Keywords: zone plate interferometer, liquid crystal panel, compensation method, systematic error, shape measurement, common path interferometer, phase shift method

Introduction
Common path interferometers are key devices for shape measurements of optical elements and precision machine parts. A zone plate interferometer is a type of common path interferometer, in which wavefronts generated by a diffraction grating called the zone plate are used as a standard surface for measurement. In other words, the zone plate functions as a null lens. The production process of the zone plate is simpler than the manufacturing process of a null lens because the zone plate pattern is obtained from calculations using geometric conditions and because it is possible to manufacture the zone plate by optical lithography. However, custom-made zone plates are required in order to measure various shapes.

We proposed the use of the pattern displayed on the liquid crystal panel as a diffraction grating. As a result, an interference fringe showing the shape of the plane mirror was obtained. The interference fringes were analyzed by the phase shift method. However, use of the liquid crystal panel resulted in measurement error, since it was not designed specifically for use with the interferometer. In this paper, a method of reducing the measurement error is proposed.

Zone plate interferometer
Figure 1 shows a schematic diagram of the zone plate interferometer with a liquid crystal panel. The zone plate is illuminated by a laser light source. The light beam passing through the liquid crystal zone plate functions as a measurement light beam. The light beam diffracted by the zone plate on the liquid crystal panel functions as a reference light beam. The measurement light beam reflects off the surface being tested and is distorted by the error in the shape of the surface being tested. The reference light beam reflects off the center of the surface being tested and is not influenced by the surface being tested because the reflecting area is very small. The measurement light beam and the reference light beam pass and diffract again at the liquid crystal zone plate. Both light beams converge on a small spot at the aperture stop. Unnecessary light beams are removed almost completely by the aperture stop. Interference fringes are obtained on
the image plane of the charge-coupled device (CCD) camera. The interference fringes include measurement error caused by the shape error and configuration error of the optical elements constituting the interferometer. The method of compensation of the error caused by the heterogeneity of the liquid crystal panel is described in the next section.

Method of the compensation
Compensation of the error is carried out by rewriting the pattern displayed on the liquid crystal panel. In other words, the light beam diffracted at the pattern can be controlled. An error map is not made for compensation of the measured value on the interferometer. The procedure for the compensation is as follows.

1) It is assumed that the interferometer does not have error and the original pattern of the zone plate is calculated. An example of an original zone plate is shown in Fig.2.

2) A known shape is measured by the zone plate interferometer using the original pattern of the zone plate.

3) The difference between the known shape and the measured shape is regarded as the systematic error of the interferometer. A modulated pattern is designed in order to compensate the error. Figure 3 shows an example of a modulated zone plate.

In the method of correcting the measured value using the error map, the light beam is distorted during the measurement. However, in the proposed method, the light beam distortion has been corrected. Figure 4 shows the process in which the corrected reference light beam is generated from the light beam distorted by the modulated zone plate.

Liquid crystal panel
Experiments were conducted using a liquid crystal panel, as shown in Fig.5. The specifications of the liquid crystal panel are as follows. The panel (KOPIN Cyber Display 320 Monochrome) with 320 x 240 pixels and thin film transistors was used. Each pixel was addressed by the active matrix method. The interval between adjacent pixels, both horizontal and vertical, was 15 μm. The gray level of the display of the panel was over 256.

Experimental results
Experiments were carried out to confirm the validity of the proposed method. The error of the liquid crystal panel was estimated using a plane mirror with an accuracy of \( \lambda/20 \). The experimental results showed that the error caused by the nonuniformity of the liquid crystal panel can be corrected by the proposed method.

Conclusions
In this paper, a method of reducing the measurement error caused by the nonuniformity of the liquid crystal was proposed. The experimental results established the validity of the proposed method.
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References


Fig.1 Schematic diagram of zone plate interferometer with a liquid crystal panel

Fig.2 Original zone plate
Fig. 3 Modulated zone plate

Fig. 4 Compensation of the distorted reference light beam by the modulated zone plate

Fig. 5 Liquid crystal panel