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Displacement Measurement –Lateral Modulation and Beamforming with A Single Steering Angle

変位計測 －横方向変調及び 1 方向の偏向角度を持ったビームフォーミング

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1. Introduction

In this report, a beamforming (transmission/reception of ultrasound) method, ASTA, is proposed to enable measurements of lateral displacement and of an arbitrary displacement vector with a very high accuracy. This method involves the steering of beams through a steering angle (ASTA) [1].

Lateral modulations (LMs) have previously been reported using other beamforming methods, and these methods permit measurements of a displacement vector [2]. In contrast, with ASTA, displacement vector measurements can be made, but the number of available methods is limited, and being dependent on the measurement method, only a lateral displacement measurement can be made even if the methods are multidimensional ones, i.e., for a displacement vector measurement, our previously developed block matching methods under the assumption of a local rigid motion [3], i.e., multidimensional cross-spectrum phase gradient method (MCSPGM), and multidimensional autocorrelation method (MAM) and multidimensional Doppler method (MDM) using a block matching, and for a lateral displacement measurement, in addition to the block matching methods, our previously developed multidimensional autocorrelation method (MAM) and multidimensional Doppler method (MDM) [3] using a mirror setting of the obtained, steered beams [1], and one-dimensional (1D) method such as an autocorrelation method can be used.

2. ASTA

In ASTA for a 2D region of interest (ROI), as shown in **Fig. 1a**, steered beams with a steering angle (ASTA) are formed. For proper beamforming, apodization and focusing is performed for transmission and dynamic reception focusing. By slanting a linear 1D array transducer, the ASTA can also be realized mechanically. For a 3D ROI, similarly, such steered beams with a steering angle can be realized by using a 2D array transducer. The results, shown in **Fig. 1b**, for a single quadrant and single octant (omitted) spectra are obtained for the 2D and 3D ROIs, respectively. That is, for both cases, two symmetric spectra are obtained.

When using the aforementioned block matching methods [3] and multidimensional cross-correlation method for both types of beamforming (i.e. ASTA and LM), a 2D or 3D displacement vector measurement can be performed. Also recall that when using LM, a displacement vector can also be measured by using MAM and MDM using no block matching [3], and a combination of 1D methods and demodulation methods or our recently reported demodulation method [1]. For the displacement vector measurements, only an attachment of a US transducer onto a target surface is required.

When using ASTA, for only a lateral displacement measurement, the aforementioned block matching methods can be used at least. However, by performing the quasi-lateral modulations [1], because plural independent equations can be obtained, MAM and MDM using no block matching [3] can also be used (however, an axial displacement cannot be dealt with).

That is, as shown in **Fig. 2a**, by setting the spectra symmetrically, i.e. specifically at the position A or B, a rf image superposed by an original rf image and the axially (**Fig. 2b**) or laterally (omitted) inverted rf image is obtained. For a steered beam or local steered beams, by using the mirror setting in a frequency domain or superposing the inverted beam, a quasi-lateral modulation can be performed. Because when the target moves in an axial direction, a conventional axial displacement measurement method (i.e., 1D measurement methods such as 1D AM) can be used, and then the quasi-lateral modulation is performed as shown in Fig. 2b for a lateral displacement measurement using MAM or MDM. For such a quasi-lateral modulation, all block matching methods can also be used.

Such a lateral displacement measurement is a very important application for ASTA (for instance, in measuring blood flow in a vessel running in a direction parallel to the body surface, e.g., carotid artery). For such measurement, *a lateral coordinate must correspond to the direction*

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of the target lateral motion to increase the measurement accuracy, although usually, the direction of beam should coincide with that of motion by slanting a US transducer, particularly, when using 1D methods. Thus, ASTA allows providing a simpler manual technique for a medical doctor than such a conventional 1D measurement technique.

Next, the qualities of the beams formed by ASTA and LM are compared. For LM, the following properties may lead to the deterioration of measurement accuracy:

(1) For a measurement in a 2D or 3D ROI, when a classical synthetic aperture (SA) is used, the US intensity transmitted from an element is small, which may yield low SNR echo data.

(2) Alternatively, when crossed beams are superimposed, although a large US intensity can be obtained, time differences between the transmission of the beams can cause measurement errors, if the displacement occurs during these time differences.

(3) If plural beams which have different paths are used, the inhomogeneity of tissue properties affects beamforming. Specifically, propagation speed affects focusing (i.e., a beam-cross position), whereas attenuation and scattering lead to different frequencies of the respective beams.

(4) At the minimum, more time is required to complete a beamforming than that required with ASTA. Occasionally, more time is also required to complete a displacement calculation than that required with ASTA.

In contrast, with ASTA, any of the above concerns, (1) to (4), will not become a problem, and a simple beamforming increases the ability to make real-time measurements together with a higher accuracy in a displacement measurement.

3. Simulations

Simple simulations regarding a lateral displacement measurement were performed. Echo data were simulated by generating a Gaussian type PSF with white data in a 2D ROI. For the lateral motion (0.01 mm), a steering angle (Fig. 1a) for ASTA was set at 45 degrees. For LM, a steering angle of –45 degrees was also used. The US frequency was changed from 3.5 to 12 MHz under these conditions including an US speed of 1,500 m/s; an axial sampling interval of 0.05 mm; and a beam pitch of 0.05 mm. By adding white noise data to the raw echo data, echo data with a SNR of 20dB was also simulated.

The SDs obtained are shown in Fig. 3. For ASTA using 2D AM and 2D DM, only those obtained using the mirror setting are shown. That is, those obtained using a block matching (a displacement vector measurement using a least squares estimation) are not shown (i.e., omitted).

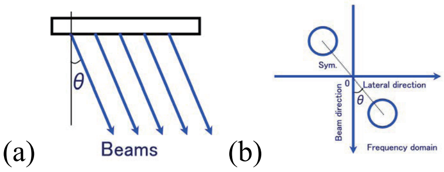

Fig. 1. ASTA.

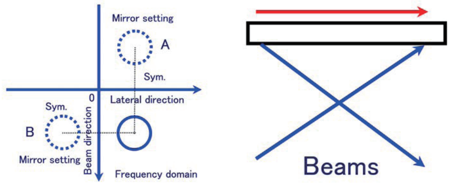

Fig. 2. Mirror setting for MAM and MDM.

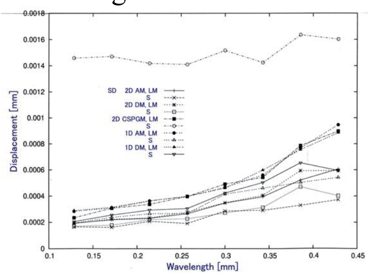

Fig. 3. SDs vs US wavelength (S: ASTA).

4. Discussions and conclusions

Considerations of the beamforming schemes using LM and ASTA show that the simple ASTA beamforming method increases capabilities for real-time measurements when compared with LM, and a two-dimensional echo simulation shows that except for the block matching methods, ASTA yields more accurate displacement measurements than LM. Moreover, as with LM, multidimensional measurement methods yield more accurate measurements than the corresponding 1D measurement methods. For measurements, although a block matching requires fewer calculations than a moving-average, however, lower accuracy measurements are obtained (omitted). Being dependent on the echo SNR and the local region (window) size, as for LM [3], a proper measurement method should also be selected for ASTA (omitted). Thus, ASTA will open new aspects of displacement measurements together with LM.

References

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