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Noise Suppression Technique Using Deep Learning for Ultrasound Images During Ultrasound-guided High Intensity Focused Ultrasound Treatment

強力集束超音波治療時の超音波画像に対する深層学習を用いたノイズ抑制技術

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1. Introduction

High-Intensity Focused Ultrasound (HIFU) treatment is a non-invasive surgery that focuses ultrasound energy from outside the body to produce a thermal damage in the target tissue, such as a cancerous tissue. In ultrasound-guided HIFU exposure, the interference between therapeutic and diagnostic ultrasound compoment makes it difficult to detect tissue changes. In our previous research[1)], we have proposed a noise suppression technique which removes only the therapeutic ultrasound component (HIFU noise) from the noise interference ultrasound image. However, the technique was limited in versatility because the raw channel signals were recquired to be processed in the diagnostic ultrasound system. In this study, we proposed a new noise reduction technique with deep learning technology using the ultrasound echo signals after the reconstruction in the presence and absence of HIFU noise. The noise reduction performance usng the proposed method was also investigated.

2. Material and Methods

2.1 Experimental setup

A schematic of the experimental setup is shown in **Fig. 1**. A chicken breast was used as a tissue sample in this study. The concave transducer was placed so that the HIFU focus was about 20 mm in depth from the surface of the tissue sample. Therapeutic ultrasound wave, which was generated by a funciton generater, was amplified by a power amplifier. The daiganostic ultrasound signals were acquired by a phased array probe with a center frequency of 3 MHz. The apature and curvature of the transducer was 46 mm. The driving frequency and the spatial-peak temporal-peak intensity was 1.67 MHz and 2 kW/cm^2 respectively. The water was degassed [dissolve doxygen (DO): 20–30%] and kept at 36 °C. Figure 2 shows the experimental sequence of HIFU exposure and data collection in this study. The exposure and intermission period of HIFU were set to 10 ms and the set of both periods were repeated 50 cycle so that the total exposure time would be 10 s. The ultrasound images with and without HIFU noise were acquired during each period and a total of 4000 data sets were obtained through 16-sample experiments.

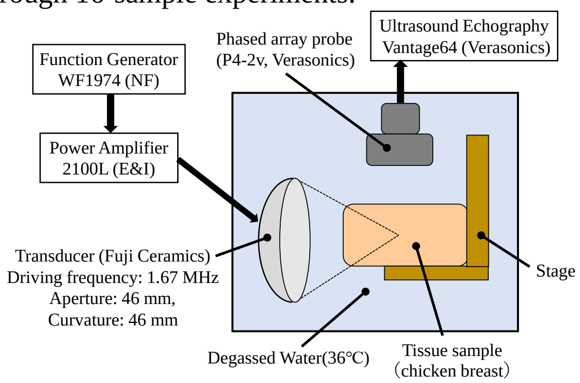

Fig.1　Experimental setup

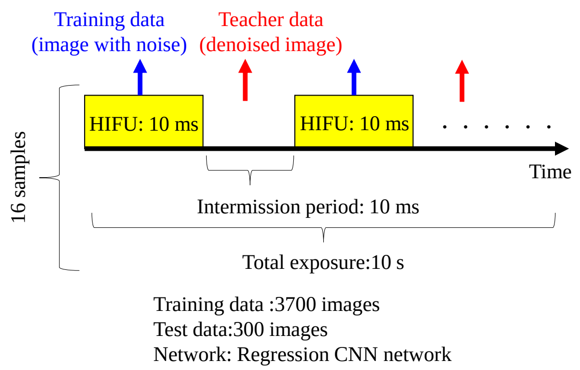

Fig.2　Experimental sequence and data collection

2.2 Structure of deep learning network

Figure 3 shows the suggested structure of a regression Convolutional Neural Network (CNN) used in this study. It consists of 4 two-dimensional convolution layers (Conv1-Conv4 in **Fig.3**). The input images are beamformed ultrasound images (demodulated IQ data) with noise. The size and number of channels of the input image was [64×64] and 1. The number of training and test data was 3700 and 300 respectively. The kernel size and stride (step size) of the kernel is [3 × 3] and was [1×1] and padding was introduced to equalize the output and input kernel size. After each convolution layer, there are 32-channel batch processing layer,

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rectifying linear unit (Relu) layer and the max pooling layer with a stride of 2 and pooling size of 2. The final convolution layer (Conv4) was connected to the regression layer to have an output. The mean square error (MSE) was used as the loss function in this study. The idea was is the sum of squared errors of the true value (T_i) and the predicted (P_i) value as expressed in Eq. (1).

$$MSE = \sum_{i=1}^{n} (T_i - P_i)^2 \qquad (1)$$

where n is the number of pixels in the images. The total number of epochs, which is a time that the learning algorithm will work through the entire training dataset, was set to 20 in this study.

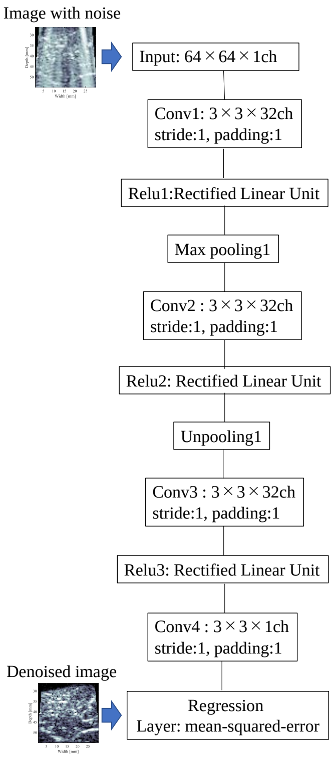

Fig.3 Structure of deep learning network

3. Results and Discussion

Figure 4 shows a comparison of (a) B-mode image during HIFU exposure, (b) noise reduced image using deep learning and (c) denoised images acquired during HIFU intermission period. HIFU is irradiated from left to right in these images. As shown in **Fig.4**, the HIFU noise was relatively removed while retaining the tissue signal in the image generated using deep learning. It is also said that hyperechoic structure to show the muscle fiber and the speckle patterns are reproduced in the almost the same way in the denoised image aquired during HIFU intermission period. However, the resolution of the image generated using deep learning was lower than that of denoised image.

To quantitatively evaluate the amount of noise reduciton level, the signal level at a point in no echo region (no refleaction area) of the images generated using deep learning or denoised images was subtracted from that of images with noise. This level was named as "noise reduciton level" in this study. Figure 5 shows comparison of noise reduction level between noise reduced images using deep learning and denoised images acquired during HIFU intermission period. As shown in **Fig.5**, the noise reduction level of noise reduced images and denoised images was -18.2 dB and -28.4 dB respectively. It seems that the reduciton level of -18.2 dB in the noise reduced image was enough to monitor the tissue duting HIFU exposure but it is needed to investigate the possibility of detection for the small tissue changes induced by HIFU using the noise reduced images.

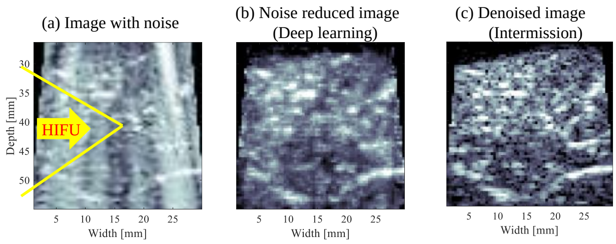

Fig.4 Comparison of (a) B-mode image during HIFU exposure, (b) noise reduced image using deep learning and (c) denoised images acquired during HIFU intermission period

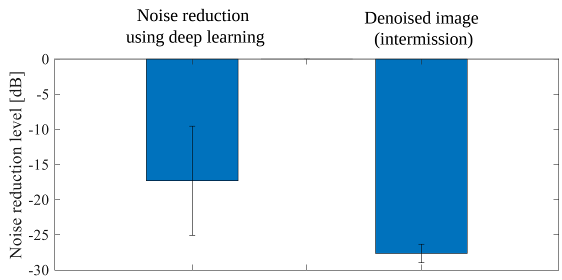

Fig.5 Comparison of noise reduction level between noise reduced images using deep learning and denoised images acquired during HIFU intermission period

4. Conclusion

In this study, a new noise supperesion method using deep learning technology during utlrasound-guided HIFU treatment was suggested. It is said that the proposed method could selevtively reduce the HIFU noise during HIFU exposure and should be useful for real-time ultrasound imaging to detect the tissue changes induced by HIFU.

References

1. R. Takagi et al: Ultrasonics 114, 106394 (2021).