Volume : 2 | Issue : 4 | Apr 2013 • ISSN No 2277 - 8179

Novel Optoelectronics Device for Measuring Pupillary Dynamics for Medical Applications

Engineering

KEYWORDS : optoelectronics, medical applications, pupil dynamics, pupil diameter.

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ABSTRACT

The pupil changes of shape, diameter as well as the pupil reaction to light and darkness are factors that become an important way to know and understand different diseases that affect the human body. There have been developed some instruments to study the pupil and there have been published along the years. This work proposes a new optoelectronic instrument for measuring the pupil dynamics and graph the relation between pupil diameter and time. The results shown the graphic interface designed for this development.

I. Introduction

The pupil is a small hole located in the center of the iris, its function is to allow light to enter in the lens of the eye. The principal characteristics of the pupil to be considered for researching objectives are the diameter of the pupil, which is controlled by smooth muscle within the iris; the pupillary size, shape, and reactivity to light that are regulated by the autonomic nervous system [1].

The diameter of the pupil is controlled by the pupilloconstrictor and the pupillodilator muscles which are controlled in turn by the parasympathetic nervous system and the sympathetic nervous system respectively [2].

In the Parasympathetic Response, also known as Pupillary Constriction, when light enters into the eye, the cones and rods of the retina serve as sensory receptors and send the impulse via afferent nerve pathways through axons in the optic nerve, optic chiasm, and optic tract [3] This impulse reaches the Edinger–Westphal nuclei in the midbrain. The parasympathetic response originates in these nuclei, and efferent nerve pathways transmit the impulse via cranial nerve III to the pupilloconstrictor muscle [4]. Both the ipsilateral and the contralateral Edinger–Westphal nuclei receive identical afferent input, which causes the consensual light reflex [5].

For the Sympathetic Response, known as Pupillary Dilation, the sympathetic pathway responsible for pupil dilation is originated in the posterior-lateral hypothalamus and involves 3 neurons [4]. The first ipsilateral preganglionic central neuron travels through the lateral brainstem to the spinal cord. The second preganglionic neuron crosses the lung apex and ascends the neck where it synapses in the cervical ganglion. The third postganglionic neuron accompanies the internal carotid into the skull base to the trigeminal ganglion and joins the nerve fibers of the abducens as it passes through the inferior orbital fissure. This neuron then continues through the trigeminal nerve until it reaches the pupillodilator muscle in the iris. The neurotransmitter responsible for this synaptic reaction is norepinephrine [6].

The eye is innervated by 3 cranial nerves (CN), III, IV, VI, which work together to provide smooth eye movements.

The oculomotor Cranial nerve III is in charge of controlling constriction due to the parasympathetic response of the pupil [7]. Cranial nerves III, IV, and VI are the responsible for extraocular eye movements (EOMs) because they innervate the muscles surrounding the eye.

In other words, the pupil is controlled by a nerve pathway in the body which starts in the brain, travelling down the spinal cord, up over the top of the lung and under the subclavian artery and through extensions of the brain and finally travels close to the optic nerve and then to the pupil. Any interruption presented along this pathway can change the pupillary reaction.

There are some conditions that might affect pupil size and these conditions could be the result of a disease. For example, a middilated pupil could represents a glaucoma; in brain tumors, if the tumor is near the origin of the pupillary nerve fibers could generate some problems within the pupil; the use of recreational drugs or medications can sometimes provoke the pupils to dilate or constrict abnormally, effects that are also caused by an aneurysm that pushes on certain blood vessels in the brain.

Some specific research has been done by studying the pupil and its relation to specific diseases, for example, the change of the pupil's light reflex and mobility in Parkinson's disease patients with and without cognitive disorder has been studied [8]. Other example of deep research that has been published does a study over more than 100 children living with diabetes where the size of the pupil has a significant content of information [9]. The authors of this work conclude that diabetic children had a significantly smaller median pupillary diameter, measured as the ratio between pupil and iris, than control children. A pupillary examination in patients with traumatic brain injuries and its associated physiologic response is studied in [6].

Human beings have an interval of light color distinctions. This is based on the existence of three types of retinal receptor cells called cones sensitive to short waves, starting from 400 nanometers, corresponding to the range of blues and violets, sensitive to medium waves, which are around 550 nanometers in the range of greens and also responsive to long waves that are found in more than 600 nanometers and correspond to the range of cells.

When excited in the whole field of long-wave receivers (R) is the visual sensation of red when excited in the whole field of medium wave receivers (V) is the visual sensation of green and when excited in the whole field of shortwave receivers (A) is the visual sensation of blue, for that reason it is impossible even to find equivalence or balance between the three.

In this work, an optoelectronic device is design and built to give the graphs obtained by measuring the diameter of the human pupil when stimulated at 400, 550 and 600 nanometers versus time of capture. Results are presented for a couple of measurements in a couple of patients which conditions are not important for this work.

II. Design and development of the optoelectronic instrument.

First, there are some considerations to be taken into account for the correct design of the optoelectronic device. 1) the pupil must be in total darkness to ensure pupil stability, 2) the initial diameter has to be recorded and all the variations on the pupil

diameter due to an external light, in this case, coming from 3 light-emitting diodes corresponding to Red (R), Green (G) and Blue (B) colors as it described above, have to be recorded with a high precision method. 3) A camera sensor has to be considered into the optoelectronics design. 4) Due to the darkness condition, it will be impossible for the camera sensor to record any pupil change; in this case, a couple of Infra Red Light-Emitting Diodes (IR LED) have to be placed in the device. Figure 1 shows the setup used in this work.

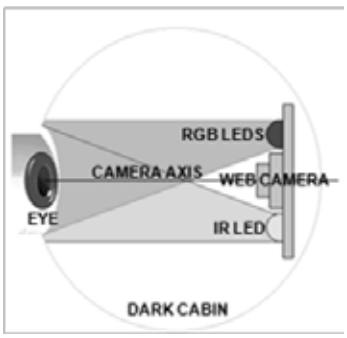


Figure 1. Experimental set up for measuring the pupil diameter changes along the time.

The electronics shown in figure 1 are inside a dark cabin in order to stabilize the pupil to an initial diameter. After a period of time, the RGB led illuminates the eye, first the red, then the green and last the blue lights give to the pupil an external stimulation that causes changes in its diameter. A white light stimulation is also projected to the eye after the RGB light stimulation. These changes are recorder by a web camera sensor that is plug into a computer by a USB port, wherein, by means of a computer program, a graph shows the response of the change in pupil diameter versus time and due to external light stimuli in the RGB color model. The eye is all the time illuminated by the IR Led with the intention to allow the camera sensor to watch the pupil; otherwise, it would be impossible to watch it due to dark cabin. The camera sensor is set up to 30 frames per second (fps), which gives the possibility to have a high speed study of the pupil diameter changes by recording data every 33ms. The functionality of the electronics is controlled by an external *data acquisition* device which employs a bidirectional communication with the computer program according to figure 2.

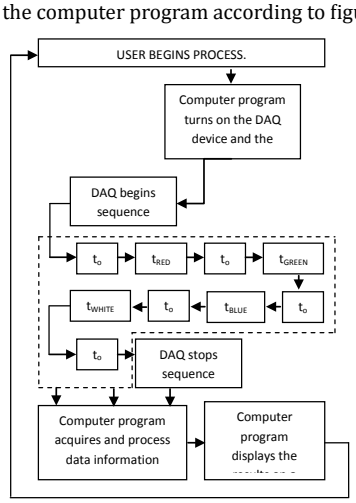


Figure 2. Structure of the optoelectronics device for measuring the pupil dynamics

The user turns on the computer program, once it is on, the computer program turns on the DAQ device as well as the camera sensor. The DAQ begins the external light stimulation sequence, first, a time in darkness, t_o, is used to stabilize the pupil diameter, after that, a red light is projected to the eye for a time, t_{RED}, a new time in darkness is used to let the pupil to resting, then a time with green light projected is on and so on until the sequence is done. At the same time of the sequence, the computer program acquires and processes the data coming from the camera sensor; at the end of the process the computer program displays a diameter versus time graph.

III. Results

Figure 3 shows the resulted graphic. It is important to mention that the time on darkness, t_o and the time with light on, t_{RED}, t_{GREEN}, t_{BLUE}, can be configured in the computer program. x – axis is in seconds, y – axis is the diameter on pixels.

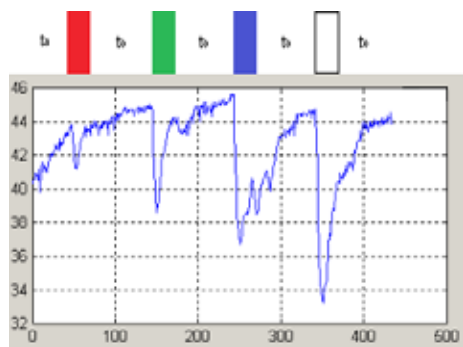


Figure 3. Resulting graph. 4 peaks are shown; all of them correspond to a pupil reaction to external light stimulations.

As shown, the resulting graph contains 4 peaks representing the pupil reaction to external stimulation of light in RGB color model and white light stimulation. This kind of non contact measurement can help to the study and diagnostic of different diseases on the human body. Because this measurement is a digital one, all the data can be mathematical processed to have a good quality correlation to all the different diseases to be studied for future works.

IV. Conclusions

The purposed optoelectronic device has big advantages; is a non contact, fast, economic and secure way to study diseases on the human body.

The resulted graph gives a very clear idea of how the changes on the pupil diameter along the time and due to external light stimulations can be correlated to neurological reactions. This is a novel idea that can help for opportune diagnostics and to follow particular diseases with the objective to improve the quality of people life.

Volume : 2 | Issue : 4 | Apr 2013 • ISSN No 2277 - 8179

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