A binocular system based on multimodality for a full optical characterization of the eye

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We present a binocular system that integrates a double-pass with a Hartmann-Shack sensor to overcome inherent limitations that these two methods present when used independently. Taking advantage of this multimodal way to extract data, we expect to perform a full optical characterization of the eye and, furthermore, provide new parameters with relevant information to describe the optical conditions of people. Our system also includes spherical correction using electro-optical devices and automatic correction of astigmatism with a lens set of cylindrical lenses.

Keywords: double-pass; Hartmann-Shack; multimodality; binocular; optical quality

1. Introduction

The optical characterization of the eye to know how images are formed on the retina is of great importance in the diagnosis and treatment of visual impairments. In this sense, double-pass (DP) systems [1] and Hartmann-Shack (HS) aberrometers [2] have arisen as excellent tools to determine optical characteristics of the eye and are even used clinical practice [3, 4].

Aberrations of the eye are well described from Hartmann-Shack data by approximating the wavefront making use of Zernike polynomials. However, there are phenomena such as intraocular scattering that affect optical quality and that are not measured by HS aberrometers [5]. On the other hand, although double-pass systems provide an overall estimation of the retinal image quality, including aberrations and scattering, it is not possible to separate the contribution of factors affecting the optical performance of the eye.

Since the visual system is itself binocular, it is natural to consider binocular studies to describe the optical performance of the visual system. Moreover, taking into account that the eye has a time-variant behavior [6], a binocular system would allow comparing measurements between eyes if they both are assessed at the same time. Although some binocular setups have been developed so far [7-9], we consider there is a lack of studies based on binocularity. In addition, currently there are no systems in clinical practice able to determine the optical quality of both eyes simultaneously.

Taking into account all the background before mentioned, we present the multimodal eye´s optical quality (MEOQ) system, an instrument able to perform a multimode evaluation of the retinal optical quality. We expect to obtain an accurate description of the optical properties of the eye by analyzing information derived from two techniques (multimodality): the double-pass and the Hartmann-Shack technique. Our system is binocular and makes use of single devices when possible and work in open field, when accommodation is performed by the own eye without using any optical artifact.

Furthermore, the system is able to correct dynamically defocus and astigmatism with devices of configurable optical power.

2. Methods

The MEOQ system

The open field multimodal eye´s optical quality (MEOQ) system is depicted in figure 1. A collimated beam from a super-luminescent diode (λ=780nm) is divided into two beams by means of the mask P1 with two circular apertures of 2mm diameter. Each beam reaches the corresponding eye after passing through the telescopic system L1-L2 and the spherical corrector LL-L3 [10]. After reflected by the retina, the light is translated by L3 to the exit pupil plane. There, the light goes through pupil P2 of 4mm diameter and lens LL and then it is translated to the corresponding camera CCD-DP and to the Hartmann-Shack sensor HS thanks to lenses L2-L1 and L2-L4, respectively. CCD-DPs present a constant illumination background under the measurement conditions and no background noise is removed when processing DP data.

The focal distances of the commercial tunable device LL and the fixed lens L3 are, respectively, f_{LL}=36 to 132mm and f_{L1}=50mm and they can be used to set up vergences in the beam entering the eye from +7.77 to -12.42 diopter (D). Regarding astigmatism, it is corrected by the lens set of cylindrical lenses C1-2. Hot mirrors HM permit the system works in open field.

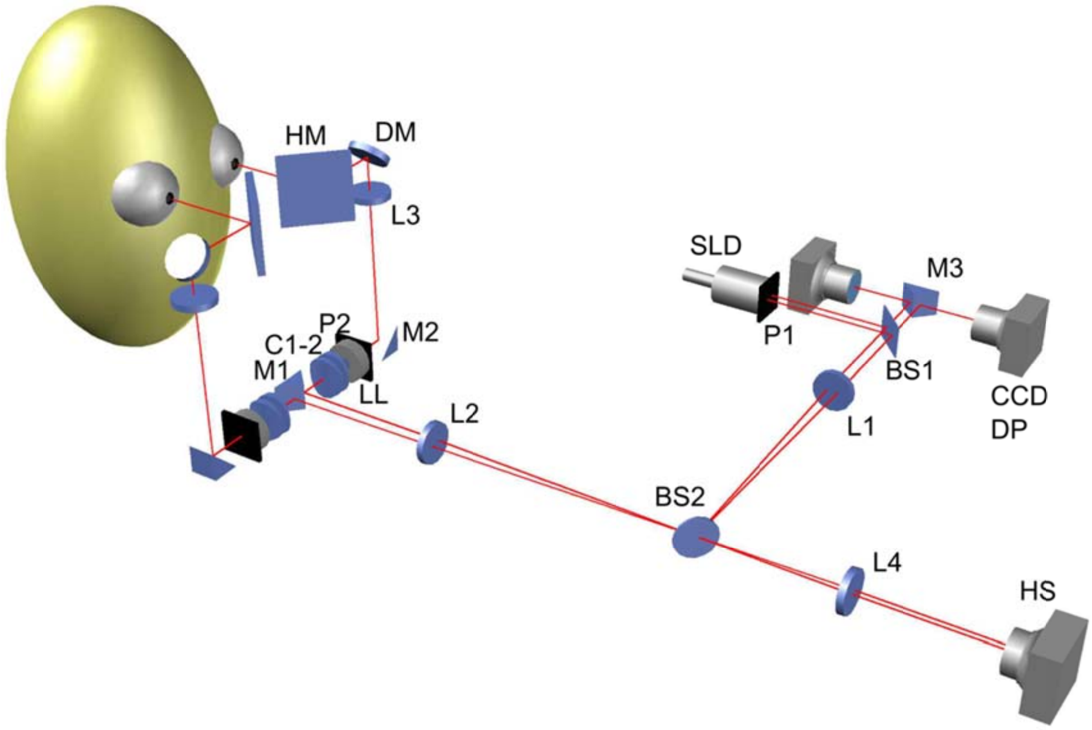

Figure 1. Schematic representation of the binocular system. Light source: SLD; pupils: P1 and P2; beam splitters: BS1 and BS2; lenses: L1, L2, L3, and L4; mirrors: M1, M2, and M3; cylindrical lenses: C1-2; dichroic mirror: DM; hot mirror: HM; camera: CCD-DP; Hartmann-Shack sensor: HS.

Measurements

We measured an artificial and real eye with and without intraocular scattering. This phenomenon was simulated by passing light through a dispersive material at the pupil plane. After capturing the Hartmann-Shack (HS) image, the wavefront aberration was expressed as a Zernike polynomial expansion up to the 14^{th} order. Then, this data was used to estimate the double-pass PSF from HS data by convolving the PSFs for pupils of 2 and 4mm diameters. We applied the Fourier transform to it and to the DP image to compute the MTF. As proposed by [5], the differences in the MTF due to the presence of scattering were computed as $SR_{HS\text{-}DP}=(SR_{HS}\text{-}SR_{DP})/SR_{HS}$, where SR_{HS} and SR_{DP} represent the Strehl ratio of the DP and HS data.

3. Results

Figure 2 depicts the MTFs for the real eye. As observed, the presence of scattering induces greater variations for DP than for HS data. The Strehl ratio $SR_{HS\text{-}DP}$ increases its value from 0.112 to 0.504 when the dispersive material is present during the measurements. This trend was also measured for the artificial eye. For this case, this parameter goes from 0.093 to 0.358, which corroborates the increment of the ratio $SR_{HS\text{-}DP}$ in presence of scattering.

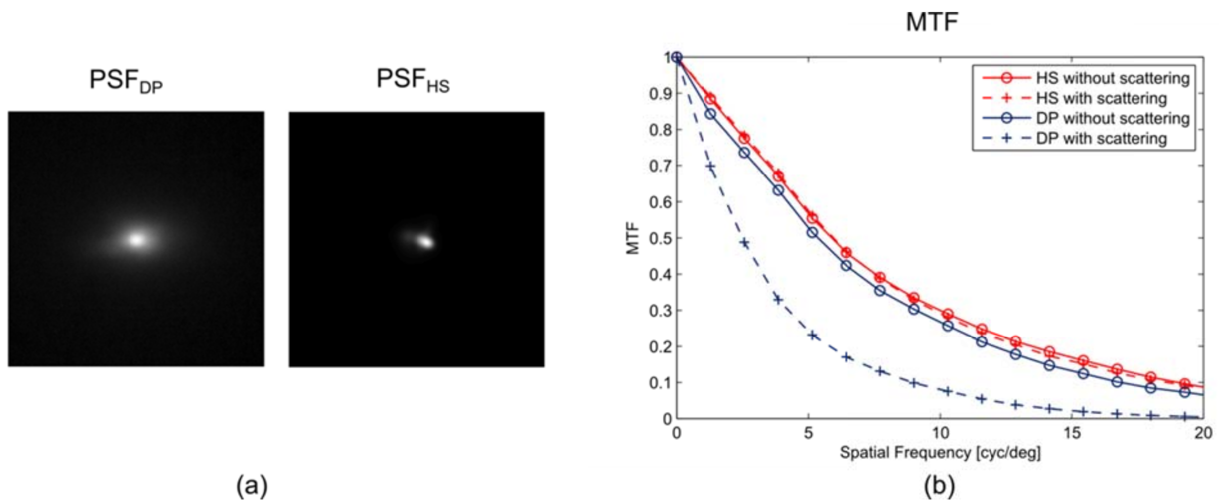

Figure 2. Double-pass (PSF_{DP}) and estimated Hartmann-Shack (PSF_{HS}) point spread functions for the real eye with induced scattering (a). MTF with (discontinued line) and without (continued line) scattering from DP (blue) and HS (red) data for the real eye

4. Conclusions

The use of multimodal data can be a very useful tool to provide an accurate optical description of the eye. In particular, using Hartmann-Shack and double-pass information shows a strong potential to quantify intraocular scattering, as corroborated by the results of this work. Although not explored here, the correction of low order aberrations, i.e. defocus and astigmatism, can have a positive impact when interpreting results; in this manner, we allow the system to use all dynamic range of the HS sensor in the measurement of higher order aberrations and avoid the use of external bancs of lenses to correct them. Moreover, the system has the advantage of measuring in normal visual conditions since it operates in open field.

5. Acknowledgements

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