Acquisition of 3-D data by a heterodyne shearing interferometer with photoelastic modulation

Haeusler, Gerd, Weissmann, Hans

Gerd Haeusler, Hans Weissmann, "Acquisition of 3-D data by a heterodyne shearing interferometer with photoelastic modulation," Proc. SPIE 1319, Optics in Complex Systems, (1 July 1990); doi: 10.1117/12.34740

Event: 15th International Optics in Complex Systems, 1990, Garmisch, Germany

Acquisition of 3d-data by a heterodyne shearing-interferometer with photoelastic modulation

Gerd Häusler, Hans Weißmann

Universität Erlangen-Nürnberg, Physikal. Institut, Abt. Angewandte Optik
Staudtstraße 7/B2, D-8520 Erlangen, FRG

1. ABSTRACT

We show a system for sequential distance measurement, which works as a 3D-sensor. One point of the object is illuminated via an xy-scanning-system. The scattered wave carries the distance information in its curvature at the location of the sensor. We collinearly measure the radius of this wave in the sensor plane by shearing interferometry. Heterodyne modulation of the interference pattern is performed by a photoelastic modulator, for high speed and robustness against environmental light. The sensor requires very small apertures for illumination and detection, so shading effects and hidden points are minimized.

2. INTRODUCTION

In industrial automatic inspection the sensor plays an important role. It supplies the relevant data about the object under test. In most industrial applications, the primary question is about the shape of the object, so 3D-data are well adapted. The set of data $z(x,y)$ is invariant against the variation of illumination and against soiling of the object. We describe a point sensor which scans the interesting scene and supplies the 3D-data of the object. The sensor utilizes common path interferometry, hence it is robust against vibrations and air turbulence.

3. RANGE SENSING BASED ON SHEARING INTERFEROMETRY

A light spot is projected onto the surface of the object under test. The scattered wave emerging from the object carries the distance information in its curvature. This curvature of the spherical wavefront is measured by means of a lateral shearing interferometer[1]. The shearing interferometer consists of a Savart plate with a preceding polarizer (see Fig. 1). The Savart plate performs the virtual duplication of the wavefront and introduces a lateral shift s between these wavefronts. The resulting interference pattern in the plane of observation at a distance z from the object consists of straight fringes (similar to Schuster fringes) with a period p:

$$p = \lambda z / s \qquad (1)$$

This result is based on a quadratic approximation of the spherical wavefront which holds for the small aperture that we utilize. Hence, for known shear s and known wavelength λ the distance z can be calculated uniquely from the fringe period.

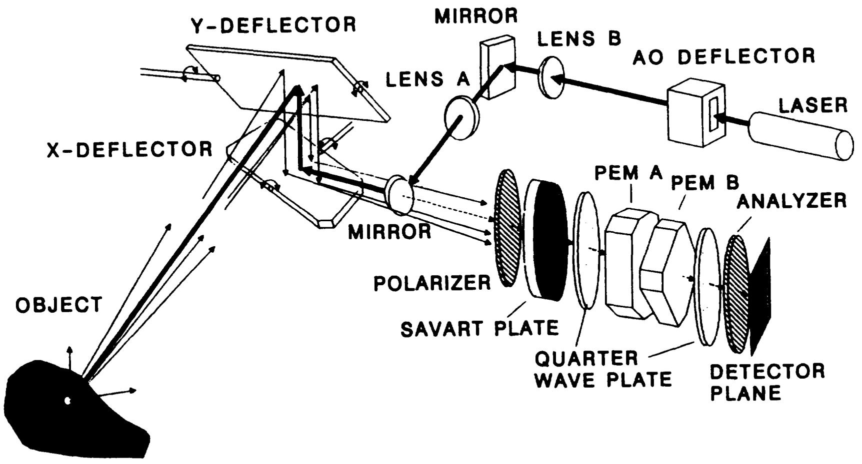

Fig. 1. 3d-sensing by a heterodyne shearing interferometer.

4. HETERODYNE MODULATION USING PHOTOELASTIC MODULATORS

A heterodyne modulation of the interference pattern is obtained by the use of two photoelastic modulators[2] (PEMs). PEMs use the principle of photoelasticity to provide polarization modulation of light. The optical element vibrates at its lowest frequency of standing compression sound wave, therefore a time varying birefringence is observed ($\lambda/4$ peak retardation). The compressed and extended axes of the PEM interchange during a complete cycle of the sound wave. This apperars as if a $\lambda/4$ plate has been turned by 90°. The combination of two PEMs (see Fig. 1: PEM A & PEM B) with an inclination of 45° between their x-axes and with a phase shift of $\pi/2$ between the sound waves, supplies an almost continuously 'rotating quarter wave plate' (RQWP)[3]. This RQWP in combination with two fixed quarter wave plates supplies the frequency shift (84 kHz) between the two orthogonally polarized spherical waves of the Savart plate. A subsequent analyzer enables interference between for the two orthogonally polarized and frequency shifted waves. In the plane of detection we get 'running fringes' with a frequency of 84 kHz.

5. FRINGE EVALUATION BY PHASE MEASUREMENT

In the detector plane there are 8 bar-shaped photodiodes. They are oriented along the interference fringes, so we get an averaging effect in one direction of the interference plane. One fringe is travelling over one detector and causes a sinusodial signal. Because of the different locations of the photodiodes (distance d between two photodiodes) there are separate phaseshifts. By evaluating the phase shifts φ, we get the the fringe periode and we get the desired distance:

$$z = 2\pi s d/\lambda\varphi \tag{2}$$

We built a new bus oriented phase meter, which can simultaneously measure all 7 possible phaseshifts between the 8 photodetectors.

6. FAST SPECKLE REDUCTION IS REQUIRED

Theoretical investigations showed that the depth resolution of the shearing system is strongly restricted by speckle noise[4]. Speckle reduction is required to get a longitudinal superresolution compared to the classical depth resolution according to the Raiyleigh $\lambda/4$ criterion. As we have a high modulation frequency, we need a high 'speckle reduction frequency' (~600 kHz), for an averaging over many speckle patterns within one period of modulation. An acusto optical deflector was placed in the focus of lens b (see. Fig. 1). Its action leads to different illumination angles and to varying speckle patterns. The photodiodes average over several speckle patterns.

7. EXPERIMENTAL RESULTS

Preliminary results show a RMS-Error of the distance measurement of 0.5 mm at a working distance of 500 mm. The measurement speed was 100 points/sec.. The apertures of illumination ($\sin u_i = 0.003$) and detection ($\sin u_d = 0.017$) are very small. The achieved depth resolution corresponds to a fivefold superresolution compared with the Rayleigh depth of field.

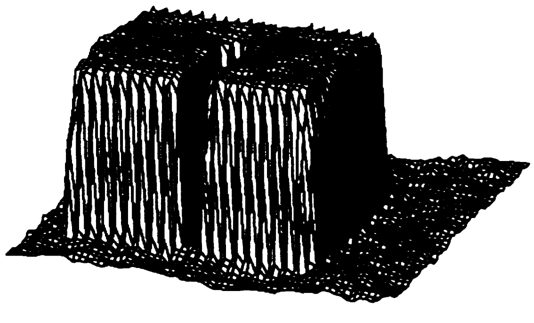

Fig. 2. object with a narrow slit (3mm wide and 35mm deep)

8. REFERENCES

1. G. Häusler, J. Hutfless, M. Maul, H. Weißmann, "Range Sensing Based On Shearing Interferometry", Applied Optics, vol. 27, pp. 4638, Nov. 1988.
2. PEM™ Trademark of HINDS International Inc., Hilsboro, OR, U.S.A.
3. J.C. Kemp, "Polarized Light And Its Interaction With Modulating Devices", internal report of HINDS International Inc. 1987.
4. G. Häusler, J. Herrmann, "Range Sensing by Shearing Interferometry: Influence of Speckle", Applied Optics, vol. 27, pp. 4631, Nov. 1988.