DEVELOPING A PUPILLOMETER

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Abstract: This project presents stable and robust optical equipment for detecting the area of the pupil and its variation on a temporal scale. An algorithm was developed to detect the pupil contour, implemented in a simple, intuitive and user friendly interface programme. Using the equipment specifically developed, measurements were taken of the area, perimeter, horizontal diameter and vertical diameter. After a statistical and comparative study, it was possible to reach conclusions regarding the general dimensions of the pupil, its variation prompted by a given stimulus and the clinical viability of the equipment concerned.

1 INTRODUCTION

The area of the pupil changes in response to the variation in light intensity in the retina, with a view to assisting the optimizing of visual perception. In dim light, pupil dilation (midriasis) is an effective way to maximize the number of photons reaching the retina, which in turn activates adaptive mechanisms to low light intensity. When exposed to bright light, miosis causes an adequate reduction in the intensity of light in the retina, acting as immediate response to the mechanisms of adapting to intense light (Kardon, 2003). The study of the way the pupil changes its size is of relevant clinical interest, for it acts as an objective indicator of the retina's sensitivity to light and, as a result, of the optical nerve functionality. The state of a person's pupil allows for several diseases to be diagnosed, among which sleep disturbances (narcolepsy), photophobia, schizophrenia (pharmacological reaction), Adie's Syndrome, Alzheimer's, narcotic addiction, among others.

2 STATE OF THE ART

Nowadays, Pupillometry is mostly based in computers. This technology, based on image processing, numerically analyses the pupil features. The sensitivity of existing systems varies much and depends to a major degree on the spatial and temporal resolution of the acquisition devices and also on the algorithms used. Pupillometers differ also in portability and applicability. The majority of current Pupillometry devices use algorithms that are based on physical models and that use a circle or an ellipsoid as an approach to the pupil contour (Kim *et al*, 2004).

Recent studies have been made using Fourier series to determine the pupil contour (Rakshit and Monro, 2007).

3 MATERIALS

3.1 Material Used

The current system is based on a LE175C LUMENERA camera that is connected, via Ethernet, to a personal computer (figure 1). A floodlight of 500W was used as external illumination and as a stimulator of the subject's pupil. The camera is placed in a mechanical arm attached to a table. The arm can be moved vertically and horizontally in a small area (figure 2a). The subject's head is positioned in a mechanical support that can be moved vertically (figure 2b).

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3.2 System Concept

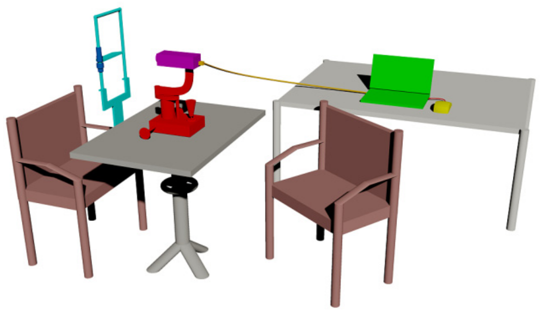


Figure 1: First version of the Pupillometer System designed in AutoCAD.

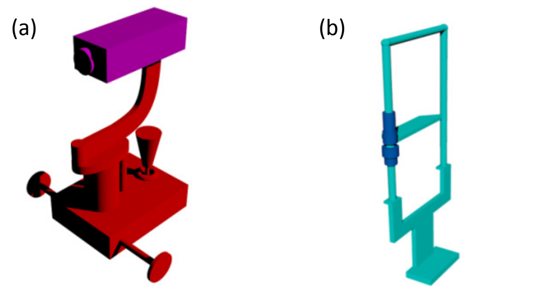


Figure 2: (a) Mechanical arm that moves the camera horizontally and vertically. (b) Mechanical device where the subject places his/her head. This device allows vertical movement.

4 METHODS

4.1 Algorithm

The Matlab programme was chosen to develop all the software required for the system, since it is a very resourceful software and has very good imaging tools and functions.

An algorithm was developed based on the concept of Intensity Threshold. It starts with an initial point (calculated by a secondary algorithm shown in figures 3 and 4) and traces lines to every direction separated by a 5 degree angle (LI, Dongheng and Derrik J. Parkhurst, 2006). It then compares the intensity of gray levels of consecutive points along the traced line. If the variation of values is bigger than the Threshold value, the algorithm stops and defines a point that characterizes the pupil contour. Then a second line is traced using the previously calculated point as the new start point, but in the opposite direction, in order to calculate the opposite contour point and so speed up the time of measurement. Once all points are defined, there are specified algorithms that calculate the area, perimeter, horizontal diameter and vertical diameter of the image. The value of Threshold can be manually inserted or can be calculated by two algorithms developed for that purpose (*Square Threshold* and *Circle Threshold*).

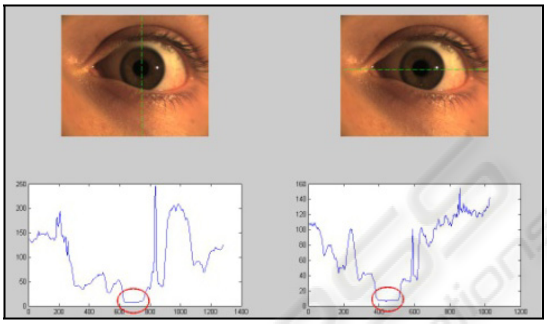


Figure 3: Analysis of gray intensity in the image. We can see the pupil zone featured by low levels of intensity. This is how the programme calculates the initial point for the beginning of the cycle.

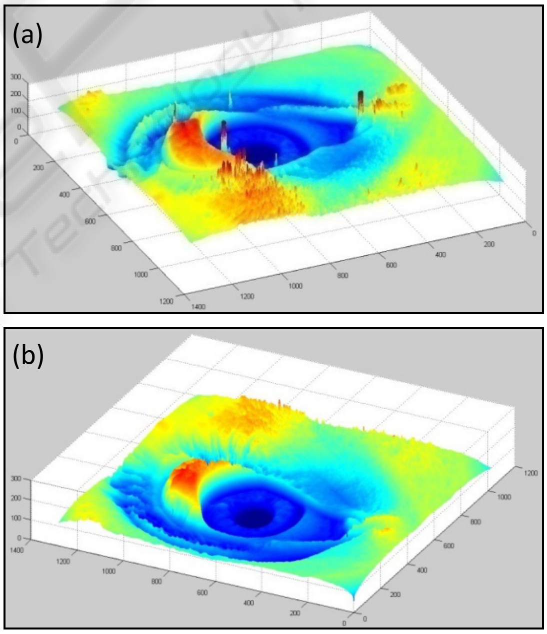


Figure 4: In order to improve the analysis shown in figure 3 we can plot the intensity of an image in a 3D mesh plot. The pupil is shown in dark blue, since it has the lowest intensity gray levels. Both images are the same, but image b) is the result of a) with a Low Pass filter applied. This feature reduces the error because the eyelashes are also dark and could be misunderstood as an area of the pupil by the algorithm.

4.2 Graphic User Interface (GUI)

To put all the algorithms together, a user friendly interface was developed in Matlab, which acquires all data by filming the eye of the subject. This interface also measures pupil dynamics by processing large amounts of images and determines the statistical data of the results.

There are three main panels: data acquisition panel, pupil detection panel and statistics panel.

The first panel (figure 5) shows the images that are being stored in real time. We can also edit the subject's demographic data and the calibration data. There are *event* buttons that store the time when a stimulus is applied to the subject (the better to analyse the statistical data).

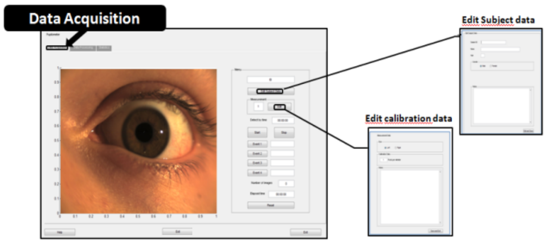


Figure 5: Data Acquisition Panel.

The second panel (figure 6) is used to measure the pupil dynamics during a period of time. There is a menu where the user can easily calculate the threshold value for automatic detection (figure 7).

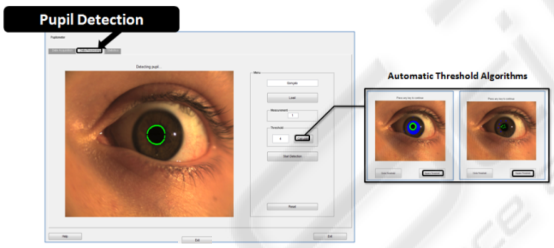


Figure 6: Pupil Detection Panel.

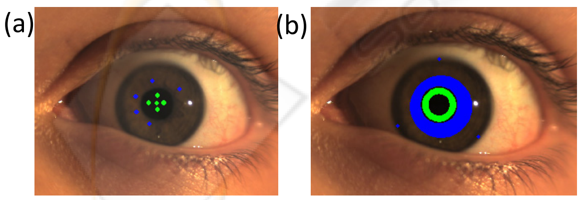


Figure 7: a) Square threshold (compares the intensity gray levels of 5 pupil points to 5 iris points). b) Circle Threshold (compares a torus of points of the pupil to a torus of points of the iris, mainly in the pupil/iris border.

The function of the third panel (figure 8) is to view all the data statistics in two ways: by plots and by tables. The user can also view the standard deviation of each variable and save all data to a *.txt* file that can easily be exported to other programmes used in Fourier and Wavelet analysis.

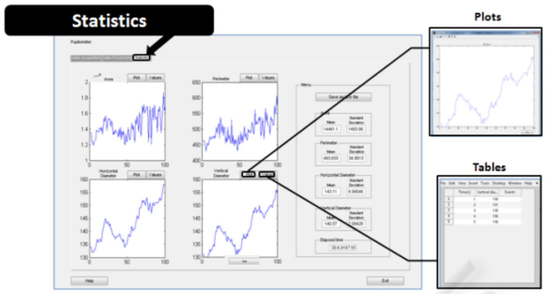


Figure 8: Statistics Panel.

Outside the three panels, the interface has three buttons, one for exiting the programme, a second one to view the help file (a *.pdf* document with the user guide of the software) and a third to consult the IDs of all subjects in the database.

4.3 Data Acquisition

For this preliminary study, the right eye of nine individuals was measured in a dark room where the only light source was a 500W floodlight. Each subject was illuminated with a bright light, so that the pupil's accommodation over time could be detected (first the pupil contracted and then the pupil dilated over time). Each subject's head was positioned at a distance of about 25cm from the camera. The light stimulus was applied to the subject and didn't change during the measurements.

In order to remove the reflexes from the subjects' eye, no direct illumination was used.

A hundred images were taken for each subject (for about 10-15 seconds, depending on the speed of image storing, which is independent of the amount of data in the camera and also with the processing speed of the computer used).

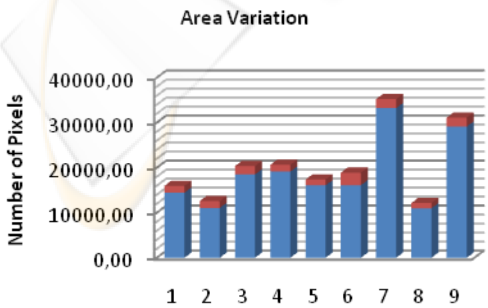
Table 1: Acquired data statistical information.

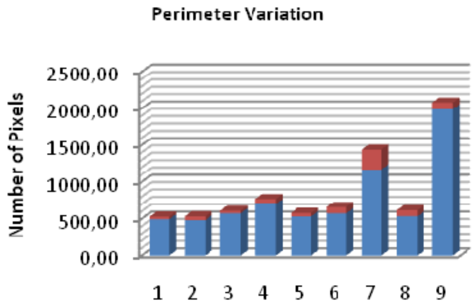
Subject Data		Mean	Standard Deviation
Test 1	*Area*	14444.80	1509.91
	Perimeter	493.35	35.20
	Horizontal Diameter	143.10	7.00
	Vertical Diameter	140.57	7.08
Test 2	*Area*	11062.80	1508.11
	Perimeter	482.12	49.79
	Horizontal Diameter	127.84	6.93
	Vertical Diameter	135.20	10.01

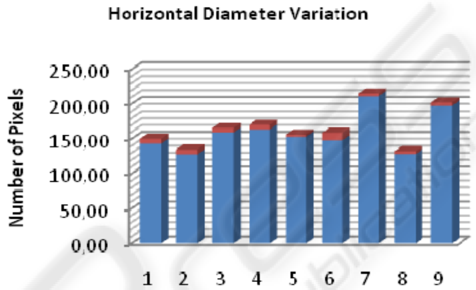
Table 1: Acquired data statistical information (Cont).

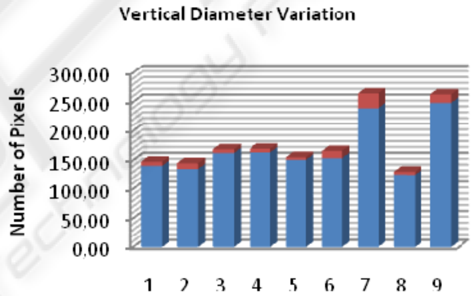
Test 3	*Area*	18489.40	1861.11
	Perimeter	574.14	32.25
	Horizontal Diameter	159.24	6.30
	Vertical Diameter	162.39	6.38
Test 4	*Area*	19133.60	1497.48
	Perimeter	698.84	68.99
	Horizontal Diameter	163.64	6.70
	Vertical Diameter	163.32	6.27
Test 5	*Area*	16065.20	1281.32
	Perimeter	529.56	47.55
	Horizontal Diameter	153.01	3.09
	Vertical Diameter	150.80	4.58808
Test 6	*Area*	16112.10	2789.19
	Perimeter	571.28	86.97
	Horizontal Diameter	147.74	11.03
	Vertical Diameter	153.64	12.29
Test 7	*Area*	33239.40	1991.74
	Perimeter	1168.96	267.96
	Horizontal Diameter	211.41	3.93
	Vertical Diameter	239.35	25.56
Test 8	*Area*	10985.10	1161.59
	Perimeter	533.17	82.11
	Horizontal Diameter	128.34	4.06
	Vertical Diameter	125.25	5.35
Test 9	*Area*	29139.60	1974.06
	Perimeter	1989.11	916.88
	Horizontal Diameter	197.40	4.75
	Vertical Diameter	248.56	14.49

Note 1: Subjects 7 and 8 used contact lenses on purpose so that the influence of contact lenses in the measurement could be studied.
Note 2: All results are in number of pixels, since the zoom lens changes the size of each pixel.









An example of the output data for one subject is shown below:

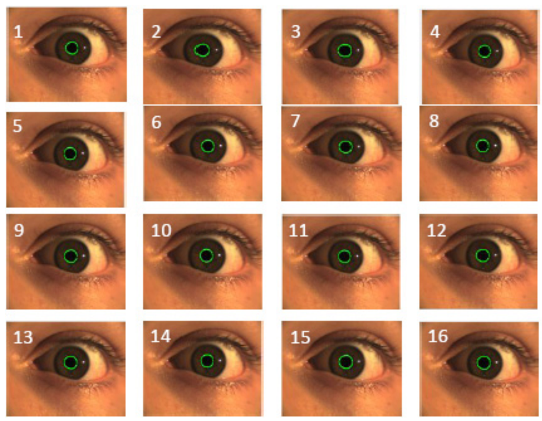


Figure 9: Example of the pupil detection of an amount of 16 consecutive frames. All frames look alike because this measurement was made at high speed.

Eye color: Brown.
Number of images: 100.

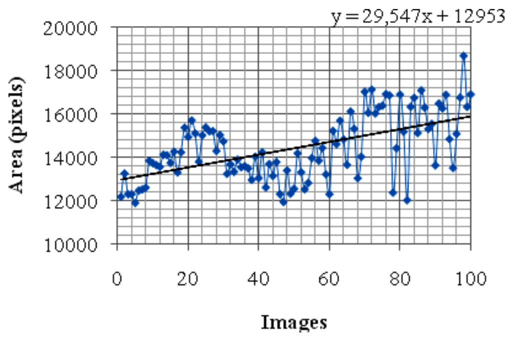


Figure 10: Plot of the Area of each frame along all 100 images.

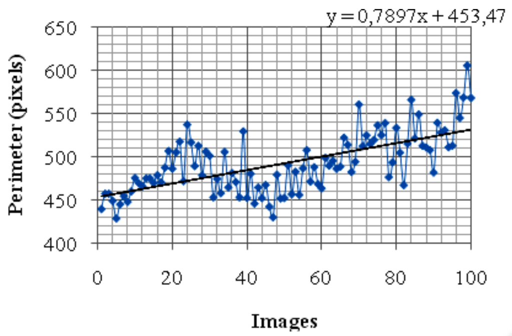


Figure 11: Plot of the Perimeter of each frame along all 100 images.

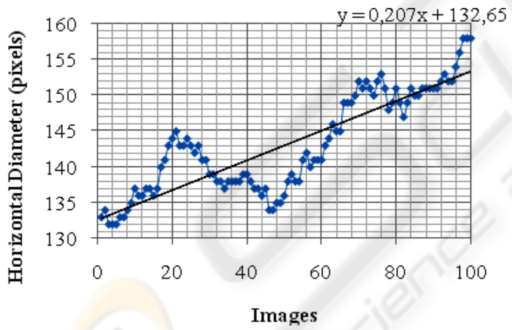


Figure 12: Plot of the Horizontal diameter of the pupil along all the thirty images.

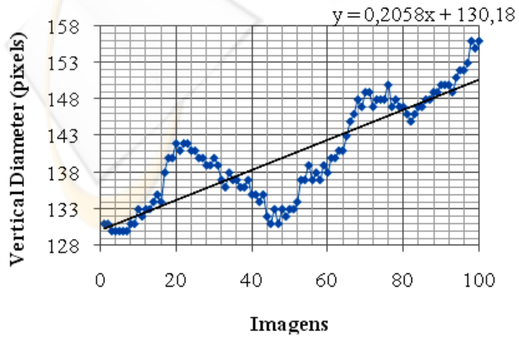


Figure 13: Plot of the Vertical diameter of the pupil along all the 100 images.

Output .txt file

```
14:24
03-Oct-2008
Id: Test 1
Threshold: 3

Area        Perim      Dist_h Dist_v
12282.0   441.2   133      131
13289.5   458.2   134      131
12339.0   458.2   132      130
                 (…)
```

Elapsed processing time: 00:07:14 (*hms*).

5 RESULTS AND DISCUSSION

The acquired results displayed in table 1 show that the subject's pupil dilated during the period of accommodation. It is clear that the pupil size changed during the acquisition period and, since this is a preliminary study, the results fit the objectives. However there is some error caused by the reflex of visible light in the images taken.

The pupils of subjects 7 and 9 showed more dilatation, since they suffer from myopia. These people tend to have a larger pupil, as this study successfully shows. A careful analysis of the pupil's diameters plots (figures 12 and 13) show that the pupil's fluctuations behave like a sinusoidal curve. This behaviour is very interesting, for we can predict the period of the sinusoidal curve.

A detailed analysis of the plots shows that we can relate the pupil's fluctuations to the sympathetic and parasympathetic nervous flows in the subject's brain. This feature can be used in the future to compare the pupil's fluctuations in a normal subject those of the pupil of a subject suffering from a neurological disorder (Alzheimer's or Narcolepsy, for example).

By analyzing the statistical values of the processed data we understand that the area and perimeter algorithms must be optimized, since they are expressing an error of about 7% and 5% (Matlab error analysis), respectively.

Because grey scale (256 levels) images were used, the system has the ability of detecting smaller variations when by comparing to some other studies made in this area, such as IACOVIELLO's (2006). This feature allows the detection of small variations in the digital image, so that the error can be reduced and more information gathered.

6 CONCLUSIONS

This paper presents a complete system that can accurately measure the dynamics of pupillary movements given various stimuli. This is commonly considered one of the most important parameters to make non-invasive diagnosis of many neurological disorders.

This system has a very user friendly interface that will allow doing clinical trials by people not specialised in this specific technique.

The acquired results showed some error in the contour detection. In order to surpass this problem the detection algorithm must be optimized and a different type of camera must be used. Since the tests were made using a camera that works in the visible wavelengths, there was some light reflex in the subject's eye. For better results an infrared camera should have been used, but no such camera was available at the time of this study.

The results also showed some *pupil noise*, that is chiefly due to the sympathetic and parasympathetic neural flow. The main algorithm has been improved to a good ratio between statistical error and processing speed.

It is relevant to say that the detection algorithm does not use physical models and does not approximate the pupil contour to any geometrical figure. The speed of the algorithm is compromised but the results are more precise.

This study sets out to design a medical instrument that can be used by any technician or physician to measure pupil dynamics. For example, it could be attached to a hospital bed, to monitor the pupil activity of patients. The interface is compiled in a *.exe* file that can easily be installed in every computer even if the computer does not have Matlab installed.

6.1 Future Perspectives

To improve the existing system it is clear that it must evolve into an optical device that works in infrared light. With this feature the light reflexes in the eye will not influence the acquired data and the system will also work in the dark. Using a CCD camera and an infrared light system, an image of the anterior surface of the eye can be obtained, even when external lighting is not present (without interference from non-controlled stimuli).

We intend to process the acquired data using Fourier and Wavelet analysis, to work in frequency and time domains.

The main algorithm will adapt to every image in such a way that the threshold value will be calculated for each frame, so that the digital image features may vary (brightness, contrast and gamma).

In the developed GUI all results are expressed in pixels, but, to facilitate the physician's work, an algorithm must be created to convert pixels into millimeters. However, it will not be easy, since the system uses a zoom lens and so the pixel size is dependent of the zoom setting.

We believe that, in the near future this methodology can be of assistance to Ophthalmology diagnosis by quantifying the sympathetic and parasympathetic pupillary dilatation components.

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