Wavefront sensor based on modified Talbot effect

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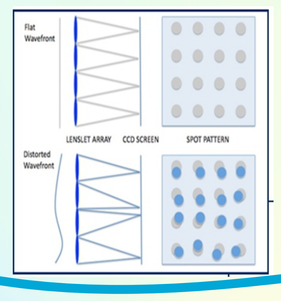
Introduction

Wavefront measurements are important in many fields of applied optics such as wavefront control of laser beams, optical diagnostics of the surface, human-eye aberration measurements, etc. The sensor, based on the Talbot effect, can be a good alternative to the Shack–Hartmann sensor. A modified method of shearing grating interferometry is presented.This novel method allows measuring of freeform wavefronts with high accuracy. The experimental results are obtained using a binary amplitude grating and a spatial filter for the zero order. The filtering of the zero diffraction order results in an improved contrast and measurement performance. By means of robust and fast software, we are able to precisely reconstruct the wavefront. A comparison of this method with Shack Hartmann Sensor (SHS) is presented.

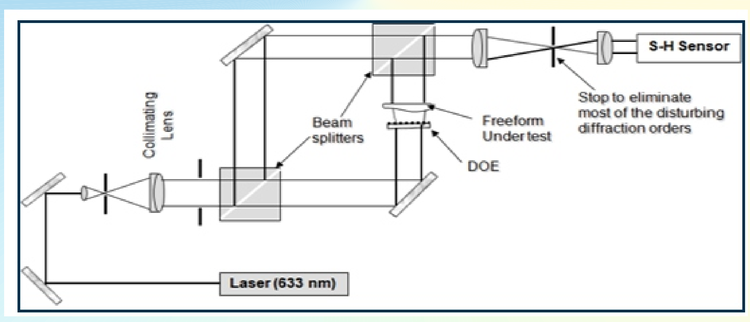
1 Standard wavefront measurement method

Shack Hartmann principle



Challenges:
Lateral resolution
not suitable for wavefront with high inclination
Limited dynamic range

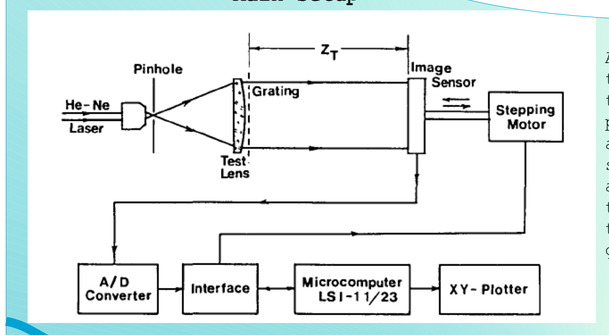
Interferometry and null test



Challenges:
High alignment
Need of a null element
High cost

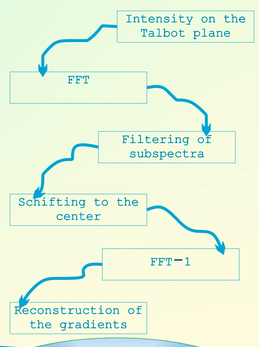
2 Talbot wavefront sensor

Main setup



Algorithm

According to Takeda theory, the subspectra of the Talbot plane intensity provide all information about the wavefront. If the subspectra are filtered and moved to the center, the x,y gradient maps of the wavefront before the grating can be measured.



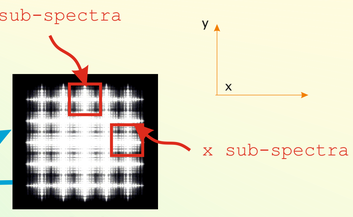
APPLIED OPTICS / Vol. 23, No. 11 / 1 June 1984

Simulation

To show the limitation of the standard Talbot wavefront sensor, reconstruction of a random signal is simulated. After the grating, the subspectra of the Talbot plane interfere and make the filtering of the right subspectra difficult. Since the reconstruction of the wavefront based on gradient integration always includes errors, we will compare in this simulation only the signal gradient maps and their reconstruction. The integration error is then eliminated.

x,y gradient maps of the test signal

Spectrum of the talbot Plane

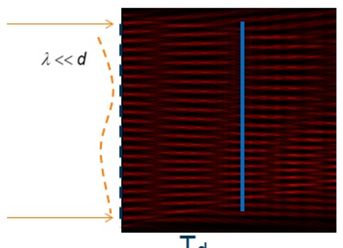


Spectrum of the intensity at the talbot distance

Recontruction

Reconstruction of the x,y gradient of the test signal with standart Talbot wavefront sensor

Challenges:
If the signal is complex, the subspectra of the intensity are mixed. The filtering of the suitable subspectrum is not possible

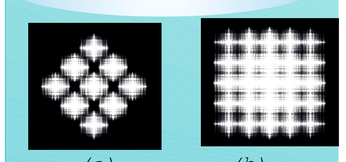


Simulation of the Talbot effect

3 Modified Talbot sensor

The idea is to image the Talbot-Plane into the Camera Plane with a 4 f System. The +1 and -1 orders in x and y direction in the Fourier plane of the first Lens are filterd . With such filtering, we are able to select the intensity of the subspectra on the camera plane without losdfgsdfgsing any information.

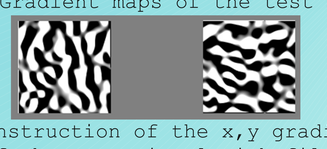
Simulation



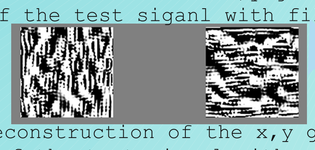
(a) (b)

Spectrum of the intensity on the camera plane:
(a) with filtering,
(b) without filtering

x,y Gradient maps of the test signal



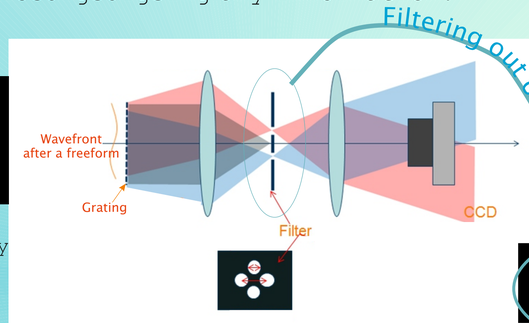
Reconstruction of the x,y gradient maps of the test siganl with filtering

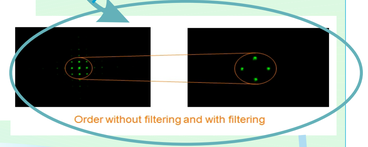


Reconstruction of the x,y gradient maps of the test siganl without filtering

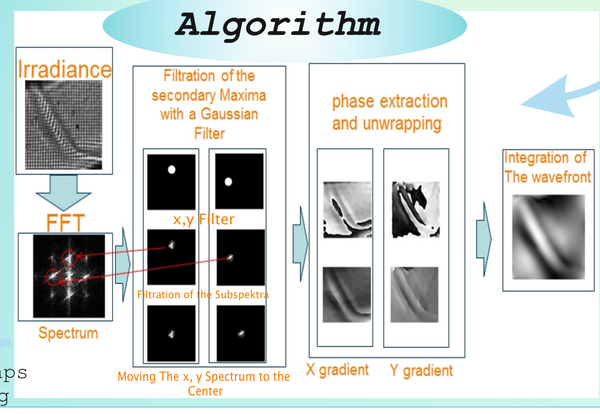
Filtering out of zero order

Idea



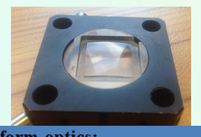


Algorithm



4 Experiment

Freeform

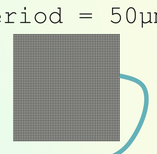


Freeform-optics:
Material: PMMA, Thickness 7 mm
Sag: 0.7798mm, 7th Order Polynomial

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \sum_{i=1}^{N} A_i E_i(x,y)$$

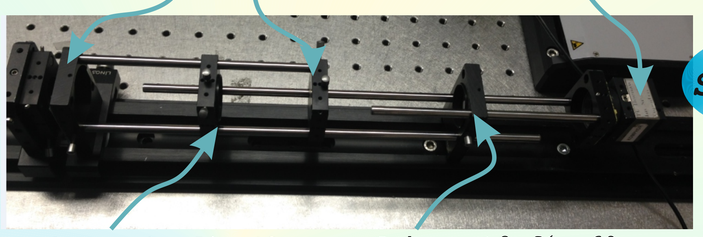
A grating with 50µm period is used to measure the freeform optic wavefront. The same wavefront is measured by SHS from Optocraft GmbH. The difference between the presented method and the SHS is mainly about the tilt , since it is difficult to align the SHS on the same place with the same tilt.

Grating
Period = 50µm



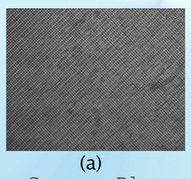
Filter

CMOS Ueye Camera
Resolution:1280x1024
Pixel size:5,3µm

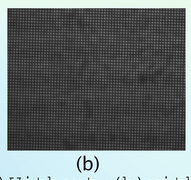


Setup

Achromat1, f´= 40mm Achromat2 f´= 60mm

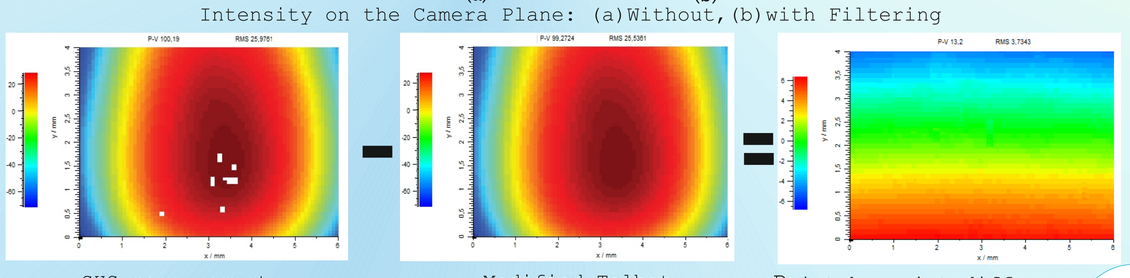


(a)



(b)

Intensity on the Camera Plane: (a) Without, (b) with Filtering



SHS measurement — Modified Talbot wavefront sensor — Point by point difference

Conclusion

We have presented a method of wavefront measurement by modified digital Talbot interferometry.The experimental results were found to be in good agreement with the result obtained by ray trace calculation in Zeemax. The technique enables a fast measurement of the wavefront with improved accuracy and sensitivity compared to conventional Talbot interferometry. A comparison of this method with Shack Hartmann sensor was presented.

literature

[1] S. Sinzinger, M. Hillenbrand, R. Hasan Abd-El Maksoud, "Freeform Surfaces in Optical (Micro-) systems: From Parabasal Theory to Applications", OSA Topical Meeting on Freeform Optics, Tucson, Az. USA, 3.-7.11.2013.

[2] G. S. Khan, M. Bichra, A. Grewe, N. Sabitov, K. Mantel. I. Harder, A. Berger, N. Lindlein, S. Sinzinger, "Metrology of freeform optics using diffractive null elements in Shack-Hartmann sensors", EOSMOC 2013: 3rd EOS Conference on Manufacturing of Optical Components, Munich, 12.5.-16.5.2013.

[3] H. Schreiber, J. Schwider"Lateral shearing interferometer based on two Ronchi phase gratings in series" APPLIED OPTICS y Vol. 36, No. 22 y 1 August 1997

Acknowledgements

This work has been funded by the Carl Zeiss Stiftung through the project“ System for Automated Cell Cultivation and Analysis (SACCA)” and the German Research Foundation DFG through the project “Adaptive Scanning Single-Facet Eye” (SI 573/7-2) within the Priority Program SPP 1337“Active Micro-optics.”

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DGaO Proceedings 2015 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2015-P009-0
submitted: 16.Jul.2015 - published: 19.Aug.2015