Propagation, structural similarity and image quality

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Abstract

Natural images usually show a strong dependency between one point and its neighbourhood. This fact helps to the image interpretation and should be considered when determining the final image quality. The aim of this work is to propose an objective index which allows comparing natural images on the retina and, from them, to obtain relevant information abut the visual quality of a particular subject. The morphological data of the subject's eye are considered and the light propagation through the ocular media is calculated by means of a Fourier-transform-based method. The retinal PSF so obtained is convolved with the natural scene under consideration and the obtained image is compared with the ideal one by using the structural similarity index.

METHODOLOGY

• Subjects

We have studied the eyes of two subjects affected of high ametropia. These subjects were surgically treated using the PresbyLasik technique[1]. Biometric magnitudes were measured using a Pentacam system and the IOL Master. We also determined the visual acuities for near and far vision both considering the ophthalmic correction (NBCVA, BCVA) and without correction (NVA, VA), and the residual accommodation amplitudes amplitudes (RA). Data are presented in Table I.

	Optometric Data			
	Subject A (hyperopic)		Subject B (myopic)	
	Pre surgical	Post surgical	Pre surgical	Post surgical
Sphere (D)	4.50	0	-4.50	0
Cylinder (D)	-0.75	0	-1,50	0
Axis (º)	85	0	180	0
Adition (D)	1.00	1.00	1.50	---
VA	0.05	1.0	0.05	0.9
NVA	0.05	0.8	0.1	0.8
BCVA	1.2	---	1.0	---
NBCVA	1.0	1.0	1.0	---
RA (D)	2.00	2.00	2.00	2.00

Table I

• Determination of the propagated patterns

Once we know the corneal elevation maps, the corneal thickness map and the size of the anterior chamber before the refractive surgery, we determine the optical path length of each ray entering cornea to the plane immediately following the lens. In order to simulate the effect of the crystalline lens, we use the Kooijman model. The obtained wavefront is fitted to Zernike polynomials and, taking into account the preoperative biometry and optometric data of the subject, we conveniently adjust the coefficients related to astigmatism and defocus. Thus, although we do not know the morphology of the crystalline lens, we can accurately estimate its action on an incident wavefront. This effect is assumed to remain constant after corneal surgery. We can compute the propagated intensity patterns at any plane around the subject's retina. To this end we used the method developed by Espinosa et al.[2]. The intensity in a plane placed at a distance z from the lens is:

$$\left|U_Z\left(x_z,y_z\right)\right|^2=\left|FT\left\{exp\left[-\frac{p}{2}\left(x^2+y^2\right)\right]exp\left[-i\frac{2\pi}{\lambda}W_0\left(x,y\right)\right]exp\left[i\frac{2\pi}{\lambda}\frac{\left(x^2+y^2\right)}{z}\right]\right\}\right|^2 \quad (1)$$

In equation (1), we have incorporated the Stiles-Crawford effect (SCE). Figure 1 show some of the obtained light distributions of hyperopic subject pre and post PresbyLasik surgery.

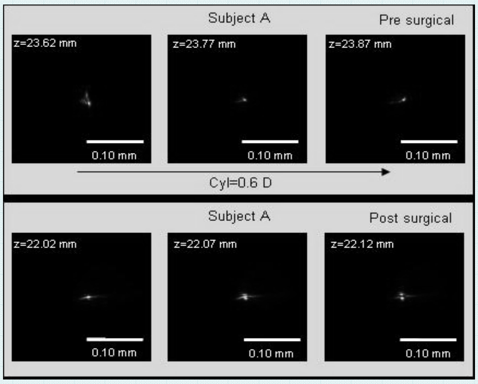

Figure 1

The following step consists in obtaining natural images at the planes of interest.

We convolve an original not distorted image (X) with the obtained light distribution at those planes of interest, that is:

$$Y_Z\left(x_z,y_z\right)=X\left(x_z,y_z\right)\otimes U_Z\left(x_z,y_z\right) \quad (2)$$

• Visual Structural Similarity Index (VSSI)

The subjective quality of human vision system (HVS) of a subject (usually measured by the decimal value of visual acuity) may be objectively evaluated using metrics that take into account the structure of the natural image[3]. Moreover, metrics must evaluate, in a compact form, all the distortions that the optical part of HVS causes to the original scene. We chose a metric whose maximum is determined by the scene just affected by diffraction and that can be directly related to the subject's VA. We call it the Visual Structural Similarity Index (VSSI):

$$VSSI\left(X,Y\right)=2.4\frac{\sum_{j=1}^{M}\left(\frac{2\sigma\left(x_j,y_j\right)+C_2}{\sigma^2\left(x_j\right)+\sigma^2\left(y_j\right)+C_2}\right)}{\sum_{j=1}^{M}\left(\frac{2\sigma\left(x_j,x_j^D\right)+C_2}{\sigma^2\left(x_j\right)+\sigma^2\left(x_j^D\right)+C_2}\right)} \quad (3)$$

where the super index *D* stands for the initial scene convolved with the diffraction mask; $\sigma(x_j)$ and $\sigma(y_j)$ represent the standard deviation of each images and $\sigma(x_j,y_j)$ is the covariance between both images. If the dynamic range of images is L, the constant C_2 is $(0.03L)^2$.

RESULTS

Figures 2 and 3 show a profile of the propagated beam as well as the values for the above proposed metric obtained at the planes of interest.

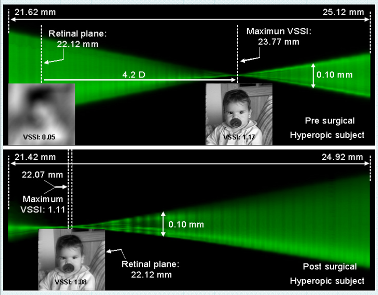

Figure 2

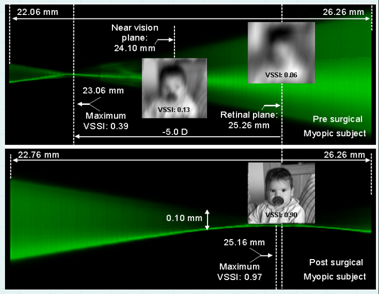

Figure 3

Objective results for the eyes under study agree with those obtained using visual test to measure visual acuity, both for far and near distances. The method and the metric objectively predicts the subject's visual capacity after have undergoing refractive surgery.

REFERENCES

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