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Space-variable analysis of infrared eccentric photorefraction

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ABSTRACT

Based on Fourier optics and the assumption of the isotropic scattering of retina, the crescent formation and light-intensity distribution of the pupil image of a myopic eye using eccentric photorefraction are presented in this paper. In the case of improved infrared eccentric photorefraction, the simulation results are compared with those obtained by normal geometrical analysis, which shows the feasibility and predominance of space-variable analysis. The new method not only accuratelylocates the boundary of dark zone, whose width and center are necessary to calculate refractive errors, but also can be generalized to other space-variable systems.

KEYWORDS

Infrared eccentric photorefraction; Fourier optics; Space-variable system.

INTRODUCTION

Ophthalmic specialists are always investigating an effective method for ocular diagnosis and correction in children, particularly the very young and pre-schoolers. [1-3] In the recent years, more children suffer from the myopia without visiting eye specialists in time. For better treatment of the visual abnormity in children, corrections are recommended by the pre-school age. [4-6] For early diagnosis and correction for children, a practical method of vision screening is needed. As a non-mydriatic diagnosis method, the eccentric photorefraction (EPR)[7-9] is able to perform binocular measurements and make measurements of very young children. This specific method is eccentric andthe image of the subject's pupil is obtained using a cameraand an off-axis illumination source. Both the camera and the light source have a comparatively large distance from the child's eyes so that the complications of the effects of cycloplegia can be eliminated.

Since 1979 when it was first suggested by Kaakienen[10], EPR has been applied and modified to satisfy its practicality. Based on geometrical optics and the assumption of an isotropic scattering of retina, Kusel *et a*l[11]analyzed the light-intensity distribution for different eccentric photorefractor setups. As shown by Chen *et al*[12], the theoretical analysis of photo-refraction reconciled the predictions using the different eye models is presented to predict photorefractive results using three-dimensional ray tracing. In the papers whose theoretical analyses are based on geometrical optics, two most important parameters in EPR images are described: the width of dark zone and thecenter location of dark zone (CDZ)representing the baseline of symmetry of crescent sizeor slope profile. However, ray tracing relying on geometrical optics ignores the diffraction effect, which must be a pivotal reason to bring the analysis results to be dubious.

In order to make the simulation results more precise, a new method depending on Fourier optics[13]instead of geometrical optics should be suggested. But the EPR is not a space invariable system as usual, the effective aperture is changing for each points on the pupil when the image of the pupil is forming on the CCD. To demonstrate the method, the light intensity distribution of pupil image with different myopic diopters is calculated.

SIMULATION OF INFRARED ECCENTRIC PHOTOREFRACTOR

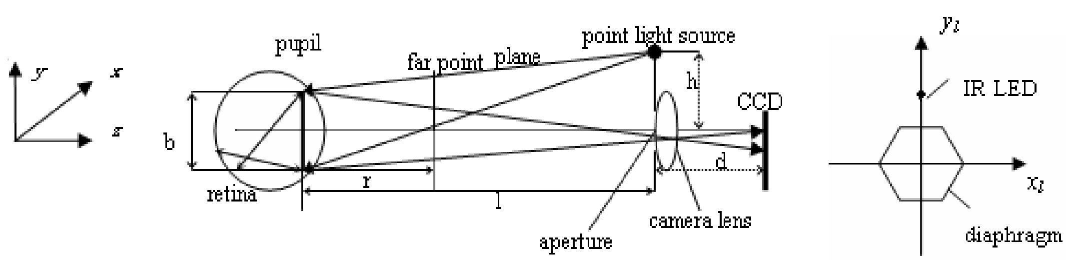


Fig. 1 : Optical geometry of infrared eccentric photorefraction for a myopic eye

For the subsequent calculations and analyses, the Kusel's reduced eye model was selected as in Fig.1which shows the typical optical system of EPR and is used to calculate the intensity distribution of the pupil image of CCD camera where the eye is assumed to be myopic.

Chen *et al* [12]chose a system whose distance between the subject and the camerais 800 mm, the aperture of camera is a circle and the eccentric, or off-axis, distance is 11 mm for simulating. The instrument used as a lightsource a broadband white photographic flash lamp.

Compared with Chen's system, we used a new photorefractor whose point light source is IR LED and the aperture i.e. the diaphragm (as shown in Fig. 1) is changed to hexagon for improving the performance. The same IR LED lying on each side of the hexagonal aperture irradiates the pupil in turn makes astigmatism measurement feasible. Assume the pupil diameter is 6mm, each side of the hexagonal diaphragm is 16mm. The CCD camera lens has aperture of 27 mm and focal length of 135 mm. The distance between the CCD camera lens and the eye is 1 m.

SPACE-VARIABLE ANALYSIS

Based on the method of Fourier optics, the light propagates from light source to the pupil, from the pupil to retina, and the back propagates from retina to the pupil, from the pupil to the aperture of the camera, from the aperture to the CCD of the camera, i.e. the whole process undergoes five Fresnel diffractions. When the light goes through pupil of crystalline lens twice and the lens of CCD camera, the complex amplitude distribution will multiply three different quadratic phase factors. Furthermore, the scattering factor of retina is random. It is obvious that the calculation of the light propagation from the light source to the CCD plane of the camera will be too complex to do. In order to simplify the process, we introduce several assumptions used by Kusel *et al*[11]: aberrations of the eye are not taken into account, the light distribution scattered from retina is isotropic, and the pupil of eye is assumed to be circular. So irradiance on the pupil is uniform and a new analysis method based on point spread function can be chosen.

In Fig.1 when the retina is illuminated by the source through the pupil of crystalline lens, the isotropic backscattered light from illuminated area of retina propagates back and makes irradiance on the pupil. Since the retina plane of the eye is conjugate with the far-point plane of the eye, the backscattered lights from every point of the pupil pass through a circle, which is the cross section of the illuminating light cone from the point light source on the far-point plane as in Fig.1, and form intermediate image of the illuminated retina. Each point of the pupil can be thought as a point light source. All emitted lights by the pupil pass through the intermediate image, and different points on the pupil have different projection light cones through the intermediate image to the CCD camera-aperture plane. The effective aperture of the CCD camera lens is variable for each point of the pupil, since the overlapping area of the CCD camera aperture and the projection cone is changing.

We have reported the space-variable analysis of eccentric photorefaration with a circular pupil.[14]To improve the optical quantity and the safety of the photography refractometer, the infrared light-emitting diode can be used as light source, the wavelength of 850 nm. Infrared spectrumcan less affect the human eye and keep better measurement state. To improve the luminous intensity, a infrared LED array could be used. And the pupil is also changed to a hexagonal aperture, with the hexagonal aperture, the crescent edge could be more smooth as shown in Fig. 2. In this space-variable system, the coherent point spread function is the Fourier transform of the exit-pupil function of the CCD camera lens

$$h_c(x_{0,}y_{0;}x_i,y_i) = K\iint_{\infty} P(x_l,y_l)\exp\{-j\frac{2\pi}{\lambda d}[(x_i - Mx_0)x_l + (y_i - My_0)y_l]\}dx_l dy_l \quad (1)$$

where *K* is a complex constant, *M* is magnification of the CCD camera lens, λ is the wavelength of the operation light, *d* is the distance between the CCD and its exit-pupil, and are exit-pupil coordinates, and is its exit-pupil function.

When assuming that the CCD camera lens is a thin lens, the exit-pupil function is the same as the entrance-pupil function and equal to the overlapping area of the CCD camera aperture and the projection circle.[14]Assume the coordinate of a point source is , as shown in Fig.1, for the hexogen pupil, the area on the camera lens illuminated by a point of pupil is also a circle with central coordinates and radius*R*

$$R = \frac{b}{2}\left(\frac{l}{r} - 1\right), \quad x_l = x' + \left(1 - \frac{l}{r}\right)x, \quad y_l = y' + \left(1 - \frac{l}{r}\right)y \quad (2)$$

where *b* represents the diameter of the pupil, *r* is the distance between the pupil and the far-point plane.

When simulation is operated iteratively by computer, firstly calculate the central coordinates and radius of the projection circle from a point of the pupil on the CCD cameraplane by Eq.(2) to obtain the overlapping area of the CCD camera's aperture and the projection circle. Then compute the coherent point spread function of CCD camera for this point of the pupil by Eq.(1) and the incoherent point spread function. Finally, picture the intensity distribution of the pupil image.

SIMULATION RESULTS AND DISCUSSION

Compared with the simulated photorefraction images obtained by Chen *et al* [4] with pupil diameters of 6mm using Navarro's eye model, the width of dark zones is similar, the width of the crescent increases and the shape of the crescent changes with the degree ofmyopic eye. This proves the feasibility of space-variable analysis of EPR.

-2.0D -3.0D -4.0D -5.0D

Chen's simulation :

Space-variable Simulation:

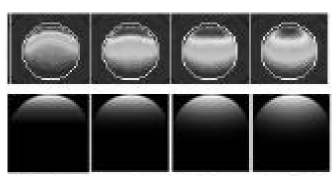
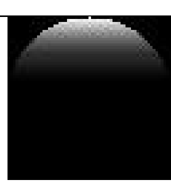
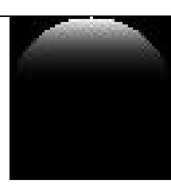
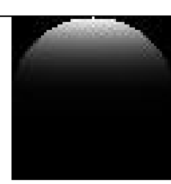
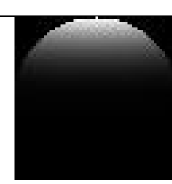


Fig.2 The crescent on the meridian of the images simulated by space-variable analysisand at different myopic diopters for-2.0and-5.0 degree compared with Chen's

			
Space-variable Analysis (-2.0D)	Geometric Analysis (-2.0D)	Space-variable Analysis (-3.0D)	Geometric Analysis (-3.0D)

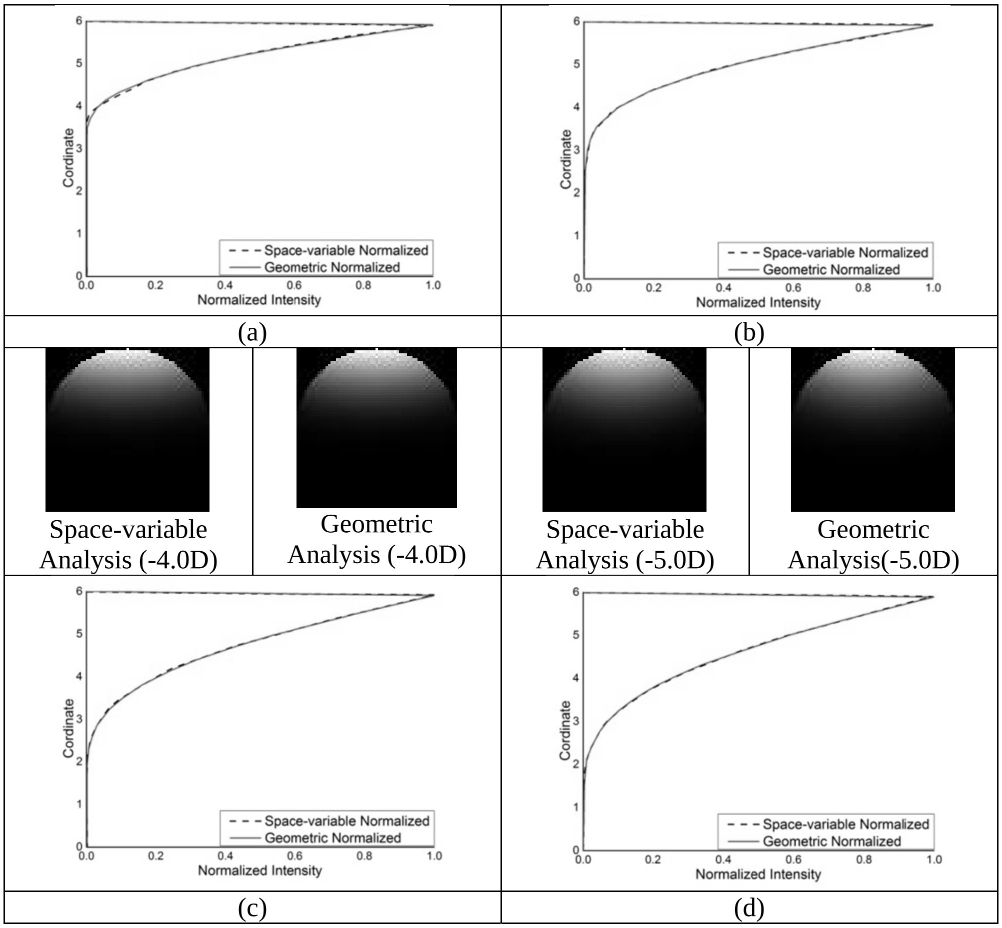


Fig.3 The crescent and the normalized intensity on the meridian of the images simulated by space-variableanalysis (left crescent and dash line) and geometric analysis (right crescent and solid line) at different myopic diopters: (a)-2.0D (b) -3.0D(c) -4.0D(d) -5.0D.

Fig.3 shows the simulation results by Fourier optics for -2.0 (a)and-5.0 (b) diopter. Each has three figures, on the left above of the three figures is the crescent simulated by Fourier optics, while on the right above is the crescent simulated by geometric optics. Below the crescent figures is the normalized intensity on the meridian of the images, in which the dash line denotes the intensity distribution simulated by Fourier optics, by contraries, the solid line is drawn based on the simulated results of geometric optics.

The intensity distributions in vertical orientation of the crescent show differences in Fig.3 (a) because of considering the diffraction effect in Fourier optical analysis. When the effective pupil of CCD camera lens is very small, diffraction effect becomes significant and could not be neglected. As the myopic diopters increase, the projection circle becomes larger, diffraction effect goes into unconspicuous, and the vertical intensity distributions get to be almost the same for the two methods in Fig.3 (b).

CONCLUSION

Instead of the normal geometrical research method, we have presented a theoretical analysis of EPR using Fourier optics, described the forming of the crescent, and calculated the intensity distribution of the pupil image for the infrared eccentric photorefractor.

Compared with geometric optics analysis, the results from this investigation show that the effective CCD camera aperture is changing with different points on the pupil, the diffraction effect is dominant when the effective CCD camera aperture is small. The simulation intensity distribution image is obviously different compared with that obtained by geometric optics analysis when myopia is not so serious. The analysis using Fourier optics is more suitable for EPR than that by geometric optics especially for low myopia, whose timely diagnosis and correction by ophthalmic specialists are particularly needed.

According to the two significantparameters in EPR, the width of dark zone andand the center of thedark zone, Fourier analysis reveals its advantage of accuracy. With aberrationa, the inhomogeneous distribution scattered from retina, and the shape of the eye’s pupil are included, this method could be also used and obtain more useful results. Depending on Chen’s research [3], more precise simulation results can be expected using he new analysis method we presented.

Furthermore, Fourier optics is not only a new method to analyze EPR, but also has very attractive application to other space-variable systems.

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