SYSTEM FOR VIDEOMETRIC MEASUREMENT OF THE VERGENCE AND ACCOMMODATION

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1 Introduction

Measuring of static parameters of accommodation and vergence is a routine strabological investigation. Dynamic parameters of these processes can be useful for diagnostics of the oculomotor disorders. However, dynamic parameters are not commonly measurable. System described in this paper is foundation of measuring method suitable for use in clinical practice.

2 Materials and methods

Changes in accommodation and eye position of the measured person are stimulated by distance change of the fixation object in virtual holographic space. Stimulation objects are located in distance 2,18 m (far fixation object) and 0,37 m (near fixation object). For determination of immediate relative accommodation is used the principle of eccentric photorefraction. Slope of the brightness profile in eye pupil (as a result of the eccentric photorefraction) relatively corresponds with immediate dioptric power of the eye lens. Eye position (vergence) is measured by Hirschberg's test comparing position of the 1st Purkinje image and center of the eye pupil. Source of measuring light for both methods is vertical array of LED emitting in NIR (Near Infrared) spectrum (λ = 850 nm). Optical phenomena on eyes (Fig. 3) are recorded by the high-speed camera sensitive in NIR (200 fps, 640 × 240 px with vertical binning). Stimulation of the visual system is performed by the virtual holographic objects. Holography allows to record 3D object on the holographic plate and to reconstruct virtual object in original distance from the plate. This solution allows reducing spatial requirements of the stimulation part of the system. In our case, four objects reconstructed by four laser sources (λ = 532 nm) are recorded on one plate (two in near and two in far position). Switching between reconstruction sources the distance of the fixation object is changed and visual system is forced to change vergence and accommodation.

Sequence acquired by the videometric system is processed by the image analysis in MATLAB. Sequence contains 1000 images with timestamp for determination of the time axis. Each image contains information about immediate accommodative state and eye position. Software processes each image according to preset parameters of analyzer algorithm. Analysis performs independently for each eye. Scheme of the image analysis is on the Fig. 1.

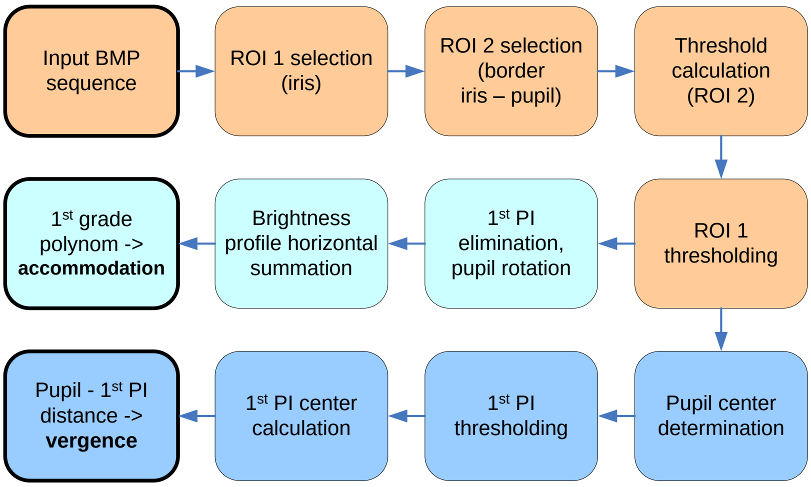


Fig. 1 – Scheme of the image analysis.

On the beginning of the analysis is manually defined region of interest (ROI) around iris and pupil of eye (ROI 1). The second region (ROI 2), (the border pupil – iris) defines area for calibration of the threshold. Threshold is calculated as 60 % of brightness range of the ROI 2 [1]. Subsequently, the ROI 1 is converted into the binary matrix in accordance to threshold. Binary matrix eliminates values around iris by zero. On the Fig. 2 is visualization of the pupil brightness profile.

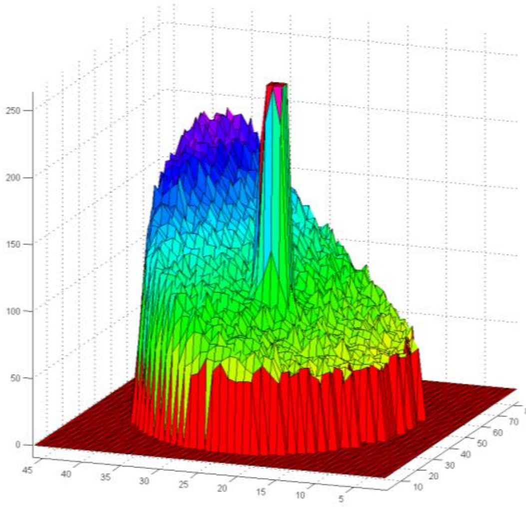


Fig. 2 – Visualization of the pupil brightness profile.

Here, the algorithm is divided into two blocks. In the first block the 1st PI is eliminated and performs rotation of the pupil (empirically found as angle 20 °). Rotation of the brightness profile is caused by location source of the measuring light in the medial axis of the face (Fig. 3).

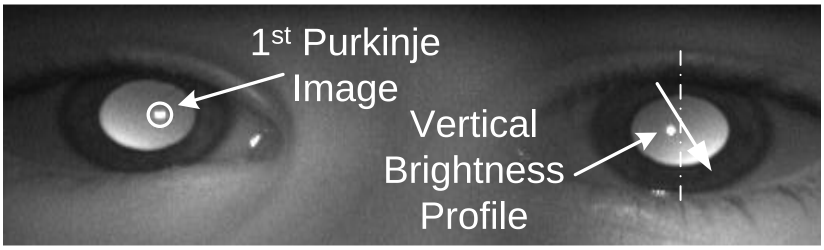


Fig. 3 – Image recorded by the videometric system.

In the next step performs horizontal summation of each row of the image and values are divided, due to normalization, by number of the non-zero values. Finally, the brightness profile of pupil is quantified by 1st order polynomial function linearly corresponding with dioptric power of the eye lens. The second block uses thresholded original images. There is determined the center of the pupil mass. Surrounding of the 1st PI is eliminated and the center of the 1st PI is determined. Vergence is calculated from the distance between center of the pupil and 1st PI. This algorithm was applied for each eye separately. Results of the analysis were stored for each image and finally exported with appropriate time stamp. Primary values for vergence and accommodation were subsequently calibrated.

It is necessary to know diameters and geometrical ratios of the system for determining standardized duction angle α of the eye. Geometrical scheme is on the Fig. 4.

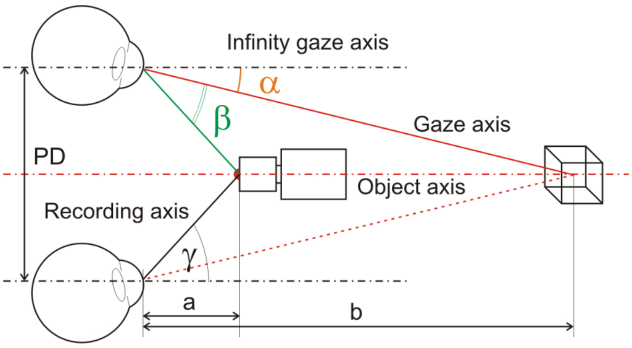


Fig. 4 – Simplified geometrical setting of the measuring part.

Camera's focus of located in front of the patient "cyclop eye" in the distance a = 223 mm. Fixation object changes its distance from 2,18 m (far fixation object) to 0,37 m (near fixation object). Pupillary distance is determined to PD = 55 mm (for infants). Angle γ could be calculated as

$$\gamma = arctg\left(\frac{PD}{2a}\right),$$

where γ is angle of camera deviation [°], a is distance between focus of the lens and eye in object axis [m] and PD is pupillary distance [m]. Because the dimensions of the system are static, angle γ is constant and angle α could be calculated as $\alpha = \gamma - \beta$, where α is standardized duction angle [°], β is measured duction angle[°] and γ is angle of camera deviation[°]. Calculation of angle β is according to Hirschberg's formula [1]

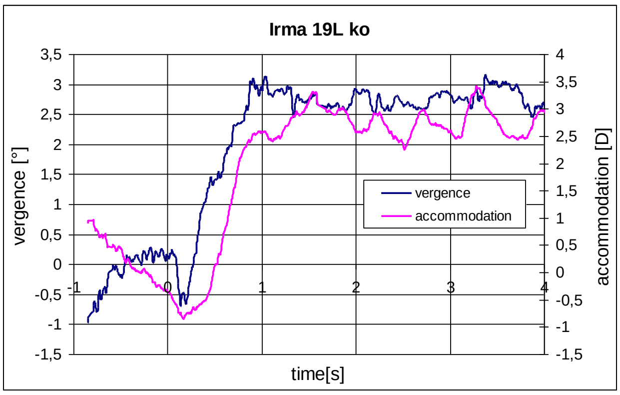
$$\beta = PC \cdot K \cdot H,$$

where β is measured duction angle [°], PC is distance between center of the 1st PI and the pupil [px], K is conversion factor [$mm \cdot px^{-1}$] and H is Hirschberg's coefficient [$° \cdot mm^{-1}$]. It depends on the diameters of the eye and position in the orbit. Hirschberg's coefficient value was empirically determined as 7 $° \cdot mm^{-1}$ [2]. Initial part (first 150 images) and final part (last 300 images) of the sequence is used for calibration of the analyzing algorithm. Result of this mathematical treatment of measured data is graph of vergence in dependence on time.

The goal of the mathematical treatment of primary accommodation data is conversion between brightness profile of the pupil and the dioptric power of the eye lens. Analyzing algorithm calculates first degree polynomial of the brightness profile of the pupil. Polynomial function corresponds with the dioptric power of the lens, therefore it is possible to calibrate algorithm by two values (from initial and final part of the sequence similarly to calibration of the vergence). Holographic objects are reconstructed in two discrete distances 2.18 m (far fixation object) and 0.37 m (near fixation object). Reciprocal value of these distances is dioptric power (0.46 D resp. 2.7 D). These values serve as points of the calibration curve (line). Equation of this line is used to determination of immediate dioptric power of the eye lens.

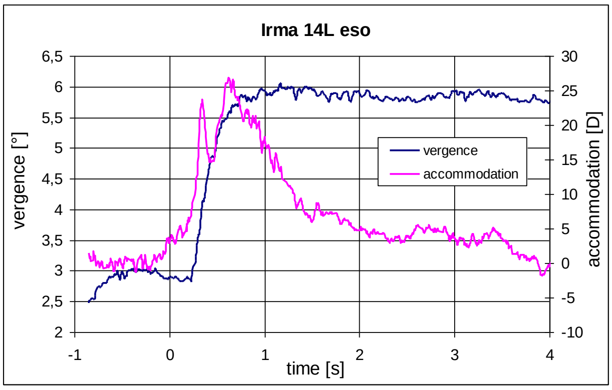
3 Results

Courses of the accommodation and vergence are characteristic for normal and pathological states of the visual system. Every graph is signed by name of the project, patient number, eye laterality and group of the patient (control – ko, esotropia – eso, exotropia – exo).



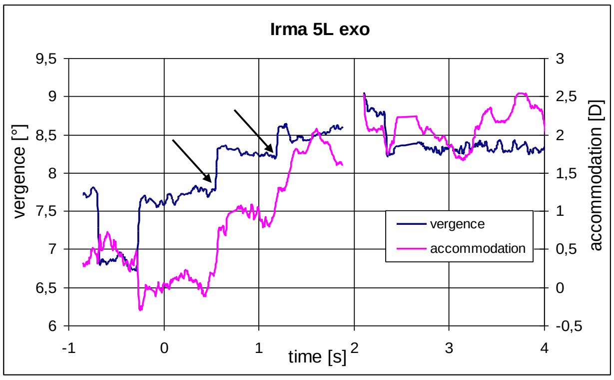
Graph 1 – Normal eye reaction.

Graph 1 shows typical reaction of subject with normal visual functions. After phase of latency (~ 200 ms) follows eye motion and change of the accommodation driven by the open-loop system (till 1 s). Last phase of the eye reaction is driven by the closed-loop system in visual center (undulation between 1 s and 4 s).



Graph 2 – Reaction of the eye with esotropia.

On the Graph 2 is shown reaction course of the subject with unstable of accommodation caused by esotropia. In the initial segment the accommodation reaches the right value, but is unstable and returns to default value.



Graph 3 – Reaction of the eye with exotropia.

Reaction on the Graph 3 has a typical course of vergence for heavier form of exotropia. When the vergence in initial segment doesn't reach at least 80 % of final vergence state, controller of the visual center schedules additional initial segment. These segments are in the graphs marked by arrows.

4 Conclusions

Designed system allows measuring of the dynamic parameters of the visual system that couldn't be commonly established yet and would be a useful diagnostic tool for investigation of the oculomotor disorders. Obtained results of videometric record analysis represent answer of visual system on spatial stimulation. Running clinical study based on experimental measurement will evaluate courses of vergence – accommodative curves in dependence on patient's diagnoses (esophoria, exophoria, etc.). Next question is an attractiveness of the virtual fixation objects. Previously published works investigates only attractiveness of the real fixation objects. Attractiveness of the virtual objects was not yet examined. However, results of this work show that measurement with the virtual fixation object is possible and corresponds with theoretical presumptions.

5 References

[1] DUŠEK Jaroslav. E.M.AN. (Eye Movement Analyzer) – software solution, Prague, 2001, pp. 66.

[2] Dostalek, M. & Dusek, J. 2004 E.M.A.N. (Eye Movement and Accommodation Analyzer) device for vergence accommodation synkinesis recording and analysis. Transactions, 28th European Strabismological Association Meeting. J.-T. de Faber. London, New York, Taylor & Francis: 357 - 361.

[3] JINDRA, Tomáš. *Ir.M.A. - Klinický přístroj pro měření dynamiky akomodace a vergence. [Ir.M.A. – Infrared Measurement and Analysis of Accommodation and Vergence]* Prague, 2011. 80 s. Thesis. Charles University in Prague, First Faculty of Medicine, Institute of Biophysics and Informatics. Supervisor Ing. Jaroslav Dušek, Ph.D.

[4] Schaeffel, F., Farkas, L., Holand, H.C. 1987: Infrared photoretinoscope, Appl. Opt 26, 1987, pp. 1505 - 1509

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