High resolution retinal defocus measurement using digital structured illumination

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PURPOSE

Retinal defocus maps can provide clinically relevant information for diagnosis and monitoring of disease. We investigated a novel construction of defocus maps of the retina using novel analyses of slit-scanning ophthalmoscopy data.

METHODS

The CLARUS™ 700 (ZEISS, Dublin, CA) slit-scanning ophthalmoscope projects broad stripes onto the retina and records images of stripe illuminations. Using prototype software, this stripe scanning was done with strongly overlapping stripes (1-pixel step) which can be converted into digital structured illumination using sinusoidal weighted sums. Sinusoidal illumination has the special property of staying a sine wave under defocus with changing amplitude. This amplitude change is a direct measure of optical defocus and can be analyzed to produce high-resolution retinal defocus maps, especially when different frequencies of illumination are used. We demonstrate the validity of the method on test-object and real eye data.

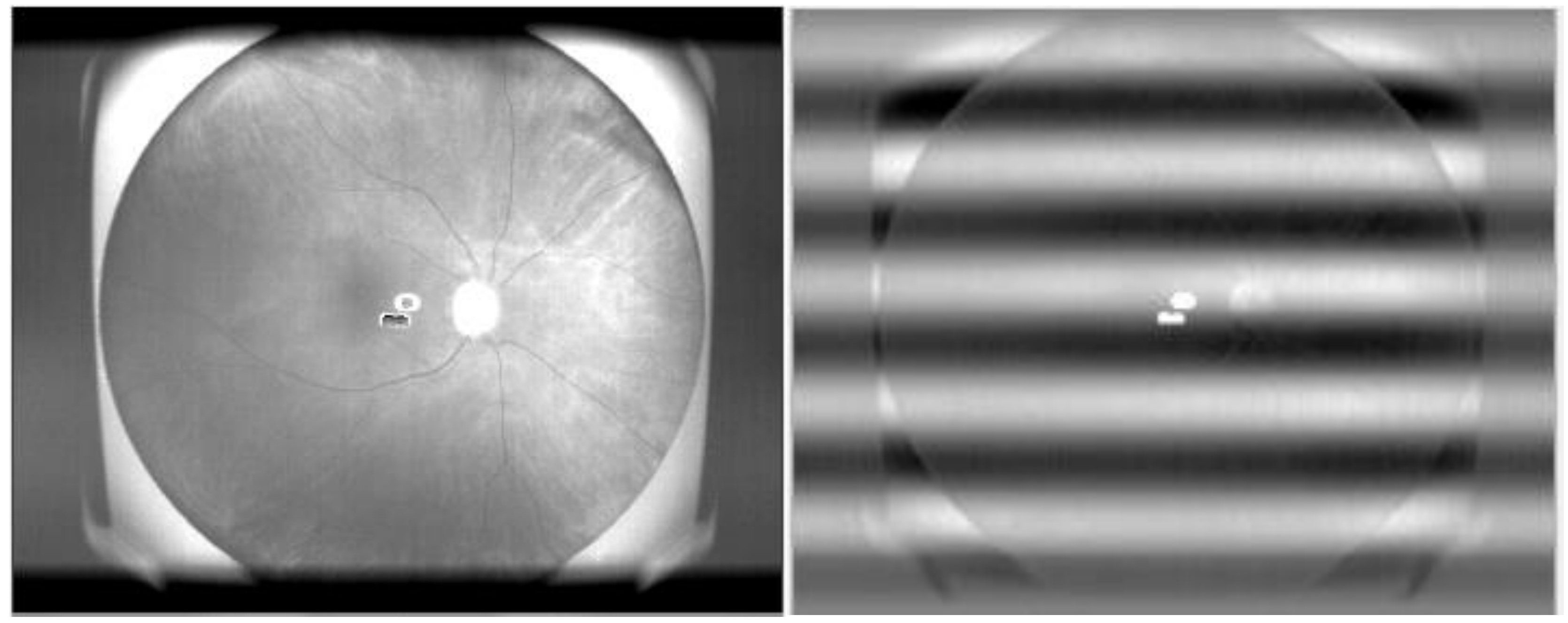

Figure 1. Example fundus image reconstruction from stripe illumination: (left) Naive stripe averaging (right) Sinusoidal illumination from weighted stripe averaging

CONCLUSIONS

Overlapping stripe illumination provides an information rich dataset, which can be analyzed using different techniques. Here we showed that conversion into structured illumination allows the direct analysis of the illumination defocus, which is a direct measure of the optical properties of the eye and the retinal height profile. This analysis could enhance the detection of retinal elevations with clinical significance, including the height of tumors, retinal detachments, or staphylomas.

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RESULTS

Defocus maps generated from the sinusoidal illumination show both the optical defocus due to the optics, and the aberrations of the eye and retinal height of structures. The sine-amplitudes as a function of frequency represent the illumination modulation transfer function and a width-analysis generates a retinal defocus map. The defocus map of a ridged test-object (Fig.2) clearly shows the different height features (e.g. ridges and plateaus), and the defocus map of a human eye (Fig. 3) shows features with expected retinal elevations (e.g. vessels, fovea, optic nerve). Quantitative analysis of defocus as height is difficult as it is not clear at which depth the light is reflected.

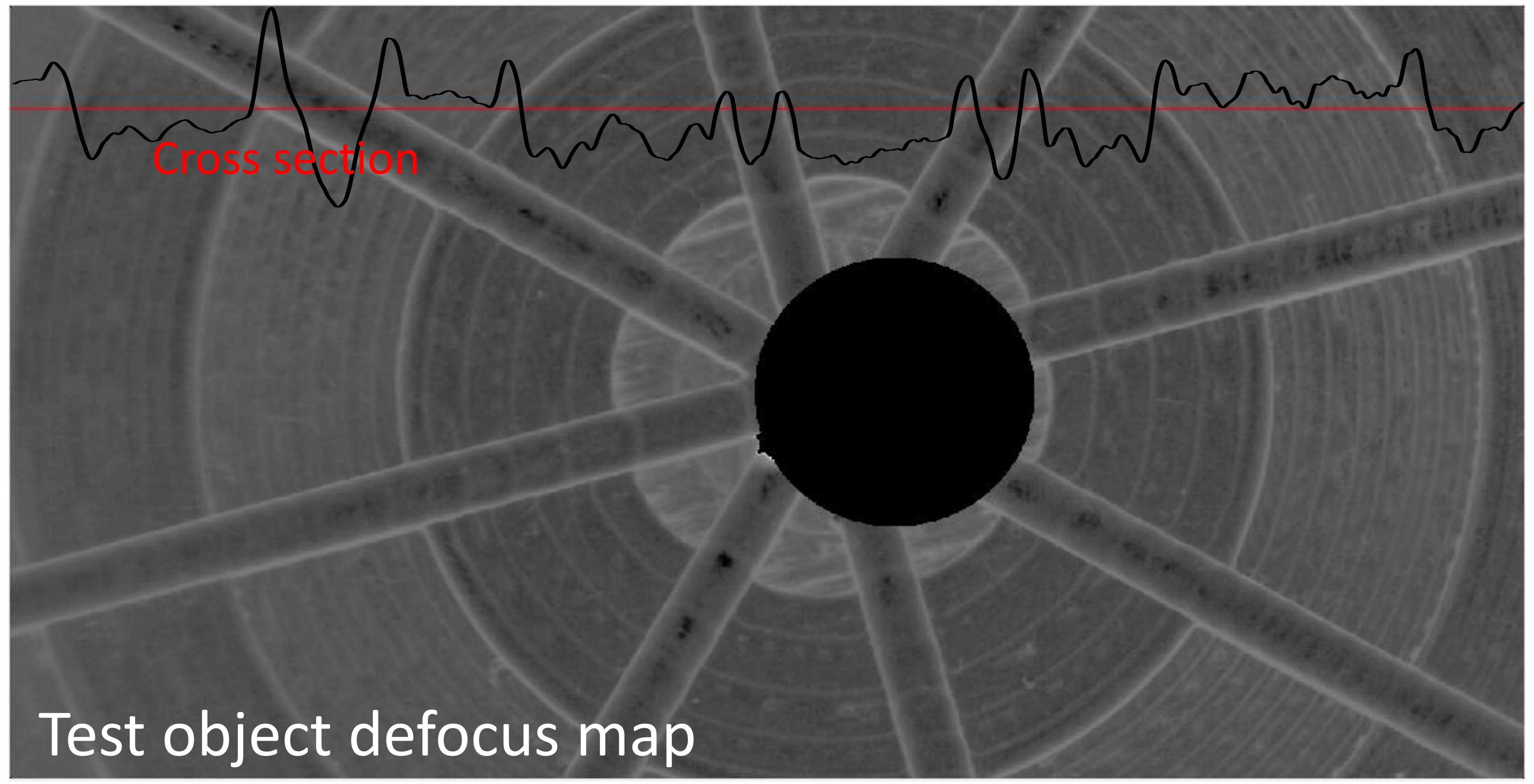
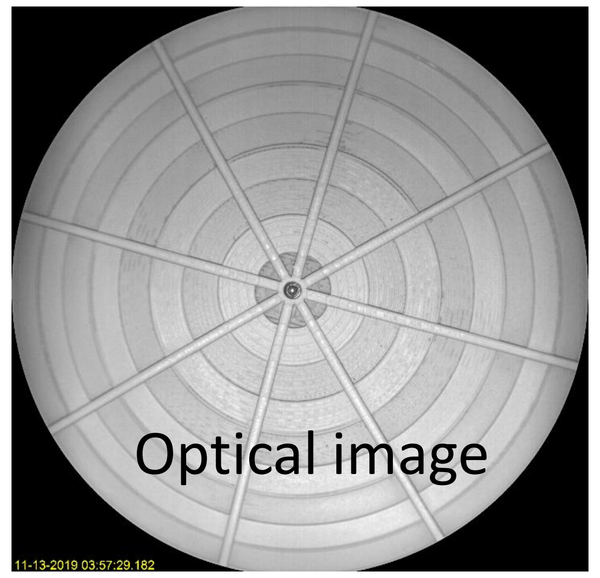


Figure 2. Ridged test-object defocus map with line cross-section showing different height features. Optical image is shown below.



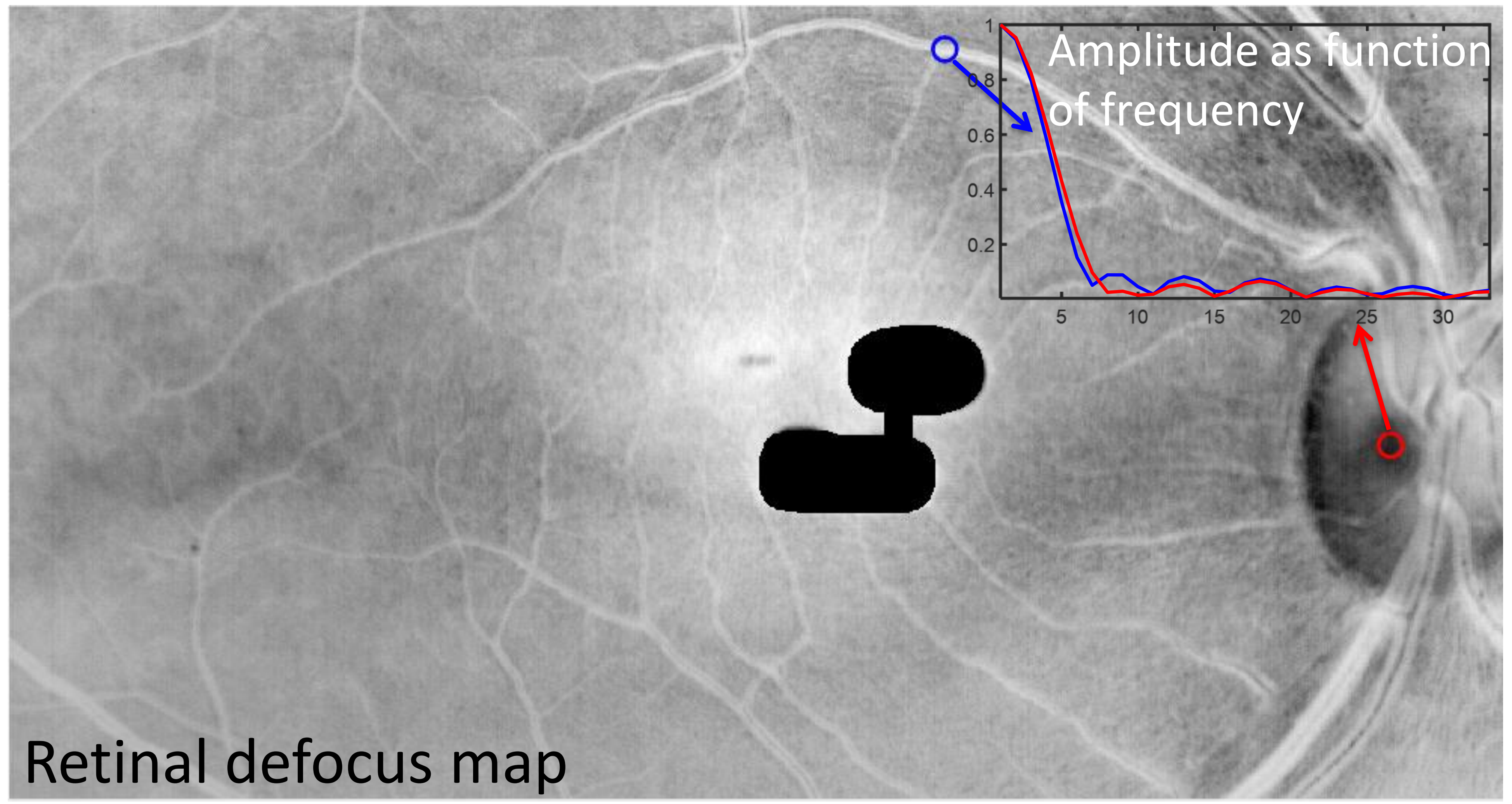


Figure 3. Retinal defocus map with amplitude responses for several sine-frequencies. The red and blue trends correspond to the red and blue image locations. Black area is masked lens reflex.