Subaperture wavefront measurement using Talbot interferometry

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A method based on sub aperture stitching for measurement of a freeform wavefront is proposed and applied to wavefronts calculated from the slope data acquired using a Talbot wavefront sensor. The presented theory is tested experimentally on the example of a cubic wavefront generated by a phase plate. A comparison with a commercial Shack Hartmann Sensor is done.

1 Introduction

Future precision optical instruments require optics with higher degrees of freedom to meet increasing demands on systems performance. Such degrees of freedom are offered e.g. by off axis aspheric and freeform optical elements. However, the successful fabrication of such freeform optical elements depends on the capabilities of metrology procedures and on the feedback mechanisms for optimizing the manufacturing process [1]. There is a growing demand from industry for precise and robust metrology techniques for freeform optics.

For the precise measurement wavefronts generated by freeform surfaces wavefronts, there is a wide range of procedures. In order to test simple surface shapes, such as flat or spherical surfaces (lenses, mirrors, etc.), interferometry is mainly used. However, this method has some drawbacks such as the necessity of vibration and temperature fluctuation free environments and the complexity of the measurement setup. This is more challenging for the implementation of the interferometric measuring systems, since it includes a large and expensive equipment costs.

One of the most widely used methods for the wavefront measurement is Shack Hartmann sensing with and without null test. Nevertheless this method lacks good lateral resolution and the alignment effort for the null tests is fairly high. Talbot interferometry is one variation of interferometric measurements with less sensitivity to environmental noise [2]. This method does not require a reference wave resulting in a reduction of the alignment and stability problems.

According to Takeda theory [3], the sub spectra of the Talbot plane intensity provide all information about the wavefront. If the sub spectra are filtered and moved to the center, the x,y gradient maps of the wavefront before the grating can be measured.

In this paper we modified the traditional Talbot wavefront. For the imaging of the Talbot plane to the camera plane, we use 4f system with a Fourier filtering.

For the measurement of large freeform optical wavefronts, we recently reported a new method based on sub aperture stitching of freeform wavefronts using Shack Hartmann Sensor [4]. In this paper, we combine this method with the modified Talbot Sensor.

2 Experimental

The schematic diagram of the proposed wavefront sensor is shown in Fig. 1. The goal of our experiment is the wavefront analysis by a two-dimensional binary cross grating. An incoming wavefront, emerged by a transparent test sample e.g., hits an amplitude binary cross grating. This grating is placed at the distance z before the focal plane of a 4f setup and is imaged on a camera sensor. The Fourier plane of this setup enables us to perform filtering operations in spectral domain.

After this filtering only +1 and -1 orders can be imaged at the camera plane. The camera captures an intensity image which is evaluated by Fourier analysis.

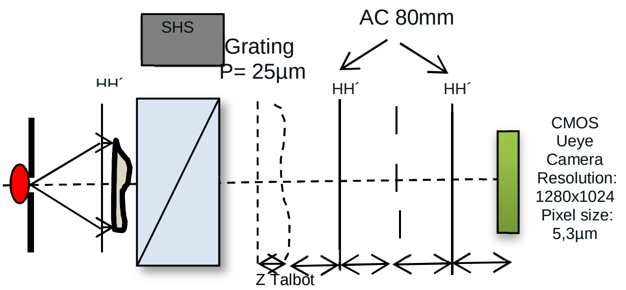

Fig1: Schematic diagram of the proposed wavefront sensor

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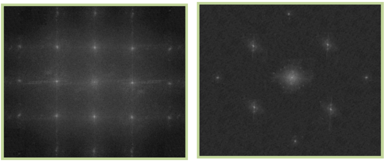
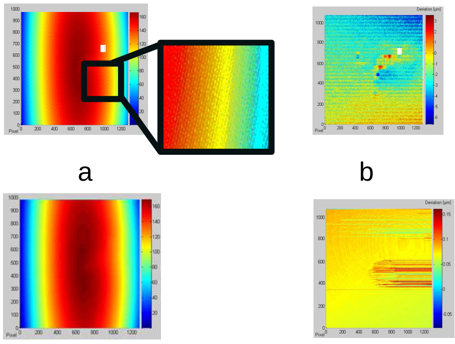


a b

Fig2: Spectrum of the captured intensity
a: Without filtering, b: with filtering.

After the extraction of the wavefront using the Takeda algorithm, we make a point by point comparison with a commercial Shack Hartmann Sensor. Without applying the Fourier filtering, he deviation to the SHS is 5,23 μm . After applying the Fourier filtering, the deviation is only 0,24 μm.



a b c d

Fig3: a: Reconstructed wavefront without Fourier filtering, b: Point by point difference to SHS without filtering c: Reconstructed wavefront with Fourier filtering, d: Point by point difference to SHS with Fourier filtering

. After the validation of the wavefront sensor using the comparison with a SHS, we measured 12 small 1,5x1,5 mm x mm subapertures of the wavefront. These subapertures have 20% overlap. Using the stitching algorithm [4], we stitch all subapertures together. Figure 4 shows the schematic of the stitching scheme.

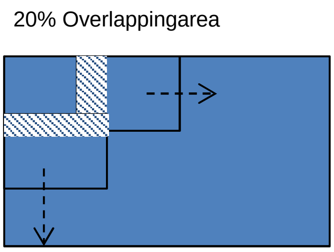


Fig4: Schematic of the stitching

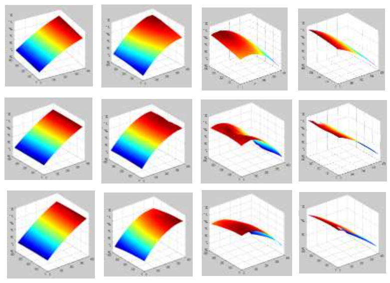


Fig5: Wavefront of subapertures

The full stitched wavefront is compared point by point with SHS and the difference is shown in Fig6. The PV of the difference is 5 Wave. As the accuracy of the linear stage used in the experiment is 1 µm, it is expected to be the reason of this deviation.

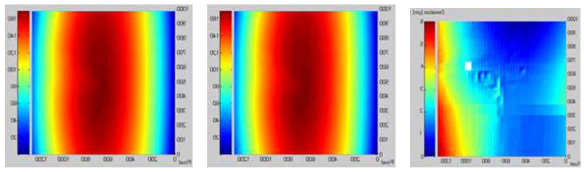


Fig6: a: Wavefront from SHS, b: Stiched Wavefront,c: Difference between SHS and modified Talbot Sensor

3 Conclusion

In this paper, a modified Talbot wavefront sensor based on Fourier filtering is presented. With this filtering, we can avoid aliasing effect and we can measure complex wavefronts. A freeform wavefront is tested with this method. A validation with SHS is presented. After this validation, we stitched a complex wavefront using a stitching algorithm developed for freeform optics. The deviation to a reference measurement is less than 5 waves. The origin of this deviation needs further investigations.

Literature

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