Basic study on a method for extracting cavitation bubble region in ultrasound imaging by triplet pulse sequence

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1. Introduction

High-intensity focused ultrasound (HIFU) treatment, in which ultrasound from outside of the body is focused on the treatment region and induces coagulation mainly by heating, is a minimally invasive treatment without incision. However, the region that can be treated by a shot of focused irradiation is very small, so the treatment has taken a long time. Thus, our team aims at increasing the efficiency of the treatment by using trigger HIFU sequence. In the sequence, a short high-intensity trigger pulse is irradiated to create cavitation bubbles, which is immediately followed by a relatively long low-intensity heating burst to volumerically vibrate cavitation bubbles and increase heating efficiency. To ensure the safety and effectiveness of this treatment, it is very important to monitor such cavitation bubbles.

In this study, we examine a method to selectively enhance cavitation bubbles in realtime ultrasonic imaging by the triplet pulse sequence[1,2] (3P).

2. Materials and methods

2.1 Triplet pulse sequence (3P)

3P is a method to extract signals from microbubbles by transmitting and receiving three pulses with phase shifts of 120° each and adding the three received signals together. It uses the nonlinear scattering property of microbubbles and detects the 1.5th fractional harmonic component that are generated only through scattering by bubbles. By the addition, the fundamental components and the second-harmonic components are canceled due to the phase difference, and the 1.5th fractional harmonic component is preserved. 3P can thereby perform selective bubble imaging.

2.2 Bubble region extraction method in 3P

In 3P, if there are high-intensity scatterers, the fundamental components and the second-harmonic components may not be sufficiently canceled out and may remain even after the addition of the three received signals. The bubble region extraction method studied in this study is expected to distinguish bubbles from other areas and extract bubble regions more precisely. First, the 3P image after the addition is compared with an arbitrary imaging frame before addition (1P image), and the amount of decrease in brightness is calculated for each pixel. Then, a threshold for the amount of reduction is determined, and the brightness of the pixel whose reduction is greater than the threshold in the 3P image is set to 0. Bubble region is extracted in 3P by such filtering process.

2.3 Setup and ultrasound sequence

Fig. 1 shows a schematic of the experimental setup. The experiment was performed by setting chicken breast in a tank filled with degassed water. Chicken breast was degassed with 0.9 % saline, and a needle was inserted into the chicken breast as a high-intensity scatterer. HIFU was irradiated with a 128-ch array transducer, and ultrasonic imaging was performed with a sector probe at the central hole of the transducer.

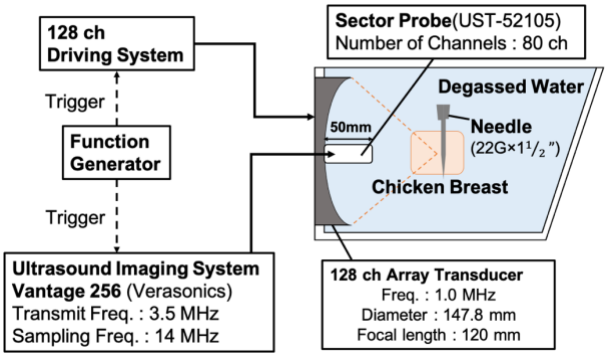

Fig. 1 Schematic of experimental setup

Fig. 2 shows the sequence of HIFU exposure and ultrasound imaging. A trigger pulse at a spatial-peak temporal-average intensity (I_{SPTA}) of 65 kW/cm^2 with a duration of 0.1 ms was transmitted from the transducer for generating cavitation bubble. In this study, a heating burst to vibrate the bubbles and heat the tissue was not irradiated. A set of ultrasound imaging at four phases, 120, 0, 180, and 240° was performed 1 ms after the trigger pulse. This sequence was repeated 10 times to obtain RF data.

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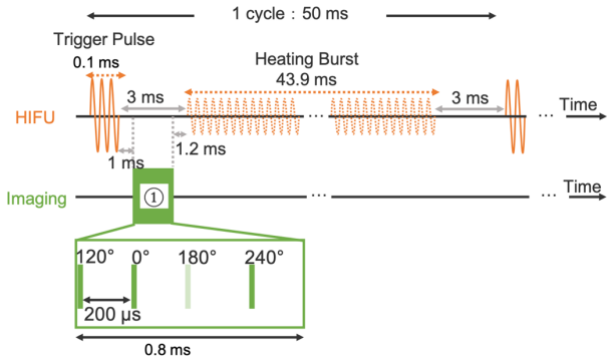

Fig. 2 Sequence of HIFU and ultrasound imaging

3. Results and discussion

Fig. 3 shows the B-mode images of 1P (using the 0° only) and 3P at the 10th cycle. The focus of trigger pulse was at a depth of 74 mm and width of -3 mm, and the needle used as a high-intensity scatterer was set around at a depth of 70 mm and width of 19 mm. Although the needle can be clearly identified in the 1P image, it is difficult to recognize the area of cavitation bubbles. On the other hand, in 3P image, t the area of cavitation bubbles can be recognized around at depth from 60 to 70 mm and width from -8 to 3 mm. However, even in 3P, the brightness did not fully decrease in the needle area, high-intensity areas of tissue and the tissue interface area, and it may not be possible to distinguish them from the cavitation bubble area if such areas are too close to each other.

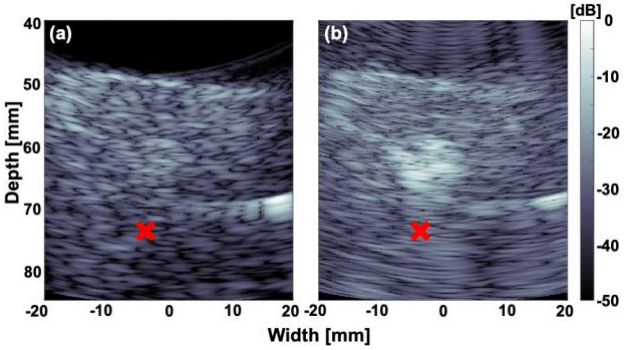

Fig. 3 B-mode images of 1P (a) and 3P (b) at 10th cycle

Fig. 4 shows the results of the bubble region extraction method on **Fig. 3**. **Fig. 4 (a)** shows the decrease in brightness when comparing 1P and 3P. This was calculated by dividing a third of the 3P image by the 1P image for each pixel after setting ROI of 2 mm depth and 2 mm width. A smoothing process, which replaces the value at the center of ROI with the average value in ROI, was applied to each of the whole 3P and 1P images. In the region of the needle and tissue, which are linear scatterers, the reduction should be large, while in the region where cavitation bubbles are assumed to be, the reduction should be small due to the 1.5th fractional harmonic component. Based on this assumption, a filter was created, in which the output is defined as 0 for pixels whose reduction is larger than -20 dB and 1 for pixels whose reduction is smaller than -20 dB. **Fig. 4 (c)** shows the filtered 3P image obtained from the data corresponding to the original 3P image shown in **Fig. 4 (b)**. While the needle and tissue are seen in addition to the bubble region in **Fig. 4 (b)**, only the bubble region is selectively depicted clearly in **Fig. 4 (c)**.

In **Fig. 4 (a)**, there are regions with a small reduction around at depth of 80 mm, which seems to be caused by multiple reflections. It is considered that it may not be removed completely in normal 3P images if such regions overlap with high brightness regions, but it is expected to be reduced in the filtered 3P images.

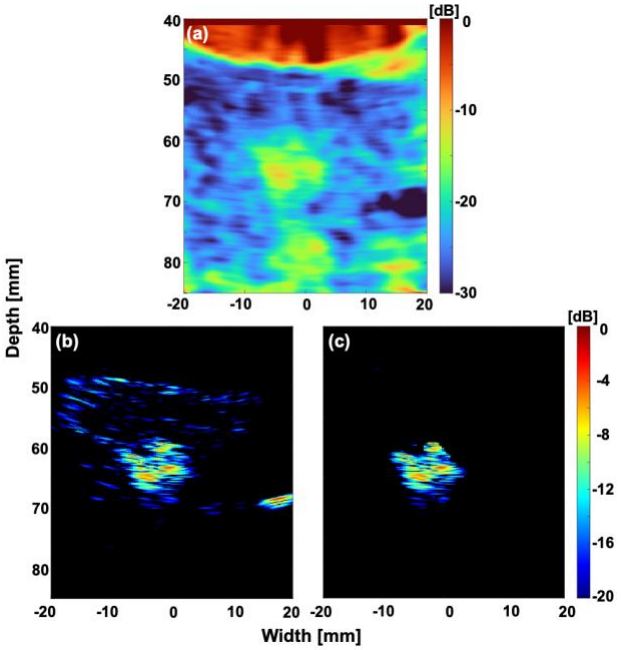

Fig. 4 Brightness reduction map from 1P image to 3P image (a), 3P image before filtering (b), and 3P image after filtering

4. Conclusion

In this study, the effectiveness of the method to selectively depict the bubble region was experimentally investigated. By the filter proposed in this study, the selectivity was further improved over the triplet pulse sequence (3P).

References

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2. I. Shiozaki, S. Umemura, S. Yoshizawa: Jpn. J. Appl. Phys. **59** (2020) SKKE05.