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Preliminary investigation on clutter filtering based on deep learning
深層学習を用いたクラッタ抑圧法に関する基礎的検討

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1. Introduction

Blood flow imaging is an important function in diagnostic ultrasound imaging. In ultrasonic blood flow imaging, a clutter filter is required to suppress clutter signals from soft and hard tissues because echoes from blood cells are significantly weaker than those signals. Recently, clutter filters based on singular value decomposition (SVD) gain significant attention in ultrasonic blood flow imaging owing to its superior properties in suppression of clutter signals to conventional clutter filters[1,2]. The superior performance of an SVD clutter filter depends on its highly adaptive property. Owing to such a property, an SVD filter performs well during an entire cardiac cycle.

Recently, deep neural networks are used for various tasks. A deep neural network can be used for varisous purposes owing to its highly adaptive property. Such an adaptive property of a deep neural network would be beneficial for clutter filtering in ultrasonic blood flow imaging. This paper reports a preliminary study on clutter filtering using a deep neural network.

2. Methods

2.1 Experimental data

In the present study, ultrasonic echoes from a carotid artery of a 46-year-old healthy male were analyzed. A 7.5-MHz linear array probe (UST-5412, Hitachi) was used for transmitting and receiving ultrasonic signals with a custom-made ultrasonic acquisition system (RSYS0016, Microsonic). One-frame ultrasonic signals were obtained by transmitting a non-steered plane wave from all of the 192 elements in the array (spacing: 0.2 mm). The pulse repetition frequency was 10417 Hz. Echo signals received by individual transducer elements were acquired and processed off-line by a custom-made software based on MATLAB (MathWorks).

2.2 SVD filter

A 3D ultrasonic dataset composed 2D $N_x \times N_z$ images (radio-frequency (RF) signals) in N_t frames were processed. An ultrasonic signal vector **S**, whose dimensions are $N_x N_z \times N_t$, is decomposed by SVD as

$$\mathbf{S} = \mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^{\mathrm{T}}, \tag{1}$$

where **U** and **V** are matrices with spatial and temporal singular vectors, respectively, and $\boldsymbol{\Sigma}$ is a diagonal matrix with singular values. The SVD filtered signal matrix $\mathbf{S}'$ is obtained as follows:

$$\mathbf{S}' = \mathbf{U}\boldsymbol{\Sigma}_t\mathbf{V}^{\mathrm{T}}, \tag{2}$$

where $\boldsymbol{\Sigma}_t$ is a matrix obtained by replacing singular

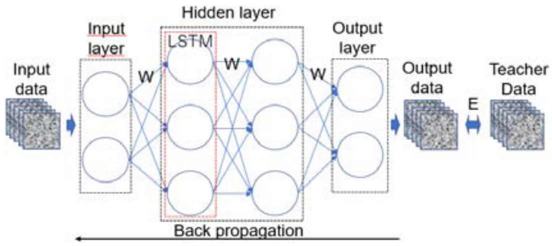

Fig. 1 Illustration of deep neural network in this study.

(a)

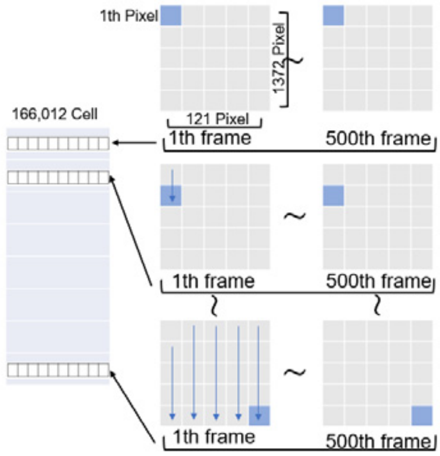

Fig. 2 Illustration of preparation of datasets for learning.

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values in $\mathbf{\Sigma}$ corresponding to echoes from soft and hard tissues and noise with zeros. The cutoff thresholds were determined based on the magnitudes of the singular values.

2.3 Clutter filtering using deep learning

The deep neural network used in the present study is illustrated in Fig. 1. The network was composed of input layer, long short-term memory (LSTM) network with 200 hidden layers, and output layer. The output layer was composed of fully connected layer and regression layer. In the present study, unfiltered RF signals were used as input, and the corresponding SVD filtered RF signals were used as teacher data. Both the input and teacher data were 1D signals which correspond to 1D temporal signal of 500 frames at every spatial position as illustrated in Fig. 2. The number of spatial positions was 166,012.

3. Result

Figure 3(a) shows a B-mode image of the carotid artery. The RF signals, one of which was used to reconstruct the B-mode image in Fig. 3(a), were used as the input data to the deep neural network. The SVD clutter filter was applied to each dataset composed of 500 frames of the RF signals.

Figure 3(b) shows a B-mode image obtained from RF signals processed by the SVD clutter filter. As can be seen in Fig. 3(b), echoes from soft tissues, such as arterial wall and surrounding tissues, are suppressed compared with Fig. 3(a). Consequently, echoes from blood cells in the lumen were visualized. As described in Sect. 2.3, the RF signals processed by the SVD filter was used as teacher data.

In the present study, the learned deep neural network was evaluated the same data used for learning. Figure 3(c) shows a B-mode image obtained from the RF signals processed by the learned deep neural network. As can be seen in Fig. 3(c), echoes from blood cells in the lumen were enhanced successfully by the learned deep neural network.

4. Conclusion

In the present study, a deep neural network was examined for clutter filtering in ultrasonic blood flow imaging. The deep neural network was learned using ultrasonic RF signals processed by the state-of-the-art clutter filter, i.e., SVD filter, as teacher data. The learned deep neural network succeeded to visualize weak echoes from blood cells. In our future work, the neural network will also be validated using other in vivo data, and we will also develop strategies for reducing noise components.

References

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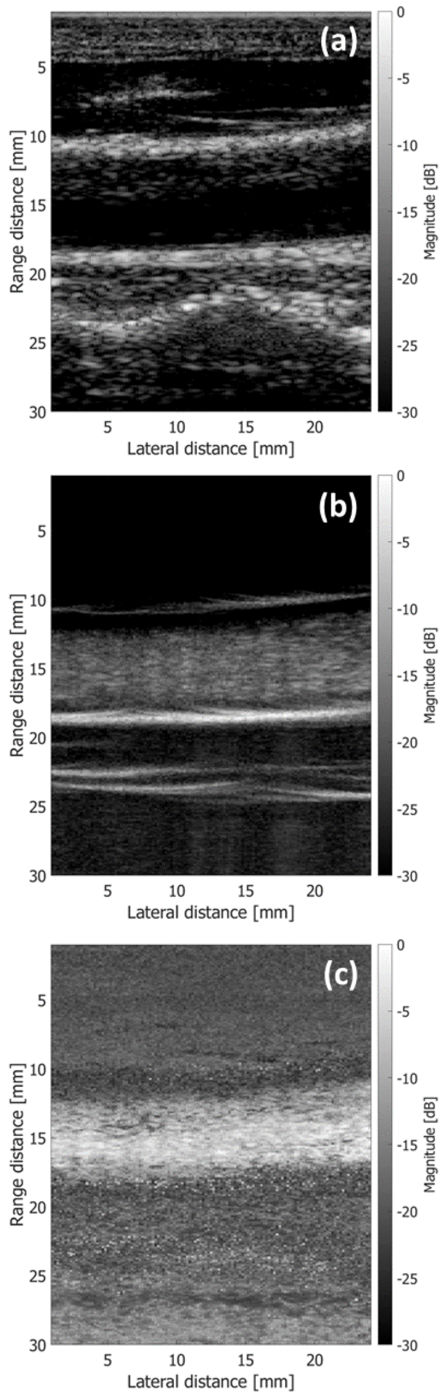

Fig. 3 Results of analyses of in vivo data from human carotid artery. (a) B-mode image from unprocessed signals. (b) B-mode image from SVD-filtered signals. (c) B-mode image from signals processed by deep neural network.