Information fusion in human eye aberration measurement

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Abstract

An information fusion method measuring human eye aberrations is presented here. We have built an optical setup to combine two systems which can measure the human eye's objective and subjective wavefront aberration separately. Then the result datum is fused on feature level by information fusion method. Finally, we have done a series of experiments to demonstrate this combined fusion method and give some discussions.

Keywords: Information fusion; wavefront aberrations; objective and subjective measurement; Hartmann-Shack wavefront sensor

1. Introduction

Aberrations blur the image of human eye, while spectacles, contact lenses or corneal refractive surgery improve human eye visual quality [1]. Currently corneal refractive surgery is based on corneal topography and wavefront aberration (WA) measurement [2]. However, the subjective image quality of the human eye depends not only on the optical blur caused by the wave aberrations but also on the experience of the observer [3]. During testing the eyesight of a subject, subject must be carried out self adjustment. Such a process is still necessary even automatic optometer has been used popular. The result obtained by automatic optometer is only a reference for optometrist, and the final decision depends on subjective adjustment. Therefore it is necessary to combine information obtained by both objective and subjective method of human eye aberrations measurement, so that information fusion technology is needed in order to obtain measurement datum better suited to human eye's actual working status. There are three kinds of information fusion technology with different levels, i.e. data level, feature level and decision level [4]. Here the feature level is chosen to fuse the Zernike coefficient measured by both objective and subjective method.

2. Methods

2.1 Experimental setup

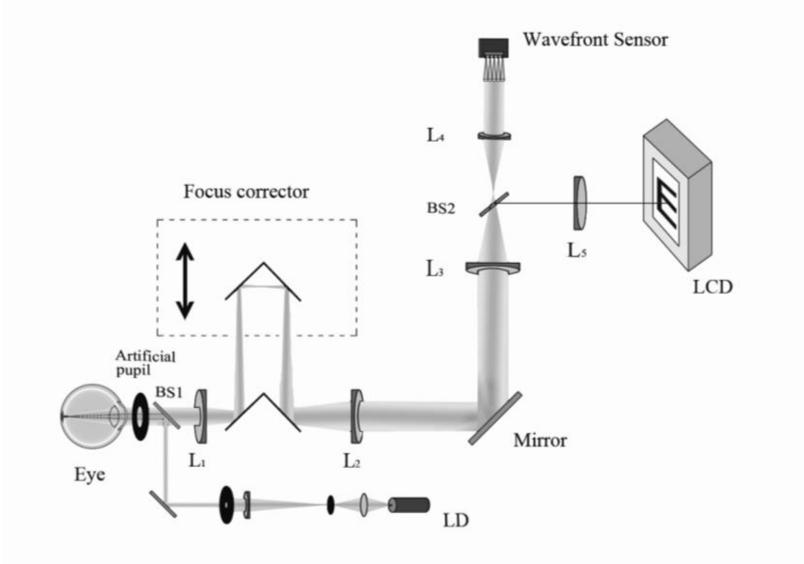


Fig. 1. Schematic diagram of the combined objective and subjective measurement system.

We have constructed a hybrid objective-subjective measurement system based on Hartmann-Shack wavefront sensor to measure the eye's WA. Figure 1 shows the schematic diagram. The Hartmann-Shack sensor has 127 lenslets and each lenslet has a 0.3mm aperture and an 18mm focal length. In this setup the pupil position is conjugated to the mirror and Hartmann-Shack sensor by two telescopes. A 4.8mm artificial pupil is placed between pupil of human eye and BS1. All lenses in the system are achromatic. A focus corrector stage, consisting of a pair of mirrors that could be moved, is used to keep the retina in focus on the CCD of Hartmann-Shack sensor. A 780nm diode laser is used to illuminate because the retina has higher reflection efficiency at this wavelength. The light beam with a diameter of 2mm would pass through the spatial filter and the neutral density filter，and arrive at the retina with a power lower than 10μW which is under the maximum exposure allowed [5]. We especially add a subjective optical path composed of a beam splitter, an image lens and a LCD. The LCD can display standard optotypes of different sizes and directions, including E optotypes and C optotypes. The LCD is self illuminated and its brightness is adjustable. The image lens can image the optotypes on a plane with a distance of 5 meters from subject's eyes.

2.2 Procedure of measurement

Measurement of aberrations includes two steps: objective measurement and subjective measurement. Since the measurement range of Hartmann-Shack wavefront sensor is limited, a focus corrector stage (see Fig. 1) is needed to compensation the defocus of human eye and to minimize the defocus as small as possible before the measurement. The aberration measurement is held after compensation. The centroids of each spot can be found by means of image processing of images detected by the sensor; then the wavefront is reconstructed with a least-squares technique [6]. The WA expressed by Zernike polynomials of 7 order, corresponding to 36 Zernike modes, and the total objective human eye WA is:

$$W_O(x,y)=\sum_{i=0}^{35} C_{Oi} Z_i(x,y) \tag{1}$$

where $W_O(x,y)$ is the WA at point (x,y) measured by the objective method, C_{Oi} is the Zernike coefficients.

The subjective measurement has two processes: vision testing and WA measurement. The subject watches LCD displayed optotypes through the image lens and beamsplitter before WA measurement. The LCD shows the 1.0 (decimal acuity) optotypes at the beginning and the higher level optotypes that the subject can discern at the end of the testing. Every time the optotypes is displayed and subject is watching, the Hartmann-Shack sensor measures the aberration to get the Zernike coefficients $C_{Si}(n,m)$ of 7 order no matter whether the subject can discern it and give a correct judgment or not. Totally j measurements are completed and finally we get Zernike coefficients by calculating

$$C_{S\,i}(n,m)=\sum_j b_j C_{S\,i\,j}(n,m), \qquad \sum_j b = 1 \tag{2}$$

where b_j is the weight factor of j_{th} measurements. The WA at point (x,y) measured by the subjective method, $W_S(x,y)$, is

$$W_S(x,y)=\sum_{i=0}^{35} C_{Si} Z_i(x,y) \tag{3}$$

We perform information fusion on the two groups of datum in Eqs.(5) and (7) to get the Zernike Polynomials using feature level information fusion

$$C_{F\,i}(n,m)=K_A\,C_{O\,i}(n,m)+K_B\,C_{S\,i}(n,m) \tag{4}$$

where K_A and K_B are weight vector of objective and subjective Zernike Polynomials separately, C_{Fi} is the Zernike coefficients after fusion, and the WA after fusion can be written

$$W_F(x,y)=\sum_{i=0}^{35} C_{Fi} Z_i(x,y) \tag{5}$$

3. Results

A series of experiments by means of this combined fusion method have been done and we describe typical one of them in detail below. The subject is the right eye of a girl who is 28 years old. First, we carried out the objective measurement. The subject was measured in the dingy environment whose pupil will dilate naturally. We compensated the defocus of the subject's eye before the measurement with the compensation value of -4.6D. Then the Hartmann-Shack sensor was used to measure and analyze the residual aberration. Figure 2 shows the measured wavefront map and the corresponding calculated point-spread functions (PSF) for the subject. The RMS value of the residual aberration is 1.19μm, from which we can conclude that the high order aberration of the subject is strong.

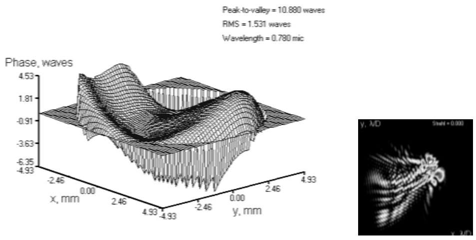


Fig. 2. The wavefront maps in objective measurement and the corresponding calculated point-spread functions (PSF) for one subject.

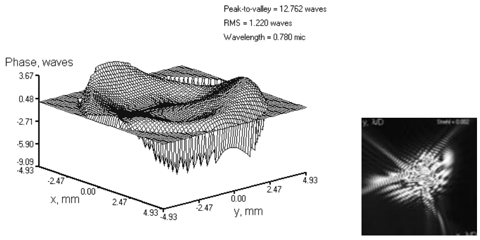
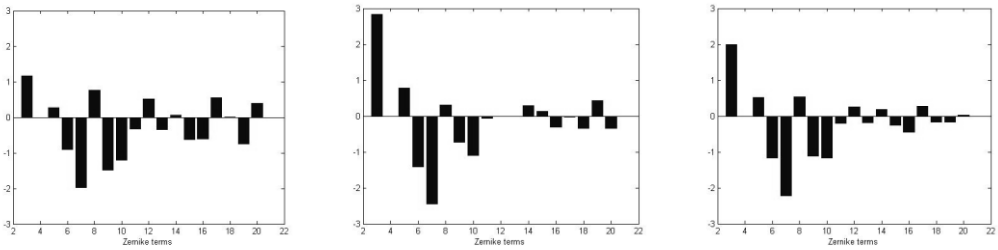


Fig. 3. The wavefront maps in subjective measurement and the corresponding calculated point-spread functions (PSF) for one subject.

When carrying out the subjective measurement, the subject watched the visual chart displayed by the LCD through the measurement system and we have got the WA of the subject according to different visual acuity of human eye when the optotypes were changed from 1.0 to 0.6. Figure 3 shows the wavefront aberration and PSF of the subject when the optotypes is 0.6, and the RMS value of the residual aberration is 0.95μm. The subjective WA is smaller than the objective WA because the subject's adjustment can decrease human eye aberration. In the subjective measurement, the WA was compensated by neural processing.

In order to get a final Zernike coefficients of eye's WA, the weighted factor K_A=K_B=0.5 were chosen for the information fusion operation. Such a weight factor implies that the influence of subjective and objective measurement on the result is equal and we will discuss this assumption in the next section. Figure 4 (a, b, c) shows the Zernike coefficients of the objective, subjective measurement and fused WA, separately. It is obvious that the Zernike coefficients of fused WA are between the Zernike coefficients of the results of objective and subjective measurement. Finally we reconstruct the wavefront after information fusion which is shown in Fig. 5.



(a) (b) (c)

Fig. 4. Zernike coefficients of the objective (a), subjective (b) measurement and WA of information fusion(c).

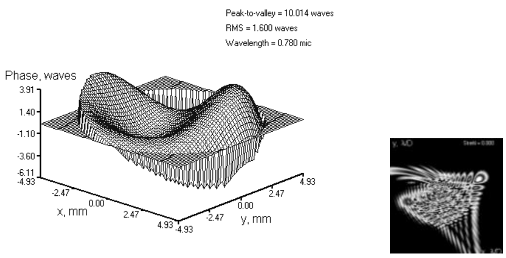


Fig. 5. Wavefront map and associated PSF for fused WA.

4. Discussion and conclusion

We build an optical system combining the objective and subjective measurement of the human eye's WA. When the subject is measured by objective and subjective methods, the result of objective measurement is different from that of subjective measurement, as depicted in Fig. 2 and Fig. 3. However, the parameters of corneal refractive surgery should be unique, so the parameters must be the compromised results of objective and subjective methods. The information fusion technology we use can efficiently combine the datum of subjective and objective measurement, and the final results can represent the aberration of human eye more reasonably. The weight factors used there was 0.5, since, at the present stage, it is difficult for us to determine which one is more important, the objective or subjective measurement for corneal refractive surgery, and the suitable weight factors should be obtained through large amount of experiments. Those experiments needed for us to determine the weight factors above will be the work of our research and will be done in the near future using our system. Finally the method presented here will give a good combination of objective measurement and subjective measurement to meet the image process of human eye, approach the real working condition of human eye and provide more comprehensive parameters for corneal refractive surgery.

5. Acknowledgements

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