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Automatic Detection of Vessel Lumen by RF Signal Analysis of Intravascular Ultrasound

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1. Introduction

Hemodynamics analysis in the coronary artery is important in diagnosis of ischemic heart disease, and intravascular ultrasound (IVUS) has played a vital role in assessing precise characteristics of the diseased coronary arteries. IVUS is equipped with a rotating ultrasound transducer at the tip, and the images of the blood vessels are obtained by withdrawing the catheter at a constant speed.

Our previous study attempted to extract 3D structure of the coronary artery from clinical IVUS images in order to estimate the hemodynamics at the plaque. In the previous study, clinical IVUS images in a form of 8-bit grayscale data were utilized but accurate vessel extractions were difficult due to various artifacts such as a low signal to noise ratio in the blood vessels. Therefore, a method to better capture features of the blood region needs to be developed.

A solution to separate blood vessel regions more accrately is utilizing spatio-temporal features of the acuiqred RF signals. There are two characteristics hypothesized in this IVUS RF signal processing. First, the center frequency is 60 MHz, which is a high-frequency band, so the signal attenuation in the blood flow is large and the signal intensity difference between the flow and tissue is difficult to distinguish. Second, there are steady-state changes in the tissue due to catheter withdrawal. When the singular value decomposition (SVD) filter[1)] is used to extract blood flow signal in IVUS RF data, those charaterics may cause different behavior in the SVD filter from that observed in the conventioanl flow imaging, e.g., for carotic artery.

In this study, we investigated the perforamance of power Doppler image (PDI) generation using IVUS RF data by changing the type of blood flow extraction approach: the global SVD filtering and the block-wise SVD filtering, which divides images into two equal parts in the depth direction[2)]. The threshold for each filtering method was selected by spatial components of each singular value number in the SVD filters. In addition, pre- and post-procesing framework to enhance the lumen extraction were designed and tested.

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2. Material and methods

2.1 Procedure of creating IVUS PDI images

First, IVUS RF signals were acquired and reconstructed into 3D data in the distance from the catheter, rotation, and temporal direction. Then, we applied 35-75 MHz bandpass filter to remove electrical noises. In PDI, after SVD filtering, we took A-line averaging and calculated the power. The power can be expressed by the following equation[3)],

$$PW = 10\log_{10}\int \left|s_{(x,z,t)}\right|^2 dt \qquad (1),$$

where $s_{(x,z,t)}$ is a three-dimensional complex In-phase and Quadrature (IQ) data and x, z, t represent the rotation angle, distance from the catheter, temporal direction, respectively. PW is PDI of the blood vessels in each block. After log compression of the B-mode data, a circular IVUS image was obtained by applying the polar coordinate transformation, which replaces the distance from the catheter and A-line (rotation) direction with the distance from the center of the IVUS image and angles, respectively. In Block-wise SVD, the signal intensity of each block was aligned by putting a bias in one of the blocks to ensure continuity between the two-divided blocks.

2.2 Experimental setup

First, we created a flow phantom with a lumen of 4 mm in diameter that mimics the human coronary artery. The composition of the tissue mimicking material was 1.7 g of potassium sorbate, 56.4 g of polyvinyl alcohol, and 5.6 g of graphite in 500 g of distilled water, and the solution was solidified with two-cycles of the freeze-thaw process. A blood mimicking fluid (Type 769DF, CIRS) was used.

RF signals were acquired with a customized IVUS system by withdrawing the catheter in the flow tract at a constant speed of 3.0 mm/s. IVUS transducer emitted ultrasound pulses at 60 MHz center frequency, and it was rotated at 180 rotations per second. 512 A-line signals were acquired in a rotation. The axial and radial spatial resolution were 30 μm at -6 dB level and 75 mm (the beam width at 1 mm depth), respectively. The ensemble size for

SVD and PDI process was 100 frames.

2.3 Evaluation method of PDI

For the analysis method of contrast ratio (CR) in PDI, first, we created a mask along the boundary of the blood flow region in the B-mode image before the polar coordinate transformation (**Fig. 1**). Then, to suppress the rapid intensity change near the boundary of two components, 5 pixels near edges of the mask were omitted for the evaluation. Then, we applied the mask to PDI, separated each component, and calculated CR by obtaining the respective signal intensities. The formula for CR is as follows.

$$CR_{[dB]} = \mu_{Blood} - \mu_{Background} \qquad (2),$$

where μ_{Blood} is the mean value (dB) of the blood signal, $\mu_{Background}$ is the mean value (dB) of the background tissue signal. All processing were performed on MATLAB (Ver. 2024a, MathWorks).

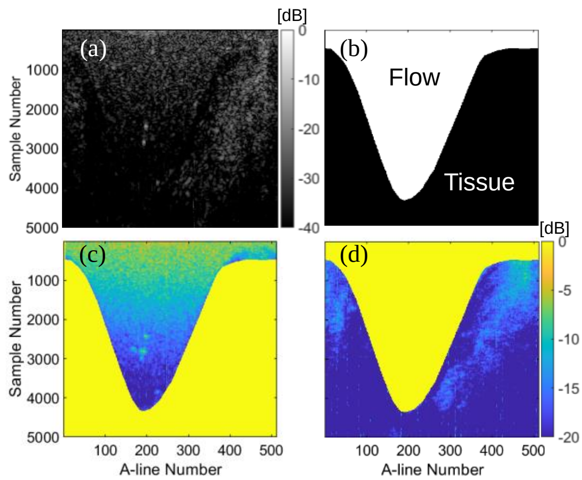

Fig. 1 (a) B-mode image before back projection with IVUS, (b) Mask created based on (a), (c) and (d) Flow, background part of PDI separated by (b)

3. Results and discussion

Fig. 2 shows the PDI created by Global SVD and Block-wise SVD, with and without A-line averaging, and the B-mode image. **Table I** shows CR of PDI in Fig. 2. Comparison of the images shows that A-line averaging is effective in suppressing noise and enhancing the blood flow signal. Also, Block-wise SVD allows better visualization of the blood flow at the region away from the catheter.

The high center transmit frequency allowed detailed structural analysis, but also caused significant attenuation of the blood scatterers. Radial line noses were observed in Fig. 2 (a) due to artifacts from the rotation actuator. Those noises disappeared after averaging with adjacent A-line. Thus, A-line averaging could clearly visualize the blood flow

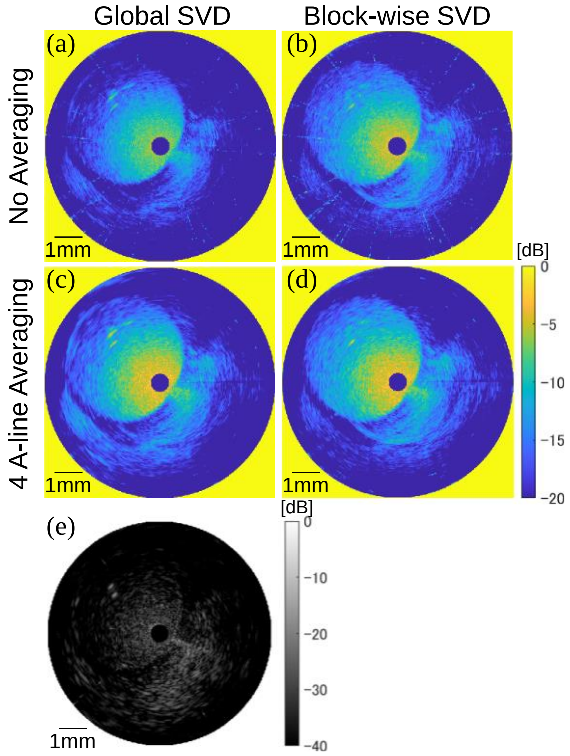

Fig. 2 PDI with (a) Global SVD, (b) Block-wised SVD, (c) 4 A-line averaging of (a), (d) 4 A-line averaging of (b), (e) B-mode image

Table I CR of each PDI in Fig.2

	(a)	(b)	(c)	(d)
CR [dB]	9.23	9.15	10.23	10.35

signals (Fig. 2 (c)). In addition, PDI in Fig. 2 (d) was able to extract blood flow with the highest CR. It was because the block-wise SVD had a threshold value for each region, and the signal intensity could be adjusted for each region, and the effect of attenuation could be reduced.

4. Conclusion

In our study, we investigate the effect of the type of SVD filtering to create PDI of IVUS to better extract the lumen of the coronary artery. The phantom study showed that block-wise SVD with A-line averaging could extract deeper regions more accurately than global SVD approach.

References

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