Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Power Doppler Imaging with a Novel Convolutional Autoencoder Based Clutter Filtering Technique: Feasibility Study

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***Abstract*—Singular value decomposition (SVD)-based clutter filters have shown its outstanding ability in clutter rejection for ultrafast plane-wave Doppler imaging. However, automatic decision on order selection still remains a big problem in vivo and the computational complexity of the SVD-based clutter filter is also high for clinical translation. In this study, we propose a novel convolutional autoencoder based clutter filtering technique for power Doppler, which retains the characteristic principle component analysis (PCA) done by the SVD filtering while being with no need for order selection and potentially lower computational load. The autoencoder is a counterpart for PCA in deep learning field. The simulation results show that the proposed convolutional autoencoder clutter filtering technique can robustly reject tissue clutter whose spectrum overlaps that of the blood signal, which is impossible to accomplish with conventional highpass filtering, and outperforms the SVD filtering. Our simulation results show that the contrast-to-noise ratio (i.e., blood-to-clutter ratio) of our proposed method is better than those of the SVD-based filter and the highpass filter by 23.97 dB and 64.17 dB, respectively.**

Keywords—power Doppler, clutter filter, singular value decomposition, convolutional autoencoder, neural network

I. INTRODUCTION

Clinical Doppler ultrasound instrument is often used to estimate blood flow of blood vessels in human body. However, the blood vessel signal is generally contaminated by the leakage of surrounding tissue due to sidelobes of the acoustic beam or tissue motion. This leakage signal called clutter is about 40 to 100 dB greater than the blood signal as described in [1] and reduces the accuracy of blood velocity measurement. It is essential to remove the clutter signal to obtain a high-quality Doppler image.

Conventional clutter filters could be classified into two categories: Fourier-based and eigen-based filters. In Recent studies, eigen-based clutter filter has proven that eigenvector basis is more suitable for separation of the clutter and blood signal than Fourier basis. Unlike the frequency selective filters, eigen-based filters are data driven filters, adaptively suppressing clutter signals based on the contaminated Doppler data. The singular-value-decomposition (SVD) based clutter filter maps the original data onto orthogonal bases, performing principle component analysis (PCA) and reserving the principal components associated with blood flow signals only. A big problem on eigen-based filters is how to decide the order selection on singular values. Besides, singular value decomposition is well known for its expensive computational cost [2]. Both problems remain big obstacles for practical implementation and clinical translation of singular value filtering.

In this study, we report a novel convolutional autoencoder based clutter filtering method for power Doppler, which is also data driven and retains the characteristic PCA done by the SVD filtering while being with no need for order selection and potentially lower computational load. The autoencoder abstracts both the spatial and temporal information then outputting the filtered vessel data. The major challenge solved by our model consists in better performance in power Doppler images than the one of eigen-based filters without any order predefined.

II. MATERIALS AND METHODS

A schematic illustration of data simulation, convolutional autoencoder architecture and power Doppler imaging is illustrated in Fig. 1.

A. Data Simulation Methods

For fast production of considerable simulation data, we assume the point spread function (PSF) of ultrasound imaging is spatially-invariant. The ultrasound imaging procedure can be simplified as a linear model and ultrasound RF data can be simulated by a 2-D spatial convolution between scatterers and PSF as described in [3]. After defining all scatterers in the scanning range, the scatterers are further separated into blood scatterers and clutter scatterers. Within each pulse repetition interval, the blood scatterers are assigned a laminar flow velocity which is parallel to the vessel and clutter scatterers are assigned a constant frequency tissue vibration displacement.

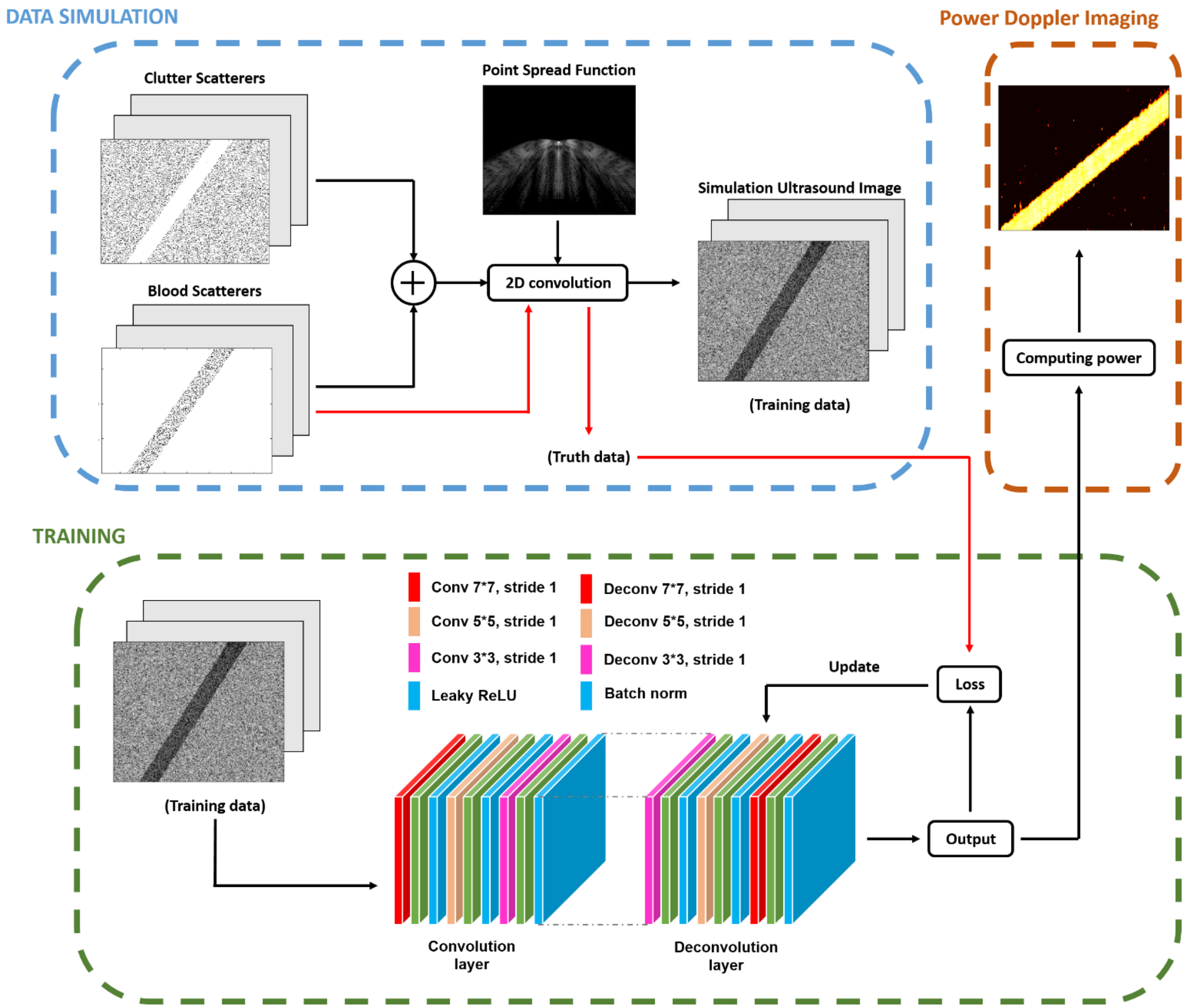

Fig. 1 Schematic illustration of the simulation procedure and the autoencoder architecture. The data simulation is on the top left. Detailed procedure of the network is depicted on the bottom and power Doppler imaging is shown on the top right.

In this study, the PSF is simulated via FIELD II framework using MATLAB (version 2018a) with the 128 elements, 5 MHz center frequency and 6 angles (-16° to 16°) compounding plane wave setup. The final size of simulation data is 360×255×200 (axial, lateral and temporal respectively). The simulation conditions emulate the phantom experiments done in reference [2].

B. Auto-encoder

The autoencoder consists of convolution layers and convolutional transpose layers. Convolutional layers are designed for the PCA task, and convolutional transpose layers use the dimension-reduced components to reconstruct Doppler data. Subjecting to the limit of our hardware, each data is divided into 255 Doppler data sets along the lateral axis with the size = 360×200 (axial×temporal), i.e., the format of conventional Doppler data set, instead of ultrafast Doppler data set. The detail of the used autoencoder architecture is depicted in Fig. 1. The model is implemented on Python 3.6.8 with TensorFlow-backend Keras framework. The loss function is mean squared error between model output and truth data. The optimizer is Adam and hyperparameters are: learning rate 10^{-5}; batch size 32.

C. Power Doppler Imaging

After the end of training, we are able to compute the mean power Doppler of the output data using Eq. 1 [4].

$$\mathrm{PW}(x,z) = \frac{1}{n_t}\sum_{1}^{n_t} |Output(x,z,t)|^2 \tag{1}$$

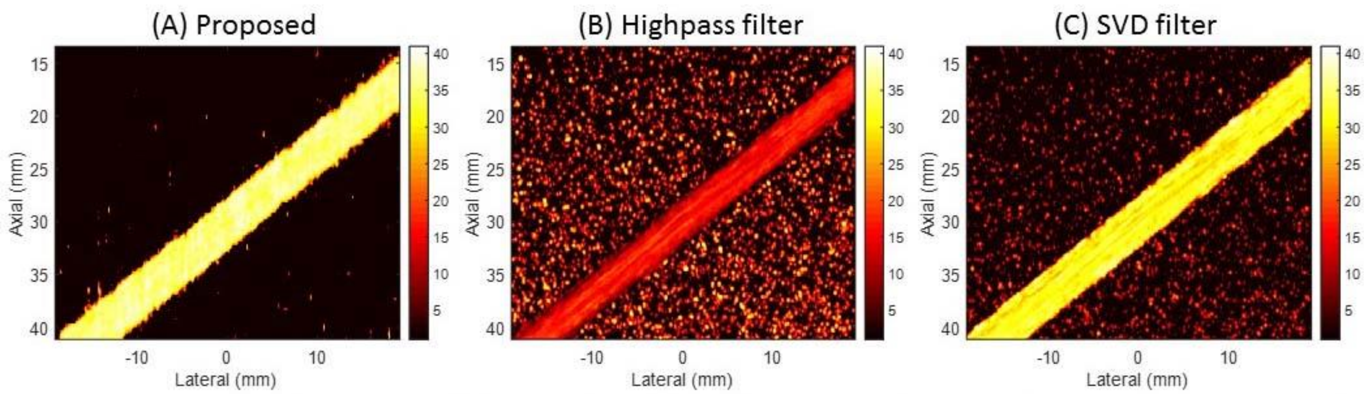

Fig. 2 Power Doppler images of the simulated flow phantom with tissue clutter with the proposed convolutional encoder filtering (A), with the IIR high pass filtering (B), and with SVD filtering (C)

Furthermore, after segmenting the data into blood area and clutter area based on the known position of the simulated vessel, the contrast-to -noise ratio (CNR) indicating blood-to-clutter ratio is calculated using Eq. 2.

$$\mathrm{CNR} = \frac{PW_{blood} - PW_{clutter}}{STD_{clutter}} \quad (2)$$

III. RESULTS

The simulation results show that the proposed convolutional autoencoder clutter filtering technique can robustly reject tissue clutter whose spectrum overlaps that of the blood signal, which is impossible to accomplish with conventional high pass filtering, and outperforms the SVD filtering. In the case of Fig. 2, the CNR of our proposed method is better than those of the SVD-based filter and the high pass filter by 23.97 dB and 64.17 dB, respectively. The computation time is also less than that of the SVD filtering.

IV. CONCLUSION

In this paper, we propose a convolutional autoencoder model for clutter filtering and prove the feasibility of better performance using simulated vessel data than the one of frequency-based and eigen-based filters. The present study is only discussed in simulation data where all data properties are ideal. More efforts need to be made to explore on the phantom experiment data and *in vivo* data.

ACKNOWLEDGMENTS

This research is partially supported by the Ministry of Science and Technology, Taiwan. (MOST 106-2221-E-007-033-MY3).

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