Characterization of an Improved, Real-Time MEMS-Based Phase-Shifting Interferometer

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Abstract

We describe and present detailed performance characterizations for an enhanced version of our MEMS Based Phase Shifting Interferometer (MBPSI) that achieves 4 times denser motion reconstruction than our original system. We measure the noise level to be $\leq \pm 6 \text{ nm } \lambda$ (for a 660 nm laser) and the frequency resolution to be $\leq 1 \text{ Hz}$ for 1 Hz motion captured at 1 Hz . We have successfully tracked a piezo based actuator driven with an arbitrary waveform composed of transients $\leq 1 \text{ Hz}$.

Keywords: optical MEMS, Phase-shifting, interferometer, transient motion

1 INTRODUCTION

We have greatly increased the motion reconstruction resolution of our previously reported MEMS Based Phase Shifting Interferometer (MBPSI) from 1 Hz to 4 Hz . This improvement enables the reconstruction of real time motion with 4 times more samples resulting in more precise measurements. The improvement is achieved through a combination of higher frame rate of the CMOS imager and newly developed post processing routines.

Our MBPSI uses a resonating MEMS mirror as the phase shifting element in conjunction with a strobing laser as shown in Figure 1. Synchronizing the strobes with the resonating element eliminates the settling time delay typically found in conventional phase shifting interferometers allowing our MBPSI to achieve camera frame rate limited captures similar to digital holographic microscopy [1]. In addition to employing faster imager rates (increase from 9 Hz to 36 Hz) we utilize a simple yet highly effective new post processing algorithm described in Figure 2 which quadruples the time resolution of measurements.

Figure 1. The laser is strobed in sync (denoted by 'x') with the resonating MEMS mirror to generate the four distinct phase shifts required for surface reconstruction within four camera frames.

Figure 2. Our new post processing routine divides images into sets for reconstruction by using images from the previous set plus the next image yielding a 4X increase in the number of reconstructed points.

We have also characterized the capabilities of the system by using a piezo bending actuator as the test sample. The noise level is $\leq \pm 6 \text{ nm } \lambda$ (for a 660 nm laser) and the frequency resolution of the measurement is better than 1 Hz for tracking 1 Hz motions captured at 1 Hz . Finally we have successfully applied our system to reconstruct arbitrary non periodic motions of a PZT actuator.

2 EXPERIMENT SETUP

We use a modified Twyman Green configuration interferometer as shown in Figure 3. The test sample is a mirror mounted on a piezo driven bending actuator.

Figure 3. MBPSI experimental setup in Twyman Green configuration

The image area was set to 6 by 64 pixels corresponding to a 6 μm by 64 μm mirror surface. The camera gain and brightness were constant for all experiments. The laser pulse width was set to μs . The laser strobes per frame were 8 and 5 for frame rates of and Hz respectively. Every experiment was conducted within a capture window of 4 seconds. Data were processed using the 4 frame phase unwrapping algorithm. The position at each point in time was calculated as the mean over the entire imaged area. The motion plots were generated by subtracting the initial position from each of the subsequent positions.

3 RESULTS

3.1 Noise level

The noise level was determined by continuously measuring a static surface over 4 seconds and analyzing the measured position variations. The histograms of position variations show Gaussian distribution with standard deviation (σ) of 47nm, 5 and 9 nm for and Hz frame rates respectively. For Gaussian distribution 95% of the values fall within $\pm \sigma$ of the mean value, yielding a noise limit of $\leq \pm 6$ nm for the system $\pm \lambda$ for 66 nm laser) at Hz. Higher frame rates show higher noise levels because the number of laser strobes decreases, resulting in a lower signal to noise ratio of the captured images.

Figure 4 Measured position variation of a static surface over time at different frame rates yields a base noise level of 6nm (σ) for Hz.

3.2 Frequency-resolution

To determine the frequency resolution, the test sample over a $\pm 75\text{nm}$ range with sinusoids at known frequencies. Analysis of the frequency spectrum shows that Hz motion can be tracked to within Hz, as shown in Figure 5.

Figure 5 Frequency resolution of a moving actuator at different capture rates shows the expected trend of decreasing accuracy with increasing sample frequency and increasing accuracy with higher capture rates.

3.3 Transient-motion capture

Arbitrary transient motion was emulated by driving the sample with a custom waveform composed of five weighted sinusoids in the range of to Hz, listed in Table 1.

Table 1 Frequency and weights of sinusoids used to generate arbitrary driving waveform

	f_1	f_2	f_3	f_4	f_5
Freq	Hz	Hz	Hz	6 Hz	Hz
Weight	6	6	8	4	

The reconstructed motion closely matches the expected motion in the time domain, as shown by Figure 6 a). The frequency spectrum plotted in Figure 6 b) shows that the largest deviation between expected and reconstructed motion arises from tracking the amplitude of the Hz component. The amplitude error is lower when the measurement rate is Hz, as expected.

Figure 6 a) Expected and measured motion b) Frequency decomposition of expected and measured motion

4 CONCLUSIONS

We have successfully demonstrated and carefully characterized the improved version of our MEMS Based Phase Shifting Interferometer for real time transient phase shifting interferometry. We obtain a noise level $\leq \pm 6\text{nm}$ and frequency resolution of 8Hz for tracking Hz motions, allowing us to accurately track the real time motion of a piezo bending actuator.

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