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Noise Reduction of Tissue Harmonic Signals using Fundamental Echo and Intensity Characteristics with Propagation Distance
基本波エコーと伝搬距離に対する強度特性を利用する生体高調波のノイズ低減法

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1. Introduction

Tissue Harmonic Imaging (THI) is used for obtaining high spatial resolution medical ultrasound images [1-2]. THI extracts harmonic components caused by nonlinear distortion through propagation of transmitted ultrasound in tissue, and generates images using them. The advantage of THI are, (1) THI has high range resolution compared with the fundamental imaging because of wide bandwidth of the harmonic components used for imaging, (2) THI has high azimuth resolutin, because nonlinear effects occur at the center of transmitted beam where sound pressure is high and (3) THI is insusceptible to artifacts such as multiple reflections and sidelobes. However, in THI, amplitude of the second harmonic component is significantlly smaller than that of the fundamental component. Additionally, frequency dependent attenuation is severe especially for the harmonic components. These phenomena means that THI is susceptible to noise.

In this study, we propose a method to reduce the noise of THI with keeping the high resolution of it. In this method, in order to reduce the noise, we estimate stably the auto-correlation function of the second harmonic component using that of the fundamental echo, and we take account of the intensity characteristics of harmonic component with propagation distance. In this paper, we show the effectiveness of the proposed method through the simulation results.

2. Method

By regarding noise and signals as stochastic process, MAP method [3] can be applied. For h, which is original envelope signal, measured signal g is as follows:

$$g = Ch + v, \quad (1)$$

where the diagonal terms of matrix C mean the carrier signal, and v is the Gaussian white noise. Using the Bayes' formula and the assumption that h is Gaussian the posterior probability of h can be formulated as follows,

$$p(h \mid g) \propto p(g \mid h)p(h) = A \times \exp[-\frac{1}{2}(g - Ch)\frac{1}{\sigma^2}(g - Ch)^{\mathrm{T}} - \frac{1}{2}(h - h_m)R_h^{-1}(h - h_m)^{\mathrm{T}}], \quad (2)$$

where σ is the standard deviation of v and is assumed to be known in advance, h_m is average of h, R_h is the variance-covariance matrix of h. Based on the MAP method, by differentiating the log of Eq. 2 with respect to h, and by setting it zero, h_{MAP}, which is MAP estimate of h, is as follows:

$$h_{MAP} = (C^{\mathrm{T}} \frac{1}{\sigma^2} C + R_h^{-1})^{-1} \times (C^T \frac{1}{\sigma^2} g + R_h^{-1} h_m). (3)$$

Equation 3 can be used using the fundamental echo and intensity characteristics of the harmonic component with propagation distance. C is a diagonal matrix with sine wave with the frequency of second harmonic and the initial phase estimated from the fundamental echo, and is defined C' below. To estimate R_h stably, we use the fundamental echo instead of the harmonic echo having low SNR. Since R_h is defined with the ACF of the envelope of the harmonic echo, we firstly compute the ACF of the envelope of the fundamental echo by the Gaussian function fitting, to the observed one, and the by reducing the standard deviation of it to half, the ACF of the harmonic echo is determined accurately. For h_m, we use the fundamental echo. The harmonic components gradually arise as the transmitted wave propagates, and the attenuation increases with the propagation distance. Therefore, the matrix P indicating such the intensity characteristics of the harmonic echo, which can be approximately evaluated in advance by simulations, is additionally used. From the above, MAP estimate for the second harmonic imaging h_{THI} is defined as follows:

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$$h_{THI} = (C'^{\mathrm{T}} \frac{1}{\sigma^2} C' + PR_h^{-1})^{-1} \times (C'^{\mathrm{T}} \frac{1}{\sigma^2} g + PR_h^{-1} \bar{h}). \quad (4)$$

3. Simulation

To confirm the effectiveness of the proposed method, simulations were conducted. **Figure 1** describes the simulation model. This model is that sound waves propagate in medium, where the

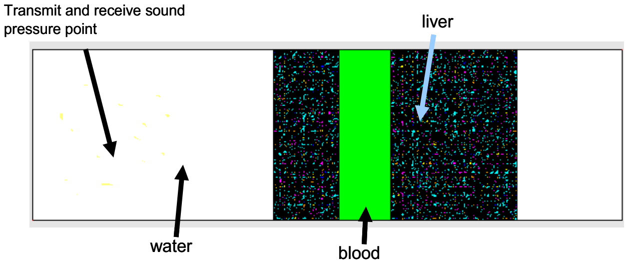
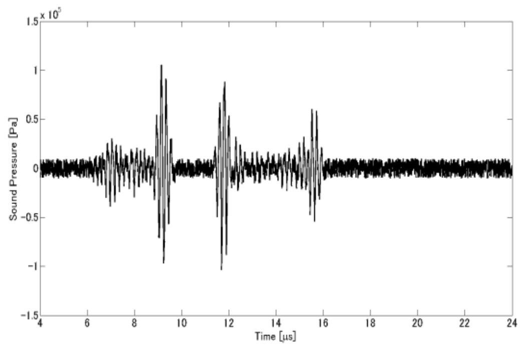


Fig. 1 Simulation model.

density, the sound speed and the attenuation rate of the each region are the same as those of the liver, blood and water respectively. We computed the echoes from them. We can consider that the second harmonic echoes simply extracted by a band-pass filtering after adding Gaussian noise are conventional. We compared the proposed THI signal with the conventional one. The transmitted signal was the Hamming weighted pulse including five cycles of 5 MHz.

4. Results and discussion

Figure 2 shows the received echo signal after adding Gaussian noise. The envelope of the estimated second harmonic signal by the proposed method (solid line) and that of the conventional band-passed signal (broken line) are shown in **Fig.3**. To examine in the difference between both in detail, decibel representation is shown in Fig. 3. This figure indicates that the noise level of proposed signal is approximately 10 dB lower than that of conventional one, if signals at 10 - 12 us and 18 -24 us are considered to be pure noise. **Figure 4** shows the envelopes of the proposed signal (solid line) and



conventional signal (broken line) and fundamental

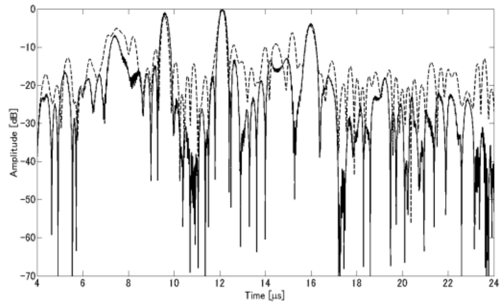


Fig. 3 Envelopes of the proposed signal (solid line) and conventional signal (broken line).

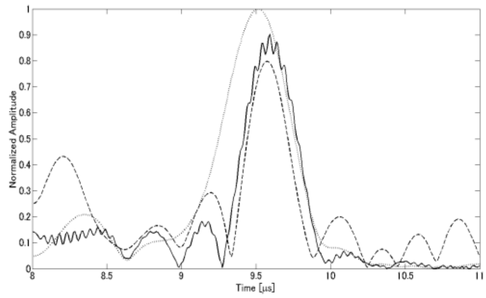


Fig. 4 Envelopes of the proposed signal (solid line) and conventional signal (broken line) and fundamental signal (dashed line)

signal (dashed line). This figure indicates that the pulse width of the proposed signal is broader than that of the conventional one, because we cannot know the average of the true harmonic component, and then, we use the fundamental echo as an estimate of it. However, this figure shows that the pulse width of the proposed signal is sufficiently narrower than that of the fundamental signal.

5. Conclusion and Future Work

In this study, we proposed a new method to reduce the noise of THI using the fundamental echo and the intensity characteristics of the harmonic component with propagation distance. Through simulations, it was shown that the proposed method can reduces the noise of THI effectively. Therefore, the performance of the method was verified. In this study, we used one line echo. In the future work, using the information of multiple lines scanned in advance, we will be able to estimate more stable covariance matrix. We hope to examine the proposed method in imaging.

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