Surface Form Measurement with Wavefront Based Modulated Lighting Technology

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Abstract

In Shack-Hartmann wavefront sensing (SHWS) system, the wavefront carries the optical information of the measured surface, and is typically sampled by a lenslet array. This paper proposes an active sampling method by making use of a patterned light beam. The absence of a physical sampling aperture helps to avoid many problems expecially when measuring aspherical surface forms. We demonstrate the feasiblity and effectiveness of this proposed technology through Matlab simulation of surface measurement of toroidal surfaces, which are a form of aspherical surfaces [1].

1 Introduction

SHWS technology uses a lenslet array to sample a wavefront that is reflected or transmitted from a surface. Each lenslet acts like an "optical probe". The centroids formed by each probe at the detector plane are recorded. Both a reference flat surface and the surface to be measured are sampled. From the displacements of the two sets of centroid locations, the wavefront slopes at the sampling plane can be calculated [2]. Although SHWS has extendable dynamic range [3], it still has very limited application in freeform surface measurements as its dynamic range is not sufficiently large. Nowadays, freeform surfaces are becoming increasingly widely used in various applications as they can offer a higher number of freedom for system simplification and performance optimization. However, till now, the measurement and characterization of such surfaces are still very difficult and open to interpretation [4]. The key factor that is responsible for preventing SHWS from achieving this purpose is the rigid setting of the lenslet array which possibly brings in the risk of incomplete sampling or cross talk. To tackle this issue, spherical lenses are replaced by elliptical lenses as they provide different optical powers in the x and y direction [3]. This technique makes sampling possible, but it still involves a physical lenslet array even if it is implemented by a spatial light modulator. In this paper, we propose to withdraw the physical lenslet array completely, and make use of a patterned lighting instead. The intrinsic characteristic of this method not only ensures high flexibility when registering the surface, but eases the sampling process as well in measuring aspherical surface forms.

2 Simulation

The basic idea of the method is to make the beams themselves as the probes. This is achieved by periodically modulating the intensity of the light beam in a pre-designed way. Thus, each "optical probe" can be thought of carrying a specially designed pattern mark. As such, we can easily register each sampling unit by identifying the marks. At the detector plane, the centroid formed by the beams reflected from the corresponding sub area can be determined (fig 1).

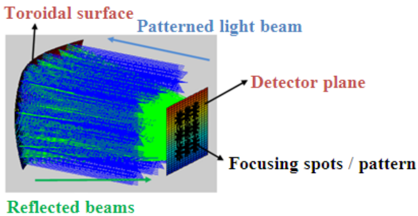
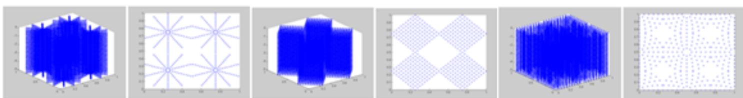


Figure 1: Illustration of the working principle of the pattern projection method

Up to this point, we have simulated three kinds of patterned lighting. They are star shaped (fig 2.a), diamond shaped (fig 2.b), and fringe shaped (fig 2.c). The specification of the toroidal surface simulated is shown in table 1.



(a) (b) (c)

Figure 2: Illustration of various patterned lighting with a 2*2 configuration

Table 1: Specifications of the toroidal surface

L_x (mm)	L_y (mm)	R_x (mm)	Surf	R_y (mm)	R_x/R_y
44	44	112.5	Concave	137	0.821

In order to compare the proposed method with SHWS technology, we also simulate the SHWS system with elliptical lenslet array. According to [3], to achieve this purpose, the specifications of the elliptical lenses are set as shown in table 2, and they are assumed to be closely attached to the sample surface theoretically. According to [5], we know that together with the increase of the number of lenslet in x and y direction, the error of the result decreases. In addition, when the configuration is beyond 16*16, the errors caused by the lenslet array are ignorable. Hence, the configuration of the elliptical lenslet array is set at 16*16, and the configuration of the patternlet array is set at this value as well.

Table 2: Specifications of elliptical lenses used in SHWS system

f_x (mm)	f_y (mm)	Surf	Detector plane ($f_{effective}$) (mm)
90	69.977	Plano-Concave	34.615

The reference surface in both systems is a flat plane perpendicular to the optical axis. The detector plane position in the proposed system is the same as that in the SHWS system, so as to facilitate the comparison of the x-gradient and y-gradient.

3 Discussion

The x-gradient and y-gradient are determined by the shift between the centroids of the reference surface, which is the flat plane, at the detector plane, and those of the sample surface, which is the toroidal surface, at the detector plane. The distances between the test surface and the sampling plane in both systems are equal to the effective focal length of the elliptical lenses in SHWS. The performance of the two systems are compared by these two gradients in the form of relative difference, which is calculated as $\frac{\partial_t - \partial_r}{\partial_r}$. ∂_t represents gradient data measured by the proposed method whereas ∂_r represents gradient data measured by SHWS technology.

It is found that the two methods give very close result, with the maximum deviation limited to 0.4% (fig 3). This means that the proposed method is suitable to measure toroidal surfaces without the necessity of an elliptical lenslet array to modulate the wavefront. Among the three patterned lighting, the star shaped beams is the closest to SHWS, which is possibly due to the reason that the edges as well as the centres in each sub area are taken into consideration. Therefore, if each “optical probe” abstracts more surface signature, the result may be more close to that of elliptical SHWS.

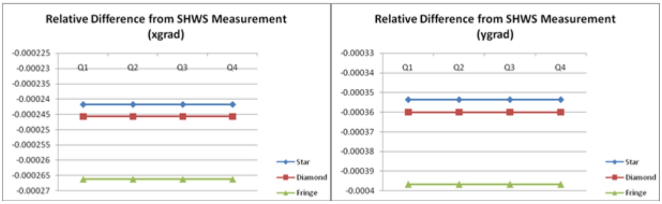


Figure 3: Comparison of the two systems. Q1, Q2, Q3, and Q4 denote the four quarters of a Cartesian coordinate system respectively

4 Conclusion

The proposed wavefront based modulated lighting technology makes use of patterned lighting to actively sample a toroidal surface. Compared to SHWS technology, the proposed method gives very close measurement result when used to measure toroidal surfaces. As such, the two technologies are considered to be comparable. Besides, as there is no physical lenslet array used in this system, it is potential for freeform surface form measurement. In the future, we will continue to carry out experimental investigation and aberration characterization of this technology.

References:

[1] C. Menchaca and D. Malacara, "Toroidal and Spherocylindrical Surfaces", Applied Optics, Vol. 25, pp. 3008-3009, 1986.

[2] Ben C. Platt, and Roland Shack, "History and Principles of Shack-Hartmann Wavefront Sensing", Journal of Refractive Surgery, Vol. 17, 2001.

[3] L. Zhao, N. Bai, and X. Li, 'Asymmetrical Optical Lenslet Array Realized by Spatial Light Modulator for Measuring Toroidal Surfaces', Applied Optics, Vol. 47, pp. 6778-6783, 2008.

[4] Henselmans, R., "Non-contact Measurement Machine for Freeform Optics", PhD Thesis, Technische Universiteit Eindhoven, ISBN 978-90-386-1607-0, 2009.

[5] Zhao Liping, Guo Wenjiang, Li Xiang, and Zhong Zhaowei, "Sensing Performance of a Shack Hartmann Wavefront Sensor versus the Properties of the Light Beam", Proceedings of the SPIE, Vol. 7390, pp. 73900E-73900E-8, 2009.