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On the Optical Measurement of Focused Ultrasound Pressure Field

集束超音波音場の光学的計測に関する研究

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1. Introduction

An acoustic pressure field can be optically measured by a Schlieren method in a short time without disturbing the pressure field. This method is great advantages when compared with the measurement using a hydrophone. Recently, optical measurements have been applied to visualization of an instantaneous acoustic field by synchronizing pulsed illumination with ultrasound [1].

Because a typical optical method provides a projection image of the acoustic field, a reconstruction method such as a CT (Computed Tomography) algorithm is necessary to obtain the acoustic field quantitatively. However, the image provided by a Schlieren method does not have the sign and is not suitable for such reconstruction. Using subtraction between images with and without ultrasound instead of the optical stop used in a conventional Schlieren method, a signed projection image can be obtained.[2] But simple subtraction is not enough for an image applicable to a CT reconstruction algorithm [3] [4].

In this study, first, we corrected the subtraction image based on geometrical optics. Next, we applied a CT algorithm to the corrected image and reconstructed the 3D (three dimensional) ultrasound pressure field and compared with non corrected reconstruction.

2. Correction by Geometrical Optics

Fig. 1 shows how the optical phase modulation by ultrasound pressure results in an optical intensity modulation, based on geometrical optics. Assuming the ultrasound pressure field is a phase object and the refractive index is proportional to ultrasound pressure. In Fig. 1, I(x) is the optical intensity at x and I_0 is the background optical intensity. Here,

$$\frac{I(x)}{I_0} \cong \frac{R}{R-D} = \frac{1}{1-D/R} \qquad (1)$$

And,

$$-\int \frac{\partial^2 p(x,y)}{\partial x^2} dy \propto D \cdot \frac{\partial^2 f(x)}{\partial x^2} = \frac{D}{R}$$
$$\cong 1 - \frac{I_0}{I(x)} = \frac{I(x)-I_0}{I(x)} \qquad (2)$$

Therefore,

$$\int p(x,y)dy \propto -\iint \frac{I(x)-I_0}{I(x)} dxdx \qquad (3)$$

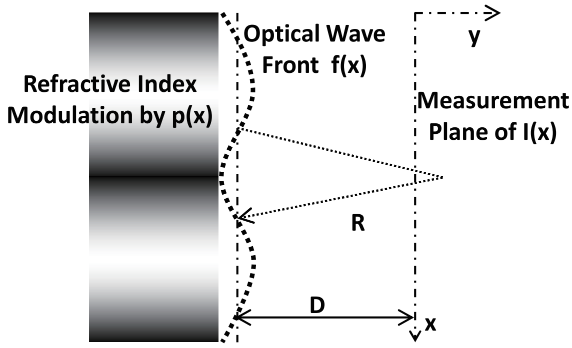

Fig. 1 Geometrical Optics

3. Materials and Methods

Fig. 2 shows the Schlieren optical system used in this study. This system consists of a spherical PZT ultrasound transducer (aperture and diameter: 72 mm, center frequency: 1.13 MHz), a crystal pulse laser as the light source (wave length: 532 nm, power: 4 kW, FDSS 532-Q2, CryLaS GmbH), a CCD camera (XCD-U100, SONY), a function generator (WF1974, NF), an RF amplifier (2100L, ENI), a water tank, a pair of Schlieren lenses (diameter: 150 mm, focal length: 1500 mm), and a convex lens (diameter: 3 mm, focal length: 3 mm). The light source and the ultrasound transducer were synchronously excited every 1 ms, and the shutter speed of the CCD camera was 1 ms.

First, 30 images with and without ultrasound exposure, respectively, were acquired and averaged. Letting I_{ON} and I_{OFF} denote the average images with and without ultrasound exposure respectively, by expression (3), the corrected subtraction image I is written as

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$$I = -\iint \frac{I_{ON} - I_{OFF}}{I_{ON}} dxdx \tag{4}$$

Next, a CT algorithm is applied for reconstructing the 3D ultrasound pressure field assuming cylindrical symmetry.

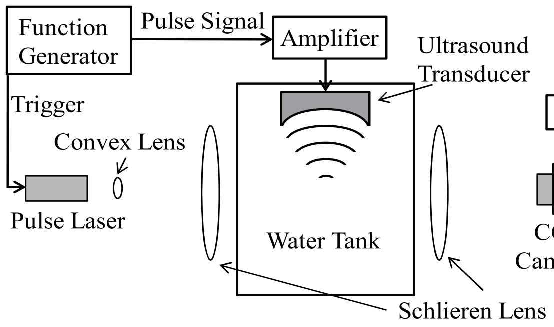

Fig. 2 Schlieren optical system

4. Results and Discussion

Fig. 3 shows the obtained corrected subtraction image. The ultrasound transducer was located at the right side of the image. A typical projection image of a focal ultrasound field is seen.

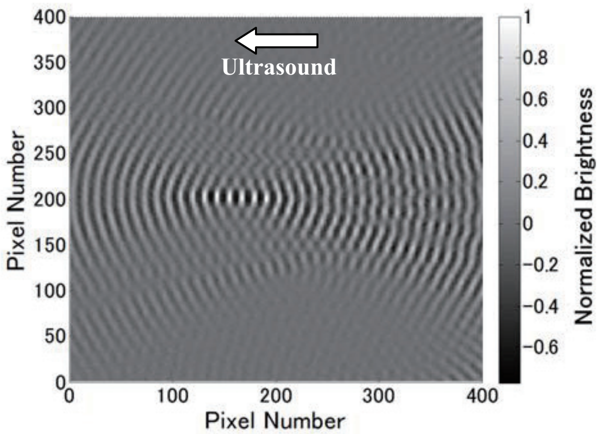

Fig. 3 Corrected Subtraction Image

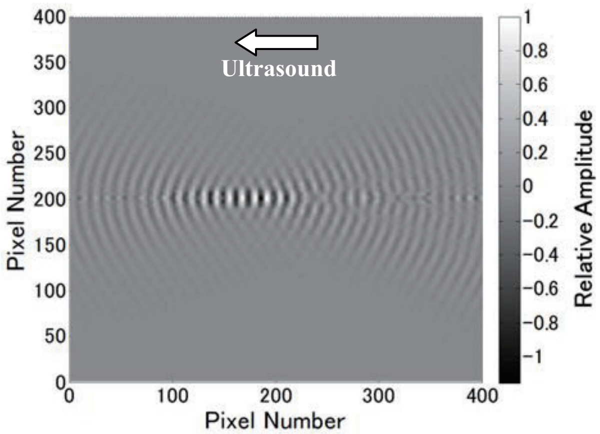

Fig. 4 Reconstruction Image

Fig. 4 shows the reconstructed relative amplitude distribution on the plane including the central axis of the transducer.

Fig. 5 shows the amplitude on the central axis. The amplitude without the geometrical optic correction is also plotted for comparison. Asymmetry in positive and negative amplitudes seen in the waveform without correction was reduced very well by the correction.

The acoustic power integral on planes perpendicular to the propagation was calculated. The integral was about the same in propagating, which is consistent with the smallness of the ultrasonic absorption in water.

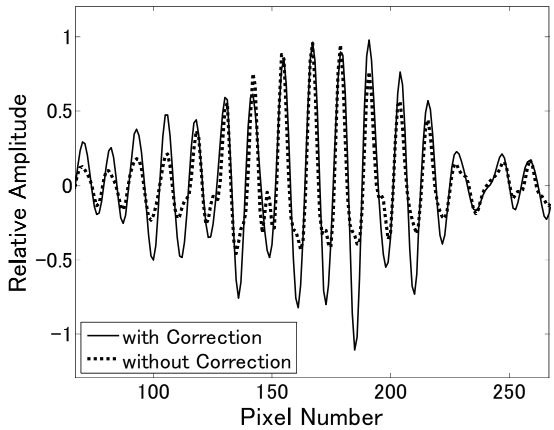

Fig. 5 Comparison between Corrected and non-Corrected Reconstruction

5. Conclusion

We reconstructed a 3D ultrasound pressure field from an optical image using a corrected subtraction method based on geometrical optics. The proposed geometrical optic correction was proved to be very effective to reduce the asymmetry in positive and negative pressure amplitudes seen without it, but further study is still needed for a reconstruction as quantitative as hydrophone measurement.

Acknowledgement

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