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A Method for Reduction of Frequency Dependent Attenuation in Tissue Harmonic Imaging

生体高調波画像化における周波数依存減衰の軽減法

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1. Introduction and Background

The goal of our study is to perform high resolution and high SNR ultrasound imaging to realize high-quality diagnosis. It is strongly required especially for a deep part in a living body. To improve the resolution and the SNR, the pulse compression technique (PCT) is effective as the method that is safe in the living body. [1], [2].

In the PCT, to improve the range resolution while maintaining the transmitted pulse length long, it is necessary to modulate the transmitted pulses having wide bandwidth. In general, as the bandwidth of the transmitted pulse is wide, the output signal of the PCT becomes narrow, and hence the range resolution is improved. To improve the SNR, the long pulse should be transmitted so as to increase the power introduced into the body. Namely, the PCT using the wide-band and the long-period transmission is suitable for our purpose.

On the other hand, tissue harmonic imaging (THI) is effective for high resolution imaging. THI uses harmonic components for fine imaging, which are caused by nonlinear distortion through ultrasound propagation in tissue. In a commercial implement, generally a second harmonic component is used, because the amplitude of it is drastically larger than that of higher order harmonic components. The advantage of THI are, (i) THI has high range resolution compared with fundamental imaging because of wide bandwidth characteristics of the harmonic components used for imaging, (ii) THI has high azimuth resolution, because nonlinear effects is limited in a center of a beam where the sound pressure is high, and (3) THI is robust against artifacts such as multiple reflection and side-lobes, because the sound pressure of echoes reflected from a reflector is much small and the amplitude of side-lobes of harmonics is 60 - 80 dB smaller than that of a main-lobe. However, in THI, amplitude of harmonic components is significantly smaller than that of a fundamental component. Additionally, frequency dependent attenuation (FDA) is severe especially for harmonic components, because harmonic frequencies are very higher than a fundamental frequency.

Applying the PCT to THI is expected to improve SNR with keeping the high resolution property of THI, but the FDA has to be considered. The distortion of echoes caused by FDA makes the exact pulse compression impossible, and hence an image blur arises [3]. To avoid such distortion without lowering SNR, we already proposed an FDA compensating method [4] in which the transmitted pulse the echo of which becomes a desired FM chirp waveform after distorted by FDA is generated using adaptive transmitting and receiving for reference. Since the method in [4] has been proposed for fundamental imaging, in this study, we extend it for THI.

2. Method

We define the mapping from the fundamental component to the second harmonic component in the frequency domain as $F_2 = H_{conv}(F_1)$, and also the inverse mapping as $F_1 = H_{inv}(F_2)$. We suppose that an arbitrary FM chirp signal $f_1(t)$ is applied to the transducer and the echo signal $g_1(t)$ corresponding to the fundamental echo is received. Using an ideal FM chirp signal $c_1(t)$, which has a rectangular spectrum with a suitable window function, the distortion function in the second harmonic domain is defined as $R_2 = C_2/G_2$. C_1 is a frequency domain representation of $c_1(t)$ and $C_2 = H_{conv}(C_1)$. G_2 is the second harmonic echo in a frequency domain against transmission of $f_1(t)$. Hence, $S_1 = H_{inv}(R_2\ H_{conv}(F_1))$ is a signal compensated for the transducer's property. After performing it, by recursively using $S_1 = H_{inv}(|R_2|\ H_{conv}(F_1))$, FDA compensation can be performed. In actual application, curve fitting is adopted to stably compute R_2 and $|R_2|$. The FDA compensation has to be done repetitively, if necessary.

3. Simulation

Fig.1 describes the simulation model of a propagation medium. Transmitted pulses are formed by a linear array transducer model with 64 elements, which is put at the left end of the medium shown in Fig.1, to focus on a spot 25mm away from the transducer. We compute the echoes reflected from the above-mentioned regions and analyze them. For receiving the echoes, likewise a transmitted signal, beam forming is performed to focus on the depth where objects exist. Table.I shows sound speed, density, attenuation coefficient, and nonlinear parameter, and conditions of transmitted signal are shown in Table.II.

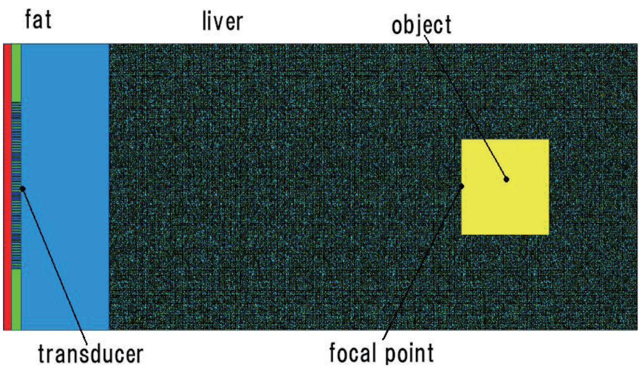

Fig.1 Simulation model similar to a living body

Table I . Various parameters in a simulation model similar to a living body

Tissue	Sound speed (m/s)	Density (kg/m^-3)	Attenuation coefficient (dB/MHz/cm)	Nonlinear parameter (B/A)
fat	1460	920	0.6	10
liver	1560~1580	1050~1070	0.75~0.95	6.75
object	2200	1045	1	7

Table II . Conditions of transmitted signal

Frequency of transmitted signal [MHz]	5
Cycles of transmitted signal	5
Window function of transmitted signal	Hanning
Focus of transmitted signal (Depth from the tranducer) [mm]	25

4. Result and Discussion

In this study, we proposed to apply the FDA compensation method which we have proposed for harmonic, and we confirmed that the compensation method is effectively.

It is also necessary for B-mode imaging and numerical evaluation, for example using peak value and half-width of compressed signal.

We should examine the proposed method in a more complicated simulation models, and evaluate the proposed method by experiment in the future.

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