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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 145-146
8-10 November, 2011

Amplitude modulation with temporal control of number of driving elements for tissue harmonic imaging
送信駆動面積制御による振幅変調法を用いた生体組織非線形イメージング

Chizue Ishihara[1†‡], Hiroki Tanaka[1] and Kunio Hashiba[1] ([1]Central Research Lab. Hitachi Co. Ltd.)
石原千鶴枝 [1†]，田中宏樹 [1]，橋場邦夫 [1] ([1] 日立中研)

1. Introduction

Tissue harmonic imaging (THI) is an imaging technique using second- and higher-order or sub-harmonic responses of tissue to an ultrasound beam, while the B-mode technique basically uses the transmitted fundamental frequency component. A harmonic signal produces a sharper image and enables us to improve contrast resolution and reduce reverberations. The current THI mainly uses the second harmonic, which is twice the transmitted fundamental frequency. There are two THI methods, filtering and pulse phase inversion (PI) [1]. The PI method is widely used in order to isolate the harmonic frequency in the detected echo including the transmitted fundamental frequency with a high signal-to-noise ratio.

In the PI method, two pulses are transmitted along each scan line. For the first sequence, a pulse is transmitted with an amplitude of P_1. For the second sequence, an inverted pulse is transmitted as P_2=-P_1. The generated harmonic signal for both sequences are in phase. Thus, summing these two echo signals makes it possible to cancel the fundamental signals, P_1+ P_2=0, and keep only the added harmonic signals.

In the PI method, the phase of the transmission pulse for the second sequence needs to be changed perfectly to cancel the fundamental signal. The waveform of the transmission pulse is controlled by the signal applied to the transducers. Thus, sonography systems such as transducers and analog front-end devices need to respond linearly to the input signals. However, this is difficult to achieve with current systems; therefore, existing THI contains a certain fundamental signal. Moreover, the PI method is probably not applicable for nonlinear devices such as capacitive micro-machined ultrasound transducers (CMUT), which exhibit significant nonlinear behavior due to the electrostatic principle [2]. To improve THI image quality, we developed a new THI technique that is not affected by the linearity of systems.

2. AM method with control of number of driving elements

To eliminate system nonlinearities, we use the amplitude modulation (AM) method [3]. It is similar to PI and can also be used to extract the harmonic signal. For the second sequence, in this method, a pulse is scaled by a factor N such that P_2=1/N･P_1 is transmitted. Upon receiving this pulse, P_2 is multiplied by N to rescale it so it is proportional to P_1. Since the amplitude of the generated second harmonic signal increases with a factor of the square of the transmitted sound pressure, the harmonic signal in the echo signal of the second sequence will be smaller. Therefore, by subtracting the scaled P_2 from P_1 we can retrieve the harmonic signal of P_1. The obtained harmonic signal will be smaller than in the PI method due to the subtraction operation but only the harmonic signal should remain.

In the AM method the amplitude of the transmission pulse needs to be changed. We propose modulating the amplitude by using the property that the sound pressure amplitude is proportional to the number of driving transducer elements. Thus, reducing the number of driving elements enables us to reduce the amplitude of the sound pressure without having to modulate the input signal to each driving element. When this technique is applied to the second sequence of the AM method, since the same input signal or no signal is applied to the transducers (and corresponding analog front-end devices) in both sequences, system linearity is not necessary. Therefore, this technique can extract harmonic signals clearly even if the transducers and front-end processes respond nonlinearly.

However, one concern is that the acoustic beam pattern is also changed by reducing the number of driving elements. Hereinafter, the aperture with a reduced number of driving elements is called a reduced aperture. The purpose of this study was to investigate how to carry out THI with the reduced aperture by considering the acoustic field using numerical simulation.

3. Simulations

We calculated the linear acoustic field using various patterns for reduced aperture, and investigated how different it was from that for the original aperture. The acoustic field is calculated in two dimensions assuming propagation in the human body. A conventional linear ultrasound probe was used; there were 42 total channels, and the channel pitch was 0.2 mm. The transmitted pulse was assumed to have a 9-MHz central frequency and 70% fractional bandwidth.

When the amplitude of the sound pressure in the second sequence is 1/N times that in the first sequence, the echo signal is rescaled by N to cancel the fundamental signal. It is best for N to be larger to obtain a harmonic signal with higher amplitude because the harmonic signal subtracted from the first echo signal is then smaller. However, an increase in N means that the number of driving elements needs to be reduced for the reduced aperture. In this case, it is obvious that the acoustic field of the reduced aperture is very different from that of the original aperture. Thus, we assume the simplified case of N=2 which indicates half the number of driving elements.

4. Results and discussion

We investigated three transmission array patterns for the reduced aperture as shown in **Fig. 1(B)**, **(C)**, and **(D)** when the original aperture was as in **Fig. 1(A)**. We define a channel as a region with the same delay time.

First, we investigated a one-channel-spaced array (**Fig. 1(B))**. This is a simple way to reduce the number of driving elements by half with almost the same aperture as the original one. To compare the acoustic field, the beam profiles at the focal point are overlaid as shown in **Fig. 2(a)**. These plots are normalized by their own peak values. The beam profile of the one-channel-spaced array differs from the original one in the direction of |sinθ|>0.3. Since the driving element pitch is expanded, the conditions to form the grating lobe are satisfied. In this case, an artifact should appear in the obtained ultrasound image. For the one-channel-spaced array, to avoid grating lobes the transmission pulse should be optimized by using a lower frequency and/or larger frequency bandwidth.

The other array patterns are discussed here in terms of grating lobe suppression. **Fig. 1(C)** and **(D)** show a centered array and one-channel sub-array, respectively. The beam profiles at the focal point are also overlaid, as shown in **Fig. 2**.

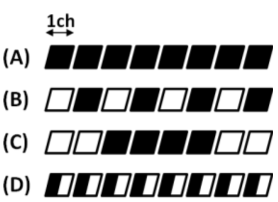

Fig. 1: Array patterns

The discrepancy of the beam profile of the centered array is not as great as that of the one-channel-spaced array even if the same number of driving channels is used. However, the lateral beam width of the centered array is larger than the original one. Since the centered array uses a narrower aperture, the focal region becomes longer in both the depth and lateral directions. This might lead to degradation of image quality.

The beam profile of the one-channel sub-array is the closest to the original one. The grating lobe does not occur because this array pattern is formed by driving a channel into two driving elements, and it keeps the same pitch as the original one. However, this pattern is equal to a half width of each channel of the original aperture. It results in lower directivity and a small difference in the direction of |sinθ|>0.7, as shown in **Fig. 2(b)**. With dynamic receive focusing, this difference will be sufficiently small. However, one problem in putting this technique to practical use is that the sub-array needs at least a double driving system. Some development of current devices is necessary, such as the addition of a switch, that will enable either sub-array to be selected.

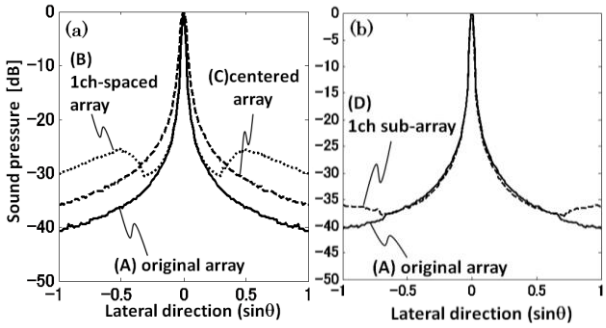

Fig. 2: Comparison of beam profiles

5. Summary

We proposed a new THI technique with temporal control of number of driving elements. We examined three possible array patterns for the reduced aperture. The best results were obtained with the one-channel sub-array since the beam profile is close to the original array, and the fundamental frequency component could therefore be canceled. For further study, a rigorous analysis is required that includes the entire acoustic field of the transmitted beam in three dimensions rather than just the focal point. Eventually, we would also like to optimize the array pattern combination with N value.

References

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