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Calibration of Pizeo Rotation Nano-positioning Stage by Digital Holography System

Yan Hao[a,]*, Anand Asundi[a]

[a]*School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore,639798*

Abstract

Pizeo rotation nano-positioning stage is used in many optics areas duo to its nano scale movement ability. But its Hysteresis loop trace influences it movement linearity and accuracy. In this paper, calibration of pizeo rotation nano-positioning stage is performed by digital holography (DH) technique. A hysteresis phenomenon is observed. The accuracy of the movement is tested. During the calibration, the axial measurement resolution and accuracy of digital holography is also demonstrated.

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Keywords: digital holography; nano stage; calibration..

1. Introduction

Pizeo rotation nano-positioning stage is used in many areas duo to its nanometer scale movement capability. However its trace suffers Hysteresis loop which influences it movement linearity and accuracy. Therefore calibration is necessary for precise positioning. Digital holography (DH) technique [1-3], by coding complex amplitude of object field in to interference pattern, can provide the accessibility to quantitative amplitude and phase information. The quantitative phase information can be used to measure axial (out of surface) displacement with tens of nanometer resolution. This capability can be used to calibrate rotation nano-positioning stage. In this paper, commercial rotation stage is used, which can provide two arc minutes of piezoelectric control with a resolution of 1 arc second. The calibration by digital holography in reflection mode is performed. A hysteresis phenomenon is observed. The accuracy of the movement is tested. At the same time, the measurement resolution, accuracy of digital holography is demonstrated.

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx .

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2. Digital Holography

In digital holography, hologram is sampled by a high resolution CCD array and the intensity of it is transferred into a computer as an array of numbers[4]. The recorded intensity distribution of hologram is multiplied by the digital reference wavefield in the hologram plane and the diffracted field in the image plane, which is another numerical array of complex numbers, is determined by the usual Fresnel-Kirchoff integral to calculate the intensity and the phase distribution of the reconstructed real image array[1-3]. Numerical reconstruction could be performed by Fresnel transform, Huygens convolution, and angular spectrum methods[5].

According to angular spectrum reconstruction method[6], The reconstructed image $\Gamma(\xi,\eta)$ of DH is:

$$\Gamma(\xi,\eta)=\Im^{-1}\left\{\Im\left\{H(x,y)\cdot R(x,y)\right\}\cdot G(\upsilon,\mu)\right\} \tag{1}$$

where $H(x,y)$ is digital hologram, $R(x,y)$ is the reference wave, $\Im$ and $\Im^{-1}$ represent Fourier and inverse Fourier transform and $G(\upsilon,\mu)$ is the transfer function:

$$G(\nu,\mu)=\Im\left\{g(x,y)\right\}=\exp[i2\pi\frac{d}{\lambda}\sqrt{1-(\lambda\nu)^2-(\lambda\mu)^2}\,] \qquad \nu^2+\mu^2<\frac{1}{\lambda} \tag{2}$$

The reconstructed image $\Gamma(\xi,\eta)$ is the complex wave front at the image plane. Its phase contains the height profile information of the object. In reflection mode, the height profile image $Height(\xi,\eta)$ can be derived from $\Gamma(\xi,\eta)$ as Eq. (3)

$$Height(\xi,\eta)=\frac{1}{2}\times\frac{\lambda}{2\pi}\times Phase\{\Gamma(\xi,\eta)\} \tag{3}$$

where $Phase\{\Gamma(\xi,\eta)\}$ calculate the phase of $\Gamma(\xi,\eta)$.

3. Experiment Process

In experiment, we use NanoFlexTM rotation stage and mount a mirror on the 20mm×20mm top plate as a sample. The stage provides ±1 arcminute of piezoelectric control with a resolution of a arcsecond. The internal piezoelectric actuator requires a voltage from 0 to 75V. When driving voltage increase from 0 to 75V, the stage rotation angle changes from 0 to 1 arcminute.

The off-axis reflection DH set-up used in experiment is as seen in Fig. 1. One laser beam is divided into two parts by beam splitter. One illuminates the sample mirror on the piezo rotation stage and the other illuminates the reference mirror. Both are reflected back and arrive at the CCD to produce hologram. The lens used in the setup is to collimate light wave. The inset indicates an off-axis geometry. We take holograms at different rotation angles of the stage. By reconstruction we can acquire the height profile of the sample mirror and therefore calculate the slope and the rotation angle of the rotation stage.

4. Experiment Results

In experiment, we take 5 groups of data. In each group we increase the driving voltage from 0 to 75V and then decrease it from 75V down to 0V. In both voltage increasing and decreasing process, we take holograms at 11 voltage points which are 0, 5, 7.5, 15, 22.5, 30, 37.5, 45, 52.5, 60, 67.5, 75V respectively. Therefore we stop at 22 voltage points and get 22 holograms at in each group.

Figure 2 (a), (b), (c) and (d) shows examples of the height map at 7.5V, 22.5V, 52.5V, 75V respectively. We take a height profile of the same line segment in all the height maps at different voltages. This line is vertical to contour line and in the direction of the maximum slope. The length of this line segment is 3.45µm. Fig. (e) shows the height profiles of these lines in (a), (b), (c) and (d) from bottom to top respectively. From these height profiles, nano-positioning stage rotation angles at different driving voltages can be derived.

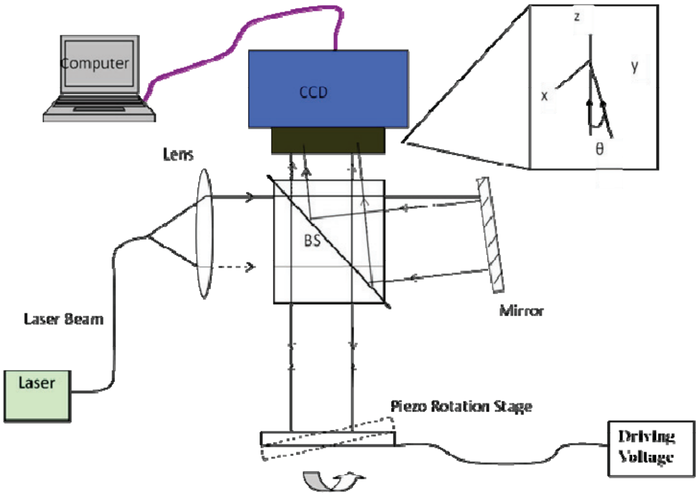

Figure 1 Reflection DH set-up.

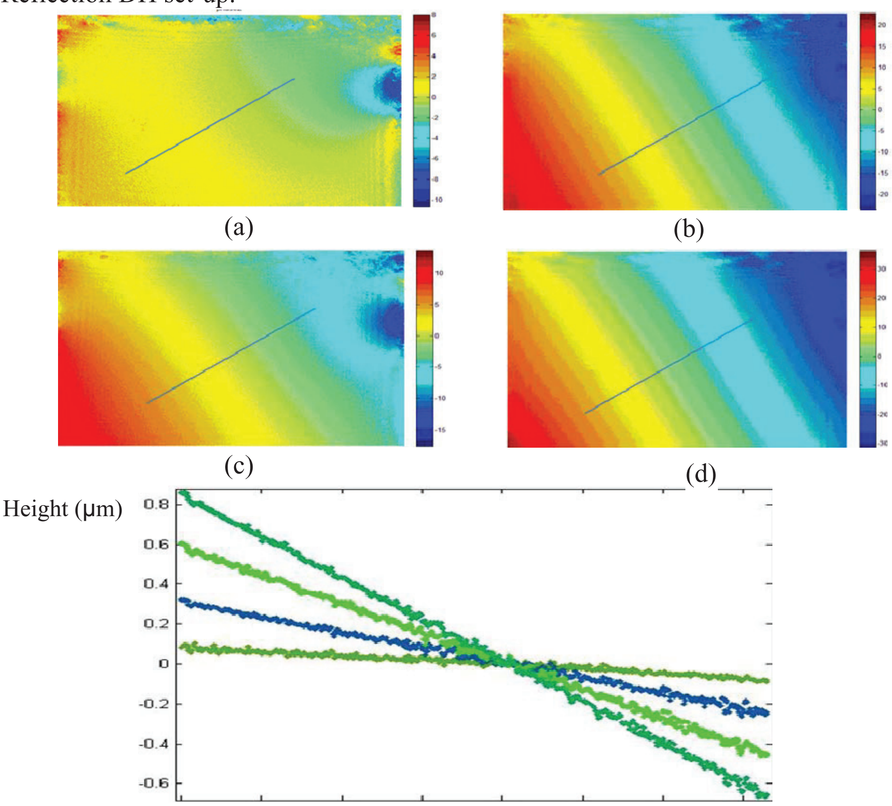

Figure 2 reconstructed phase map at (a) 7.5V, (b) 22.5V,(c) 52.5V, (d) 75V; (e) are the height profile along the black line in (a), (b), (c) and (d). From bottom to top are profiles from(a), (b), (c) and (d) respectively.

We totally perform the experiment five times. Mean and variance of the each rotation angle at each driving voltage is calculated among five data sets as seen in Fig. 3. The relation between rotation angle and driving voltage is shown is presented. The green line shows the rotation angles on the voltage decreasing line with deviations as deeper green triangle markers. The blue line shows the rotation angles on the voltage increasing line with deviations as lighter purple triangle markers. Hysteresis phenomenon is clearly observed and quantified. The deviations are less than 0.03 arcmin at each voltage.

When the voltage is 5V in the increasing line, the stage rotation angle is 0.0831 arcmin with 0.0181 arcmin deviation which corresponds to a 84.4nm slope height with 18.1nm deviation. Therefore measurement accuracy of less than 20nm in reflection digital holography is demonstrated.

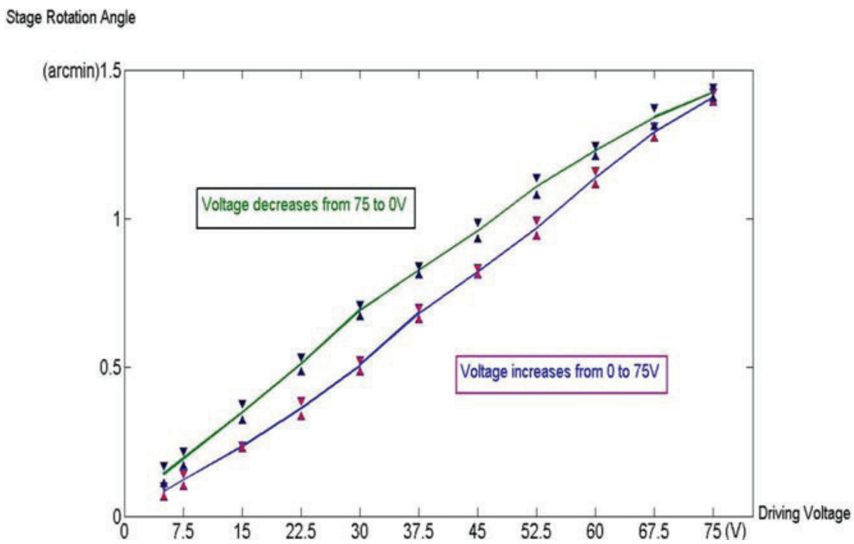

Figure 3 Stage rotation angle VS driving voltage in voltage increasing and decreasing cases.

5. Conclusions

In this paper, calibration of pizeo rotation nano-positioning stage by reflection digital holography technique is performed. Its hysteresis loop trace is acquired with 0.03 arcmin accuracy. With this calibration, the movement accuracy can be enhanced. At the same time digital holography measurement accuracy of less than 20nm is demonstrated in reflection mode.

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