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Human Eye Response to Pupil Size Variation Programmatically

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Abstract: The human eye is the best optical device in the world. The performance of this eye is influenced by optical aberrations. Several human eye models were developed to treat and correct this issue. This work depends on the Liou and Brennan eye model to design and analysis the perfect and an aberrated human eye. This model is more suitable than other models, since, it depends on using a gradient refractive index (n) with aspherical lens surface. The effect of entrance pupil diameter on optical aberrations was evaluated by programmatically by ZEMAX, computer software (Version 14) at 555 nm monochromatic light under the influence of Semi-Diameter values Variation by 1.25, 1.5, 2, 3, 4 and 5 mm. The Modulation Transfer Function (MTF), wave front aberration and Root Mean Square of the spot sizes (RMS) were used to analysis the performance of the eye. The results show that the best image quality obtained at 1.25 and 1.5 mm Semi-diameter which mean the lowest values of aberrations can be achieved by smaller pupil size and small field of view under monochromatic light.

INTRODUCTION

The human eye is an interesting optical instrument. The principles of image formation by the eye are the same as for man-made optical systems. The light enters the eye through the cornea and then is refracted by the cornea and the lens to be focused at the retina. The cornea with refractive index 1.376 also it has a greater power than the lens. However, the corneal power is constant and its optical properties can be altered according to diseases affecting the cornea[1]; the power of the lens is variable and it changes when the eye needs to focus at different distances. The iris (the colored part of the eye) and the pupil (the iris opening) control the incoming light beam diameter and it forms the eye stop aperture. As with all optical systems, the aperture stop is a very important component of a system, affecting a wide range of optical processes[2]. The eye shape approaches a spherical ball. Figure 1 gives details of its geometry and the most important optical data of the human eye are given in Table 1. A distinction is made between the relaxed eye, for objects at infinity and the accommodated (or focused) status[3].

Optical aberrations: The human eye as an optical system; focuses the incoming light by its optical components to form the image onto the retina. Imperfections in these components may cause deviation of light from its path. Such deviations are called optical aberrations which cause blurred image and decreasing in visual performance which affected by several kinds of aberrations such as:

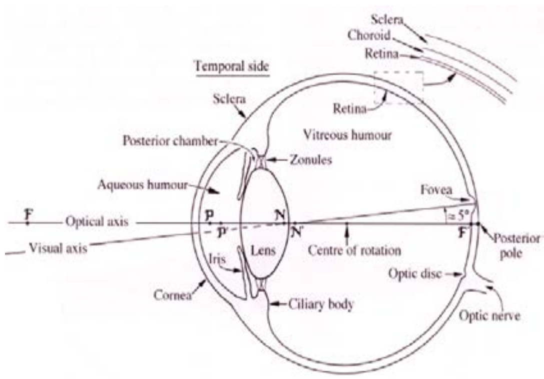


Fig. 1: Details and geometry of the human eye

Table 1: Major optical parameters of the human eye

Propertyes	Relaxed	Accommodated
Refractive power	58.63 D	70.57 D
Focal length in air	17.1 mm	14.2 mm
Refractive power of the crystalline lens	19 D	33 D
Field of view-maximum	108°	
Field of view-fovea	5°	
Pupil diameter	2-8 mm	
F-number	6.8-2.4	
Diameter of the eye-ball	24 mm	
Distance of the front vertex from the rotation point	13.5 mm	
Wavelength of largest sensitivity	555 nm	
Distance of the nodal point N from the front vertex	7.33 mm	
Distance of the principal plane P from the front vertex	1.6 mm	
Distance of the entrance pupil from the front vertex	3.0 mm	

Spherical Aberration (SA): It is observed in optical devices that occur due to the increased refraction of light[4] where the non-spherical surfaces are free of SA[5]. The correction of SA can be done with lens shape changes or bending of the lens, to reduce[6].

Coma aberration: It is the most pronounced just off the optical axis (at small field angles)[6] in thin lens it depends on its position and shape factor[7].

Astigmatism: Occurs when the beam from the off-axis object will converge on the two different image planes[8].

Distortion aberration: When the image of an off-axis point is formed farther from the axis or closer to th $w(v)=\frac{\int_{-\infty}^{\infty} h(x)\sin(2\pi vx)dx}{\int_{-\infty}^{\infty} h(x)dx}$ e axis than the image height, the image of an extended object is said to be distorted[9].

Chromatic aberration: A lens will not focus all wavelengths of light to exactly the same place. These aberrations are not only on axis but exists off axis as a function of field angle, two types of chromatic aberrations are referred to as longitudinal chromatic aberration and transverse (or lateral) chromatic aberration[6].

Human eye image analysis criteria

The Optical Transfer Function (OTF): The optical transfer function as shown in Eq. 1 consists of two components; they are the Modulation Transfer (MTF) which is responsible for the reduction in image modulation (or contrast) and the Phase Transfer Function (PTF) which is responsible for the lateral shifting of the pattern[10]:

$$OTF(V)=MTF(v)\exp(-iPTF(v)) \quad (1)$$

where:

$$MTF(v)=\sqrt{v^2(v)+w^2(v)} \quad (2)$$

and:

$$PTF(V)=\tan^{-1}\left[\frac{w(v)}{V(v)}\right] \quad (3)$$

where:

$$v(v)=\frac{\int_{-\infty}^{\infty} h(x)\cos(2\pi vx)dx}{\int_{-\infty}^{\infty} h(x)dx} \quad (4)$$

and:

$$w(v)=\frac{\int_{-\infty}^{\infty} h(x)\sin(2\pi vx)dx}{\int_{-\infty}^{\infty} h(x)dx} \quad (5)$$

Where:

v(v) = The real part

w(v) = The imaginary part of the optical transfer function

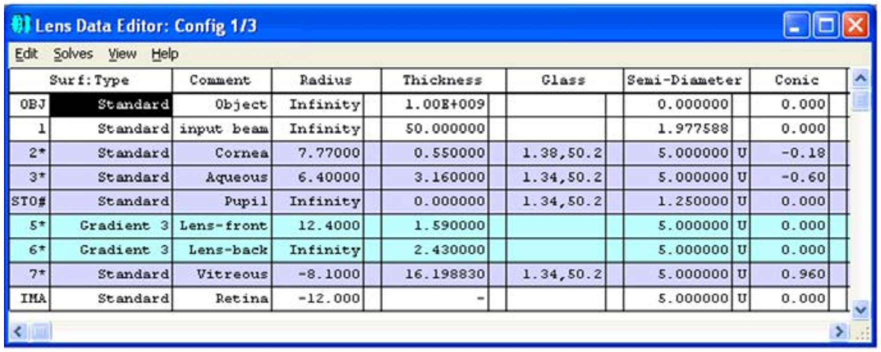
Root Mean Square (RMS): Spot diagram is a way of visualizing the effect aberrations have on image quality. Another measure of quality that realize on the spot diagram is the RMS spot radius. The RMS spot radius is defined as[10]:

$$RMS=\sqrt{\frac{\Sigma_i\left[(x_i+x_c)^2+(y_i+y_c)^2\right]}{n}} \quad (6)$$

MATERIALS AND METHODS

Analytical work: In order to study the effect of pupil size and Field of View (F.O.V.) with different values in the visible region on monochromatic and polychromatic aberrations; Liou and Brennan in 1997 eye model was constructed by using ZEMAX (Version 14) optical design computer program. This model uses the cornea and crystalline lens together as a single element to converge the light beam and focuses it onto the retina.

Construction of Liou and Brennan eye model was done by Inserting 7 surfaces; they are the input beam,



Lens Data Editor: Config 1/3

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Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter		Conic
OBJ	Standard	Object	Infinity	1.00E+009		0.000000		0.000
1	Standard	input beam	Infinity	50.000000		1.977588		0.000
2*	Standard	Cornea	7.77000	0.550000	1.38,50.2	5.000000	U	-0.18
3*	Standard	Aqueous	6.40000	3.160000	1.34,50.2	5.000000	U	-0.60
STO#	Standard	Pupil	Infinity	0.000000	1.34,50.2	1.250000	U	0.000
5*	Gradient 3	Lens-front	12.4000	1.590000		5.000000	U	0.000
6*	Gradient 3	Lens-back	Infinity	2.430000		5.000000	U	0.000
7*	Standard	Vitreous	-8.1000	16.198830	1.34,50.2	5.000000	U	0.960
IMA	Standard	Retina	-12.000	-		5.000000	U	0.000

Fig. 2: Liou and Brennan in 1997 eye model was constructed by using ZEMAX (Version 14)

cornea, aqueous humour, pupil aperture, the lens front portion, the rear portion of the lens and finally the vitreous body of the eye; all these surfaces were inserted between the object and retina surfaces each one with its parameters were entered into the ZEMAX software as shown in Fig. 2. The field of view was set at 5 degrees. The Semi-Diameter values were chosen with values of 1.25, 1.5, 2, 3, 4 and 5 mm. Modulation Transfer Function (MTF) (the magnitude response of the optical system with different spatial frequencies[11]) was obtained for each case of the cases mentioned above. Also the wavefront aberration coefficients and the spot diagrams Root Mean Square (RMS) were evaluated for all fields of view and pupil Semi-diameters for both monochromatic light.

RESULTS AND DISCUSSION

MTF and RMS analysis: Liou and Brennan model was used and analysis by using different criteria, Modulation Transfer Function (MTF), spot radius on the retina and wavefront aberration coefficients. The effect of eye iris size (Semi-Diameter); Entrance pupil diameter E.P.D. on the response of the retina image were studied in details. Also, the effects of E.P.D. on each of the Siedel aberrations were evaluated at 555 nm.MTF curves presented in case of Fig. 3 and that illustrated in Eq. 2, indicate that the MTF for pupil diameters (1.25 mm) represents the diameter of the diffraction limited optical system. Also, MTF was decreased because of the distortion aberration.

For more explanation, RMS variations were studied to show the retinal image performance under variation of pupil size and for the affixed field of view of monochromatic light (555 NM). The RMS plot in μm as a function of the pupil size (1.25, 1.5, 2, 3, 4 and 5 mm) at field of view values (5°). The results showed that the RMS values getting increase as the pupil size increase at specific F.O.V. as shown in Fig. 4.

Table 2: RMS values of retinal image according to pupil size variation

Semi-diameter (mm)	Monochromatic RMS (μm)
1.25	17.382
1.5	20.160
2	24.635
3	29.107
4	33.087
5	29.524

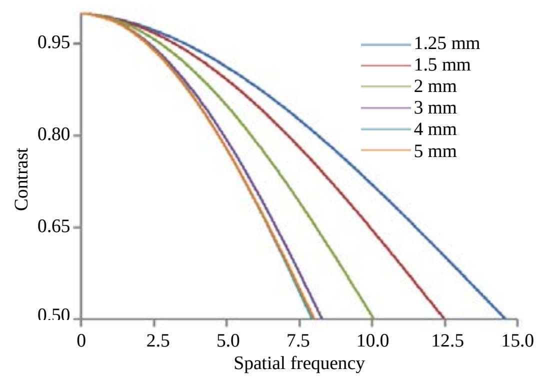

Fig. 3: Image contrast at different iris sizes

RMS values of spot diagrams calculated from Eq. 6 give an indication about the amount of aberration and its kind, in comparing with MTF curves; the highest amount of aberrations appearing when the spot size is large (RMS value is high) and this is clear when the pupil Semi-diameter≥3 mm while the MTF curves provide better image contrast when MTF has large values (≃1). Table 2 clears the RMS values of retinal image according to pupil size variation.

Wavefront aberration coefficients: The most effective aberration kind on MTF degradation and then affect the image quality obtained from the human intraocular lens can be known from the aberration coefficient curves as shown in Fig. 5. MTF was decreased when the Semi-Diameter is increased, this is because of spherical aberration (W_{040}) generated inside the eye. W_{040} increased

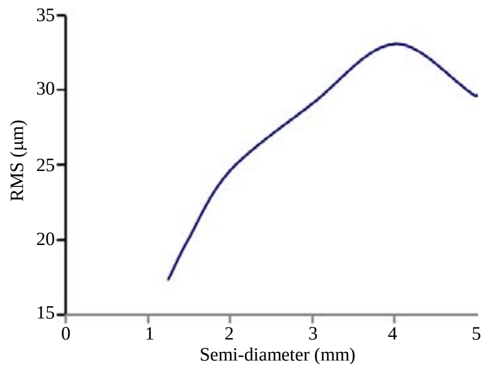

Fig. 4: RMS variation with pupil diameter change

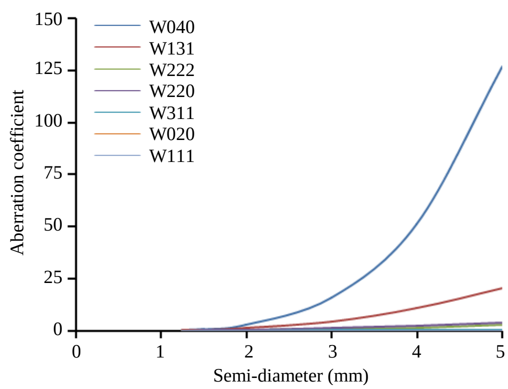

Fig. 5: Monochromatic wavefront aberration coefficient at 5°

when the pupil Semi-diameter enlarged >1.5 mm which in turn prevented the light rays from being focusedon the same spot on the retina. The other kinds of aberrations in these cases are ineffective because the rays are on axis and the F.O.V. is fixed.

CONCLUSION

This research showed that the performance of the eye model was at the best values if the iris size (Semi-diameter) is small (1.25 and 1.5 mm) and F.O.V. at (5°) for monochromatic light. MTF was decreased when the Semi-diameter increased, this is because the amount of aberrations generated inside the eye and this affects the image quality. Also, one can conclude that the spherical aberration and distortion aberration are responding about the degradation in the image quality of the when EPD increases. From all the results which consist of MTF, wavefront aberration coefficients and RMS, one can say that the minimum E.P.D.<4 represent the case of near diffraction limited (perfect eye system) diffraction limited at EPD$\leq$1.25 mm and FOV$\leq$5°.

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