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Measurement of the fixational eye movements based on observation of the eye pupil kinetics

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Abstract: *The paper presents measurement method of fast eye movement by use of the high-speed CCD camera, with recording rate 200fps. Sequences of the pupil's images recorded within 10 seconds were next decomposed into frames and processed numerically. The position of the center of eye pupil were used to describe the eyeball movement during fixation. The calculated results allowed to achieve the goal of this paper, that is to characterize the fixational eye movement.*

Keywords: *the pupil of the eye, fixational eye movements, eye pupil kinetics*

1. Introduction

Eyeball is in constant motion. Even during visual fixation on a particular point, it performs a quick, uncontrollable movements of small amplitude. These movements are indispensable to ensure correct vision, their role is still not completely understood though[1]. Rotational horizontal and vertical eye fixation movements are currently divided into three types: tremor, drifts and microsaccades [2, 3]. Tremor is a very fast movement of the eye with the smallest amplitude of approximately a few seconds of arc, characterized by a frequency within the range of 30 to 100 Hz. Drift occurs simultaneously with tremor and is much slower, with an amplitude of several tens of seconds of arc. Rapid movements of the highest amplitude of about a few minutes of arc are microsaccades, which affects less than one second.

There are many investigations on fixational movements of the eye [1]. They are described in various aspects, such as during sleep [4, 5] or when changing fixation object [6]. Though these movements are still intensively investigated, the role and nature of fast movements of small amplitude is still not entirely understood .

The pupil size undergoes a small, continuous fluctuations known as hippus [7,8], which appears even in constant level of illumination. However, in this paper this fluctuation were not taken into account. Therefore, it was assumed that even if the pupil changes its size, this change in proportional and has no effect on changing the position of the pupil center.

2. Method

A system for recording images of the human pupil and its fast variations in time was designed [9]. The main element of the system is a fast CCD camera (AOS Technologies AG, model S-PRI), working on recording speed 200 fps. It is equipped with the photo lens and the bellow for microphotography, which ensures optimal image size of the pupil on the image sensor (800 × 600 pixels). Due to differences in magnification of the pupil, for each sequence calibration of the pupil size was performed. To exclude the pupil response to the lighting system the infrared illumination was used. In order to obtain contrast image, the pupil was illuminated in such a way that the rays reflected from the fundus reached the camera, brightening the aperture of the pupil. Exemplary image of the analyzed eye pupil, with the edge of the pupil (white line) and center of gravity marked is shown in Figure 1.

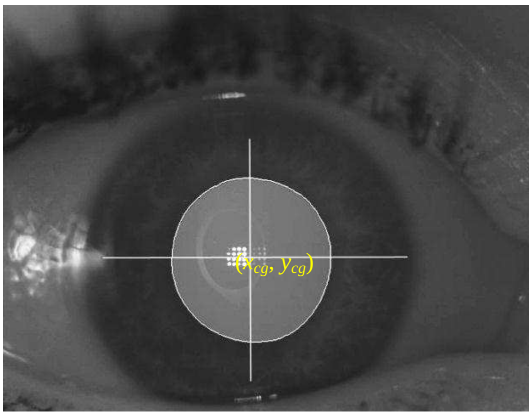

Fig. 1. Image of the pupil

Sequences of the pupil's images recorded within 10 seconds were next decomposed into frames and processed numerically. Selection of border points of the pupil was held automatically, using edge detection procedure. The shape of the pupil was treated as a filled plane figure.

For each single image from the sequence, coordinates of the center of gravity (x_{cg}, y_{cg}) of the pupil were defined by

$$x_{cg} = \mu_{10} = \frac{1}{s}\sum_{i=1}^{M}\sum_{j=1}^{N} x_i I_m(x_i y_j) \quad (1)$$

and

$$y_{cg} = \mu_{01} = \frac{1}{s}\sum_{i=1}^{M}\sum_{j=1}^{N} y_j I_m(x_i y_j), \quad (2)$$

where the pupil area s was defined as

$$s = \mu_{00} = \sum_{i=1}^{M}\sum_{j=1}^{N} I_m(x_i y_j) \quad (3)$$

and I_m stands for

$$I_m(x_i y_j) = \begin{cases} 1 & \text{for points inside the estimated pupil} \\ 0 & \text{for points outside the estimated pupil} \end{cases} \quad (4)$$

Based on the numerical analysis for each frame of the sequence, the center of the pupil with sub pixels accuracy was determined, and change of its position over time was analyzed.

3. Results

Examination of the pupil movements was performed on a group of 8 healthy subjects. From 2 to 5 sequences of successive frames were recorded and analyzed for each subject, in constant, dim illumination. Patients were asked to focus the eye on a small point and abstain from blinking. Recording sequences lasted up to 10s.

Fig. 2 and Fig.3 present variability of center of pupil position for sequences recorded for subject B and C, respectively.

The trajectory shows how the position of the center of pupil changes during time. The movements differed between patients, however it was within the range 300 μm in all cases. It was observed that for some patients the "preferable directions" of the movement are noticeable.

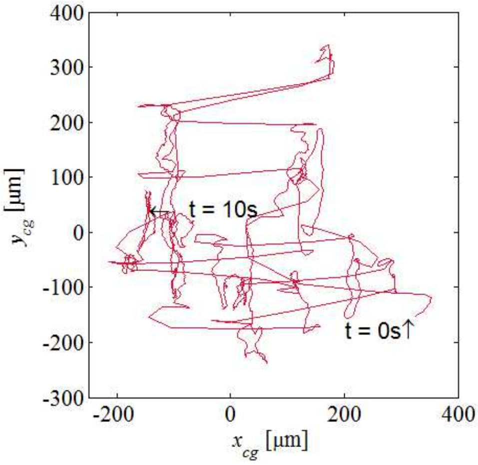

Fig. 2. The pupil center variability of subject B

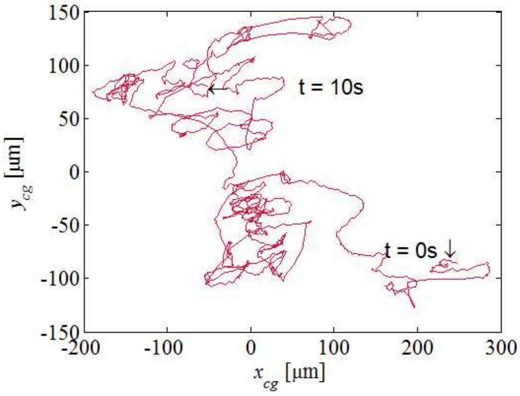

Fig. 3. The pupil center variability of subject C

Fig. 4 and Fig. 5 present change of horizontal and vertical coordinate of the center of the pupil versus time, respectively. Those results are for the same sequence of subject B and C, respectively.

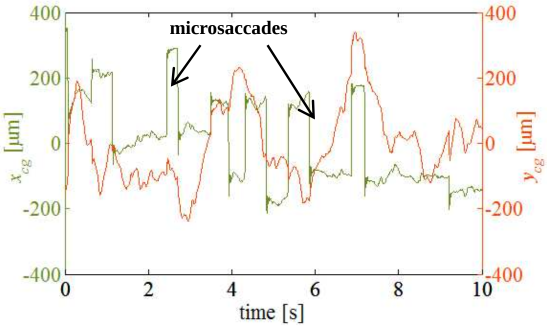

Fig. 4. Horizontal and vertical coordinate of the pupil center versus time for subject B

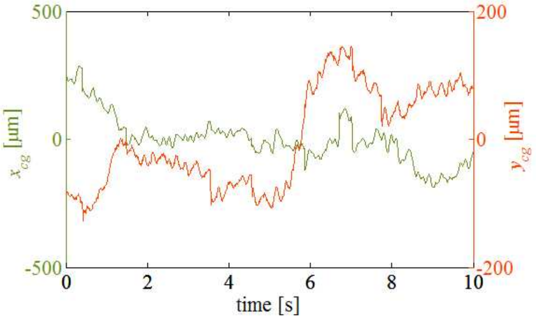

Fig. 5. Horizontal and vertical coordinate of the pupil center versus time for subject C

Microsaccades can be identified as sudden substantial movements of up to 300µm. This movement appeared in 0.01 to 0.015 seconds. In presented case majority of the microsaccades had significantly greater horizontal component.

For some of the sequences also decreasing linear trend of values of x_{cg} coordinate can be observed. This trend is not frequent in changes of y_{cg} coordinate.

To check directions of the pupil center movement, the reposition angle ω was calculated. The angle ω was defined as angle between x-axis and the path from point (x_i, y_i) to (x_{i+1}, y_{i+1}), where i

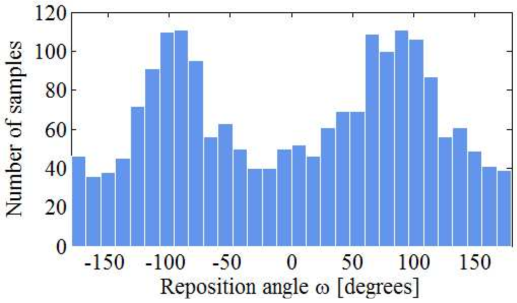

Fig. 6. Histogram of reposition angle ω for subject B

is number of frame in sequence. Fig. 6 and Fig. 7 present the histogram of value of ω angle for the same sequence of patient B and C.

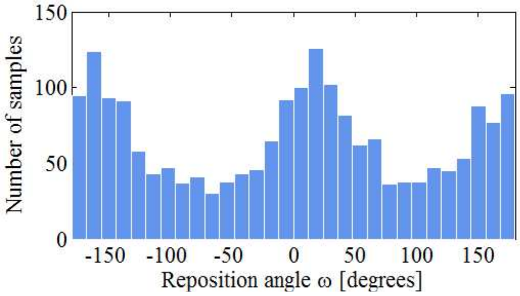

Fig. 7. Histogram of reposition angle ω for subject C

For subject B the greatest number of movements occurred in vertical direction (around -90 and 90 degrees), while for subject C the greatest number of movements were in almost horizontal direction. Comparing results between patients, the most "popular" directions were noticed as characteristic for some of the patient. That means that for all sequence of those patients one eye, the directions were unchanged.

4. Conclusions

Analysis of the eye pupil center allows tracing and description of small fixational eye movements with high accuracy. However, this method does not allow to study small torsional eye movements, which are also not exactly explored.

The results can be used in ophthalmology, e.g. in the difficult diagnosis of orbitopathy, a disorder of structures in orbit, beyond the eyeball. These structures can significantly affect the quantitative characteristics of eye movements.

Acknowledgments

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