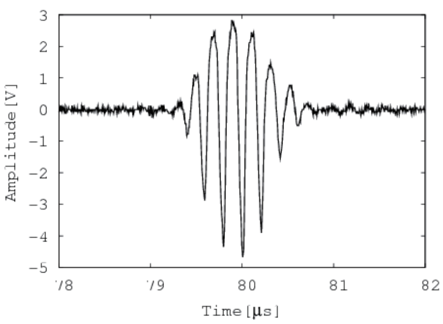

Fig. 3 Example of received echo signal.

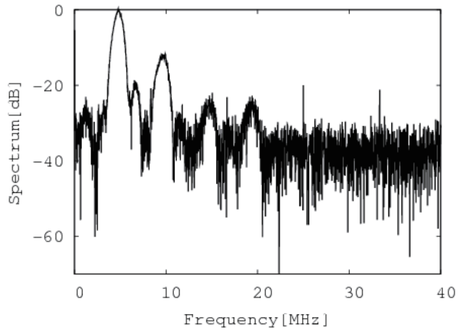

Fig. 4 Spectrum amplitude of received echo signal.

than that of the simply extracted harmonic signal. We confirmed that the noise level of the proposed signal is almost the same as that of the fundamental signal. However, the bandwidth of the proposed signal is close to that of the fundamental signal. As shown in Fig. 4, it is confirmed that the second harmonic component does not have twice the bandwidth of the fundamental one. This phenomenon can be thought as interference between the both components.

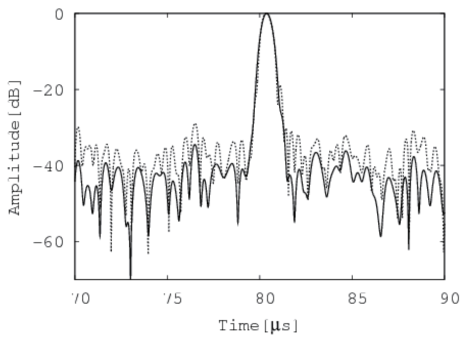

Fig. 5 Envelopes of the proposed signal (solid line) and conventional signal (broken line).

5. Conclusion

In this study, we proposed a new method to improve the SNR of the harmonic signal using the fundamental echo as prior information. Through experiments, it was shown that the propose method provides high SNR. Therefore the performance of the method was verified. However, in these experiments, the pulse width was not sufficiently narrow due to the interference between the fundamental and harmonic components. In the future work, we will solve this problem and aim to further a good estimation.

References

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