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Elimination of Therapeutic Ultrasound Noise from Pre-beamformed RF Data in Ultrasound Imaging for US-guided High-Intensity Focused Ultrasound Treatment

超音波治療ガイド用超音波イメージングの整相前処理による治療用超音波ノイズの除去

Ryo Takagi‡, Kota Goto, Hayato Jinbo, Keiko Matsuura, Ryosuke Iwasaki, Shin Yoshizawa, and Shin-ichiro Umemura (Tohoku Univ.)
高木亮‡，後藤功太，神保隼人，松浦景子，岩崎亮祐，吉澤晋，梅村晋一郎（東北大）

1. Introduction

High-Intensity Focused Ultrasound (HIFU) is therapeutic treatment in which ultrasound is irradiated outside the body and focused on a target tissue such as cancer to be thermally coagulated. In conventional ultrasonic monitoring of this treatment, a significant length of interval between HIFU shots is set for monitoring target tissue to avoid interference between HIFU noise and RF echo signals. This way, it is difficult to detect tissue changes in the order of milliseconds, which is required for dynamically controlling the HIFU exposure especially in cavitation enhanced HIFU treatment.[1]

In this study, a new filtering method to handle RF signals before beamforming is proposed, which will enable truly real-time detection of tissue coagulation during HIFU exposure.

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 100 mm at a driving frequency 1.0 MHz. Degassed chicken fillet was used as the object for HIFU irradiation. The water was degassed (DO: 20-30%) and kept at 36 degrees. A programmable ultrasound imaging system (VerasonicsV-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.

2.2 HIFU exposure and data acquisition

The ultrasound sequence “triggered HIFU” is a HIFU method employing cavitation bubbles. [1] In this method, a high-intensity short pulse, named "trigger pulses", generate and grow cavitation bubbles first. Then, a low-intensity long-duration burst, named “heating waves” oscillate the cavitation bubbles to enhance the heating effect. The sequence of HIFU exposure and RF signal acquisition is shown in **Fig. 2**. First, trigger pulses at an intensity of 50 kW/cm^2 (I_m) with a total duration of 100 µs were irradiated. After the trigger pulses, heating waves with an intensity of 2.0 kW/cm^2 (I_m) with a total duration of 200 ms were irradiated. This cycle was repeated 50 times, resulting in a total duration of 10 s. For high-speed ultrasonic imaging, we applied plane wave transmission followed by parallel beamforming at a rate of 25 Hz during the heating wave exposure.

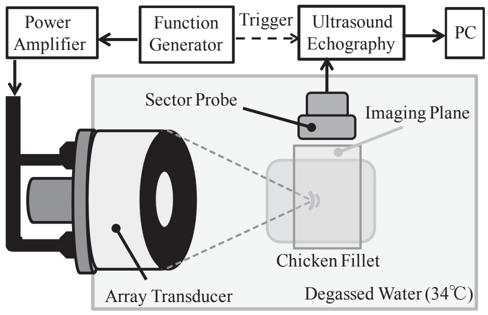

Fig.1 Schematic of experimental setup

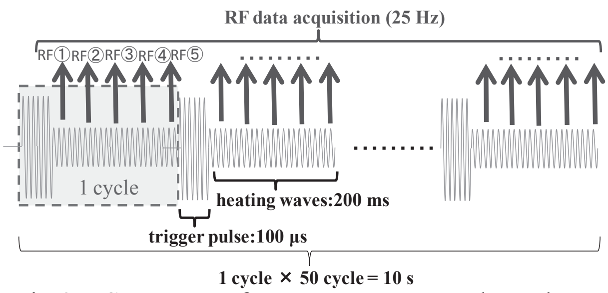

Fig.2 Sequence of HIFU exposure and RF data acquisition.

2.3 Pre-beamformed RF data processing

The RF signals were processed before beamforming. Figure 3 shows the raw RF signals in a channel of the ultrasonic probe. The horizontal

takagi@ecei.tohoku.ac.jp

and vertical axis represents time and amplitude, respectively. As shown in **Fig. 3(a)**, only continuous-wave response due to HIFU is observed in the early time region (corresponding to water bolus), but pulse responses are also observed in later time region (corresponding to tissue). The continuous-wave response was subtracted from the entire RF signal as shown in **Fig. 3(b)** to selectively eliminate the HIFU noise, and then dynamic focusing was applied to form B-mode images. It is important to process raw RF signals before beamforming in this method because the HIFU frequencies are shifted and broadened through a dynamic focusing process.

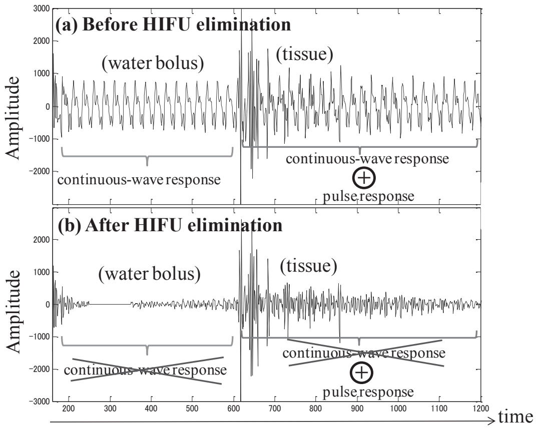

Fig.3 raw RF signals in a channelof the ultrasound probe (a)before and (b) after HIFU elimination

3. Results and Discussion

Figure 4 shows the comparison between B-mode images (a) before and (b) after applying the proposed method during HIFU exposure. HIFU propagated from left to right in these images. As shown in **Fig. 4**, HIFU noise was eliminated completely by the proposed method while the tissue image remained intact, even in case that there were acoustic emissions from cavitation bubbles generated in focal point. Figure 5 shows the comparison between HIFU noise components (1MHz and 2MHz) included in RF signals before and after applying the proposed method before and during HIFU exposure. The horizontal and vertical axis represents HIFU exposure time and average of power spectrum, respectively. The maximum spectral power of 1 MHz component with HIFU noise was set to 0 dB in **Fig. 5**. As shown in **Fig. 5**, the fundamental and second components of HIFU noise were reduced about 35 dB and 10 dB by the new method, respectively. The 2MHz components remaining after subtraction were considered to be echo signals from tissue.

4. Conclusion

In this study, a new filtering method to handle RF signals before beamforming is proposed. HIFU noise was selectively eliminated by this method in case of interference between the HIFU noise and RF echo signals. These results imply that the proposed filtering method is useful for truly real-time detection of tissue changes such as coagulation in HIFU treatment by B-mode imaging.

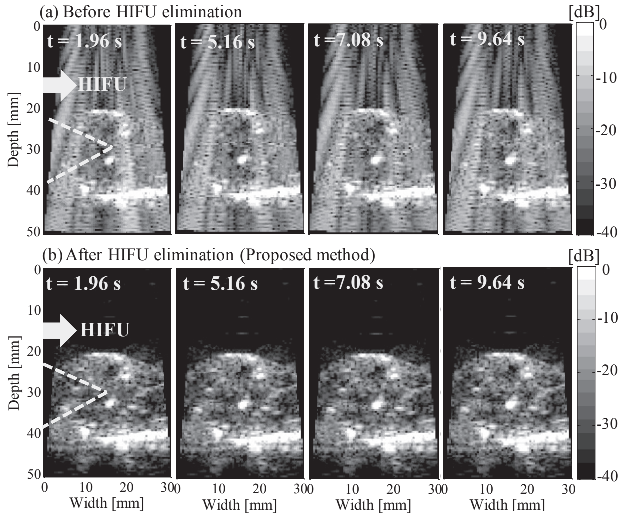

Fig.4 Comparison between B-mode images (a) before and (b) after applying the proposed method during HIFU exposure

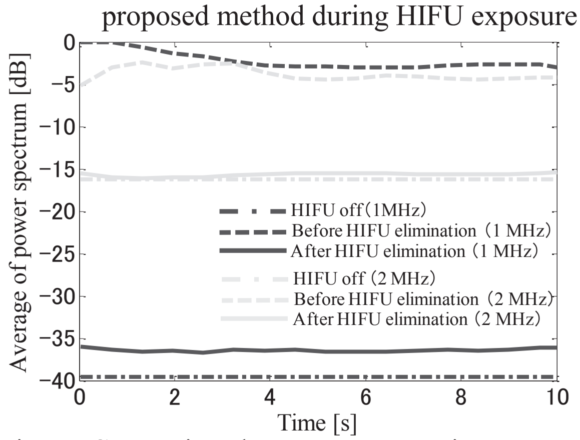

Fig.5 Comparison between HIFU noise components (1MHz and 2MHz) before and after applying the proposed method during HIFU exposure

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References

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