High-speed Fizeau interferometry and digital holography for dynamic phenomena measurement

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ABSTRACT

An optical system based on a Fizeau interferometer with instantaneous phase-shifting using a Wollaston prism is presented. To measure dynamic phase change of objects, a high-speed video camera of 10^{-5} s with a pixelated phase-mask. The laser light is split into orthogonal polarization states by passing through a Wollaston prism. Then the beam is passed through expanding and collimating optics onto a sample through a half mirror. The half mirror acts as the reference surface. The light beams reflected back from the sample and the reference half mirror are filtered with a pin hole and arrives at the pixelated camera. By adjusting the tilt of the reference surface it is possible to make the reference and object beam with orthogonal polarizations states to coincide and interfere. Digital holography based on this system is also discussed.

Keywords: Optical metrology, Interferometry, High-speed measurements, Fizeau interferometer, digital hoilography

1. INTRODUCTION

Interferometry is one of the promising candidates for high-speed phenomena studies as it can measure many parameters as a function of optical path length difference.[1–3] However interferometry requires multiple measurements with different phase shifts in order to get the complete information.[4,5] This induces a lot of huddles when measuring high speed dynamic events. The most important issue is the environmental turbulence that changes with time at very high speeds and introduces a lot of errors between the different phase shifted measurements. The best possible way to overcome this issue is instanteneous interferometric data acquisition. Its several techniques have been discussed, including the spatial carrier method,[3] the multiplec-channel phase-shifting method,[1,4,5] the use of the pixelated camera and thereby acquire all the phase shifted frames simultaneously through spatial multiplexing.[6,7] This paper reports the design, development and testing of such a measurement using a Fizeau interferometer accompanied by a Wollaston prism [2]and high speed camera with pixelated phase-mask. In this paer, the principle of the Fizeau interferometer with instanteneous phase detection method for some interferometric testing and digital holography.

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2. FIZEAU INTERFEROMETER WITH WOLLASTON PRIZM

Figure 1 shows a Fizeau interferometer with instantaneous phase-shifting using a Wollaston. A high-speed video camera of 10^{-5}s of shutter speed is used with a pixelated phase-mask of 1024 $\times$1024 elements (Photron CRYSTA PI-1P). The light source used is a laser of wavelength 532 nm which is split into orthogonal polarization states by passing through a Wollaston prism. Then the beams are passed through expanding and collimating optics onto a half mirror and a sample through the half mirror surface. The half mirror surface acts as the reference surface. The light beams reflected back from the sample and the reference half mirror are collected back and guided through to the pixelated camera. Two pairs of spots are generated back in the return path of the beams, each corresponding to an object and a reference beam. By adjusting the tilt of the reference surface, the reference and object beams with orthogonal polarizations states are coincided and interfered at the camera plane.

A single pixel in the camera (called as macro pixel) is a combination of four pixels, each having a different phase mask and capable of producing four phase shifted interference patterns all at once. A total of 512 $\times$ 512 macro pixels are present in the camera which produces four phase shifted interferograms, from which the wrapped phase changes can be calculated. By applying unwrapping techniques[8] the exact phase change and hence the optical path length difference can be calculated.

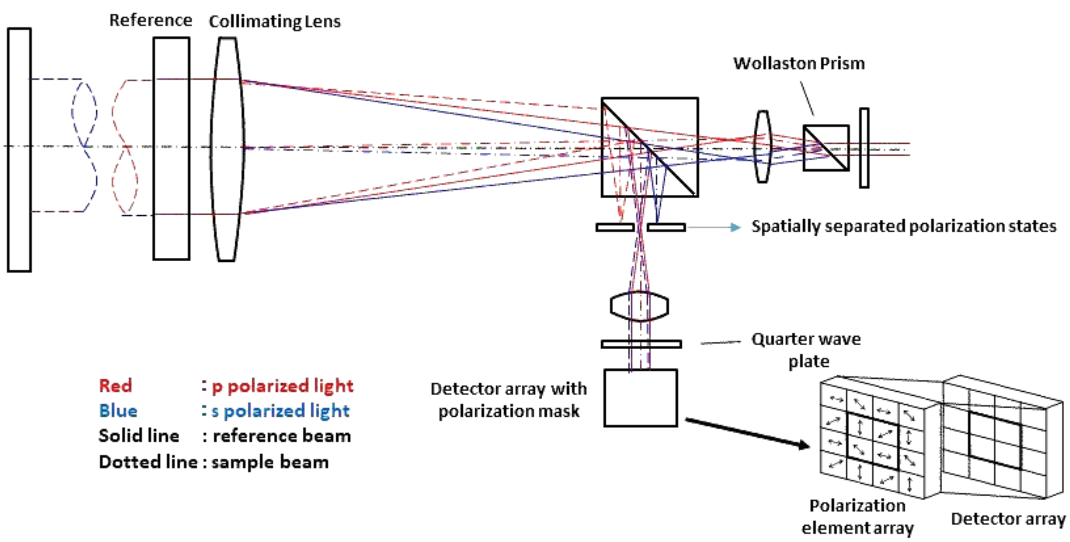

Figure 1. Optical Setup of Fizeau Interferometer with Wollaston Prizm.

3. HIGH-SPEED PRESSURE WAVE PROPAGATION

One of examples of high-speed phenomenum observations is the propagation of bullet in air fired from an air gun. The bullet was fired across the cavity of a Fizeau interferometer. The test surface was a standard flat mirror. The fringes were acquired at 7kHz which is the maximum frame rate of the camera. Figure 2(a) shows the unwrapped phase map of the propagating pressure wave when the bullet was fired. A shock wave (b) and a bullet wave (c) are also observed. These results prove that the Fizeau interferometer designed and built, can be used to study the effects fast moving projectiles through a medium.

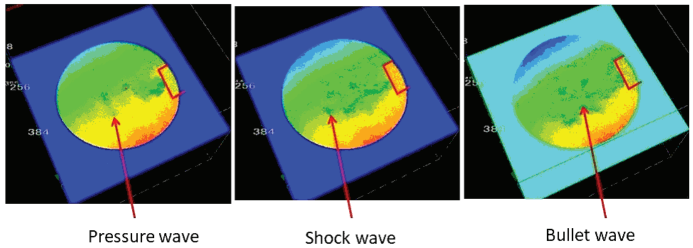

Figure 2. Unwrapped phase distribution from an air gun. (a): a forward propagating pressure wave, (b): a shock wave and (c): a bullet wave.

4. DIGITAL HOLOGRAPHY

The Fizeau interferometer with a Wallaston prizm is applied to the digital holography, as shown in Fig. 3. The phase distribution of the object is detected by a polarization camera. The image of the object is reconstructed by an angular spectrum method. Figure 4 shows reconstructed images with different foci.

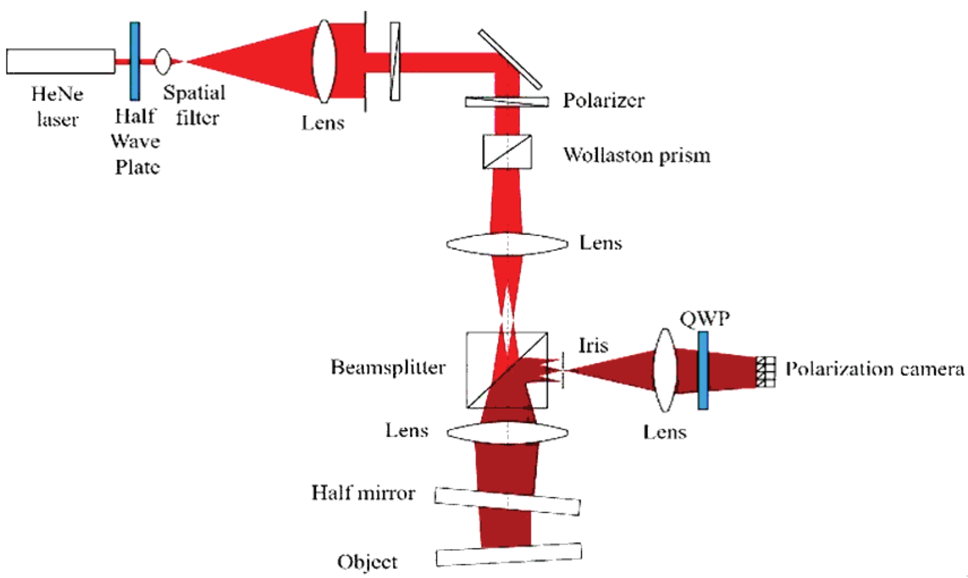

Figure 3. Optical setup of digital holography based on Fizear interferometer with instanteneous phase analysis.

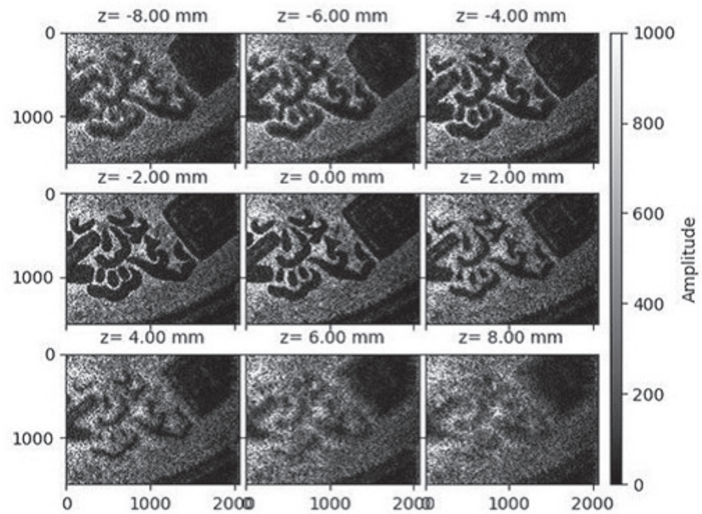

Figure 4. Coin surface reconstruction images with different foci.

5. CONCLUSION

An interferometer has been designed, built and successfully tested to measure very fast dynamic events. The interferograms were unwrapped and exact surface profile of the vibrating sample can be reconstructed. This interferometric setup can be very useful for making measurements through airturbulence or measuring vibrating objects due to environmental disturbances. This technique is applied to digital holography.

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