BIOMETRICAL ANALYSIS OF PUPILLARY OPENING USING IMAGE PROCESSING PROCEDURES

Mihaela I. Baritz[1]
[1] Transilvania University, Brasov, ROMANIA, mbaritz@unitbv.ro

Abstract: *Pupil reflex as a feed-back reaction at the visual function level is a complex mechanism that can indicate, through deviations from normality, a very large range of ocular dysfunctions. In the first part of the paper are presented some anatomical and pathological aspects related to the configuration of the iris and the pupil, and respectively the physiological limits of functioning. In the second part of the paper there are some other researches that have as main purpose the determination of the behavior of the visual system through the pupil reflex, when the visible light radiation reaches the level of the iris and the pupil. In the third part of the paper is presented the image processing procedure applied for determining the contour of the iris-pupil assembly and the dimensional measurement of the pupil opening in real time, in the case of the IR (infrared radiation) illumination, in the case of the experimental setup. In the final part of the paper are presented the results and the conclusions regarding the methodology and the possibilities of dimensional evaluation of pupil and iris through image processing procedures.*
Keywords: *eye iris, image processing, pupil diaphragm diameter,*

1. INTRODUCTION

The iris, through its complexity and uniqueness, is an essential biometric element in behavioral analysis procedures on human subjects. The iris and the pupil respectively, as anatomical structures, have the role of limiting the amount of light radiation entering the eyeball and also protecting the lens from exposure to ultraviolet radiation.
The photo-motor reflex developed at each ocular globe indicates the visual perception level and establishes the neuro-motor equilibrium through the feed-back reaction following the sensitization of the retina with light radiation with visible wavelengths (400-700 nm).
Normally, in each eye there is only one pupil on each iris and its opening must be centered on the edges of the iris, as in both eyeballs. The opening / closing movement of the pupil under the influence of light radiation is achieved by the antagonistic action of the two muscle groups in each iris - sphincter and dilatators.
As shown in the paper [1] "under conditions of constant illumination and accommodation, pupil size has been observed to vary systematically in relation to a variety of physiological and psychological factors, including nonvisual stimulation, habituation, fatigue, sexual and political preference, and level of mental effort. All these sources of pupillary variation can be headed with the word *attention*".

Figure 1: Different eye pupil dilatation (anizocorie) [4]

Also, other studies "established the validity of the pupillary response as an indicator of attention effort, they did not establish it as a measure in a stricter sense. In particular, the function relating attention effort to the pupillary response was never analyzed."[1]
In another series of research it was found that "the pupil does not respond only to variations of illumination, but changes in the dilation also reflect cognitive load, arousal, or emotional valence. Task-evoked changes of pupil size in response to cognitive demands were documented for experimental manipulations of mental calculation working memory load and visual search.
Typically, increased cognitive demands are reflected by an increased dilation of the pupil. The pupil, in general, starts to dilate about 200– 300ms after stimulus presentation and reaches a task dependent ceiling during stimulus processing." [2]
From the point of view of pupil characterization, in the paper [3] a synthesis of the analyzes on the dimensions and the position was made and from these resulted the following aspects: "as a first approximation the pupil can

be considered circular, but recent studies show that a more accurate analysis such as departures from circularity may be important; the departure from circularity accounts for anisotropies of structure and/or innervations; moreover with increasing age the pupil sometimes ovalizes.
In other researches a first attempt to characterize the pupil as an ellipse is presented with the measures of the longest and shortest diameters; more recently, a method based on wavelets allows the identification of the centre, the length of the semi-axes and the orientation of the best ellipse fitting the pupil.
The measure of pupil size can be performed by ad-hoc pupillo-meter, with lens suitably provided by rules or by digital photography. The localization of pupil center is useful in video based systems for calculating eye orientation; it is useful also as an attempt to perform the design of an efficient human–computer interface.
Some correlations between human fatigue during a visual display terminal task and the variation in the pupil diameter have been noted in other research papers. The pupil fluctuations seem to be a sensitive indicator of mental activity." [3]
"Changes in pupil reaction to light stimulus are studied in Alzheimer's and Parkinson's disease patients and the aim is to obtain early diagnosis and to study the effects on pupil size and pupillary light reflexes of specific pharmacologic treatment." [3] As more particular applications of pupil diameter analysis in research paper [3] it is mentioned as "the variation of pupil diameter is studied also with respect to dark adaptation.
The effects of consuming medicines, drugs and alcohol may be observed analyzing the variations of pupil size. An instrument that measures pupil movements to detect fatigue, alcohol and the presence of illicit drugs has been recently proposed."

2. THEORETICAL ASPECTS

If the human visual system is exposed to light radiation with wavelengths in the visible field, pupil response is directly proportional to luminous intensity and exposure duration, while respecting the synergy of the process.

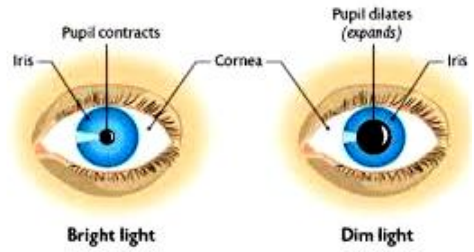

Figure 2: Exposure of the visual system to different light radiation intensities [4]

As they are presented in various research synthesized in the paper [3] „pupil diameter fluctuations are usually studied by fast Fourier transformation.
An interesting procedure to analyze the variation of the pupil diameter, applied to narcoleptics, is described in other researches papers; the pupil dilatation during a cognitive task has been observed; a model of the resulting pupil diameter variation has been proposed and it is also shown that the model parameters have a physiological interpretation.
To analyze the pupil dynamic attempts to model the pupil from a mechanical point of view have also been made" and the results have been applied in areas such as psychology of phobias or dependence on exciting substances.

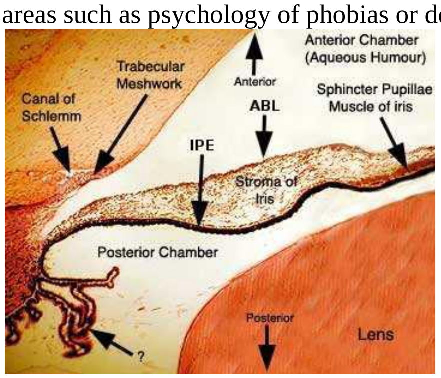

Figure 3: A sketch showing the dilator muscle and the sphincter muscle of eye iris [5]

Human iris is a bio-structure composed of tissues, muscles, and an innervation system having a circular shape with about 12 mm in diameter.
Through its action, the iris adjusts the amount of light that enters the eyeball, modifying the pupil opening from 1.5 mm to 8 mm. The method of opening / closing of the iris pupil are made after a determined geometric

trajectory of the Archimedes spiral, in which the more blades are, the more the aperture is approximated by a circle.

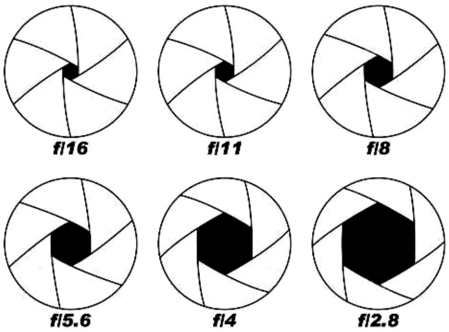

Figure 4: A sketch of eye pupil opening mechanism [6]

In the case of studies on pupil biomechanics, the method of stabilizing the process of accommodating the lens is chosen as the starting point because this process influences both the pupil opening and the iris surface biometry.

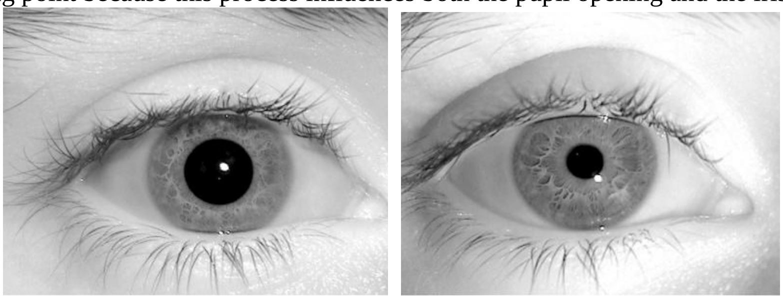

Figure 5: Eye pupil diameter during dilatation and accommodation processes [7]

The main method for assessing pupil biomechanics is based on a series of models that measure the values of some parameters as incidence functions of incidence light beam.
In more researches the incidence of radiation was "placed in front of the subjects' irises and, by varying the intensity and frequency of the light, they measured the pupillary latency, a time delay between the instant in which the light pulse reaches the retina and the beginning of iridial reaction due nerve transmission, neuro-muscular excitation and activation delays.
Their results are summarized in the model represented by Equation 1."

$$\tau(R, L_{fL}) = 253 - 14\ln(L_{fL}) + 70R - 29R\ln(L_{fL}) \quad [8] \qquad (1)$$

"where τ is the latency in milliseconds, L_{fL} is the luminance measured in foot-Lambert (fL), and R is the light frequency measured in Hz." [8]

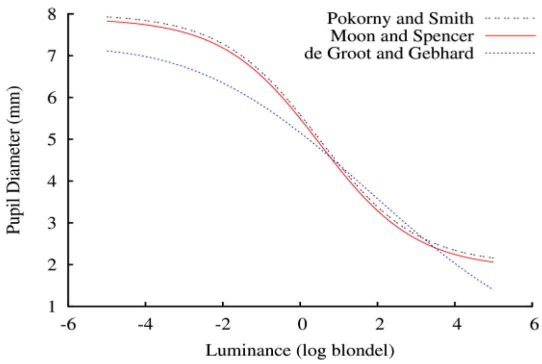

Figure 6: Pupil diameter models [8]

The most cited model of pupil response and pupil diameter dimensioning is the one developed by Moon and Spencer in 1944 and represented by Equation 2.

$$D = 4.9 - 3\tanh[0.4(\lg(L_b) - 0.5)] \quad [8] \qquad (2)$$

"where the pupil diameter D varies from 2 to 8mm, L_b is the background luminance level expressed in Blondels, varying from 10^5 Blondels in sunny days to 10^{-5} Blondels in dark nights, and *tanh* is the hyperbolic tangent." [8]
Along with this model, other authors developed, on the same principle, other sizing patterns and implicitly representing the dynamics of the pupil opening.
The models made by the authors as Groot-Gebhard and Pokorny-Smith respectively are based on studies carried out on a sample of subjects and express the pupillary diameter in relation to the brightness of the background, measured in millilamberts (mL) or cd/m^2.(Equation 3 and 4).

$$D = 10^{\left(0.8558 - 0.000401(\lg(L_a) + 8.1)^3\right)} \quad [8] \qquad (3)$$

$$D = 5 - 3\tanh\{0.4[\lg(L_{cd})]\} \quad [8] \qquad (4)$$

Of all the physiological models of pupil dynamics, the Moon-Spencer model and the Longtin-Milton model (for biological analysis) are most commonly used for various biometric and biomechanical applications.

3. EXPERIMENTAL SETUP

During the experiment, a procedure for the analysis of the iris movements and to evaluate the eye dynamics and to measure the diameter by the procedure of image processing was developed.

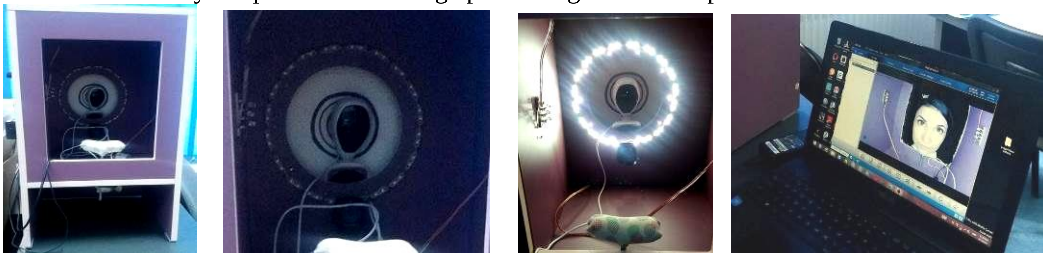

Figure 7: Experimental setup to analyze light/dark adaptation process and measure eye pupil diameter

Figure 8: Images acquired in the visible field

Thus, a sample of subjects of the same age, occupation, without refractive disfunctions at the level of their two eyeballs was selected and evaluated in a visual stimulation device (fig.7).
The device is an dark room equipped with a circular / concentric optotype, with a visible and infrared (IR) image video camera, a circular illumination system with LEDs in the visible and lateral IR range. The sample of subjects was instructed to look directly into the video camera mounted inside the device at the center of the circular optotype and captured images in both situation, the visible and IR radiations (Fig. 8 and 9).
Images from visible range are necessary to highlight the light-to-dark adaptation process (minimum pupil diameter goes to maximum diameter).
Images acquired in the IR wavelength range are used to measure the maximum pupil opening diameter according to the duration of the light / dark adaptation time.

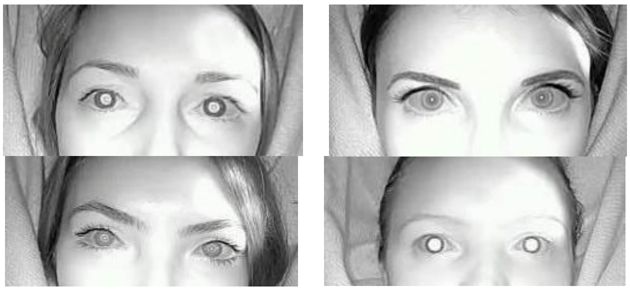

Figure 9: Images acquired in the IR field

4. RESULTS AND CONCLUSIONS

This process causes fluctuations of pupil diameter (hippus) and through pupil dynamics, these fluctuations are attenuated when the system is fully adapted (the adaptation time differs from subject to subject but falls within an average of 15.3 minutes). In order to evaluate the pupil aperture in the dark, a process of image processing based on filtering in the upper band was used and by comparison with the *Layer* menu (fig.10), and the *IC-Measure* software package determined the diameter, area and pupil perimeter for sample subjects (fig.11)

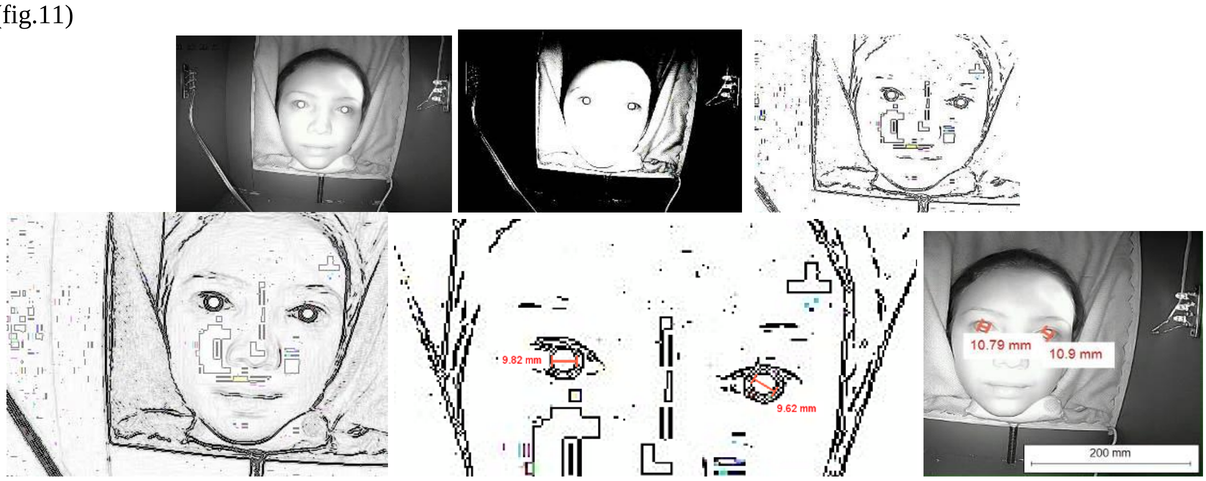

Figure 10: Image processing procedure applied to eye pupil diameter measurements (IC-Measure software)

Figure 11: Image analyze to eye pupil diameter measurements (IC-Measure software)

From analyzing the images captured with the video cameras (visible and IR) and making measurements on the eye pupils, it was found that the image processing procedure initiated in advance allows for a more accurate measurement of this diameter.

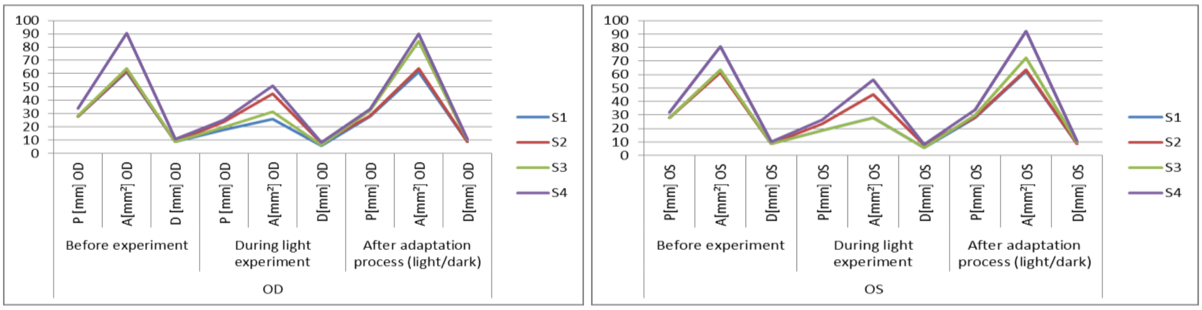

Figure 12: Pupilary dimensions from image analyze (IC-Measure software)

Table 1

OD	Before experiment			During light experiment			After adaptation process (light/dark)		
	P [mm]	**A[mm²]**	**D[mm]**	**P [mm]**	**A[mm²]**	**D[mm]**	**P[mm]**	**A[mm²]**	**D[mm]**
S_1	27.77	61.37	8.84	17.96	25.67	5.72	27.77	61.37	8.84
S_2	28.05	62.62	8.93	23.8	45.09	7.58	28.37	64.03	9.03
S_3	28.34	63.92	9.02	19.79	31.17	6.3	32.55	84.29	10.36
S_4	33.73	90.54	10.74	25.31	51	8.06	33.59	89.8	10.69
OS	Before experiment			During light experiment			After adaptation process (light/dark)		
	P[mm]	**A[mm²]**	**D[mm]**	**P[mm]**	**A[mm²]**	**D[mm]**	**P[mm]**	**A[mm²]**	**D[mm]**
S_1	27.95	62.17	8.9	18.73	27.91	5.96	27.99	62.37	8.91
S_2	27.77	61.37	8.84	23.8	45.09	7.58	28.28	63.63	9
S_3	28.23	63.4	8.98	18.77	28.03	5.97	30.14	72.29	9.59
S_4	31.91	81.02	10.16	26.52	55.97	8.44	34.04	92.22	10.84

Measurements on the sample of subjects indicate a variations in perimeter, pupil area and pupil diameter between 5 and 10.4%. (Table 1). Also pupil diameter varied throughout the experiment (before, during the light experiment and after the adaptation process) to each subject from the sample, with an average percentage of 33%. In order to assess the effect of strong illuminations (800 lx) and short duration (1 min) on the visual system, the subjects from sample were evaluated for visual acuity immediately after interruption of illumination.
All subjects had a decrease in the initial visual acuity (normal-emmetropic eye) with four acute-optotype lines (Snellen), indicating a visual stress of adaptation and accommodation process that varied between 14 and 24 minutes. The image processing procedure in this experiment is an efficient, fast and practical method for obtaining the biometric elements of the subject's iris and pupil.
In conclusion, the effect of strong illumination and light-to-dark changes and vice versa causes temporary changes in the visual performance of the subjects, creating a cumulative visual stress that may lead to visual impairment (visual acuity, chromatic perception, visual field, poor posture) and biometric measurements should be performed after a minimum of time or recovery the normal visual parameters. [9,10,11]

Acknowledgements
In these experiments we've developed the investigations with equipment from "Advanced Mechatronic Systems Research Center - C04" and Applied optometric Laboratory at University Transylvania of Brasov, with students help of Optometric study Program.

REFERENCES

[1] Hoeks B., Levelt W.J. M., *Pupillary dilation as a measure of attention: A quantitative system analysis*, Behavior Research Methods, Instruments, & Computers, 25 (1), 1993, 16-26;
[2] Gagl B., Hawelka S., Hutzler F., *Systematic influence of gaze position on pupil size measurement: analysis and correction*, Behav. Res. 2011, 43:1171–1181; DOI 10.3758/s13428-011-0109-5;
[3] Iacoviello D., *Analysis of pupil fluctuations after a light stimulus by image processing and neural network*, Computers and Mathematics with Applications 53, 2007, 1260–1270, www.elsevier.com/locate/camwa ;
[4] https://www.aic.cuhk.edu.hk/web8/Dilated%20pupil.htm; [online] accessed nov.2017;
[5] Bell A. L., *Histology lab IX: the eye.* http://faculty.une.edu/com/abell/histo/histolab3b.htm;
[6] www.dreamstime.com [online] accessed nov.2017
[7] Hollingsworth K., *The Importance of Small Pupils: A Study of How Pupil Dilation Affects Iris Biometrics*, Computer Science and Engineering University of Notre Dame;
[8] Pamplona V., *Photorealistic Models for Pupil Light Reflex and Iridal Pattern Deformation*, Thesis (Master) Universidade Federal do Rio Grande do Sul. 2008;
[9] Barbu D.M., *Visual Field Evaluation Method Of The Automobile Drivers In Traffic*, Annals of the Faculty of Engineering Hunedoara - International Journal of Engineering, Aug. 2016, Vol. 14 Issue 3, p163-168.
[10] Braun B., *Assisted procedure for monitoring and improving oculo-motor behavior for preschool children*, Proceedings of the IXth International Conference on Product Design, Robotics, Advanced Mechanical and Mechatronic Systems and Innovation, PRASIC, 2016;
[11] Braun B., *Life Style Influence On Body Stability For Young Subjects*, Bulletin of the Transylvania University of Brasov, Vol. 9 (58) No.1, 2016, Series I Engineering Sciences;