MEMS/NEMS Dynamics Measurement Tool Using The Stroboscopic Principle

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ABSTRACT

High resolution and noncontacted measurement tools for the dynamic characterization of micro devices are necessary to develop high performance/precision and reliable microelectromechanical systems (MEMS). In this paper, a three-dimensional dynamic measurement system based on stroboscopic and interferometric methods is presented. This system can capture bright-fielded and interferometric images at the same time and will not have any phase error when constructing three-dimensional solid-models. The accuracy of in-plane motion measurement using this system has been calibrated by using piezoelectric nano-platform. The measurement of in-plane motions of the comb-drive actuator using this developed tool have been demonstrated.

Keywords: MEMS, characterization, machine vision, stroboscopic, interferometer

1 INTRODUCTION

Recently, the rapid growth of micro- and nano-electromechanical systems (MEMS/NEMS) boosts the demands of advanced diagnostic tools and characterization techniques. One of the most critical demands is the high-resolution tool for measuring MEMS/NEMS dynamic behaviors, such as displacement and velocity. In [1], the laser Doppler vibrometer is used to characterize a micro-mirror. In [2], a white-light interferometry surface profiling technique is used for material characterization and device inspection. In [3,4], in-plane motions of MEMS devices can be measured up to nano-meters resolution using the stroboscopic principle as well as gradient-based algorithm. Also, with a focus controller, the out-of-plane motion can be measured [5]. In [6], the focus controller was replaced with a splitter and vibrating mirrors that can be integrated inside a microscope, and the out-of-plane resolution was significantly increased. The combination of the optical interferometry and the stroboscopy enables 3D measurement of MEMS devices [7-11]. The hybrid laser Doppler vibrometer/strobe video system can be used to measure periodic in-plane motions and real-time out-of-plane motions [12]. In this work, we develop a MEMS/NEMS dynamics measurement tool which employs the stroboscopic principle.

2 METHOD

2.1 Stroboscopic System

Typically, the maximum frame rate of a traditional CCD camera is on the order of tens of Hz. Therefore, stroboscopic illumination is widely used for measuring the high frequency devices with a low-frame-rate CCD. Figure 1 shows the principle of a stroboscopic measurement system. Here we use the arbitrary waveform generator (Tektronix AWG2005) to generate the driving signals for actuating devices to be measured, and the pulses for activating LED strobe light. The strobe light is used to freeze the motion of a periodic moving microstructure for CCD image capturing. The time resolution is given by the duration of the stroboscope flash. At shot 1, the LED flashes several times at the same phase (e.g., phase I) of different cycles of the driving signal. Similarly, at shot 2, the LED exposes at another phase (e.g., phase II) in each cycle. Therefore, we can snap the images at different phases of the device moving in periodicity.

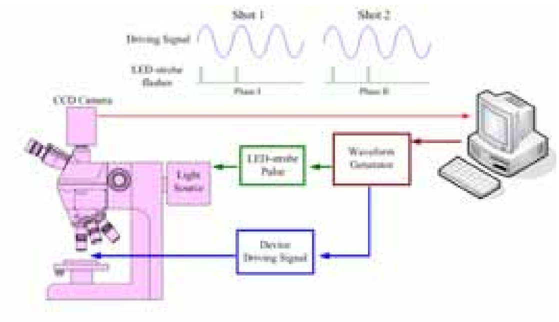

Figure 1: The principle of the stroboscopic system.

2.2 Setup of the Measurement System

The system for measuring the dynamics of microstructures uses strobe-bright-field for the measurement of in-plane motions and stroboscopic interferometric methods for the measurement of out-of-plane motions. Figure 2 is the proposed schematic of the strobe-bright-field/interferometric microscope. One objective lens is focused on the measured device and the other is focused on the reference mirror. When the LED flashes, CCD1 snaps the bright-field images of the device and CCD2 acquires the interference images at the same times. Therefore, the images of the bright field can be totally matched with the interference images and the measurement of three-dimensional motions can be completed in a single experiment. The quarter-wave-plate between P1 and NBS2 ensures that the light is directed onto a CCD2 instead of returning to the CCD1. A piezoelectric actuator that actuates the reference mirror is used to change the phase in the interferogram by adjusting the optical path-length difference.

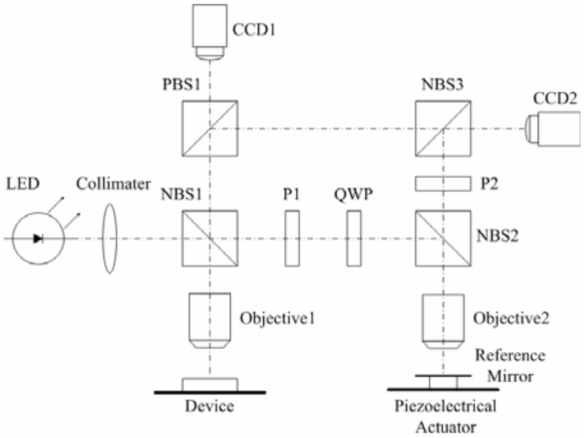

Figure 2: The schematic of the stroboscopic system. QWP is the quarter-wave-plate, PBS is polarization beam splitter, NBS is nonpolarization beam splitter, P is linear polarizer.

2.3 Procedure of Image Processing

The structure of the algorithm, which computes full three-dimensional motion, is implemented in MATLAB®. Figure 3 is the procedure of the three dimensional dynamic measurement and analysis. First, we set the region of interest (ROI) in the reference image (usually we do not actuate the device when define the ROI). The least-square optimization algorithm is used to analyze the bright-field images to obtain the in-plane displacement in one-pixel resolution. If the ROI is too small, it will discern in error and get the wrong results of the displacement. However, if the ROI is too big, the computation time increases unnecessarily. Furthermore, the gradient-based algorithm [4] is used to analyze the bright-field images. The interference images are also analyzed in frequency domain. Then the in-plane displacement of sub-pixel resolution and out-of-plane displacement are obtained separately. The three-dimensional dynamic motions of the devices can be rendered by combining the results of the in-plane and out-of-plane motions.

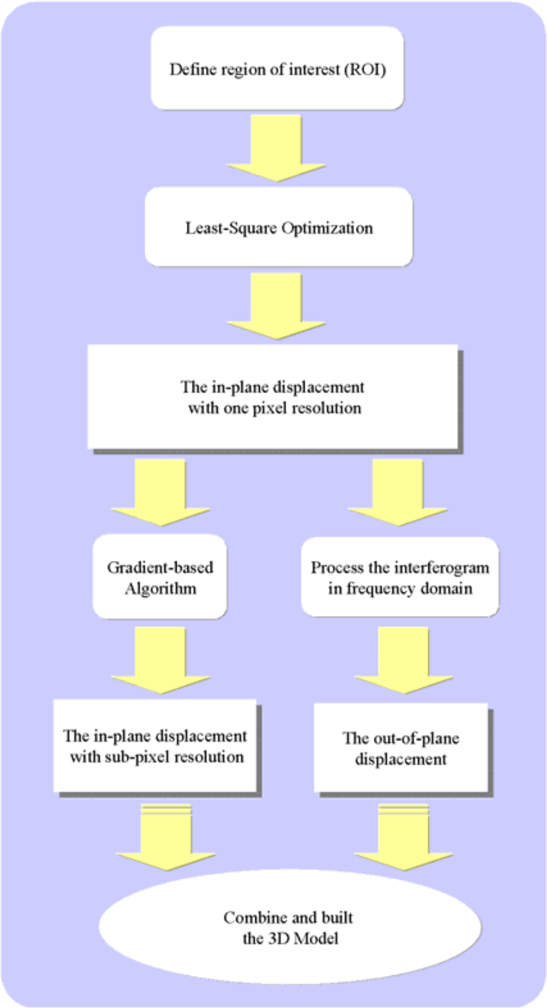

Figure 3: Procedure of estimating the 3D dynamic motion for MEMS device.

3 EXPERIMENTS

3.1 Piezoelectric Nano-platform

In order to verify the results of in-plane motion measurement, a piezoelectric nano-platform (PI P-621.20L) is used. To supply the accurate voltage to the piezoelectric nano-platform, we use the Keithley 2400 SourceMeter® to drive the nano-platform for a one-axial motion. The results of the measurement are shown in figure 4. It is shown that the maximum difference between the measurement value and the theoretic value of the piezoelectric platform is 10 nanometers.

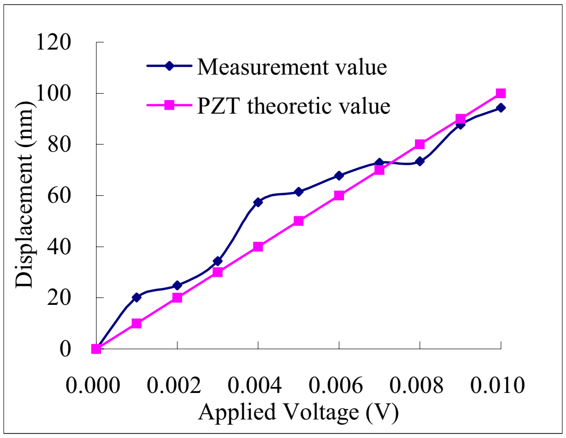

Figure 4: The displacement versus applied voltage for the piezoelectric nano-platform.

3.2 Comb-drive device

The test subjects for this study is a comb-drive actuator fabricated by MUMPs® process which is shown in Figure 5. The comb-drive device is actuated by applying voltage to either of two comb electrodes. The driving signal is applied to pad 2, and pad 1 is grounded. Two sets of folded springs provide a mechanical restoring force that pulls the shuttle back to its rest position when the voltage is removed. At the right side of the figure, there are pictures captured when we applied the driving signal.

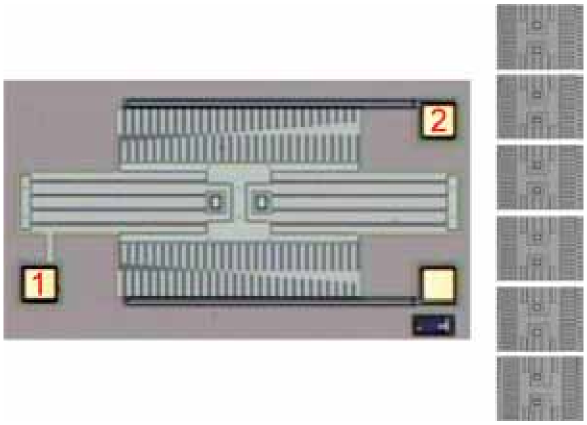

Figure 5: The CCD picture of a comb-drive device measured in this work.

The images at different applying voltages are taken to analyze displacement. The experiment results of displace vs. applied voltages for the comb-drive device is shown in Figure 6. The displacements are proportional to voltage-squared as governed by the electrostatic force.

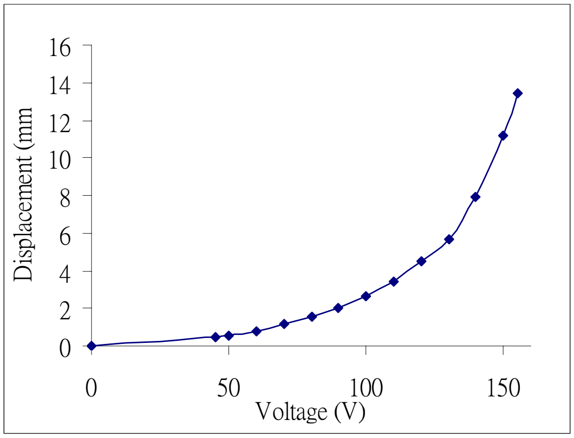

Figure 6: The displacement versus applied voltage for the comb-drive device.

4 CONCLUSIONS

This paper presents a three-dimensional dynamic measurement tool that can capture bright-field images and interferometric images at the same time. We have constructed a motion measurement system based on stroboscope. Measurements of in-plane motion implemented on a piezoelectric nano-platform and a comb-drive device have demonstrated that the in-plane resolution is about 10 nm. At present, we are trying to do the compensation of the gradient-based algorithm to improve the in-plane resolution to the level of less than 5nm. The construction of the section of interferometric system to measurement the out-of-plane motion is under way.

ACKNOWLEDGEMENT

This work is partially supported by the NSC (National Science Council, Taiwan, ROC) through the Grant contact No: NSC-93-2212-E-002-023.

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