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Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 495-496
20-22 November, 2013

Accurate ultrasound imaging of the embryo surface based on Range-Point-Migration method with synthetic aperture

Range-Point-Migration 法と開口合成技術を用いた高分解能超音波胎児体表イメージング

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1. Introduction

Medical ultrasound imaging has an excellent ability to depict soft tissues without the risk of radiation exposure. Therefore, medical ultrasound imaging is commonly used to depict embryo. A more accurate and safe embryo depiction desires to improve the spatial resolution and to decrease the transmit intensity in ultrasound imaging. Range-Point-Migration (RPM) method is one of the high-resolution imaging methods that depict clear boundaries [1]. Employment of a semi-broad transmit beam ensures that RPM method works in the existence of multiple targets; however, the transmit directivity causes the distortion of the estimated boundaries [2]. In the present study, we report a technique that compensates for the effect of the transmit directivity. We investigate the performance of the proposed technique in the suppression of the boundary distortion.

2. Materials and Methods

The proposed imaging method is based on RPM method. We describe RPM method, and subsequently explain the technique that suppresses the boundary distortion.

2.1 RPM method

RPM method estimates target boundaries by using path lengths, as shown in Fig. 1. When the *i*-th transmit point and *j*-th receive point are employed, the reflection point exists on the ellipse with the focal points of the transmit and receive points and with the major axis of the path length. We call this ellipse $O_{i,j}$. RPM method calculates intersection points between ellipses of various transmit and receive points. In this study, we estimate the direction of the reflection point when the *i*-th transmitter and *j*-th receiver are employed by the following equation as

$$\theta_{\mathrm{opt}}(i,j) = \arg\max_{\theta} \sum F'(\theta,i,j,k) \quad (1)$$

$$F'(\theta,i,j,k) = P(i+k,j+k)\,f(\theta,i,j,k)\,f'(R_k) \quad (2)$$

$$f(\theta,i,j,k) = \exp\left(-\frac{(\theta-\theta(i,j,k))^2}{2\sigma_\theta^{\,2}}\right) \quad (3)$$

$$f'(R_k) = \exp\left(-\frac{R_k^{\,2}}{2\sigma_X^2}\right) \quad (4)$$

where $\theta(i,j,k)$ is the direction of the intersection points between $O_{i,j}$ and $O_{i+k,j+k}$, $P(i,j)$ is the echo intensity when the *i*-th transmitter and *j*-th receiver is used, and R_k is the center distance of $O_{i,j}$ and $O_{i+k,j+k}$. In the paper, we fixed σ_θ and σ_χ, as 1 degree and twice the wavelength at the center frequency, respectively. RPM method locates the position of the reflection point by using the estimated direction and the path length. Echo intensity at the reflection point is estimated as the summation of $F'\{\theta_{\mathrm{opt}}(i,j),i,j,k\}$ over k.

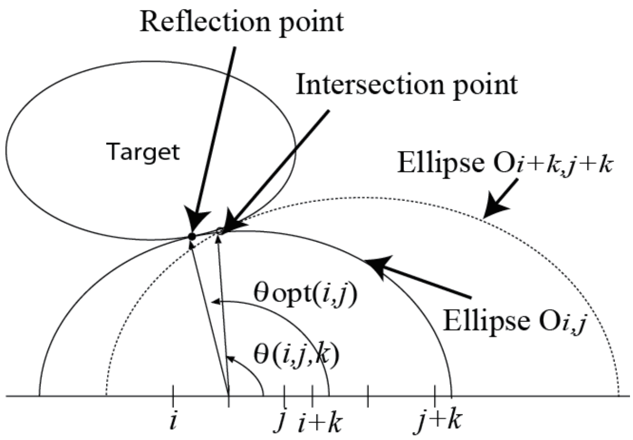

Figure 1. The principle of RPM method

2.2 Compensation technique for the effect of the transmit directivity

When multiple echoes of similar intensity returned from different reflection points are received at the same time, RPM method tend to fail in estimating the positions of the reflection points. Therefore, we have employed a semi-broad transmit beam that reduces the above mentioned cases [2]. However, the change of the echo intensity caused by the transmit directivity also affects the evaluation value $F'(\theta_{\mathrm{opt}},i,j,k)$ that is used in estimating the direction of the reflection point. Therefore, the employment of a semi-broad transmit beam results in the distortion of the estimated boundaries.

In this study, we compensate for the effect of the transmit directivity by the pre-determined transmit beam pattern. The evaluation function with the compensation for the transmit directivity is expressed by

$$F'_{\mathrm{B}}(\theta,i,j,k)=P_{\mathrm{B}}(i+k,j+k)f(\theta,i,j,k)f'(R_k) \quad (5)$$

$$P_{\mathrm{B}}(i+k,j+k)=\frac{P(i+k,j+k)}{B(\phi,\theta)} \quad (6)$$

where $B(\phi,\theta)$ is the transmit beam pattern for the direction of θ when the focal direction is ϕ.

2.3 Experimental setting

We used a concave element array that consists of 128 elements. The element interval is 0.6 mm and the radius of the curvature is 5 cm. 13 elements are excited to make a semi-broad transmit beam, where the transmit center frequency is 2 MHz and the -6 dB bandwidth is 1 MHz. We used two acrylic cylinders of 2 cm in diameter.

3. Results

Figs. 2 and 3 show the evaluation functions of different center distances k for the estimation of the target direction employed by the conventional RPM method and the proposed RPM method, respectively. In this case, we used the 100-th transmitter and 60-th receiver, i.e. i = 100 and j = 60. In the conventional RPM method, the peak direction of the third highest intensity is different from those of the first and second highest intensity. In the proposed RPM method with the compensation technique, the peak directions of top three intensity are the same. These results indicate that the proposed compensation technique may ensure the robustness of RPM method in a low signal-to-noise ratio condition.

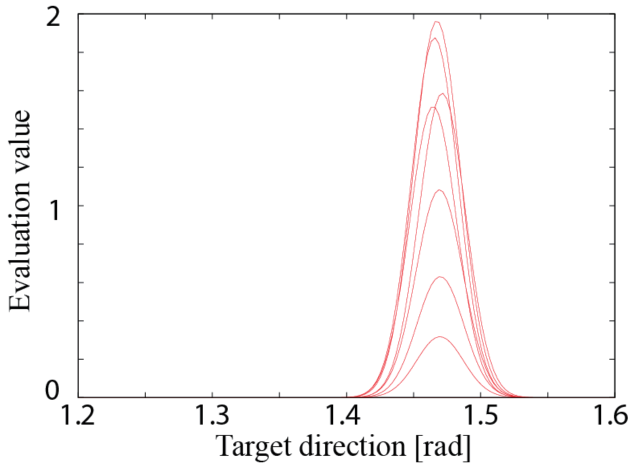

Figure 2. Evaluation functions of different center distances for the estimation of target direction $F'(\theta,i,j,k)$ used in the conventional RPM method

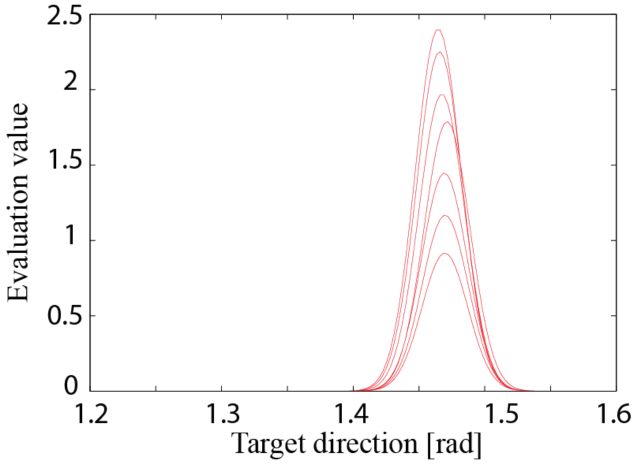

Figure 3. Evaluation functions of different center distance for the estimation of target direction $F'_{\mathrm{B}}(\theta,i,j,k)$ used in the proposed RPM method.

Acknowledgement

This work was partly supported by the Innovative Techno-Hub for Integrated Medical Bio-imaging Project of the Special Coordination Funds for Promoting Science and Technology, from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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