Nano-scale full-field surface profilometry using one-shot simultaneous phase-shifting interferometry with two lasers

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KEYWORDS : Simultaneous Phase-shifting Interferometry, Multiple wavelengths, One-shot Measurement, Automatic Optical Inspection

In this article, a surface profilometric system is developed by employing one-shot simultaneous phase-shifting interferometric measurement. The advantages of using one-shot measurement are that the system can be isolated from the external vibration and that errors introduced by nonlinearity of PZT translator for phase shifting can be removed. In order to overcome the phase ambiguity, the system employs two lasers with different wavelengths, 633 nm and 532 nm. The developed method employs two-step phase shifting with 0 and π phase differences. A cosine phase unwrapping technique is employed in the system to reconstruct the phase distribution. The main advantage of employing two wavelengths in the system is to form a longer equivalent wavelength, so the method can measure surfaces with deeper step heights. The measurement capability of the system can be enhanced by adding a microscope objective into the system for measuring micro structures and surfaces, e.g. micro lenses. A proper calibration technique to compensate phase distortion caused by the microscope objective is employed in the system prior to measurement. The experiment result shows the system can successfully measure an 85.2-nm step height.

Manuscript received: January XX, 2011 / Accepted: January XX, 2011

1. Introduction

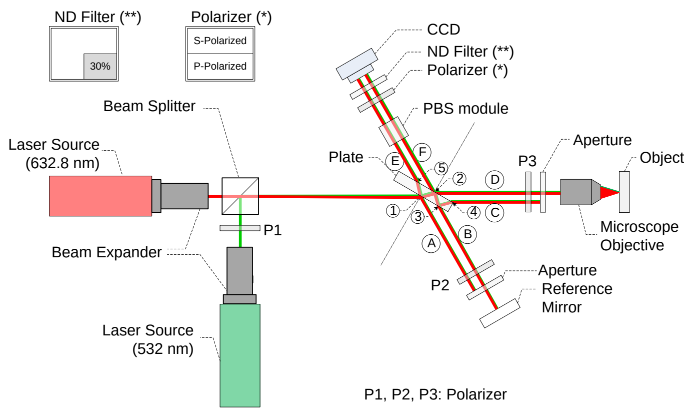
Phase-shifting interferometry (PSI) has become a useful tool for measuring nano-meter scale areas for about 30 years. The traditional PSI systems, like the Michelson interferometer, usually have two prolong problems to be resolved, such as environmental vibration and phase ambiguity. Conventional PSI measurement needs at least three different phase-shifted interferograms for object phase identification. Under this circumstance, unexpected environmental vibration easily affects the phase-shifted interferograms and it can induce unacceptable measurement errors. There are two kinds of method that have been developed for overcoming the noises from the environment disturbance by active feedback compensation and one shot simultaneous phase-shifting interferometry (SPSI). SPSI has an important advantage in comparison with the traditional phase-shifting interferometry in minimizing the noises caused by unexpected vibration and air turbulence.

In general, SPSI method [1-4] may reduce the measurement errors caused by environmental influences, but sophisticated system calibration and complex optical structures are essentially needed, especially for multi-camera configuration. Therefore, we here propose a simple but effective method to perform simultaneous phase-shifting interferometry with single camera configuration. Most particularly, the proposed method only uses a single glass plate to derive four sub-beams with two shifted phases and one single CCD to capture four interferograms simultaneously. The phase difference shifting can be 0 or π only. Therefore, the system employs two-step phase-shifting algorithm with 0 and π phase shifting for reconstructing the surface profile. The developed system is improved from what proposed by Chen et al. [5-6] by adding multiple lasers into the system to increase the measurement range and to resolve the phase-ambiguity for cosine phase unwrapping.

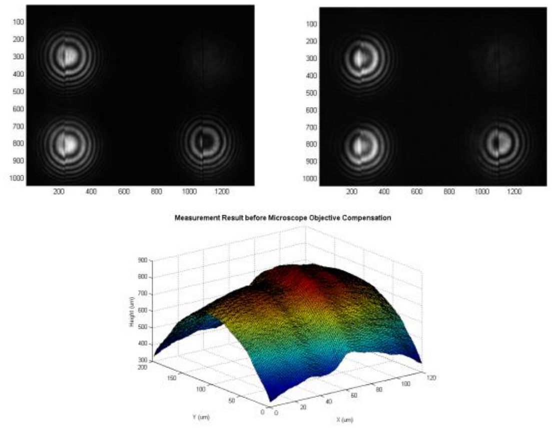
2. Dual wavelength SPSI

Fig. 1(a) shows the diagram of the developed SPSI system. There are two lasers, a red laser (633 nm) and a green laser (532 nm), in the system. Two beam expanders are employed to enlarge the beam sizes of both lasers. A polarizer is set in front of the green laser to control the intensity. Then the two laser beams are combined using a non-polarization beam splitter so both beams can be overlapped in the interferometer. The system produces two sets of four interferograms with 0 and π phase shifting. A color CCD is employed to capture the two sets of interferograms simultaneously. The developed interferometric system only employs an objective on the object arm. It is different from the Linnik configuration, with a first objective in the reference arm and with a second objective in the object arm. Therefore, the interference in the proposed system is the combination of a plane wave from the reference arm and a spherical wave from the object arm. The surface-distortion effect of the objective can be compensated by measuring a calibrated flat mirror. The distorted distribution for the two surfaces is saved and it must be subtracted by other reconstructed profiles derived from the same setup.

Fig. 1(b) shows the interferograms captured by the CCD for the green and red lights. The developed phase calculation algorithm is applied for calculating the phase map corresponding to the profile of the measured object. The unwrapped phase map is then converted into the surface profile of the measured object. After the raw surface profile is obtained, the profile distortion caused by the objective is compensated to derive the compensated surface profile.



(a)

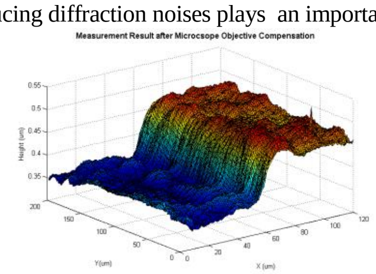


(b)

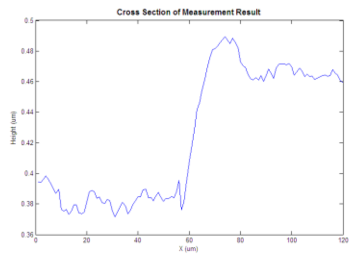
Fig. 1 (a) Setup of the dual-wavelength SPSI system (b) The interferograms captured from the CCD from green and red light and the reconstructed surface before profile distortion compensation

2.2 Experiment Result

To validate the feasibility of the system, a standard step height of 85.2 ± 1.1 nm is measured. An objective with 20x magnification is employed in the system. Fig. 2(a) and Fig. 2(b) show the surface profile of the measured object after distortion compensation and cross section of the profile. Based on the data, the calculated step height is 82.0 nm, so the difference from the nominal value of the step height is about 3.2 nm (3.7%). This experimental result proves that the system can perform a measurement of step heights with a nano-scale order while the performance of the system can be further enhanced by removing the diffractive noises. This can be improved by reducing the diffraction noises caused by the step height, so reducing diffraction noises plays an important work for the next.



(a)



(b)

Fig. 2 (a) The compensated surface profile after distortion compensation, (b) cross section profile of the result

4. Conclusions

A simultaneous phase shifting interferometry system with dual laser sources has been established and the developed measuring system is able to measure microscopic objects. The system calibration has to be performed to compensate the effect of microscope objective in the object arm of the interferometer. From the preliminary experimental result, the system is able to measure the standard step height. The result of the step height measurement is 82.0 nm. The accuracy of the measurement result is 3.2 nm (3.7%). The next step is to perform a repeatability measurement test to evaluate the stability of the system.

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