1J5-4

Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 131-132
13-15 November, 2012

Focus Control Method Aided by Numerical Simulation in Heterogeneous Media for HIFU Treatment

集束超音波治療におけるシミュレーションを援用した多媒質中の焦点位置制御手法の開発

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1. Introduction

High intensity focused ultrasound (HIFU) allows low-invasive energy concentration at focus and can induce localized temperature elevation, which generates tissue necrosis. This method is clinically used or under clinical trials to treat variety of diseases, such as prostate cancer, uterine fibroid, breast cancer, and liver cancer.

However, in HIFU treatment for deep place cancers, the acoustic heterogeneities aberrate ultrasound propagation and cause focal errors in beamforming. One of the solutions to this problem, time reversal approach [1] was proposed as a promising method. Moreover, numerical simulation was applied to support time reversal for low-invasive treatment [2][3]. In this study, time reversal based on numerical simulation using phased array transducer was used to correct focal errors in heterogeneous media. In addition, difference of focus control based on fluid and elastic models in the simulation was discussed.

2. Material and Methods

2.1 Simulation aided focus control method

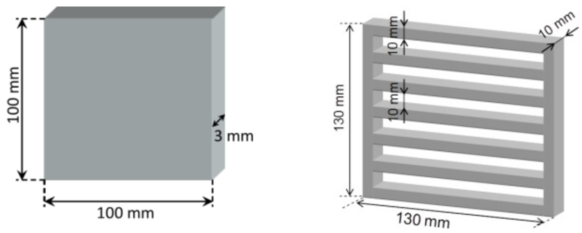
It is needed to input appropriate phase delays into array transducer elements to implement focus control in heterogeneous media using phased array. Therefore, time reversal based on numerical simulation was applied. Here is the procedure.

1. Ultrasound emitted from a sound source at the target was received by the array transducer in the simulation.
2. Take cross correlations of the received signals in each element and choose the phase delays to make the cross correlation maximum.

Focus control experiment was implemented by inputting phase delays obtained by numerical simulation to transducer elements respectively.

2.2 Experimental setup

Objective of this experiment was to estimate efficiency of the simulation aided focus control. Two types of acrylic phantom were installed in beam path to mimic heterogeneous media system in human body because acoustic properties of acryl are close to those of bone. These acryl phantoms are shown in **Fig. 1**. Moreover, experimental setup is shown in **Fig. 2**. A 56 channels array transducer was used with a frequency of 2 MHz. Sound pressure distribution around the geometrical focus was measured by a needle hydrophone.



(a) Acrylic plate (b) Slitted acryl

Fig. 1 Acrylic phantom

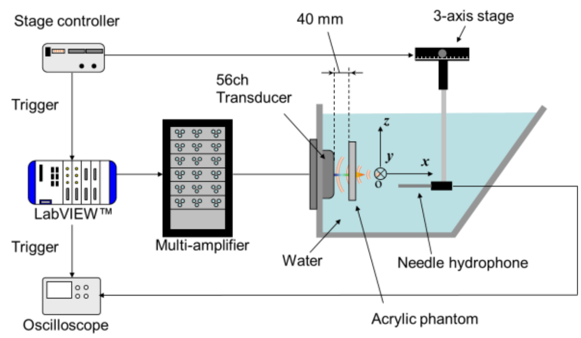


Fig. 2 Experimental setup

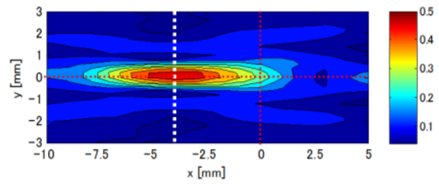
3. Results and discussion

3.1 Experiment using acrylic plate (without slits)

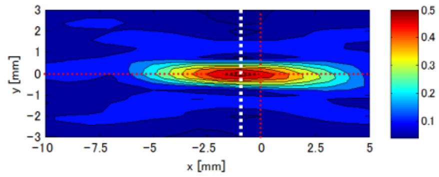
Experiments using the acrylic plate which is shown in Fig. 1 (a) were implemented. Installation angle between the acrylic plate and HIFU propagation direction were set at 0 and 20 degrees.

Fig. 3 shows acoustic pressure distribution in the case of 0 degree. In this case, focal point was displaced about -4 mm on x direction from geometrical focus. However, applying phase delays obtained by the simulation to the transducer elements, focal point was converged near the target.

In the case of 20 degrees as shown in **Fig. 4**, secondary and tertiary peaks were observed. Nevertheless, this method could realize good focus quality on the target as well as the case of 0 degree.

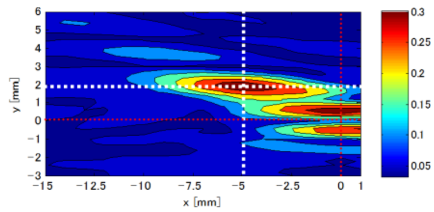


(a) Without control

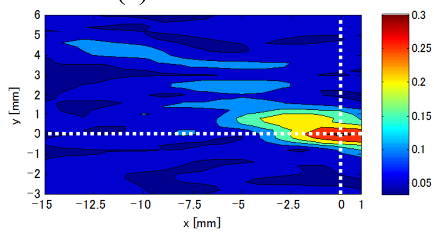


(b) With control

Fig. 3 Focus control using acrylic plate (0 deg.)



(a) Without control

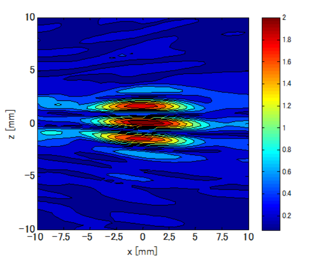


(b) With control

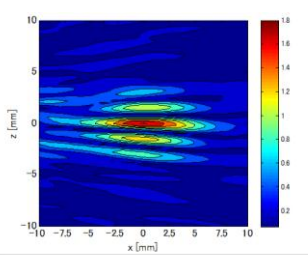
Fig. 4 Focus control using acrylic plate (20 deg.)

3.2 Experiment using slitted acryl (with slits)

Fig. 5 shows results of focus control for the slitted acrylic phantom which is shown in Fig. 1 (b). By phase control, the maximum sound pressures at the secondary peaks were relatively reduced by approximately 30 %. However, secondary peak could not be suppressed completely. Further consideration is necessary in the future.



(a) Without control



(b) With control

Fig. 5 Focus control using slitted acryl plate

3.3 Comparison of models in the simulation

Results in 3.1 and 3.2 were based on the simulation using fluid model which calculated only longitudinal wave propagation. However, actually, transverse wave also propagates in elastic body such as bone or acryl in addition to the longitudinal wave. Therefore, simulation based on elastic model which calculated both of transverse and longitudinal wave propagation was performed and compared with that based on fluid model.

Fig. 6 shows comparison of respective models in the case of 0 degree using acrylic plate phantom. In the case of elastic model, focal point was accurately converged on the target in contrast with the case of fluid model. This result suggests that phase error due to transverse wave was effectively corrected by the focus control based on the simulation using elastic model.

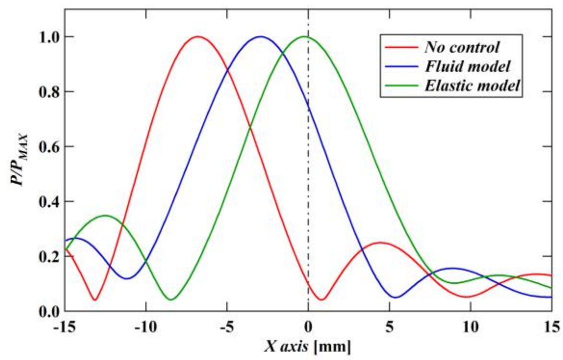


Fig. 6 Normalized pressure distribution on x axis

4. Summary

Effectiveness of the simulation aided focus control was estimated. The results of simulations and experiments suggest that this method could enhance focusing quality through heterogeneous media whose structure was known. Moreover, focal errors based on both fluid and elastic models in the simulation were estimated. The results of the simulations based on respective models suggest that elastic model could enhance accuracy of the focus control in contrast with fluid model. In the future, a new phase control method will be introduced and soft tissues such as fat, connective tissue, and muscle will be targeted as heterogeneous media.

References

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