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Real-time Treatment Feedback Using Novel Filter for Eliminating Therapeutic Ultrasound Noise in US-guided High-Intensity Focused Ultrasound Treatment

治療用超音波ノイズ除去手法を用いた超音波ガイド下超音波治療フィードバックシステム

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1. Introduction

High-Intensity Focused Ultrasound (HIFU) is therapeutic treatment in which ultrasound is generated outside the body and focused on a target tissue such as cancer to be thermally coagulated. In our previous study[1], the filtering method to eliminate the HIFU noise in the ultrasonic RF signals during HIFU exposure was proposed. The ultrasonic monitoring the tissue changes such as coagulation while simultaneously irradiating therapeutic ultrasound was demonstrated through off-line processing.

In this study, this filtering algorithm was implemented to monitor the tissue changes in real time during HIFU irradiation. In additon to that, the tissue coagulation was detected automatically using cross-correlation algorithm[2] and the HIFU exposure time was controled acording to the tissue changes.

2. Material and Methods

2.1 Experimental setup

A schematic of the experimental setup is shown in **Fig. 1**. HIFU was generated from a 128-channel array transducer (Imasonic) with a focal length of 120 mm at a driving frequency of 1.25 MHz. Degassed chicken breast was used as the object for HIFU irradiation. The water was degassed (DO: 20-30%) and kept at 34 degrees. A programmable ultrasound imaging system (Verasonics V-1 System) and a sector probe with a center frequency of 3 MHz (Hitachi Aloka Medical UST-52105) was used to acquire the RF data of B-mode images during HIFU exposure. In this study, it is demonstrated for sequential exposure with multiple foci, which consider to be more practical. A stage to place an excised block of the tissue was controlled by a PC to scan the HIFU focus in the tissue mechanically. The focal positons are numbered with the order of exposure as shown in **Fig. 1**.

2.2 Timing chart

The timing chart of this HIFU monitoring system is shown in **Fig. 2**. The ultrasound imaging system and the stage to place the tissue were controlled by the host PC. The PC transmitted the trigger for starting the RF signal acquisition and HIFU exposure at the beginning. The RF signals with HIFU noise were acquired by the PC while simultaneously during HIFU exposure. The proposed filtering method[1] was applied to these RF signals to form the RF frames without HIFU noise and the cross-correlation coefficient was calculated between these RF frames[2]. The maps acquired by this signal processing were named as "correlation coefficient maps" in this study. The ROI around the HIFU focus in the correlation coefficient maps and the threshold of the decorrelation within the ROI were set to determine the completion of the treatment at each single focus. When the correlation coefficient, calculated at a rate of 10 Hz during HIFU exposure at the ultrasonic intensity of 1.5 W/cm^2, was below the preset threshold, the exposure was discontinued and the stage was mechanically moved for the next location of the focus. This sequence of exposure automatically performed HIFU treatment with multiple foci (9 points). For high-speed ultrasonic imaging, we applied plane wave transmission followed by parallel beamforming during HIFU exposure.

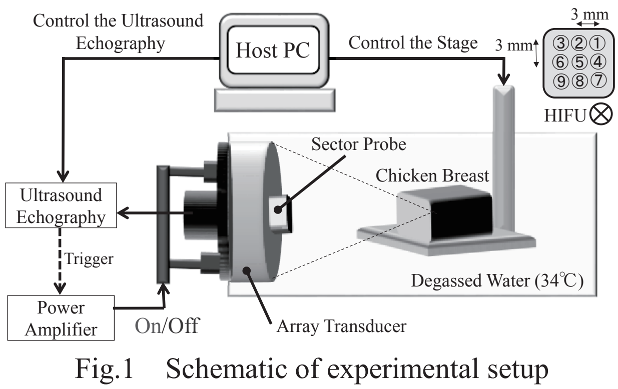

Fig.1 Schematic of experimental setup

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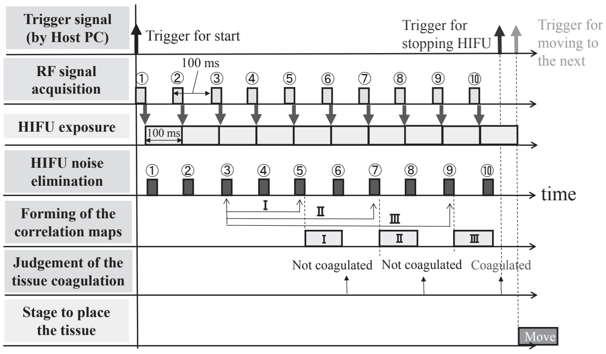

Fig.2 Timing chart of this HIFU monitoring sytem

3. Results and Discussion

Figure 3 shows the relationship between the positions of HIFU foci and the exposure time to complete the treatment at each focus in the case of the threshold of the decorrelation was set to (a) 0.8 and (b) 0.9. It also shows a slice of the tissue sample after the series of HIFU exposure. As shown in **Fig. 3(a)**, the tissue was coagulated homogeneously around HIFU foci. On the other hand, the tissue between the HIFU foci was not coagulated because of the insufficient heating time in the case of setting the threshold to 0.9. These results imply that HIFU treatment with multiple foci can be completed automatically and safely by setting the appropriate threshold in this treatment feedback system.

Figure 4 shows that the comparison of the exposure time and the treated region (a) without and (b) with the treatment feedback. Cross-sectional slices of the tissue after the series of HIFU exposure were binarized to form two areas consisting of treated (white) and non-treated region (black). As shown in **Fig. 4(a)**, the tissue coagulation at the 1st, 4th and 7th shots was not sufficient in the case of the fixed exposure time (5 s). This is because the initial exposure cannot utilize the residual heat from the previous exposure and there is relatively large interval time after heating the HIFU foci adjoining the 4th, 7th spots. The tissue was treated homogeneously with the treatment feedback as shown in **Fig. 4(b)** though average exposure time was almost the same as **Fig. 4(a)**. The exposure time was longer for the 1st, 4th and 7th HIFU foci compared with another spots. This result implies that the tissue coagulation was accurately detected using the proposed method and the residual heat from the previous shot can be efficiently utilized for the tissue coagulation with the treatment feedback.

4. Conclusion

In this study, real-time ultrasonic monitoring and control of HIFU treatment with multi foci using the proposed filtering method was demonstrated. The tissue coagulation was automatically detected during simultaneous HIFU irradiation and the exposure was discontinued accordingly. The residual heat from the previous HIFU shots can be utilized to the treatment and tissue was coagulated efficiently using this proposed monitoring system. The proposed method is thought to be useful for the true real-time monitoring of HIFU treatment while preventing overheating.

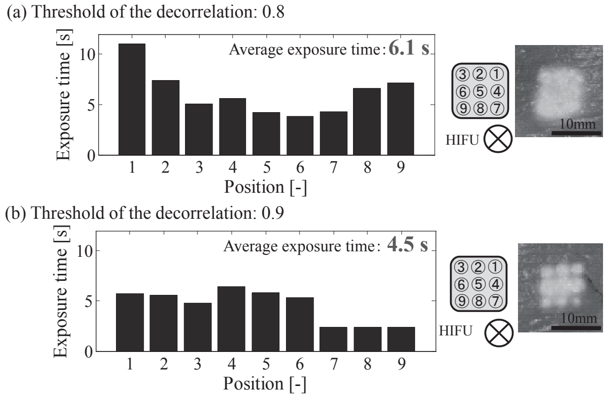

Fig.3 Relationship between the positions of HIFU foci and the exposure time to complete the treatment at each focus in the case of the threshold of the decorrelation was set to (a) 0.8 and (b) 0.9

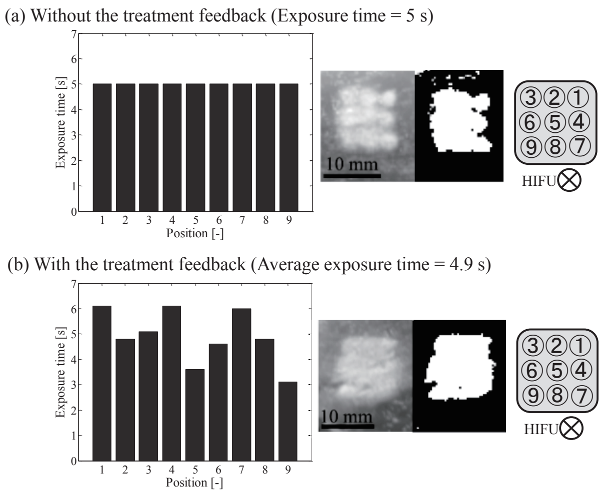

Fig.4 Comparison of the exposure time and the treated region (a) without and (b) with the treatment feedback.

References

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2. R. Matsuzawa et al: Jpn. J. Appl. Phys. **51** (2012) 07GF26.