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Evaluation of contrast of blood flow image obtained with deep learning

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1. Introduction

Blood flow imaging is an important function of diagnostic ultrasound imaging. In ultrasonic blood flow imaging, a clutter filter is used to suppress signals from soft and hard tissues to display echoes from blood cells. In recent years, a clutter filter based on singular value decomposition (SVD) reportedly performs better than the traditional clutter filter in suppressing clutter signals. The excellent performance of the SVD clutter filter is due to its adaptive properties that perform well throughout the cardiac cycle.

Recently deep neural networks are used in various tasks due to their highly adaptive properties. In our previous study, we considered a clutter filter based on deep neural network, that successfully visualized weak echoes from blood cells[1)]. The contrast of the deep learning filter based on long short-term memory (LSTM) is generally higher than the SVD filter, but it is significantly lower than the SVD filter in the initial prediction. In this study, we considered another deep learning network, and successfully visualized echoes from blood cells.

2. Methods

2.1 Experimental data

In this study, the carotid ultrasound echoes from a 46-year-old healthy male were analyzed. A 7.5 MHz linear array probe (RSYS0016, Hitachi) was used to transmit and receive ultrasonic signals through a custom-made ultrasonic acquisition system (RSYS0016, Microsonic). The pulse repetition frequency was 10,417 Hz. We prepared 2 sets of 5,000 frames of RF in vivo data.

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2.2 Signal process

In this study, the in vivo RF data were processed by the delay-and-sum (DAS) beamforming. Let us define $e_m(t)$ as the signal from the m-th receive element, $t_m(x,z)$ as the round-trip time of the ultrasonic wave between scattering source and m-th receive element, and $S(x,z)$ as the signal from DAS beamforming processing. This process is shown as follows:

$$S(x,z) = \frac{1}{N_{elem}} \sum_{m=1}^{N_{elem}} e_m\big(t_m(x,z)\big). \quad (1)$$

The RF signal processed by the DAS method is used as input data for deep learning. The DAS beamformed signal was transformed into a matrix form S, and SVD clutter filtered data was used as the teacher data.

2.3 Deep neural network

In this study, a U-Net deep neural network was used[2)]. As shown in **Fig. 1**, the U-Net neural network mainly consists of two parts: encoder and decoder.

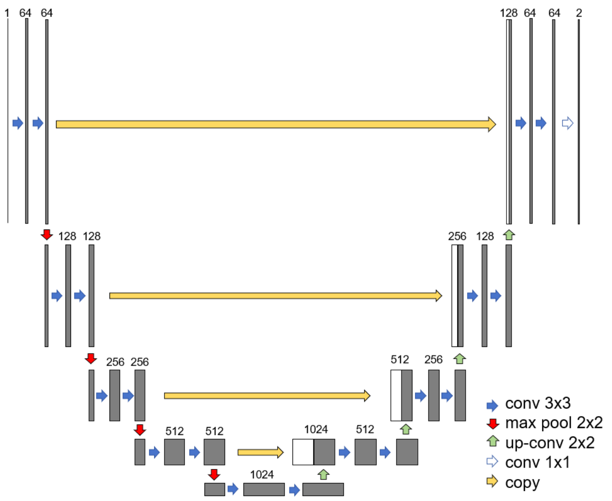

Fig. 1 U-Net deep neural network

In the encoder part, the input data is convolved through four convolutional layers using a 3×3 convolution kernel to obtain 1024 layers of feature data. In the decoder part, the data is deconvolved through four convolutional layers using a 3×3 convolution kernel to generate the output data.

In this experiment, a set of 5000 frames processed by the DAS method was used for 200 epochs, with a learning rate of 0.001 and a 20% random dataset validation data.

3. Result

In this study, we used a pair of data from a healthy 46-year-old man for training. **Fig. 2(a)** shows a B-mode image of a carotid artery obtained by beamforming. The signal processed by the SVD clutter filter was used as teacher data, as shown in **Fig. 2(b)**, and **Fig. 2(c)** shows the B-mode image of the deep learning clutter filter prediction. The blood flow was successfully visualized. The red and yellow rectangles are the areas manually assigned as the lumen and tissue, respectively, to compare the contrast between the SVD data in Fig. 2(b) and the predicted data in Fig. 2(c).

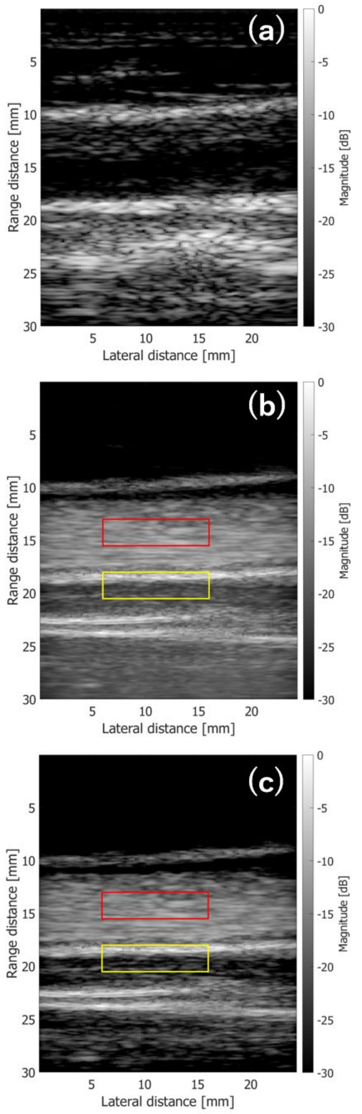

Fig. 2 (a) B-mode image from unprocessed signals obtained by DAS beamforming. (b) B-mode image from signals processed by SVD filter. (c) B-mode image from signals processed by deep neural network.

The contrast values of the deep learning clutter filter are lower than those of the SVD clutter filter as shown in **Fig. 3**.

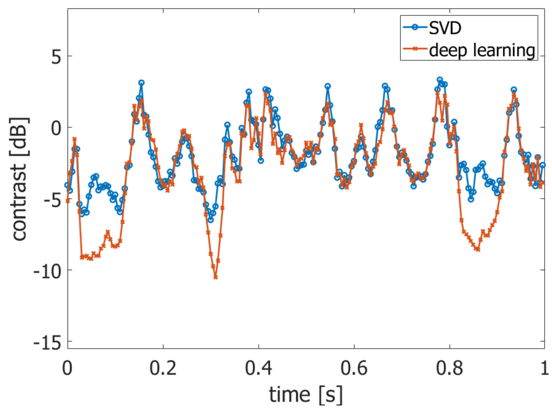

Fig. 3. Contrast values evaluated with respect to the data in Fig. 2.

4. Conclusion

In this study, the RF data processed by a DAS method was used as input data, and an SVD clutter filter-processed beamforming data was used as teacher data. A U-net-based deep learning network was used for training, successfully predicting the weak echoes of blood flow throughout the cardiac cycle and evaluating the contrast between lumen and tissues. In our future study, we will consider the combination of various effective deep learning architectures and estimation of blood flow velocity based on deep learning clutter filtering.

References

1. H. Wang, M. Omura, R. Nagaoka, and S. Gao, H. Hasegawa, JJAP **60** SDDE21 (2021).
2. O. Ronneberger, P. Fischer, and T. Brox, arXiv: **1505.04597** (2015).