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Study on influential factors of measurement precision using Fourier transform profilometry

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ABSTRACT

This paper investigated the effects of various factors on measurement precision using Fourier transform profilometry (FTP). The spherical cap profile was tested by FTP. Firstly, the profiles under different grating frequencies and incident angles were investigated in order to examine the effects of grating frequency and incident angle on measurement precision and acquire suitable grating frequency and incident angle. Further, random speckles were added on the surface of spherical cap, and its profiles under the conditions with different speckle numbers and sizes were measured for exploring their effect on the measurement precision. Finally, different filtering methods were adopted for testing the spherical cap profile with random speckles and based on the results an effective improvement method was proposed. In conclusion, this study found some factors determining the measurement precision using FTP and proposed some effective schemes for its improvement, which were helpful to the application of FTP.

1. Introduction

Non-contact measurement has gradually become a mainstream technology in the field of precision measurement owing to a series of practical advantages such as high automation degree and low cost. With the rise and development of computer vision technology, the measurements of three-dimensional (3D) surface profile by non-contact optical and electrical methods have appeared as an inevitable course, among which grating projection shows the brightest prospects. The principle of grating projection is described as follows: When a grating is projected to the surface of the object to be measured, the projection gets deformed due to being modulated by the object height; accordingly, the measured object height information is encoded in the grating deformation. In other words, the object height information can be acquired by calculating the phase variation. Currently, there exist many grating-projection-based 3D profile measurement methods, based mainly on Fourier transform profilometry (FTP) [1–5], phase measuring profilometry [6–11], modulation measurement profilometry [12,13], spatial phase detection, phase lock loop profilometry, moiré technique [14,15] and wavelet analysis [16,17].

FTP was proposed by Takeda et al. in 1982, and since then it has been extensively applied in many fields. FTP was successfully used in the processing of interference fringe for detecting the quality of optical devices. Using FTP, the structured light produced by Ranchi grating (or sinusoidal grating) is projected to the surface of the object to be measured; after being modulated by the surface, the deformed stripped optical field is acquired and then imaged on the plane-array detector by

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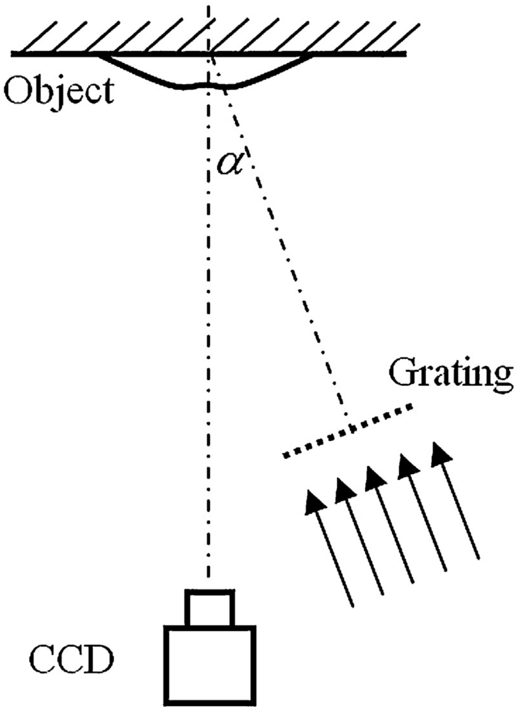

Fig. 1. Illustration of the light path in surface profile measurement based on projection moiré method.

the imaging system. FTP exhibits many advantages including rapid data acquisition and high precision and is suitable for computer processing.

This paper investigated the effects of various factors on measurement precision using Fourier transform profilometry (FTP). The spherical cap profile was tested by FTP. The profiles under different grating frequencies and incident angles were investigated in order to examine the effects of grating frequency and incident angle on measurement precision andacquire reasonable grating frequency and incident angle. Moreover random speckles were added on the surface of spherical cap. Its profiles under the conditions with different speckle numbers and sizes were measured for exploring their effect on the measurement precision. Finally, different filtering methods were adopted for testing the spherical cap profile with random speckles and an effective improvement method was proposed.

2. Experimental principle

The surface profile of the object can be measured by the projection moiré method. Fig. 1 shows the optical path in the projection moiré method. The grating is projected onto the surface of the object and the lines of deformation caused by the uneven surface of the object are recorded by the charged couple device (CCD) camera. The contour line of the surface of the object can then be obtained from the superposition of undeformed and deformed grating lines. The intensity distribution of the grating projected on the plane can be expressed as follows:

$$I = A(x, y) + B(x, y)\cos 2\pi f_0 x \quad (1)$$

where $A(x, y)$is the function related to background light intensity; $B(x, y)$is the function related to amplitude; f_0 is the grating frequency. The intensity distribution of the grating projected on the surface can be expressed as:

$$I' = A(x, y) + B(x, y)\cos[2\pi f_0(x - w\tan\alpha)] \quad (2)$$

Where w is the height and α is the incident angle of projection grating. At this point, both the parallel stripes and the deformed grid lines are recorded.

There is a relationship between the fringe order and height.

$$w = \frac{n}{f_0 \tan\alpha} \quad (3)$$

where n is the fringe order.