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Motion Compensation in Coded THI Using Frequency Adjoining Multi Chirp Signals
連続帯域を有するマルチチャープ信号を用いた Coded THI における動き補正の検討

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1. Introduction

Our goal is to obtain finer medical ultrasound images. For higher signal-to-noise ratio (SNR), coded excitation with chirp is useful, and has been invesigated[1)]. For higher spatial resolution, Tissue harmonic imaging (THI) has been used in commercial implements[2)]. The combination of coded excitation and THI has been proposed[3)].

When the harmonic component overlaps the fundamental component in frequency domain, the spectral overlap causes the undesirable artifacts. Although pulse inversion (PI) has been used for avoiding the artifacts, the method is suscpetive to the influence of motion of region of interest (ROI) because the fundamental component can not be cancelled completely. The residual fundamental component has a bad effect on the imaging, and thus, the THI can not be acquired. In this study, we propose a novel method which can extract broader bandwidth of the harmonic component and also can compensate the motion of ROI. Through FEM simulations, the feasibility of the proposed method is evaluated.

2. Preliminaries

2.1 Coded Excitation

A chirp signal is described below

$$s(t) = \sin\left[2\pi\left\{f_0 + \frac{B}{2T}t\right\}t\right] \quad (0 \le t \le T), \quad (1)$$

where f_0 is the start frequency, B is the bandwidth and T is the duration time. After transmission, an echo signal $r(t)$ is received. To decode the echo signal, cross-correlation function (CCF) is given as a function of the time lag τ :

$$p(\tau) = \int_0^{\infty} r(t)s(t-\tau)dt \,. \quad (2)$$

When the echo signal $r(t)$ is the same as the transmitted signal $s(t)$, a half-width of the envelope of CCF is $1/B$ [s] and the SNR is TB times larger than that of a single-carrier pulse with a Gaussian envelope.

2.2 Tissue Harmonic Imaging and Spectral Overlapping Consideration

THI makes use of the nonlinearity of the sound propagation in the medium. A half-width of the second harmonic component is approximately half as width as that of the fundamental component.

If the harmonic component overlaps the fundamental component in frequency domain, the overlapped component cannot be extracted by the band-pass filtering. For avoiding the spectral overlap, the PI method has been used. The PI transmits two phase-inverted pulses. Summing two echo signals, the fundamental component is cancelled, and the harmonic component is doubled. However, if the PI is used in the target which moves fast, phase decorrelation occurs and the PI cannot be done.

2.3 Coded Tissue Harmonic Imaging

To obtain both sufficient SNR and spatial resolution, THI and coded excitation are combined[3)]. The harmonic component of the echo signal is also chirp because chirp maintains their coded phase relationship in the harmonic domain[1)]. Therefore, the harmonic component can be compressed with a matched filter. The matched filter for the harmonic component is designed as the same time duration, and twice as bandwidth as the fundamental component of the chirp.

There still remains the problem of the spectral overlap, which exists in coded excitation. When the spectral overlap occurs, the fundamental component around the overlapping frequency is cross-correlated with the matched filter. As a result, undesirable peak occurs at a different time. Although the problem does not occur by suppressing the bandwidth of the transmitted signal, the spatial resolution becomes worse.

3. Method

3.1 Principle

To avoid the spectral overlap, multi chirp signals are used[4)]. The frequency of the each signal is designed for not overlapping between the fundamental and the harmonic components. After

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transmissions, N echo signals are received separately. Each matched filter $m_i(t)$ has same time duration and twice frequency bandwidth as the each transmitted signal bellow

$$m_i(t) = \sin\left[2\pi\left\{2f_i + \frac{B}{T}t\right\}t\right] \quad (0 \le t \le T), \quad (3)$$

where f_i is the starting frequency of the i^{th} transmitted signal. The echo signals are decoded bellow

$$q(\tau) = \sum_{i=1}^{N}\left[\int_0^{\infty} r_i(t)\, m_i(t-\tau)\, dt\right]. \quad (4)$$

The each matched filter $m_i(t)$ does not decode the fundamental component of the i^{th} echo signal because the spectral overlap does not occur.

3.2 Motion Compensation

If the target moves while transmitting N signals, it is obvious that the each echo signal is different. In this study, supposing that ROI moves parallel, the envelope of CCF of the i^{th} echo signal can be expressed below

$$Env\{p_i(\tau)\} = Env\{p_{i+1}(\tau + \xi)\}, \quad (5)$$

where ξ is the time difference caused by motion. To obtain the time difference ξ, the phases at the same frequency between neighboring shots are examined and compensated in frequency domain.

4. Simulations

The robustness of the proposal method against target motion is evaluated through FEM simulator PZFlex. A PZT and a stainless steel block are located face-to-face in a water tank. In the PI method, the each transmitted signal is 2−5 MHz and 20 μs. In proposal, the number of shots N is 2, the each time duration is 20 μs, and the each frequency is 2−3.8, and 3.2−5 MHz, separately.

In PI, The frequency spectra of the sum of the two echo signals are shown in **Fig. 1**. When ξ=0.05 μs, the fundamental components are not cancelled and the spectral overlap occurs. **Figure 2** shows the results of the proposed method. When ξ=0.05 μs, the half-width of CCF is wider than that when ξ=0 μs, but the artifact does not occur. As shown in **Fig. 3**, it is obvious that the half-width becomes narrower by compensation.

5. Conclusion

In this study, it is shown that the propose method is robust against target motion. Although the Doppler shift was ignored in this study, the proposed method is still valid if the target moves at the constant speed. In future work, we will consider a situation that the target moves at an accelerating pace.

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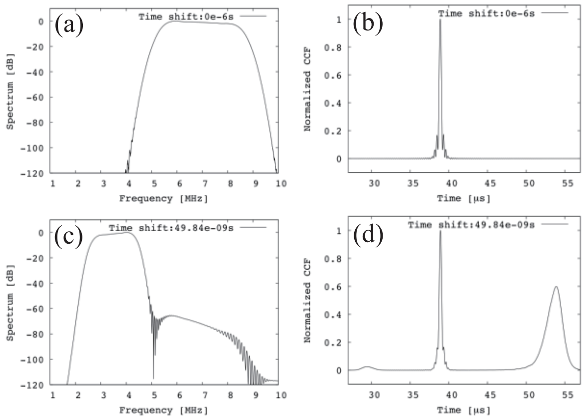

Fig. 1 Echo signal after pulse inversion.
(a) Spectrum (ξ =0), (b) CCF (ξ =0),
(c) spectrum(ξ =0.05 μs), and (d) CCF (ξ =0.05 μs).

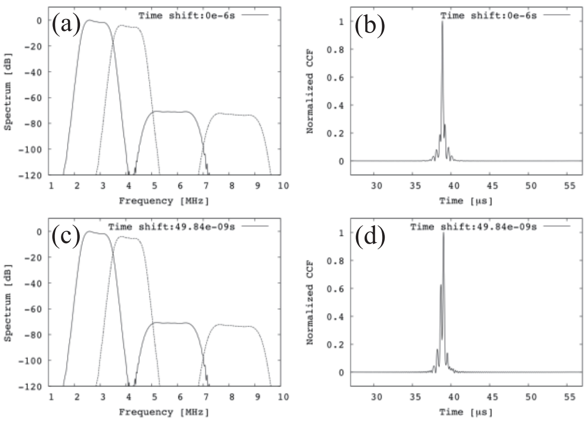

Fig. 2 Echo signals with proposal before motion compensation. (a) Spectrum (ξ =0), (b) CCF (ξ =0), (c) spectrum(ξ =0.05 μs), and (d) CCF (ξ =0.05 μs).

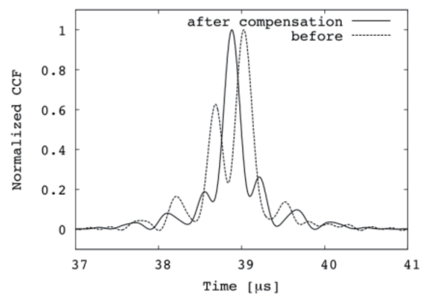

Fig. 3 CCFs before and after motion compensation.