Single-Shot Phase Measuring Deflectometry for Cornea Measurement

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Phase-measuring deflectometry (PMD) has become a standard tool to measure the topography of specular surfaces. We report a novel implementation of PMD, namely for measurements of the human cornea. We overcome two problems: by a special geometry a large angular dynamical range is achieved and by single-shot deflectometry motion blur is avoided

1 Introduction

The cornea is responsible for about 70% of the eye's refractive power. The cornea topography is therefore an important aid for the ophthalmologist. It is commonly measured with several methods. The most widely used instruments are the "keratometer" and the "keratoscope"[1]. However, the keratometer measures only in two directions separated by 90 degree and the keratoscope measures only the radial component. Neither method provides locally resolved full field data. We adapted an earlier idea of Lingelbach et al. [2] and demonstrate that "Phase-measuring Deflectometry" has the potential to measure the cornea, with large angular range (± 27 degrees), in a single shot. We will discuss the challenges: large field, large slope range, motion blur, low fringe contrast.

Challenges:

PMD exploits the image of a fringe pattern that is reflected at the surface under test. With careful calibration, the surface topography can be determined from the image distortion [3] [4] [5].

PMD has shown to be a highly accurate and flexible tool, so it should be a proper method for the cornea measurement as well. But we are facing severe challenges in the implementation.

First, the cornea is strongly curved, with a wide angular range (± 40 degree), which is why a specific geometry is required. Second, as the eye is a non static object, we cannot measure the phase of the fringes by the common temporal phase-shifting method. A single shot measurement is required.

2 Solutions

2.1 Novel Geometry

For the required very large angular dynamic range, the 17" screen is placed in close distance (100 mm) to the cornea, as shown in Fig. 1, for an angular slope range of ± 27 degrees.

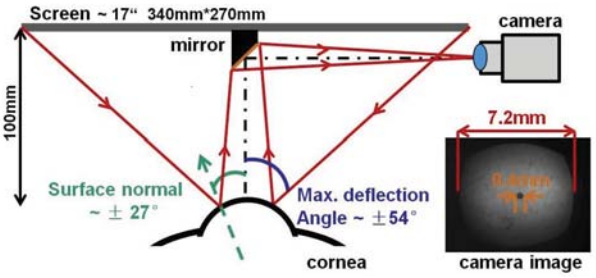

Fig. 1 *Novel geometry of PMD: small planar mirror at the center of the screen.*

As the reflected light rays cannot go through the screen, a small planar mirror is mounted at the center of the screen to send the reflected image to the camera, which is located besides the screen.

The mirror obscures a certain area of the cornea, but the mirror image is strongly demagnified, by the cornea: with a planar mirror of 10mm diameter, only 0.4mm of the 7.2mm measured cornea field is missing. See camera image in Fig. 1, which was obtained, by using a bearing ball dummy, replacing the eye.

2.2 Single shot measurement

The eye movement requires a single shot measurement. We implement a method developed by Liu et al [6], based on single sideband demodulation. This method allows for a measurement within one single exposure.

But for a successful application, the input image must display narrow band bandwidth. Unfortunately, the observed fringe pattern is strongly distorted because of the high angular slope range and the image reflected from the cornea is not narrow bandwidth, as shown in the Fourier spectrum of Fig. 2c.

A further disadvantage of the distortion is the low contrast in the peripheral area, where the fringes are very dense, see Fig. 2b.

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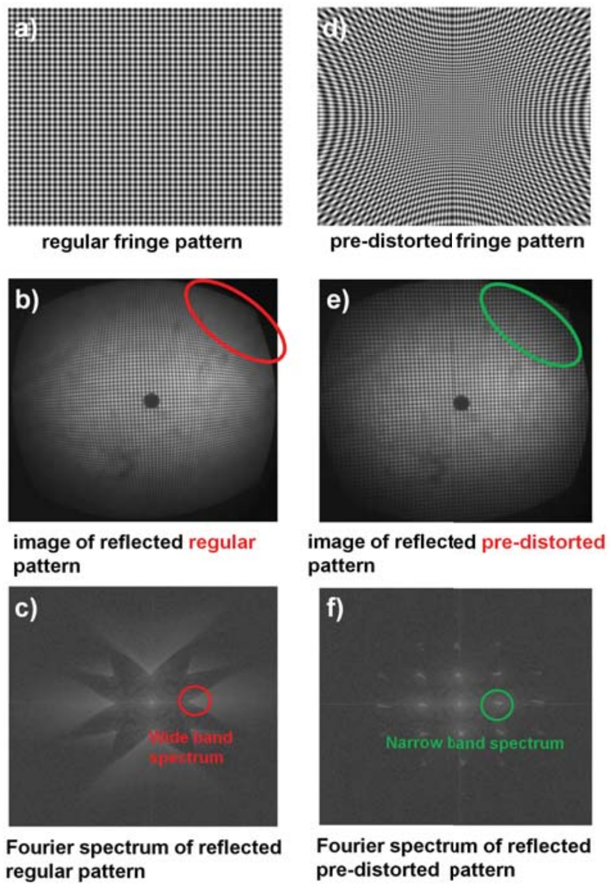

Fig. 2 *camera images of regular and pre-distorted fringe patterns and their fourier spectrum*

Both problems can be overcome by properly pre-distortion of the input fringe pattern, as shown in Fig. 2d. The nicely regular reflected image, with high contrast, is shown in Fig. 2e, and the (narrow band) Fourier spectrum is displayed in Fig. 2f.

The data shown in the previous section were taken via a bearing ball eye dummy. Handling the human cornea is comparably more difficult, due to the low reflectance, parasitic reflections and the blurring of the image by eye motion. Will the method be useful for the human eye as well?

The answer is illustrated in Fig. 3. The camera image of the pattern reflected from the cornea displays high contrast, with approximately constant fringe frequency. On the right preliminary results are shown, still achieved without calibration. We measured a sag of 1.4 mm over a diameter of about 7 mm. The mean curvature map displays a refractive power, ranging from 34 D to 45 D, while the nominal average curvature of a human cornea is about 45D at the center.

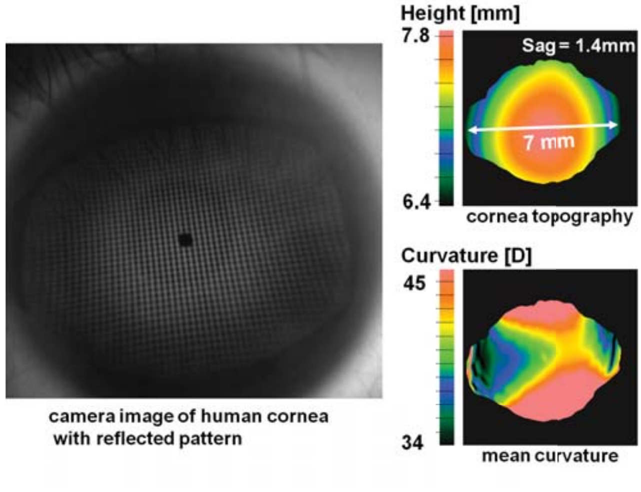

Fig. 3 *Preliminary topography and curvature map*

3 Conclusions

With the special geometry and the pre-distorted fringe pattern, phase-measuring deflectometry can be adapted to the measure the human cornea. Measuremtens of the pixel dense topography of the cornea over a diameter of about 7 mm with angular dynamic range of $\pm$ 27 degree are demonstrated. The implementation displays an angular range still lower than requested for the complete cornea, but covers the most important part. An wider angular range can be implemented just by a larger screen. A bigger challenge is precise calibration.

References

[1] C. Mejia-Barbosa, D. Malacara-Hernandez, ”A Review of Methods for Measuring Corneal Topography”, OPTOMETRY AND VISION SCIENCE, Vol. 78, NO. 4, pp.240-253

[2] B. Lingelbach, J. Massig, “Topometer for shining surfaces, ”Patent EP0924494 A2, 23.06.1999.

[3] G. Häusler, ”Verfahren und Vorrichtung zur Ermittlung der Form oder Abbildungseigenschaften von spiegelnden oder transparenten Objekten” Pat. DE 19944354. 1999

[4] M. C. Knauer, J. Kaminski und G. Häusler. ”Phase Measuring Deflectometry: a new approach to measure specular free-form surfaces”, in Optical Metrology in Production Engineering, Proceedings of SPIE Vol. 5457, pp 366-376 Strasbourg, 04.2004

[5] C. Faber, E. Olesch, R. Krobot and G. Häusler. ”Deflectometry challenges interferometry-the competition gets tougher!”, Proc. SPIE 8493, Interferometry XVI: Techniques and Analysis, 84930R, 2012, San Diego, USA

[6] Y. Liu, E. Olesch, Z. Yang and G. Häusler, “Fast and accurate deflectometry with crossed fringes, ”Adv. Opt. Techn. 2014; 3 (4): 441-445.

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