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A New Ultrasonic Imaging Sensor Using Fabry-Perot Interferometer and High-Speed Camera

Fabry-Perot 干渉計と高速撮影カメラを用いた超音波イメージングセンサ

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1. Introduction

Mapping ultrasound fields in water for imaging purposes is most commonly achieved by piezoelectric detectors. Because the sensitivity of detectors falls off with decreasing element size, this becomes a specific limitation of piezoelectric detectors. Additionally, in the case of systems based on a piezoelectric detector mechanically sacnning, acquisition speed can be unacceptably low, while the use of a 2D array of detectors to overcome this limitation is prohibitively expensive.

Optical ultrasound detection techniques may offer a potential to overcome those limitations [1]. A promising technique is based on the detection of acoustically induced changes in the thickness of a Fabry-Perot interferometer (FPI). A FPI based ultrasonic sensor can provide broadband frequency responses of several tens of megahertz, optically element size of a few tens of micrometers and high sensitivity, comparable to those of piezoelectric detectors. A rapid data acquisition approach is that illuminating the sensor with laser pulse and the acoustic field can be mapped in parallel at discrete time intervals using a 2D CCD array. The concept is notionally similar to that of an acoustic camera taking snapshots of the acoustic field [2]. It samples signals of acoustic field by switching the laser irradiation, which is not easy to realize high frequency sampling such as megahertz. Then, we proposed a new approach, which illuminates the sensor with a large diameter CW laser beam and utilizes high-speed camera to sample the signals with shutter of the high-speed camera.

2. Method

FPI is typically made of two parallel highly reflecting mirrors. The varying transmission function of FPI is caused by interference between the multiple reflections of light between the two reflecting surfaces. Constructive interference occurs if the transmitted beams are in phase, and this corresponds to a high-transmission peak of the FPI. If the transmitted beams are out of phase, destructive interference occurs and this corresponds to a transmission minimum. Interferometer transfer function (ITF) of the FPI as a function of phase difference Φ, is shown in **Fig.1**. An incident acoustic wave modulates the optical thickness of the FPI, producing an optical phase shift $d\Phi$ and resulting in a corresponding reflected intensity modulation dI_R [3].

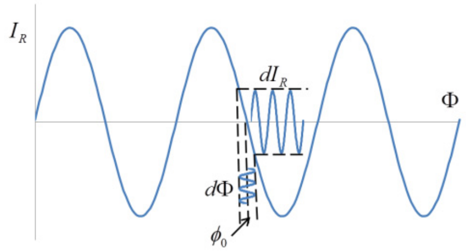

Fig.1 Interferometer transfer function of the FPI.

A schematic of the FPI based ultrasonic imaging sensor is shown in **Fig.2**. It comprises a glass backing stub onto which a thin polymer (Parylene C) film spacer sandwiched between the dielectric multilayer mirror and the golden coating mirror is deposited in order to form the FPI. An antireflective (AR) coating is deposited over the entire structure to reduce reflection form first mirror and to protect the external FPI sensor from damage due to abrasion or water ingress.

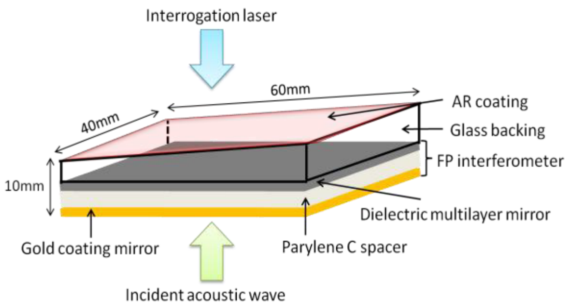

Fig.2 FPI based ultrasonic imaging sensor head.

When interrogation laser wavelength is swept,

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the wavelength dependent ITF can be obtained as a function of wavelength. To obtain maximum sensor detecting sensitivity, it is necessary to optimally bias the sensor by tuning the interrogation laser wavelength so that it corresponds to the point of maximum slope on the ITF. This procedure must be performed at each point of sensor. For each sensor point biased, the sensor is said to be optimally biased and the signal of incident acoustic wave can, in principle, be obtained as the interrogation laser intensity changes.

3. Experimental results

The practical implementation of the acoustic field mapping system is shown in **Fig.3**. A 5mm diameter tunable laser source (TLS) laser (TL780-B, Thorlabs Inc.) beam illuminates the sensor and the beam reflected from the sensor is imaged onto a high-speed camera (Phantom V710, Vision Research Inc.) with 128 x128 elements (2.56 x 2.56 mm^2). The interrogation laser wavelength is swept with an interval of 30 pm from 786.8 nm to 789.8 nm. The sensor is mounted on the top of a full water tank and a focused 1 MHz PZT transducer (v314-su, OLYMPUS Inc.) is situated near the focus length of 25.4 mm. The transducer is driven by a waveform generator and a power amplifier at a repetition rate of 1 kilohertz. The pulse generator is trigged by waveform generator and a time delay Δt (= N * 125 ns, where N is 0, 1, 2, …) introduced in order to synchronize the timing of recording image after the emission of the acoustic wave, which means sampling the signal of acoustic wave by using shutter of the camera. The reflected beam is also incident on a single photodiode and the output of photodiode is recorded by a digitizing oscilloscope to correct the variation of the output of laser. All data of camera and oscilloscope are downloaded to a note personal computer via local area network.

The achieved sampling frequency is 8 MHz and the exposure time of camera is 294ns, which is the minimum settable value but 2.5 times longer than sample interval, leads to the sensor detection sensitivity decrease. **Fig.4** shows the signal waves detected by the FP sensor is in agreement with that detected by the hydrophone previously. The corresponding acoustic field distribution induced by the transducer at positive peak (A: t=20.125μs) and negative peak (B: t=19.625μs) are depicted in **Fig.5** left and right, respectively. The reconstructed acoustic field distribution appears as a circular region of uniform amplitude, which being characteristic of the planar nature of the wavefront at the focus of the acoustic field. The diameter of this region is approximately 5mm.

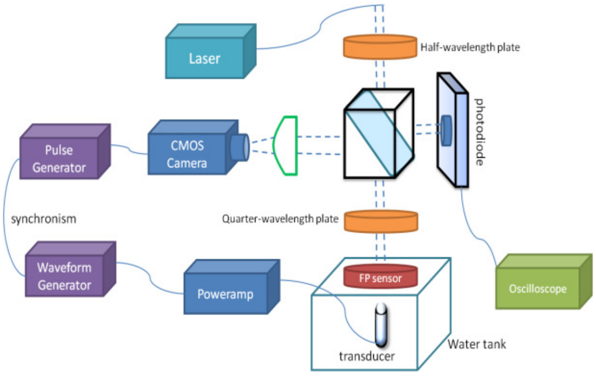


Fig.3 Acoustic field mapping system based on FPI ultrasonic imaging sensor and high-speed camera.

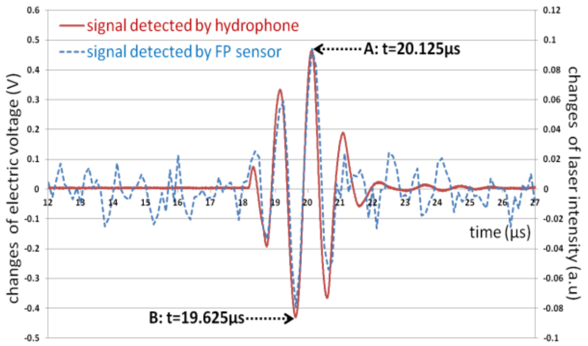
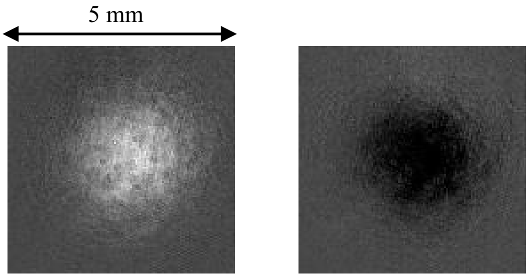


Fig.4 Signal waves detected by hydrophone and FPI based ultrasonic imaging sensor.



A: t=20.125μs B: t=19.625μs

Fig.5 Reconstructed acoustic field distribution.

4. Conclusion

A method of Acoustic field mapping using FPI based ultrasonic imaging sensor and high-speed camera has been successfully demonstrated by imaging the acoustic field at the focus of a pulsed 1 MHz PZT transducer. This approach offers an alternative to piezoelectric based methods for high resolution biomedical and industrial ultrasonic imaging.

References

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