Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 397-398
3-5 December, 2014

Optical Methods for Visualization of Ultrasound Fields
光学的手法による超音波音場の可視化

Nobuki Kudo† (Grad. School Info. Sci. ＆ Tech., Hokkaido Univ.)
工藤信樹† (北大院 情報科学)

1. Introduction

In the field of biomedical ultrasound, measurement of acoustic fields is important not only for quality control of products but also for ensuring safety of ultrasound diagnosis and therapy. In the measurement of diagnostic ultrasound fields, a membrane hydrophone is the gold standard for measuring a pressure field distribution. However, in the measurement of therapeutic ultrasound fields, higher intensity ultrasound prevents the use of a friable hydrophone, and optical methods, including Schlieren and shadowgraph techniques[1)], are used as alternative methods for evaluation of ultrasound fields.

In this manuscript, optical techniques that are widely used for visualization of the inhomogeneous distribution of refracted index in a transparent medium are briefly described, and a new simple method that can be used for visualization of ultrasound fields is introduced.

2. Schlieren and shadowgraphy

When light propagates inside a transparent object with an inhomogeneous distribution of the refractive index, the phase of light that transmit through this phase object is modulated according to a local difference in the light speed, and light changes its direction according to the change in the angle of the wave front. The deflection angle of the light increases with an increase in the first order spatial derivative of the refraction index. This basic principle is the same for both Schlieren and shadowgraphy techniques, but practical optical systems are different.

Figure 1 shows a typical optical system used for the Schlieren technique. Light from a point light source is collimated by the first lens, and the collimated beam that transmits through the phase object changes its direction. The second lens converges the light to its focus. The light not deflected in the phase object is eliminated by the optical stop placed at the focus, and other light deflected in the phase object make a Schlieren image. Sensitive detection can be achieved by this elimination of non-deflected light.

Shadowgraphy has a simpler optics as shown in **Fig. 2**. Collimated light is deflected by a phase object and then just projected on a screen placed behind the phase object. Light deflection causes displacement of light incident on the screen and results in an inhomogeneous brightness distribution, i.e., shadow. This technique is less sensitive than the Schlieren technique because it has no function to eliminate non-deflected light. The simple optical system enables application of shadowgraphy for visualizing a large-scale phase object such as a shockwave field generated around an airplane flying at supersonic speed.

Visualization of an ultrasound field is one of the important applications of the Schlieren technique. A continuous ultrasound field works as a phase grid, and a time-independent diffraction pattern is produced at the focus plane of the second lens. Non-deflected light and 0-th order diffraction light are eliminated by the optical stop, and a visualized image that represents the envelope of the ultrasound wave can be visualized. Use of the time-independent diffraction pattern enables visualization of propagating ultrasound without synchronization. The shadowgraph technique also visualizes ultrasound fields; however, synchronization is essential to obtain an instant pressure distribution. On the other hand, a pulsed

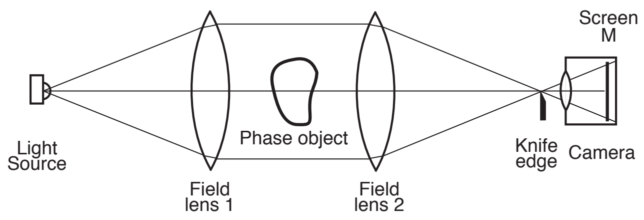

Fig. 1. Optics for the Schlieren technique.

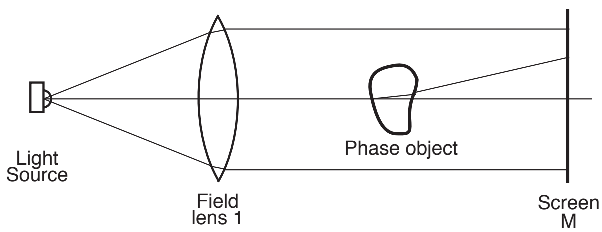

Fig. 2. Optics for the shadowgraph technique._

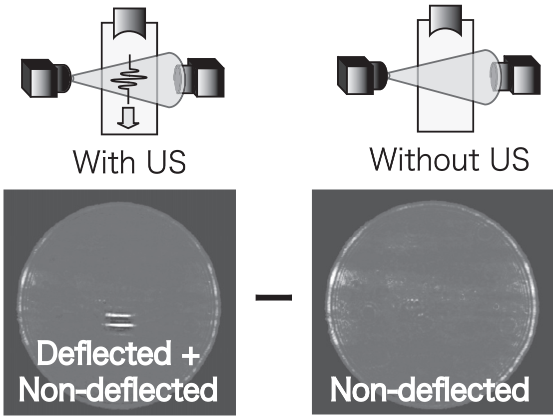

Fig. 3. Basic concept of the image subtraction Schlieren technique.

ultrasound field can be visualized because shadowgraphy does not use light diffraction.

3. Image subtraction Schlieren technique

A simple method for visualization of medical ultrasound fields was proposed in our previous reports[2–4]. The technique uses an optical system similar to that used for shadowgraphy, but the screen is replaced by a camera of which the focus is set to just behind the ultrasound field. The basic concept is shown in **Fig. 3**. Two shadowgrams are taken with and without ultrasound exposure, and subtraction of the image without ultrasound exposure from that with ultrasound exposure realizes sensitive detection. It is difficult to produce a Schlieren image by a simple processing of shadowgrams because they have lost information on incident light angle. However, light deflected by an ultrasound field can be easily detected using image subtraction because detection of light displacement does not require information on light incident angle.

Figure 4 shows the instantaneous pressure field of a short-pulsed ultrasound beam used for diagnostic ultrasound[5]. Red and blue color regions represent those of positive pressure and negative pressure, respectively.

4. Conclusion

The proposed technique cannot replace hydrophone measurement because quantitative evaluation of the images is still under discussion. However, we believe that the simplicity of the method opens up a wide range of applications in the research field of ultrasound application.

Acknowledgment

This study was supported by JSPS KAKENHI Grant Number 23300182.

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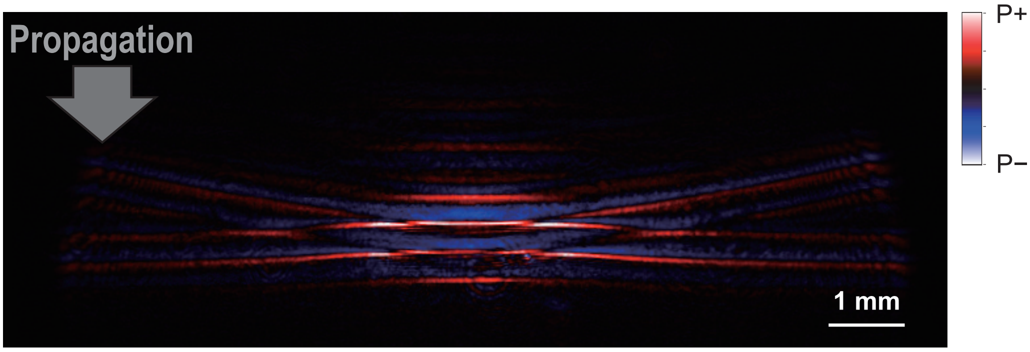

Fig. 4. Instantaneous ultrasound field of a diagnostic ultrasound pulse of 3.5 MHz in center frequency.