One-Shot Digital Holography Using Polarization Imaging with a Pixelated Micro-Retarder Array

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ABSTRACT
A new approach to simultaneous acquisition of phase-stepped interferograms using a CCD camera equipped with a pixelated micro-retarder array is proposed for digital holography. An optical setup of a polarization interferometry is constructed to record a hologram. Light emerging from the interferometer is recorded using a CCD camera that has micro-retarder array on the CCD plane. This micro-retarder array has four different principal directions. That is, an image obtained by the CCD camera contains four data corresponding to four different optical axes of the retarder. The four images separated from the image recorded by the CCD camera are reconstructed using gray level interpolation. Then, the distributions of the Stokes parameters that represent the state of polarization are calculated from the four images. This method is applicable to time-dependent phenomena because multiple exposures are unnecessary for sufficient data acquisition in the completion of phase analysis.

INTRODUCTION
Digital holography is becoming a popular technique in the fields not only of experimental mechanics but of optical information processing [1-4]. Phase-shifting technique is usually used for obtaining reconstructed images efficiently and accurately. However, the phase-shifting technique requires more than three images for a fully complex field. That is, the current phase-shifting method has the disadvantage of a time lag during phase-shifting and acquisition between phase steps. This means that the current techniques cannot be applied to time-variant problems such as mechanics of vibrating objects or time-dependent materials. Recently, some techniques have been proposed for reducing images for phase-shifting digital holography [5,6]. However, it is not yet possible to record phase-stepped images simultaneously in a single frame.

This paper presents a new instantaneous phase-shifting technique for digital holography using a CCD camera that equips a pixelated micro-retarder array. An optical setup of polarization interferometry using a Twyman-Green type interferometer with two retarders is constructed to record a hologram. Light emerging from the interferometer is recorded using a CCD camera that has the micro-retarder array on the CCD plane. This micro-retarder array has four different principal directions. That is, an image obtained by the CCD camera contains four types of information corresponding to four different optical axes of the retarder. The four images separated from the image recorded by the CCD camera are reconstructed using gray level interpolation. Then, the reconstructed image is obtainable from the separated images using Fresnel diffraction integral.

CCD CAMERA WITH A PIXELATED MICRO-RETARDER ARRAY
Figure 1 portrays a CCD camera configuration with a pixelated micro-retarder array [7,8]. Many sets of four (2 × 2) micro-retarders with uniform retardation values, whose fast axes subtend four different angles, form the large array on the polarizer and the CCD, as shown in this figure. The size of a single micro-retarder is equivalent to a single pixel of the CCD. The micro-retarder position is aligned with the CCD sensors. A single CCD sensor detects the intensity of light that passes through a single retarder with a specific angle of the fast axis. Then, the four light intensity distributions corresponding to the four retarders are obtained as a single image. Spatial reso-
olution of each light intensity distribution is reduced to one-fourth of the CCD’s resolution. In addition, the spatial positions of the four light intensity distributions do not mutually correspond. Therefore, light intensities other than the angle of the retarder at the point are determined from light intensities at the neighboring points using interpolation such as bilinear or bicubic interpolation methods. This study employs a bilinear interpolation method. Then, the four light intensity distributions whose respective sizes are equivalent to the CCD are obtained by a single exposure. The four light intensity distributions are therefore phase-stepped images, similar to those obtained in other phase-shifting methods.

Figure 2 shows microscopic photographs of the part of the pixelated micro-retarder array that is produced using a micro-fabrication technology [9]. A 10-mm-thick polarizer is placed on the CCD with 640 × 480 pixel resolution and 7.4 μm × 7.4 μm pixel size. For the retarder shown in this figure, the subwavelength structure with a period of 300 nm is made of TiO2 on a silica substrate. The grating thickness is 1.03 μm and the single retarder area is 7.4 μm × 7.4 μm. The phase retardation of the retarder is controllable by the groove depth and the duty cycle of the grating. The optical axis coincides with the grating direction. The optimized combination [10] of the retarders with the retardation of 2.30 rad, whose fast axes make angles of ±0.264 rad and ±0.902 rad with the optical axis of the polarizer, for polarimetry is used for designing the micro-retarder array in this study.

**EXPRIMEMNT & RESULTS**

Figure 3 shows an optical setup used in this study for recording a hologram. Both two orthogonal polarizations, that is, an object beam and a reference beam are recorded using the CCD camera equipped with a pixilated micro-retarder array. Figure 4 shows an example of the light intensity distribution obtained by the CCD camera with the micro-retarder array. From this image, the phase and amplitude distributions at the CCD plane are obtained. Then, the reconstructed image is obtainable from the separated images using Fresnel diffraction integral. Figure 5 shows an example of the reconstructed image of a dice. The spots mark on the dice surface are recognized from this figure.
CONCLUSIONS

An instantaneous phase-stepping method for digital holography using a CCD camera with a pixilated micro-retarder array is proposed. It is emphasized that this method is applicable to time-variant problems because multiple exposures are unnecessary for sufficient data acquisition. The authors appreciate the financial support by the Grant-in-Aid for Encouragement of Young Scientists from the Japan Society for the Promotion of Science.

REFERENCES