Research of the measuring technology of MEMS

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Abstract. Due to the small size of the MEMS, the traditional method of contact measurement seriously affects the parameter of the object being measured, and high accuracy measurement cannot be acquired. Therefore, a new kind of method is needed to meet the requirement. Laser interferometry has the advantages of non-contact, high accuracy, full-field and fast speed, so it is used to measure the displacement and vibration of MEMS in the paper. A time average measurement method of digital speckle interferometry is proposed to measure the vibration mode of the MEMS in the paper. Through the speckle average technology, high accuracy phase-shift, continuous phase scanning technology, combined with optical amplify technology, the resolution of the measurement system reaches 1nm, and the accuracy of the amplitude reaches 5nm. Because the principle of the measurement system is full-field, the measuring speed of the measurement system is 512*512 points per one minute. Another measurement system based on laser speckle correlation algorithm is set up. It is used to measure the displacement of small objects. The rapid searching algorithm is proposed in the paper, and it is used to measure the mechanic property of carbon nanocube.

1. Introduction
The development of the research of micro-electronic mechanics system (MEMS) calls for accurate measurement of the displacement, vibration, and deformation of the MEMS. Digital speckle pattern interferometry (DSPI) has the advantages of non-contact, full-field, high precision and not affecting the nature of vibration characteristics of the object to be measured [1], so the principle of this method is described in the paper and an experimental system is setup. Because of the inevitable environment disturbance, the error of phase-shifter calibration can not be eliminated, so the high quality of measurement result of traditional DSPI can not be obtained. In the paper, the phase continuous scan technique is presented, it can eliminate the background and speckle items, and a nanometer vibration mode measurement system is designed, and the result of small vibration mode of ultrasonic motor whose diameter is 1mm is obtained. A non-contact displacement measurement based on speckle correlation is described in the paper. The shortcoming of traditional speckle correlation algorithms used widely at present is analyzed [2], and a new rapid correlation algorithm is described. The speed of the measurement system is two times that of traditional correlation by the new method. The measuring range is proved widely. In the end, a wide range and high accuracy, non-contact displacement measurement system is setup, and it is used to measure the mechanical property of a carbon nanocube.

2. Theory and experiment
2.1. The optical phase continuous scan.

When the vibration frequency of the object to be measured is much higher than the grabbing rate of a CCD camera, the output of the CCD camera is the time integration of the coherence light intensity, and the output of CCD camera is described as [3]:

\[ I = I_0 + I_r + 2\sqrt{I_0 I_r} \cos \phi(x,y) J_0 \left( \frac{4\pi}{\lambda} \left( a_0^2 (x,y) + a_r^2 - 2a_0(x,y)a_r \cos \phi(x,y) \right)^{1/2} \right) \]  

(1)

It is noticed that speckles are caused by a cosine item. When \( \phi = 0, \pi, \cos(\phi(x,y)) = \pm 1 \), and the irradiance \( I \) will be maximum or minimum. So we can place the optical phase-shifter in the reference beam path and make the phase of reference beam scan continuous in a range large enough. The maximum and minimum of irradiance of every point can be found, which can be represented by \( I_{\text{max}} \) and \( I_{\text{min}} \). So we call this method phase continuous scan technique. Then, an image can be gained by:

\[ I_{\text{out}} = I_{\text{max}} - I_{\text{min}} = 4\sqrt{I_0 I_r} J_0 \left( \frac{4\pi}{\lambda} \left( a_0^2 (x,y) + a_r^2 - 2a_0(x,y)a_r \cos \phi(x,y) \right)^{1/2} \right) \]  

(2)

By this technique, the background and speckle items can be eliminated completely, and there is no need to calibrate exactly the phase-shifter in the phase continuous scan method.

2.2. Quantitative analysis of nanometer vibration mode

The relationship between the light intensity and the vibration amplitude depends on the zero-order Bessel function of the first kind \( J_0 \). \( J_0 \) changes linearly near the half of first zero point of \( J_0 \), through the linear approximate calculation, (2) can be described as:

\[ I_{\text{out}} = I_b(x,y) - k(x,y)a_0(x,y) \cos \phi(x,y) \]  

(3)

Where \( I_b(x,y) \) is the background, and \( k(x,y) \) is the slope of the static work point. Use the phase-shifting network make phase change 90°continuously. Through (3) we can get the phase distribution:

\[ \phi_0(x,y) = \arctg \frac{I_{90^\circ}(x,y) - I_{270^\circ}(x,y)}{I_{180^\circ}(x,y) - I_0(x,y)} \]  

(4)

Turning off the vibration of object, increasing and decreasing the reference vibration \( \delta \), two image \( I_{\pm \delta} \). \( I_{\pm \delta} \) can be obtained, so the vibration amplitude of the object is:

\[ a_0(x,y) = \delta \left[ \frac{\left| (I_{180^\circ} - I_0^\circ) \right|^2 + \left| (I_{90^\circ} - I_0^\circ) \right|^2}{I_{\pm \delta} - I_{\pm \delta}} \right]^{1/2} \]  

(5)

The error of the linear approximation can be corrected by the error lookup table. In the experiment, a small ultrasonic motor (diameter is 1 mm) is measured. Figure 1 shows the results of measurement: (a) is gray level map of amplitude, (b) is the vibration phase map, (c) shows the amplitude distribution of axes (d) express the phase distribution of axes. The whole field distribution of vibration amplitudes can be seen clearly.
Figure 1. Result of vibration measurement

2.3. principle and experiment of displacement measurement
When a rough surface is lit by a laser, laser speckles can be seen. The speckle is distributed randomly, so the speckle distribution is used to calculate the displacement by image correlation. The correlation coefficient between area A and area B is [4]:

\[ c(\Delta x, \Delta y) = \frac{\sum_{i=0}^{k} \sum_{j=0}^{k} \left[ f(x_i, y_j) - \bar{f} \right] \left[ g(x'_i, y'_j) - \bar{g} \right]}{\left[ \sum_{i=0}^{k} \sum_{j=0}^{k} \left[ f(x_i, y_j) - \bar{f} \right]^2 \right]^{1/2} \left[ \sum_{i=0}^{k} \sum_{j=0}^{k} \left[ g(x'_i, y'_j) - \bar{g} \right]^2 \right]^{1/2}} \]  \tag{6}

\( f(x_i, y_j) \) is the image grey value of point \((x_i, y_j)\) in area A. \( g(x'_i, y'_j) \) is the grey of point \((x'_i, y'_j)\) in area B. \( f \) and \( g \) is the average grey value of A and B. When point \((x, y)\) has max correlation coefficient, the displacement of the point \((x_p, y_p)\) is:

\[ \Delta X = X - X_p \quad \Delta Y = Y - Y_p \]  \tag{7}

When an amply optics system is being used, the small displacement of small objects can be measured. As finding the solution to the equation involves much calculation, and costs too much time, so a new rapid searching correlation arithmetic method is proposed.

Figure 2. Image of speckle of carbon nanotubes

Figure 3. Result of 2-D strain of carbon nanocube (F=5mN)
The main principle of the rapid searching method is based on the fact that there is only one point that has the max correlation coefficient. The searching work is not done line by line. Find the point of 8 points around the central point which has extreme maximum value of correlation coefficient, and replace the central point by it until the max correlation point is found. Calculation time is decreased rapidly by this method. The speckle image of carbon nanocube is shown in Figure 2. The result is shown in Figure 3.

3. Conclusion
The optical phase continuous scan and the speckle average technique are combined to analyze vibration mode quantitatively in this paper. The background and speckle items can be eliminated completely by the optical phase continuous scan. So the quality and sign-to-noise of interferogram are improved, which lead to better measurement result. The laser speckle correlation measurement system is setup, and a high speed searching algorithm is described. It is used to measure the strain distribution of the carbon nanocube.

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