Digital Holographic Adaptive Optics for Retinal Imaging

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Abstract A new adaptive optics retinal imaging system is presented that is based on the principles of digital holography and dispenses with the wavefront sensor and wavefront corrective element of the conventional adaptive optics system.
OCIS codes: 090.1995; 110.1080; 170.4470

1. Introduction

The normal human eye suffers from many monochromatic aberrations that degrade the retinal image quality. If the eye's aberrations could be completely corrected, the eye's optical quality would be greatly improved. The Shack–Hartmann sensor that was first adopted in astronomy to measure the phase aberration due to the atmosphere was first incorporated into an adaptive optics (AO) system for vision science in 1997 by Liang and colleagues [1]. Using a deformable mirror they were able to correct the higher-order aberrations of the eyes of their subjects. Retinal images with unprecedented resolution capable of resolving individual photoreceptors were readily obtained. Since that time the field of AO in vision science has been rapidly growing with more and more systems being developed [2]. These AO systems all contain three hardware components: the wavefront sensor that measures the phase aberration at conjugate plane of the pupil, the wavefront corrective element that corrects the phase aberration and the fundus imaging device to capture the retinal image. In this summary, we present a new AO retinal imaging system that is based on the principles of digital holography and dispenses with the wavefront sensor and wavefront corrective element of the conventional AO system. Digital holography (DH) is an emergent new imaging technology that gives direct numerical access to the phase of the optical field, thus allowing precise control and manipulation of the optical field [3]. Incorporation of DH in an ophthalmic imaging system can lead to versatile imaging capabilities at substantially reduced complexity and cost of the instrument. The presented digital holographic adaptive optics (DHAO) system replaces these hardware components with numerical processing for wavefront measurement and compensation of aberration through the principles of digital holography.

2. Principles

The schematic diagram of the DHAO system is illustrated by Fig.1. L1 and the resolution target are employed to simulate the eye lens and the retina of the human eye. The target is put at the back focus of the eye lens. The CCD is focused at the pupil plane. The DHAO is composed of flood illumination imaging, phase aberration sensing and phase aberration correction. Fig.1 shows the flood illumination imaging process. The lens L5 focuses the laser beam at the front focus of L1 and the collimated beam from L1 will strike the target and be reflected by the target. An artificial phase aberrator will be inserted at the pupil plane. So the reflected light will experience the added phase aberration. The CCD will capture a hologram from which the distorted complex amplitude at the CCD plane can be recovered. The retinal image can be obtained by introducing a numerical lens and numerical propagation. The final image quality will be degraded by the artificial phase aberration. Then, the flood illumination show by Fig.1 is changed into "guide star" setup to measure the added phase aberration by simply replacing the L5 with an adjustable aperture. The collimated beam will be brought to a focus at the retina. This focused spot like a guide star in astronomy emits a spherical wave that is collimated by the eye lens. This collimated wave will experience the same added phase aberration as the output optical field in flood illumination and this phase aberration can be recovered from a second hologram. Finally, the phase aberration contained within the distorted complex amplitude at the CCD plane in the flood illumination process can be removed through multiplying the distorted complex amplitude by the complex conjugate of the phase aberration data. Thus the focused retinal image quality will be greatly improved.

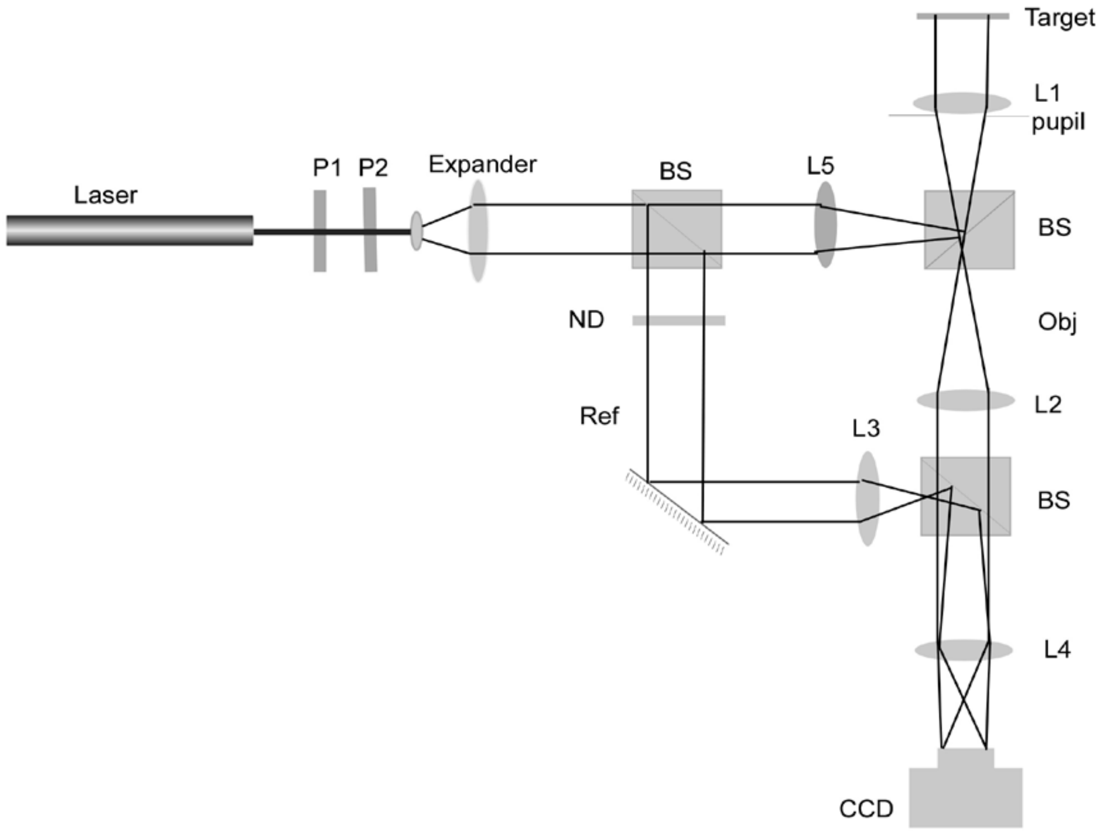

Fig.1 The schematic diagram of the DHAO system. P1 P2: polarizer. ND: neutral filter. L1-L5: lens. Target and L1 comprise an eye model.

3. Experimental Results

From Fig.1, it can be seen that the laser light passes the optics of the eye twice. It is still unclear that the specific effects of the double pass on the phase measurements. To clearly demonstrate the basic principles of DHAO without considering the effect of the double pass, the DHAO system in Fig.1 is modified into a single pass setup simply by directing the laser beam before L5 to strike the target from behind for flood illumination and inserting a lens that focuses the laser beam at the target plane for the guide star setup. This kind of modification will not influence the basic principles of DHAO and can also provide a comparison method for our further study on the double pass case. The phase aberrator is a piece of glass from a broken beaker. Fig.2(a) and (b) are retinal images without and with the phase aberrator respectively. Fig.2(c) shows the phase aberration measured by the guide star procedure. Fig.2(d) is the retinal image corrected by the measured phase aberration represented by Fig.2(c). It is obvious that the corrected image, Fig.2(d), is much better than the uncorrected image,Fig.2(b), except some damage at the lower left corner.

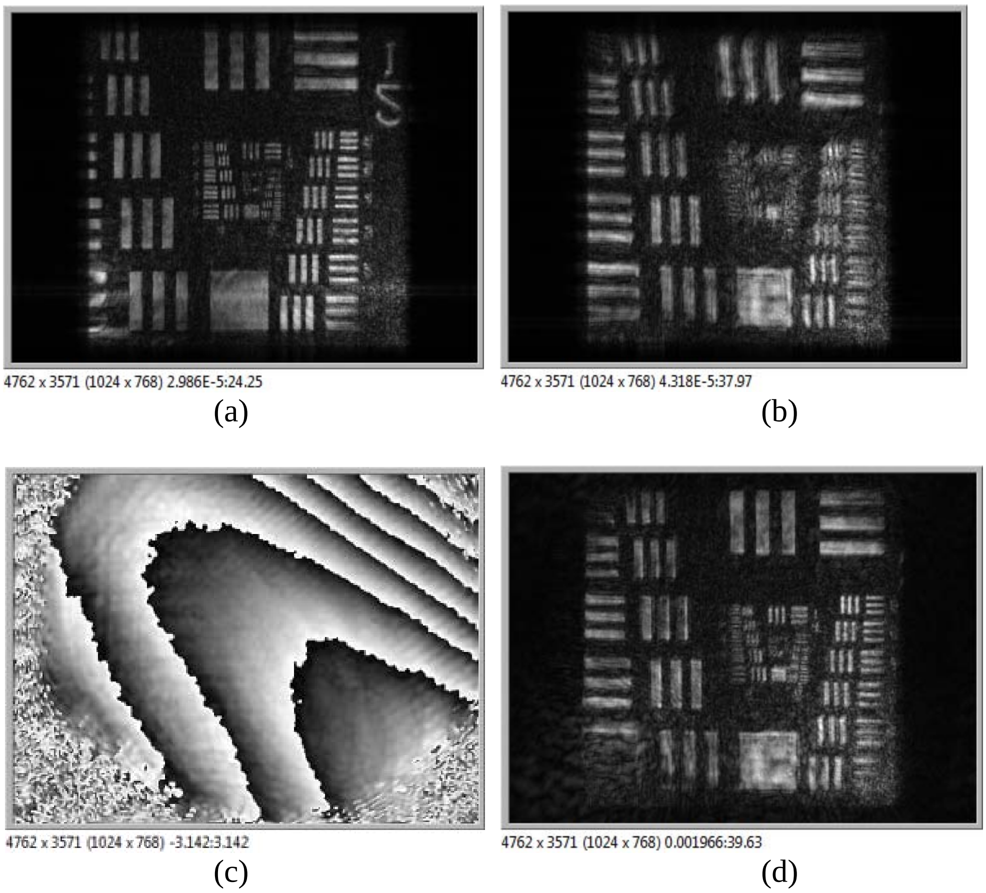

Fig.2 Phase aberration sensing and correction by DHAO. (a) (b) the retinal images without and with artificial phase aberration.(c) the measured phase aberration. (d) the corrected retinal image.

4. Conclusions

The basic principles of the digital holographic adaptive optics are demonstrated. These results will not only provide important evidence of the validity of the DHAO, but also a comparison method for further study on the double pass case and application on the real human eyes.

This work is supported by the National Science Foundation under the grant No.0755705.

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