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Automatic Carotid Arterial Wall Detection Using Correlation between Adjacent Receive Scan Lines
隣り合う受信ラインの相関を用いた頚動脈血管壁自動検出法

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1. Introduction

Noninvasive methods of measuring intima-media thickness (IMT) of carotid arterial wall from ultrasonic B-mode images have been confirmed to be a marker for diagnosis of early-stage atherosclerosis[1,2]. IMT is manually or automatically measured as distance between lumen-intima boundary (LIB) and media-adventitia boundary (MAB) of posterior wall of carotid artery. The manual measurement is time consuming and results in inter- and intra-observer variability because it is based on subjective operator assessment. The standard automatic measurement is based on measurement of intensity and/or intensity gradients of each scan lines. Most of clinical B-mode images of posterior carotid arterial wall have partly weak echo boundaries and multiple reflection noise from the tissue between the skin surface and the anterior wall, making it difficult to measure IMT precisely. Simple methods, such as thresholding of intensity and/or its gradient in a local area have been used for boundary detection[3]. A major disadvantage of these methods is its amplitude sensitivity, which complicates threshold setting. To overcome the disadvantage, in the present study, the LIB and MAB were detected using the dynamic programming (DP) algorithm using correlation between adjacent receive scan lines.

2. Method

The DP algorithm is a technique for finding the boundary by minimizing or maximizing a certain cost function, and was applied to automatic IMT detection by taking boundary continuity, the change in vertical distance, into account[4]. We added correlation coefficient between adjacent receive scan lines to cost function to detect weak and noisy LIB and MAB more precisely.

Figure 1 shows a cross-sectional B-mode of a carotid arterial wall and measured log-compressed envelope signals of the beams of interest.

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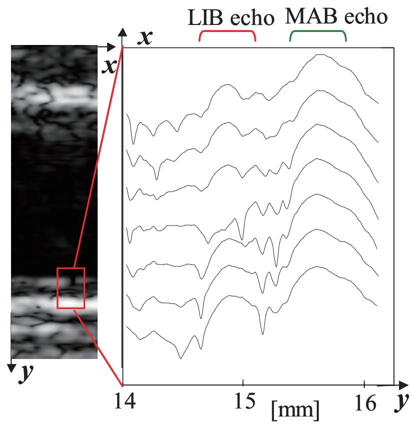


Fig. 1. Cross-sectional B-mode image of a carotid artery and measured log-compressed envelope signals in interest.

LIB echo of the center beam of interest is weak, the simple method using intensity and its gradient has difficulty in detecting LIB. However, even at the line of weak echo, adjacent signals are similar in shape. Therefore, we employed the simple method for distinct boundary and the DP method using cost function, which includes the cross-correlation coefficient of adjacent signals and decreasing function of change in vertical distance, for the estimation of fuzzy boundary.

All the possible fuzzy boundary lines and its adjacent distinct lines are considered polylines with N vertices represented as a vector **b**,

$$\mathbf{b} = (b_1, b_2, \cdots, b_{i-1}, b_i, \cdots, b_N), \quad (1)$$

where b_{i-1} and b_i are horizontal neighbors, b_1 and b_N are calculated in advance by the simple method at distinct boundary and N-2 is the number of lines of a fuzzy boundary. At point b_i, a local cost $C(b_i)$ is defined by

$$C(b_i) = w_1 R(b_{i-1}, b_i) + w_2 D(|b_{i-1} - b_i|), \quad (2)$$

where $R(b_{i-1}, b_i)$ is the cross-correlation coefficient of adjacent signals, $D(|b_{i-1} - b_i|)$ is the decreasing function of the change in vertical distance between the boundary being estimated and w_i is their associated weight factors. The cost function is defined as a sum of local costs along polyline.

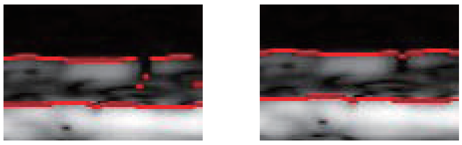
$$C_{sum} = \sum_{i=1}^{N} C(b_i). \quad (3)$$

The desired boundary is the optimal solution of **b,** which is the one that maximizes C_{sum}.

3. Results

Experiments were conducted using Fujifilm Fazone M US device and L10-5 linear probe. Scan line distance is 0.15 mm. The range interval of IQ data is 0.04 mm.

Figures 2(a) and **2(b)** shows the boundaries of **Figure 1** detected by the simple method and the proposed method, respectively.



(a) (b)

Fig. 2. Detected boundaries of posterior carotid arterial wall of Fig. 1 by (a) the simple method and (b) the proposed method

The presented method keeps smooth boundary even in a scan line with weak echo.

Quality control of IMT measurement was studied by IMT mimicking phantom[5]. To evaluate the accuracy of the proposed method, we prepared the arterial wall mimicking phantom made of silicon rubber. **Figure 3** shows a structure of the arterial wall mimicking phantom. To mimic high echo from adventitia, adventitia layer was contained 30% graphite. Sound speed of the silicone rubber was 1015 m/s, IMT was measured 1.02 mm (flat portion) and 1.62 mm (convex portion) by US device.

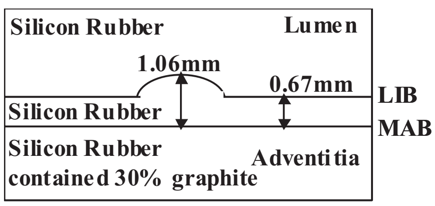


Fig. 3. Structure of the phantom mimicking the arterial wall.

To mimic clinical B-mode images of posterior carotid arterial wall, swine fat layer was located on the phantom. **Figure 4** shows a B-mode image of the arterial wall mimicking phantom on which swine fat layer was located. Multiple reflection noise from the tissue between the skin and artery are reproduced inside lumen. **Figures 5(a)** and **5(b)** show the boundaries in the region of the interest in **Figure 4** detected by the simple method and by the proposed method. The proposed method keeps smooth boundary even at the presence of the noise.

We estimate Max. and Min. IMT of the phantom from the thickness of silicone rubber layer.

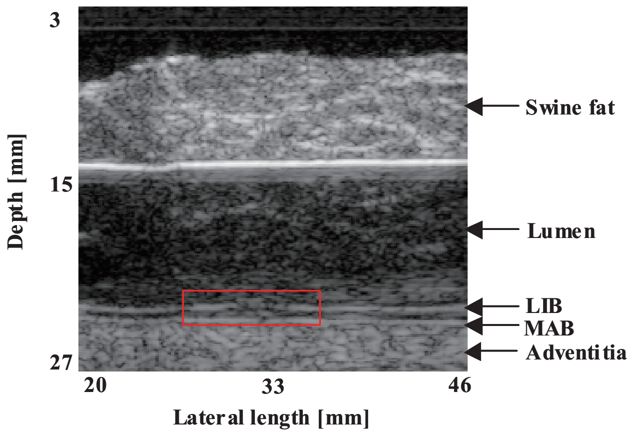


Fig. 4. B-mode image of arterial wall mimicking phantom on which swine fat layer is located

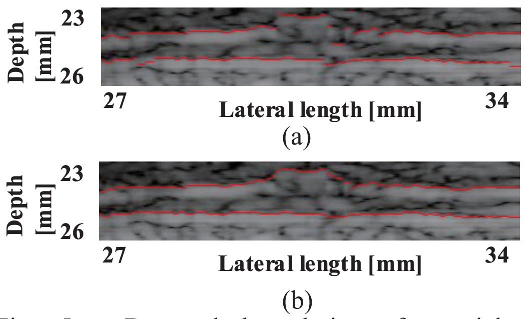


Fig. 5. Detected boundaries of arterial wall mimicking phantom by (a) the simple method and (b) the proposed method

The comparison results are presented in Table 1. The proposed method gives closer value to the true thickness because of its smaller variation of LIB and MAB position.

	Simple Method	Proposed Method	True value from phantom layer
Max IMT (mm)	1.74	1.59	1.62
Min IMT (mm)	0.68	0.84	0.91

Table. 1. Comparison of Max. and Min. IMT.

4. Conclusion

We examined the performance of the border detection DP method using correlation between adjacent receive scan lines. This method has a potential to detect LIB and MAB appropriately even in the presence of noise.

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