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Study on The Feasibility of Noise Reduction Method in Ultrasound Monitoring of High Intensity Focused Ultrasound Treatment

強力集束超音波治療の超音波モニタリングにおけるノイズ低減手法の有効性に関する検討

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1. Introduction

In High-Intensity Focused Ultrasound (HIFU) treatment, ultrasound is focused at tumors from outside the body and the tareget tumors are coagulated with heat induced by ultrasound. In this treatement, it is imortant to monitor the target tissue and detect tissue changes non-invasively while irradiating thrapeatic ultraound. In our previous study[1], noise reduction method utilizing continuous wave response of HIFU signals has been developed and it was applied to the static cases, where the tissue samples were not moved. However, the target body and organs are moving randomly at relatively slow speed because of breathing and also rapid tissue changes such as cavitation bubble generation occur in the actual HIFU treatment.

In this study, the developed noise reduction method was applied to the cases, where the excised block of gel phantom was moved assuming the respiration-induced motion and the feasibility of this method for the actual HIFU treatment was investigated.

2. Material and Methods

2.1 Algorithm of Noise Reduction Method

In this study, the noise reduction method suggested in our previous study[1] was applied to the experiments assuming the respiration-induced motion. There are two responses in the signals received in ultrasound probe during HIFU exposure. One is the pulse response to the imaging pulse and the other is the continuous wave (CW) response to HIFU. In this algorithm, the CW response to HIFU is estimated from the reference signals reflected from the water region (water balloon) which is located between tissue and the transducer. At a certain time after HIFU starts to be exposed, the response to the HIFU reach the steady state and all of signals reflected from the water region are the CW response to HIFU because there are no reflectors such as tissues. Therefore, the CW response to HIFU can be estimated from a portion of the RF signal with no pulse response to the imaging exposure. The estimated CW response to HIFU was subtracted from the original RF signals to eliminate the original CW response to HIFU while pulse response to the imaging pulse remains.

2.2 Experimental Setup

A schematic of the experimental setup to investigate the feasability of noise reduction method is shown in **Fig. 1**. The polyurethane gel phantom was used as a tissue specimen, and placed on the stage which is controlled by a PC. The speed of the stage was increased in increments of 5 mm/s up to 45 mm/s, assuming the respiration-induced motion. A programmable ultrasound imaging system (Vantage64 System, Verasonics, Inc) was used to acquire the RF signals. In this study, RF images were produced by applying plane wave transmission to detect relatively rapid changes such as cavitation bubble generation. RF images with and without HIFU noise was obtained using a phased array probe (P4-2, Verasonics, Inc) alternately at a rate of 10 Hz during HIFU exposure and the proposed method was applied to the noisy RF images. The driving frequency of diagnostic and therapeutic ultrasound was 2.50 and 1.67 MHz, respectively. The water was degassed [dissolve doxygen (DO): 20–30%] and kept at 34 °C. The spatial-peak temporal-peak intensity (I_{SPTP}) of the HIFU was 130 W/cm2.

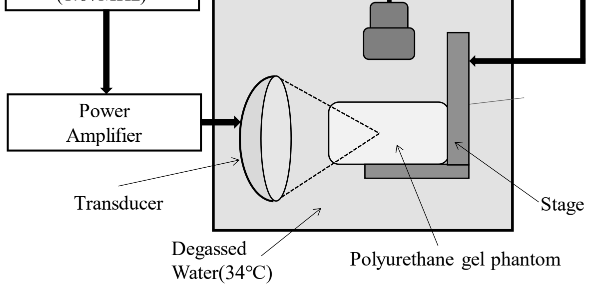

Fig.1 Schematic of experimental setup

3. Results and Discussion

Figures 2 shows actual RF images with and without HIFU noise and after signal processing in a case that gel phantom was moved at a speed of 45 mm/s which is maximum speed of these experiments. Figure 3 shows one of the average power spectra of received RF signals in all channels. As shown in **Fig. 2**, almost all of the HIFU noise was able to be eliminated using the proposed method and the gel phantom was clearly detected with HIFU irradiation even when the target phantom was moving. As shown in **Fig.3**, the fundamental frequency component (1.67 MHz) of HIFU was reduced by about 20 dB from original RF images after applying the proposed noise reduction method. There are no harmonic components of HIFU because the intensity of therapeutic ultrasound was relatively low and cavitation bubbles were not generated in these experiments. the feasibility of this method for the case where cavitation bubbles are generated with HIFU should be investigated as a future work

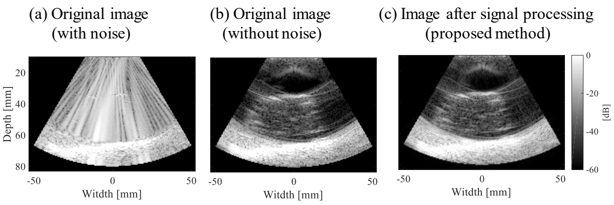

Fig.2 Actual RF images (a) with and (b) without HIFU noise and (c) after signal processing in a case that gel phantom was moved at a speed of 45 mm/s.

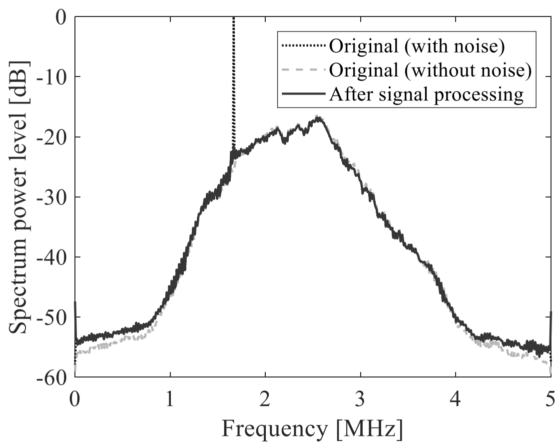

Fig.3 One of the average power spectra of received RF signals in all channels in a case that gel phantom was moved at a speed of 45 mm/s.

Figure 4 shows the difference in power level of the fundamental HIFU component (1.67 MHz) between the original RF images without noise or after signal processing and original noisy RF images when the gel phantom was moved at a speed of up to 45 mm/s. As shown in **Fig.4**, Noise reduction level was about 20 dB and it was almost the same when the speed of movement was varied. These results show that the proposed method has a robustness and the feasibility for the monitoring of actual HIFU treatment where respiratory motion occurs. Noise reduction level of RF images after signal processing was 5 dB smaller than the one of original RF images without noise. This is thought to be because the timing of taking two RF images (with and without noise) was different.

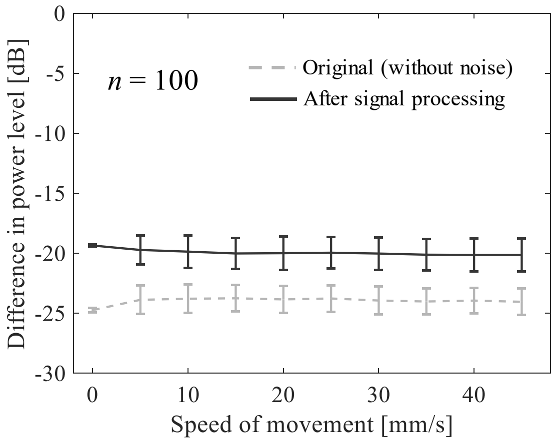

Fig.4 Difference in power level of the fundamental HIFU component (1.67 MHz) between the original RF images without noise or after signal processing and original noisy RF images when the gel phantom was moved at a speed of up to 45 mm/s.

4. Conclusion

In this study, the tissue phantom was moved asuuming the respiratory motion in the actual HIFU treatment and the proposed HIFU noise reduction method was applied to monitor the tissue changes. As a result, this proposed method can be applicable in the case that tissue phantom was moved at a speed of up to 45 mm/s. These results imply the proposed method has a robustness and the feasibility for the monitoring of actual HIFU treatment.

Acknowledgment

The authors would like to express their sincere thanks to Dr. S. Yoshizawa and Dr. S. Umemura of Tohoku University for their cooperation in constructing the experimental setup.

References

1. R. Takagi et al: Jpn. J. Appl. Phys. **54** (2015) 07HD10.