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Single-shot deflectometry for cornea metrology

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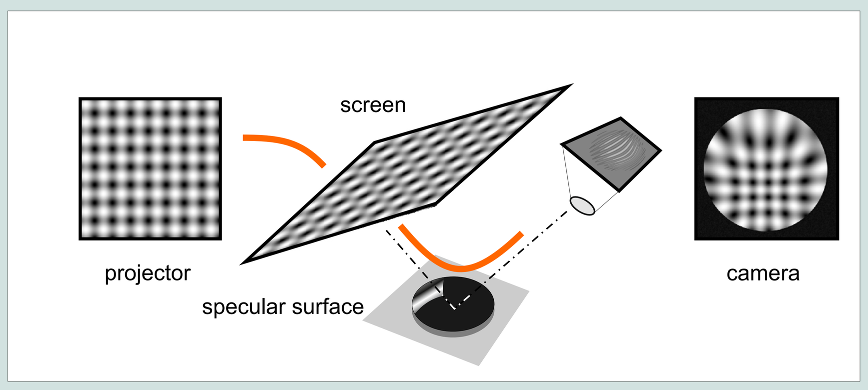
Motivation



We introduce “single shot deflectometry” which allows for the measurement of non static objects and which does not require phase shifting electronic displays. We apply the method for human cornea metrology.

Measurement Principle

We developed a novel deflectometric method which allows for single-shot metrology by avoiding the temporal phase shifting sequence [XXX 5]. Non static objects (such as the human cornea) can be measured and no allocation of controllable opto-electronical displays is necessary. The basic idea is to use a cross fringe pattern (for both components of the surface gradient), see Figure 1, and to evaluate the fringe image in the Fourier domain, by single sideband (SSB) demodulation. PMD is a paradigm application for SSB demodulation, because the fringe images are commonly narrow band signals (see Figure 1). We optimized the method by using the highest possible carrier frequency and achieved nearly the same performance as the standard method (~ 10-20 arcsec repeatability), while maintaining a high lateral resolution and minimizing the (unavoidable) artifacts at edges and fine details, see Figure 2.

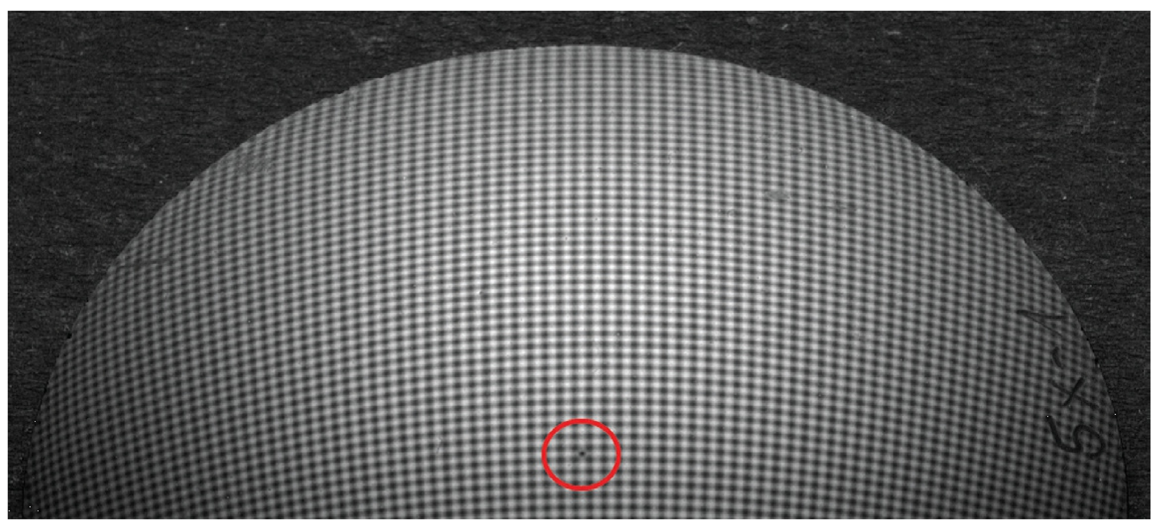


Fig. 2 *Camera image captured from cross fringe deflectometry. The object is an eye-glass surface with ~8.5 D. The marker helps to identify the fringe number.*

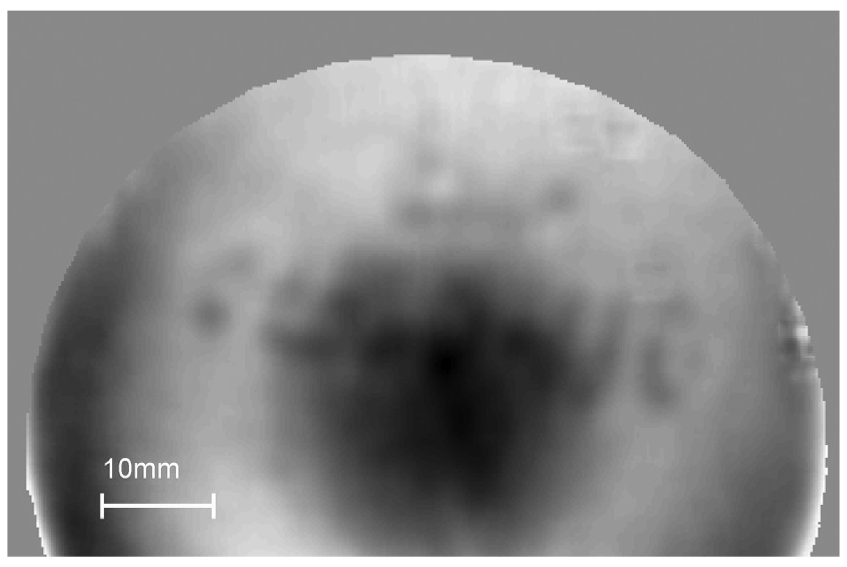


Fig. 3 *Curvature, calculated from the measured slope. The variation of the curvature range is from 9.2 D (bright) to 8.2 D (dark). The number-structure displays an about 10 nm (!) local material wear by an earlier (cleaned) felt pen marking and proves that the lateral resolution is still sufficient, in spite of the inherent band filtering.*

Cornea Measurment

We are investigating, if cornea measurements are possible by single shot deflectometry. There is a challenge: The cornea has a high curvature (±XXX D) and a large angular dynamic range (± XXX degrees). This requires a large fringe pattern in close distance to the cornea making the standard geometry inapt. The large angular dynamical range causes strong distortion of the fringe images and the observed signal is not anymore narrow band. We overcome these challenges by a novel geometry (Fig. 3) and by proper pre-distortion of the fringe pattern as shown in Fig. 4a. Figure 4b displays the (now regular) fringe image after reflection at the cornea (model).

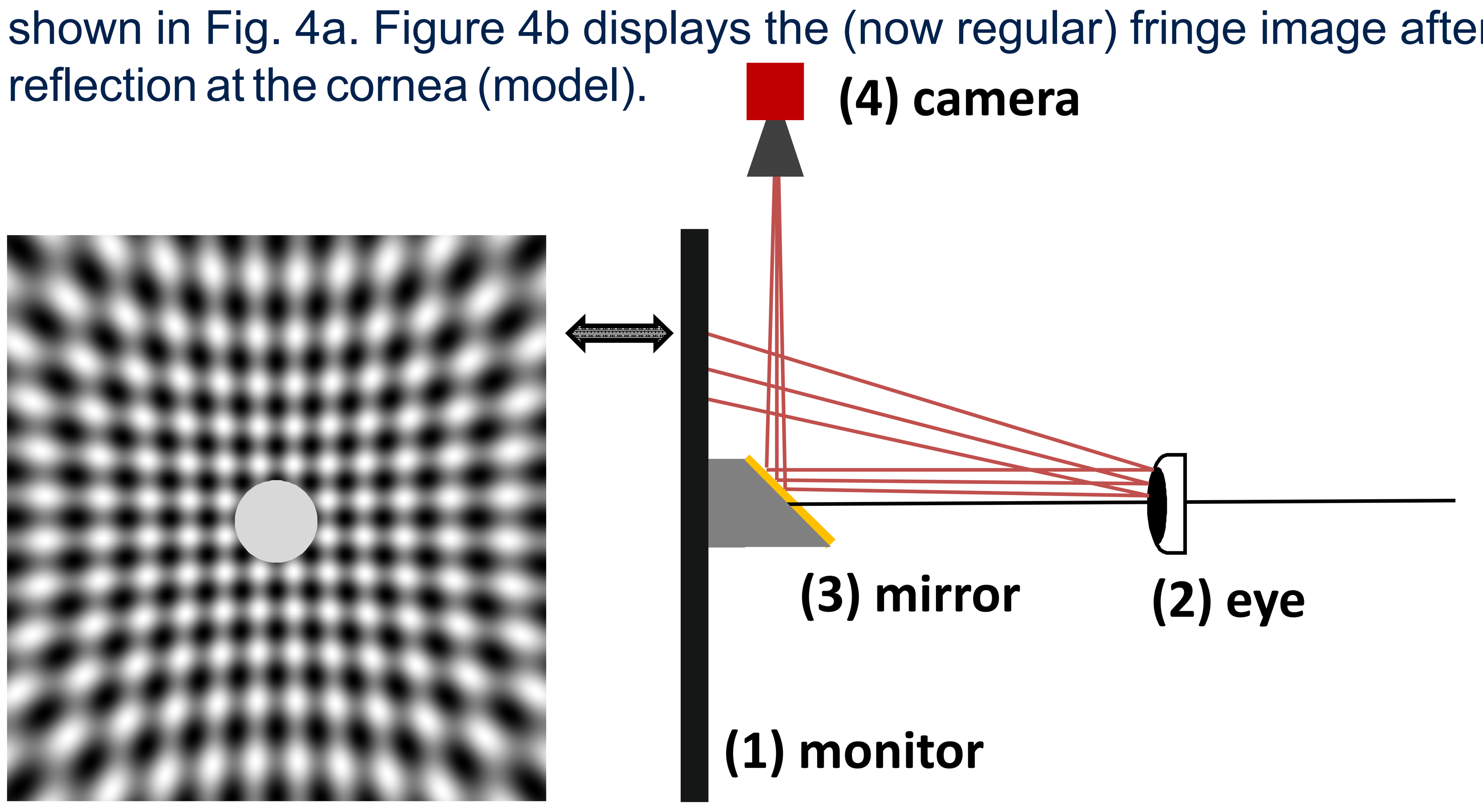


Fig. 4 *Novel scheme for the cornea measurement: A large cross fringe pattern (1), generated by an LCD screen is located in close distance from the eye (2). The reflected pattern is observed via the small mirror (3) and the camera (4). This geometry enables an angular dynamics of ± XXX degrees, a field of XXX mm at the cornea and a missing central spot of only XXX mm.*

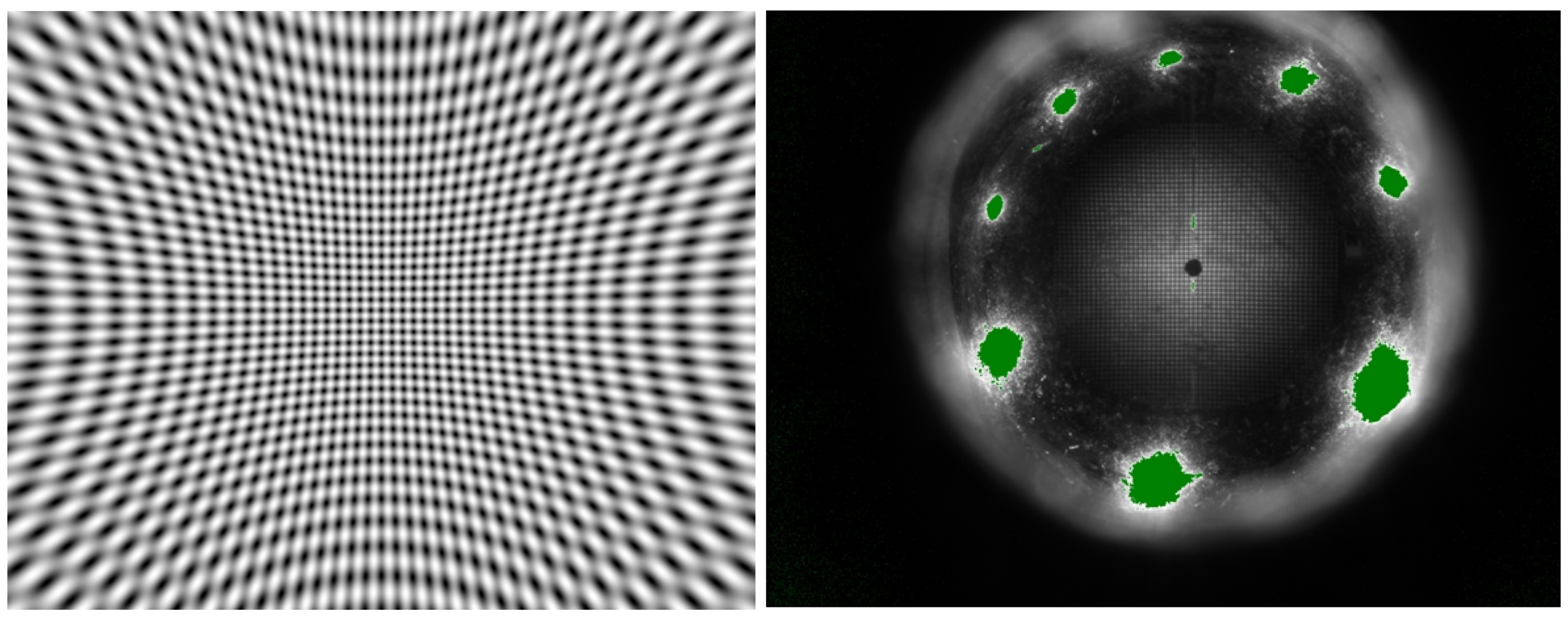


Fig. 5 *pre-distorted fringe pattern, b) the fringe image after reflection is approximately regular and displays a narrow bandwidth, for better single-sideband-evaluation.*

Summary

A single-shot deflectometric method and apparatus is introduced that may have the potential for human cornea metrology. Still open questions are: perturbation by parasitic reflections, fringe contrast, exposure time, calibration, positioning and stabilization of the eye during the measurement.

[1] Liu, Yuankun, Evelyn Olesch, Zheng Yang, and Gerd Häusler. "Fast and accurate deflectometry with crossed fringes." Advanced Optical Technologies 3, no. 4 (2014): 441-445.