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# Accuracy Enhancement of HIFU Beam Imaging

# 集束超音波ビーム可視化技術の高精度化に関する検討

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## 1. Introduction

High Intensity Focused Ultrasound (HIFU) has been considered as a non-invasive or minimally invasive medical procedure for precise tumor ablation such as prostate cancer, liver cancer, breast cancer, etc. [1]. The focused acoustic energy in human body is absorbed by tissue and is converted into heat so as to ablate tumors. We developed a HIFU beam imaging (HBI) method to monitor HIFU beams in real time during the HIFU exposure [2]. However, the HIFU beam intensity delivered into the tissue cannot be accurately estimated from the echo image by HBI, since HBI is subject to inhomogeneous scattering in the tissue. Therefore, HBI cannot reflect the real therapeutic effect. In this study, we introduce a new method to estimate the HIFU beam intensity from the echo image by canceling the inhomogeneous scattering. We validated this method by computer simulations.

## 2. System

The HIFU treatment system is shown in Fig. 1(a). Our system consists of a robot manipulator, a HIFU transducer that is integrated with a diagnostic ultrasound probe, and some control units.

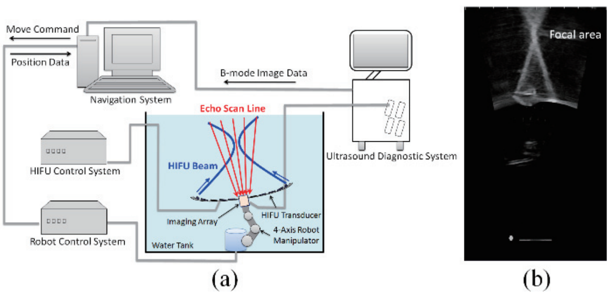


Fig. 1(a) HIFU treatment system configuration
(b) HIFU Beam Imaging (HBI)

The integrated transducer is mounted to the robotic end effector and its focus is adjusted and located to the target tumor by visual feedback.

Fig. 1(b) shows the echo image (B-mode) by HBI displayed on the ultrasound diagnostic system. The HIFU focal point and its beam path are imaged by HBI as follows: the HIFU transducer transmits the beams, and the diagnostic probe receives the reflected beams to form an echo image. As a result, the target tumor and the HIFU beam can be simultaneously imaged in real time.

## 3. Method

The method to estimate the HIFU beam intensity is explained in this section. To explain simply, one dimension case is considered. If the diffraction, absorption, and multiple scattering during the echo propagation can be neglected, the received echo intensity in HBI is expressed:

$$E(x_f, x) = I(x_f, x)S(x) \quad (1)$$

where $E(x_f, x)$ and $I(x_f, x)$ represent the intensity of the received echo and the delivered beam at position $x$ with the focal point being at $x_f$; $S(x)$ is the scattering coefficient at position $x$. $E(x_f, x)$ can be obtained directly from the echo image. $I(x_f, x)$ is what we want to get. However, $S(x)$ is also unknown, which brings difficulties in solving (1). The objective of our method is to obtain $I(x_f, x)$ by canceling $S(x)$. In our system, $x_f$ can be adjusted by adding the phase delay of the HIFU transducer. Therefore, we shift the focal point to position $x$ and we have:

$$E(x, x) = I(x, x)S(x) \quad (2)$$

$E(x, x)$ means the echo intensity at $x$ when the focal point is also at $x$. In (3), $I(x, x)$ is constant since the HIFU transducer's elements are assumed to be sufficiently small:

$$I_0 = I(x, x) \quad (3)$$

$S(x)$ can be canceled by calculating the ratio between (1) and (2):

$$\frac{I(x_f, x)}{I_0} = \frac{E(x_f, x)}{E(x, x)} \quad (4)$$

By this way, the HIFU beam intensity $I(x_f, x)$ can be estimated from (4).

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## 4. Simulation

The purpose of the simulation is to compare the theoretically calculated $I(x_f, x)$ and the $\hat{I}(x_f, x)$ estimated from (4). The simulation was performed on the x and y axis (one dimension), respectively, as shown in Fig. 3. The origin of the x-y coordinate system coincided with the geometric focus of the HIFU transducer. The echo positions were distributed from -2 to 2 with the interval of 0.08 and 0.04 on the x and y axis, respectively. The HIFU transducer emitted 2MHz, 3-cycle burst waves multiplied by the Hanning window. The acoustic velocity was 1540m/s. The HIFU transducer was composed of 256 elements, and the imaging probe was 128 elements. The scattering coefficient $S$ was set as:

$$S = \begin{cases} 0.3 & (-1 \leq x, y \leq 0) \\ 1 & (otherwise) \end{cases}$$

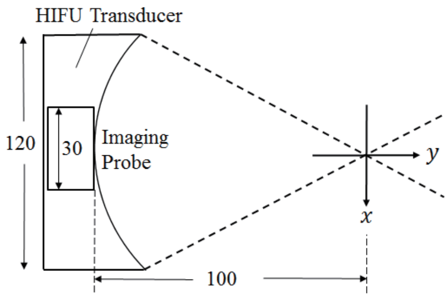


Fig. 3 Arrangement of a HIFU transducer and a linear array probe for the computer simulations.

In our simulation, the focal position of the $E(x_f, x)$ and $I(x_f, x)$ are fixed to the origin of the x-y coordinate. The $E(x, x)$, $E(x_f, x)$, $I(x_f, x)$, $I(x, x)$, $S(x)$ on each echo position can be calculated as follows:

・$E(x_f, x)$, $E(x, x)$

1. Every HIFU transducer's element emits the impulse to position $x$, and imaging probe receive the reflected impulses.
2. Calculating the transmission and reception time of the impulses, and synthesizing the impulse response on each imaging element.
3. Convolution of the impulse response and the burst waves emitted by the HIFU transducer.
4. Phasing addition is performed to calculate echo signals at $x$.
5. Calculating the absolute value at $x$ to obtain the $E(x_f, x)$ and $E(x, x)$.

・$I(x_f, x)$, $I(x, x)$

1. Every HIFU transducer's element emits the impulse to position $x$.
2. Calculating the transmission time of the impulse from the HIFU transducer's elements to $x$ to get the impulse response.
3. Convolution of the impulse response and the burst waves emitted by the HIFU transducer.
4. Calculating the absolute value at $x$ to obtain the $I(x_f, x)$ and $I(x, x)$

## 5. Results and Conclusion

Fig. 4 and Fig. 5 are results of the computer simulations. The results show that $\hat{I}(x_f, x)$ on x and y axis coincide with $I(x_f, x)$ on x and y axis, respectively. Therefore, we confirmed that $I(x_f, x)$ can be estimated from (4) by canceling $S$. In the future, this simulated method can be applied to phantom experiments.

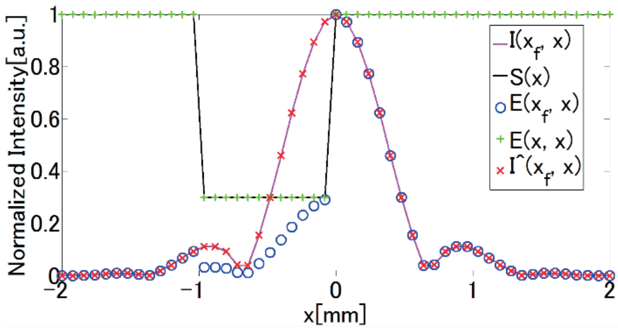


Fig. 4 Normalized intensity on x axis

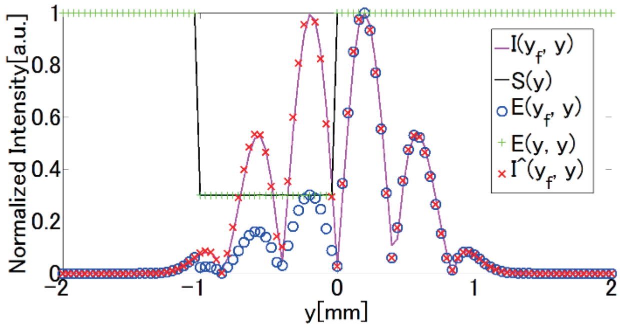


Fig. 5 Normalized intensity on y axis


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