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Analysis of Therapeutic Ultrasound Pressure Field with Schlieren Optical System
シュリーレン光学系を用いた治療用超音波音場の解析

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1. Introduction

An acoustic pressure field can be optically measured as a Schlieren method in a short time without disturbing the pressure field, which are 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].

Since a projection image of acoustic field is obtained by an optical method, it is necessary for quantitative measurement to reconstruct the three dimensional acoustic field. It may be reconstructed with a CT (Computed Tomography) algorithm as used in X-ray CT. However, conventional Schlieren method can not be applied to a CT algorithm, because the conventional Schlieren images do not have phase information. Subtracting the image without ultrasound from that with ultrasound, the phase information can be obtained. The direct light component of the image can be used as the reference light to restore the phase of the diffracted light component in the subtraction image.[2][3].

In this study, we compared subtraction Schlieren images with conventional Schlieren images, and discussed the usefulness of the subtraction Schlieren method to measure an acoustic field quantitatively.

2. Principle of Measurement that Keeps Phase Information

Brightness I_1 measured by a conventional Schlieren method with a stop is

$$I_1 = A_{diff}^2 \qquad (1)$$

where A_{diff} is the diffracted light component. We can not obtain phase information from I_1. Brightness I_2 measured by a subtraction Schlieren method is

$$I_2 = I_{ON} - I_{OFF} \qquad (2)$$

where I_{ON} and I_{OFF} is the brightness obtained without a Schlieren stop with and without ultrasound exposure, respectively, and written as

$$I_{ON} = (A_{diff} + A_{nondiff})^2 \qquad (3)$$

$$I_{OFF} = A_{nondiff}^2 \qquad (4)$$

here $A_{nondiff}$ is the direct (non-diffract) light component. Using Eq. (3) and Eq. (4) in Eq. (2) gives

$$I_2 = A_{diff}^2 + 2A_{diff}A_{nondiff} \qquad (5)$$

Therefore, we can obtain amplitude with phase information from Eq. (5)[4].

3. Materials and Methods

Fig. 1 shows the Schlieren optical system used in this study. When the subtraction Schlieren method was tested, the slit knife edge was not used. 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-V60, SONY), a function generator(WF1974, NF Co.), an RF amplifier(MODEL 2100L, ENI), a water tank, a knife edge(slit type), a pair of Schlieren lenses, and two convex lenses (ϕ : 3 mm, f : 3 mm and ϕ : 50 mm, f : 300 mm, respectively, from the side near the light source.).

We drove the light source and the ultrasound transducer synchronously. The drive signal of the light source was delayed using the function generator. By doing this, we can measure a specific wave front of ultrasound. The ultrasound exposure was 5 cycles long and the pulse laser was excited every 1 ms. The shutter speed of the CCD camera was 3 ms, thus the CCD averaged 3 images each time.

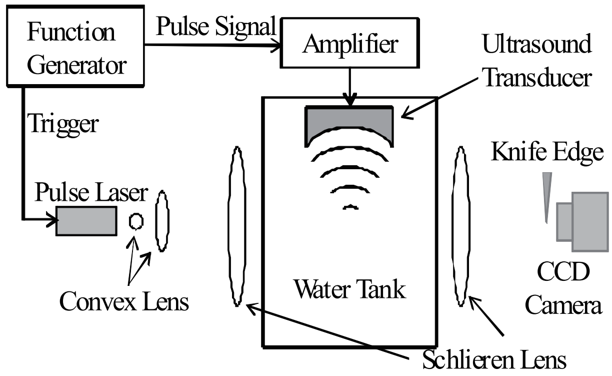

Fig. 1 Schlieren Optical System

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We took 50 images respectively with and without ultrasound, and averaged these images to obtain a subtraction Schlieren image. The obtained image was compared with a conventional Schlieren image, obtained similarly as an average of 50 images taken.

4. Results and Discussion

Fig. 2 and **Fig. 3** show the results of subtraction and conventional Schlieren measurement respectively. The ultrasound transducer was located at the far right side in both images. The focal ultrasonic field was seen.

Fig. 2 also shows interference pattern in the background. The interference pattern comes from fluctuation by direct light component, which we could not completely eliminate.

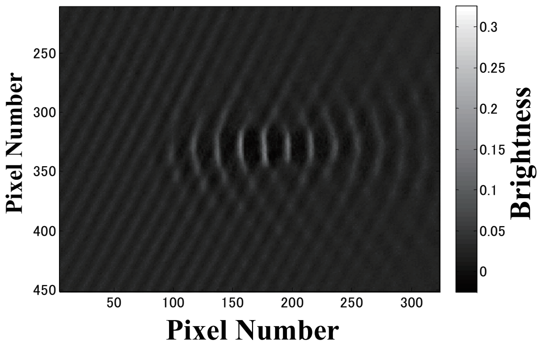

Fig. 2 Subtraction Schlieren Image of Focused Ultrasound

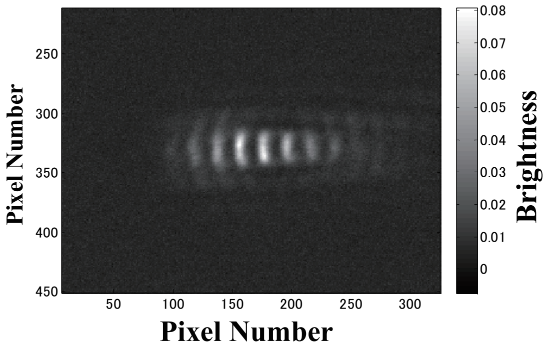

Fig. 3 Conventional Schlieren Image of Focused Ultrasound

Fig. 4 shows brightness distribution of Fig.2 and Fig. 3 at center axis of the transducer. The conventional Schlieren image has approximately the same height of brightness peaks as the subtraction Schlieren image in the focal zone. However, the brightness peaks are clearly higher in the subtraction image than in the conventional both in front of and beyond the focal zone. This is probably because the peak heights are proportional to the pressure in the subtraction images while they are proportional to the intensity in the conventional images. A part of the diffract light would have been cut off by knife edge in the conventional Schlieren method. This may have also affected the conventional images.

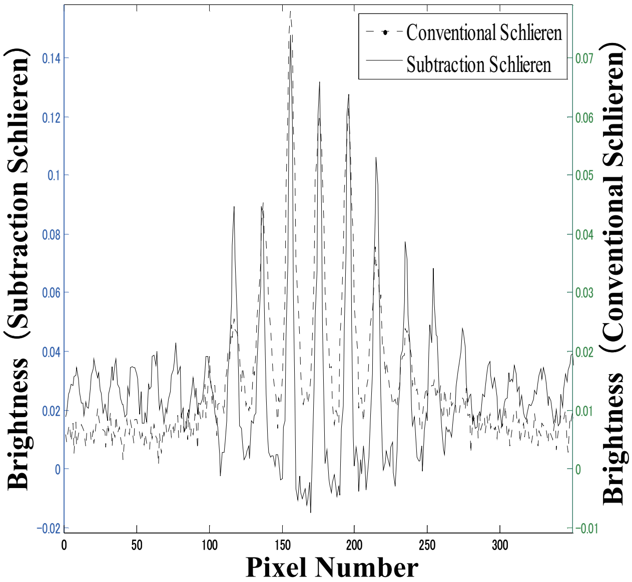

Fig. 4 Comparison of Subtraction and Conventional Schlieren Image (at Center Axis of Transducer)

5. Conclusion

The overall brightness distribution was similar in both subtraction and conventional Schlieren images in the ultrasonic focal zone, but significant difference between them was observed both in front of and beyond the focal zone. Further study is needed to apply the proposed method to reconstruction of a three dimensional acoustic field.

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