Analysis of Oscillatory Eye Movements as a Nystagmus, Manifested in the Visual System

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Abstract The state of normality of the oculomotor equilibrium is determined by the characteristics of eye movements that are analyzed from the point of view of kinematic and dynamic dimensions. A great deal of research has highlighted and identified the connections between eye movements and the mode of action of stimuli in the environment. Depending on the degree of action of these stimuli, the reaction in the visual system may allow the identification of functional, neuromotor or normal physiological abnormalities. The first part of the paper analyzes the types of eye movements that the visual system can perform both monocular and binocular and the normal and abnormal physiological limits are identified. Of all these, the emphasis was placed on the oscillatory movements of the eyeball to highlight the importance of binocular balance on the stability of the formation of the corresponded retinal images. In the second part of the paper, we present the experimental system designed and built to record these continuous and/or oscillatory movements in order to compare the ideal trajectory with that performed by each ocular globe. In the final part of the paper, the results of image processing of the eyeball movements and the conclusions regarding the influence of external stimuli on oculomotor balance are presented.

1 Introduction

Eye movement is considered an essential element in defining the normality state of the visual system and how binocular vision is achieved and eye balance maintained.

The human visual system is characterized by a series of movements that it develops in the form of reflexes or conscious movements, programmed and controlled by the

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N. Herisanu and V. Marinca (eds.), *Acoustics and Vibration of Mechanical Structures—AVMS 2019*, Springer Proceedings in Physics 251,
https://doi.org/10.1007/978-3-030-54136-1_22

central nervous system. The main types of eye movements are: nystagmus, saccade, miniature, pursuit, smooth, compensatory and vergence.

Nystagmus is a condition of involuntary movement acquired in the first years of life or maybe even later. This form of eye movement results in a reduced or even limited view of the axes of the visual system. These moves are even more evident when the head rotates around an axis and the remote images of the visual system are supported by turning the eyes in a direction opposite to the movement of the head to compensate for the rotation.

From a functional point of view, there are two forms of manifestation of the nystagmus: physiological and pathological, presenting, within each group, other variants of manifestation. Forms of interest for oculographic computational analysis are represented by physiological nystagmus, the pathological one requiring a medical approach of ophthalmological and neurological specialty. The forms of nystagmus may be determined by a variety of causes, such as nervous system disorders, congenital disorders, acquired disorders, toxicity and medication. As mentioned in many research papers, physiological nystagmus is a form of involuntary eye movement that is part of the vestibulo-ocular reflex (VOR), characterized by alternating smooth pursuit in one direction and saccadic movement in the other direction [1]. In turn, the physiological nystagmus presents the following forms of manifestation: downbeat nystagmus, upbeat nystagmus, seesaw nystagmus, periodically alternating nystagmus.

Other forms of manifestation of physiological nystagmus, which are of interest for studies on biomechanical posture, dynamical or static behavior of the human body, are the form of opto-kinetic and post-trophic nystagmus, respectively. The form of opto-kinetic nystagmus is induced by the pursuit of visual stimuli (vertical or horizontal), the post-trophic form is determined by the rotation motion of the body around the vertical axis, and the rapid phase of the nystagmus is performed in the opposite direction of this rotation, trying to compensate some internal physiological manifestations (Fig. 1).

Another form of movement determined in each ocular globe is saccade movement, a rapid eye movement, conjugated and performed under voluntary control from the central cortex (visual cortex). Generally, the purpose of these oscillatory movements is to form the images of the surrounding space in the foveal area; therefore, the saccade oscillations are considered as an important mechanism for characterization of selective visual attention.

In the case of saccade movements, an important problem was identified, which is to analyze how the visual system works during these movements (whether or not images are formed on the retina to be transmitted to the visual cortex). Thus, it is stated in the literature that in fact visual information, in this case, is obtained as sequential images and interrupted by fixation processes, a phenomenon aware of the subject with this form of eye movement [2]. Fixation periods last up to 200–300 ms, and the fixation sequence is related to the sampling rate of the eye movement recording technique that has been used. Saccade movements are very rapid, resulting in a phenomenon of sacred suppression, a phenomenon during which visual perception is not completely eliminated but only substantially reduced. From the experimental point of view, the

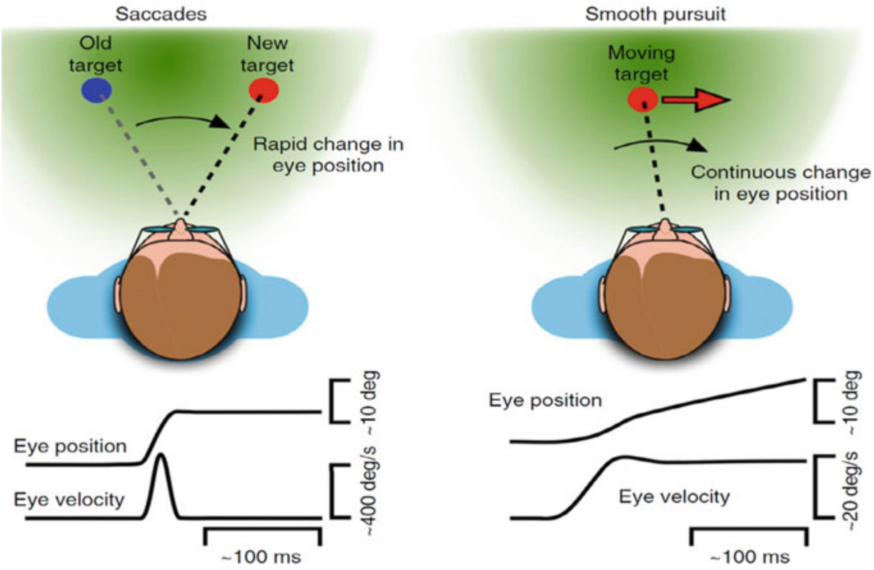

Fig. 1 Eye movements that redirect gaze and saccades change the line of sight to place the retinal image of visual targets onto the fovea [8]

saccade movements are pre-programmed movements such that during fusing, both foveal and peripheral information help to guide to the associated fixation site and respectively the occurrence of the next saccade movement. Eye tracking movements are conjugated, and they easily track objects that move slowly in the field of vision that the eye fixes. Their primary purpose is to stabilize objects' movements on the retina, allowing the subject to perceive the details of the object. Compensatory ocular movements are related to tracking movements and act to compensate for the movement of the head or body in order to partially stabilize the image of an object on the retina. For the evaluation of ocular movements, different techniques of real-time recording of ocular microscopes are used in order to highlight the normal, physiological or possibly existing state of eye pathologies.

Eye tracking technology offers the ability to measure eye movements of users, allowing you to identify the areas in the field of view frequently viewed and the time when your eyes move from one fixation point to another. For example, the use of eye tracking technology in measuring online interactivity can confirm the results obtained by using other methods or can be directly applied in evaluating the proposed interactivity attributes for evaluation [3].

There are various techniques for eye movement monitoring, including dual Purkinje image, electro-oculography, search coils, known as scleral contact lens or search coil, photo-oculography and video-oculography. Photo-oculography or video-oculography is a technique that involves measuring the characteristics of the moving eye. The technique is the most used today and consists in mounting an infrared camera either at the bottom of the monitor or at the base of the laptop screen, or on the frame of a special eyewear designed for this activity. This camera, equipped with image processing software, locates and identifies the reflection of the cornea and the center of the pupil to be able to analyze the eyeball trajectory and evaluate the preferences of visual interest in site images [4, 5]. The optical and video means used in the visual system analysis are the myGaze device, along with the related software.

MyGaze-n system is designed to be used with the myGaze software SDK and to create applications based on the visual system and its motor features but is limited to laptop or display attachment systems and cannot be used wirelessly, mobile on a glasses frame [6].

2 Experimental Setup

The experimental system designed to analyze the eyeball oscillatory movements in the convergence-fixation process is based on the use of captured images with a video camera mounted on a special pair of spectacles, and on the processing of images through specialized acquisition and processing software. Also, eyeball motion analysis is performed on the basis of a dynamic nonlinear and predictive model of saccadic system. The study of the control of eye movement and oculomotor disorders was based on theoretical control concepts. This model analyzes the displacements through a set of equations that correlate the velocities and positions of the eye globes, obtained from the quantitative investigations of the physical movements of the eyes. Another aspect as important as defining the analysis model of nystagmus moves determines the set of fixation time ranges, from the initial position to the final position [7] (Fig. 2).

A complementary approach based on the theory of nonlinear dynamic systems, presented in the paper [7], allows development by using a nonlinear dynamical model of the saccadic system, comprising a symmetrical, linear and uniform system consisting of six autonomous differential equations. A first result of the modeling showed that, besides generating the normal saccades, it could also simulate random, oscillating instability.

Therefore, an experimental system that highlights these saccadic movements must allow the acquisition of positional data and the oscillation velocity of the eyeball to

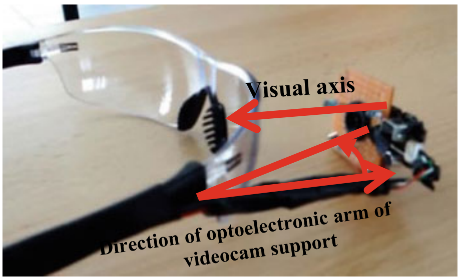

Fig. 2 Optoelectronic device to record ocular movements

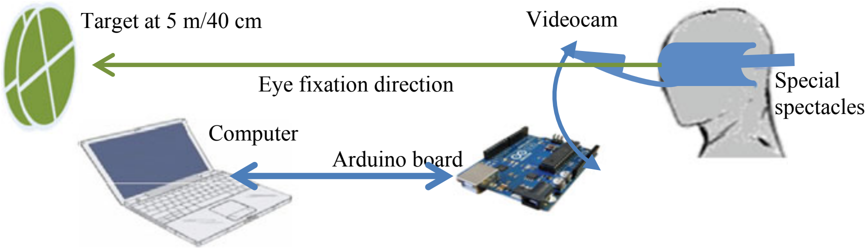

Fig. 3 Experimental setup

model the dynamics of normal jaws and random jaws. This system is made up of an assembly of images based on a autofocus videocam (30 frames/s) and a special eye glasses. The optoelectronic image acquisition system at the eye level, fixed on the right side of spectacles, has the ability to position at different distances (10–15 cm) and angles (0–30°) from the subject visual system axis (see Fig. 3).

3 Results and Conclusions

With this system, macro-eye and micro-eye movements can be tracked when the subject is shown a certain visual behavior (fixation at a fixed point at a distance of 5 m or fixation at a distance of 40 cm in front of it). The subject was every time in the bipedal postural position, with no biomechanical motion in the body, with the hands next to the body and with the convergent visual system, accommodated at the analysis distances (see Fig. 4). The video-captured images of eye movements were processed by image processing and analyzed dimensionally, after calibration procedure (see Fig. 5).

The ideal trajectory taken into account was to perform eyeball movements corresponding to the eight initial analysis positions and without any influences of postural movements. The analysis of horizontal and vertical displacements, as well as the velocity variation graph for a subject without a nystagmus, shows variations of µm, respectively µm/s (see Fig. 6), and the number of micro-oscillations made by the eyeball is approximately 300 for 10.5 s recorded. For a subject with saccade eye movement, variations on both directions are much higher, and the speed chart highlights the peaks of movement in successive saccade. Variations in oscillations of

Fig. 4 Image processing to evaluate eye dimensions

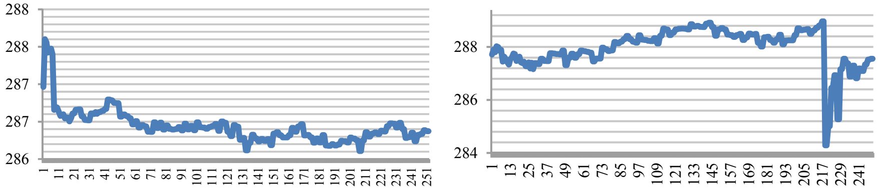

Fig. 5 Displacements [µm] on *X*-direction without nystagmus (left) and with nystagmus movements (right) (in abscise are no. of samples)

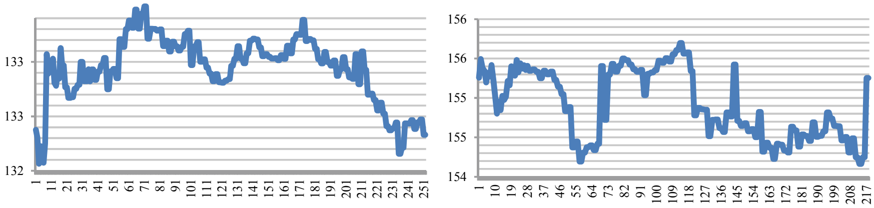

Fig. 6 Displacements [µm] on *Y*-direction without nystagmus (left) and with nystagmus oscillations (right) (in abscise are no. of samples)

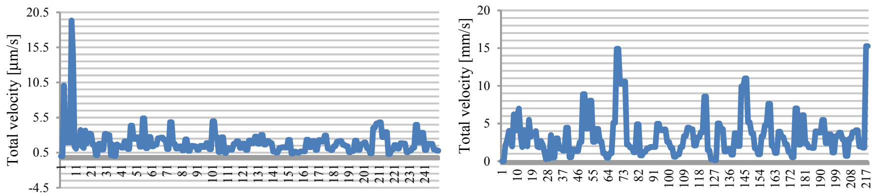

Fig. 7 Total velocity [µm/s] measured for eye without nystagmus (left) and with nystagmus oscillations (right) (in abscise are no. of samples)

the nystagmus eye movements exceed with 26% the variation limits in the case of a physiological (functional) nystagmus, values were determined in the same conditions for subjects with and without the emphasis of the saccade movements. These variations may indicate a form of visual stress and may be monitored over longer periods to identify the cause of the oscillations changes in the eyeball and the possibilities to rehabilitation if the saccade movements are only physiological. Immediate applications of this recording system can be developed by taking into account several parameters of the state and functioning of the visual system to track the evolution of nystagmus over time (Fig. 7).

Acknowledgements In these experiments, we have developed the investigations with equipment from *Advanced Mechatronic Systems Research Center*—C04 and *Applied optometry Laboratory* at University Transylvania of Brasov, in Ph.D. school Program.

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