OBER2, eyemovements, squint, strabismus, oculomotoric system, multilayer, levels, model

Dariusz POJDA*, Józef OBER*

MULTILAYER MODEL OF THE OCULOMOTORIC SYSTEM FOR COMPUTER BASED DIAGNOSIS OF SQUINT

Classical models of the oculomotoric system only represent the relationship between neural stimulation and eye movement. If we cannot determine the neural activity, then classical models prove inapplicable. At this paper we outline a system for simulation of the neural activation signal based on simple visual stimulation. We have used the idea of a multilayer brain structure. Different layers of the brain are responsible for subsequent layers of perception. Measurements made with the OBER2 system allowed us to evaluate the relationship between two signals: visual stimulation presented on the screen and eye movement measured by detectors. Applying the proposed multilayer model to generate a signal that will be the input for classical model of the oculomotoric system should make it possible to estimate some parameters that describe the work of muscles. We do not need to measure neural activity, provided that the neural system is working normally.

1. OBJECT OF RESEARCH

Squint (strabismus), often called "crossed-eyes", is a condition in which the eyes are not properly aligned with each other. One eye is either constantly or intermittently turned inwards, outwards, up, or down. This ocular misalignment may be accompanied by abnormal motility of one or both eyes, double vision, decreased vision, ocular discomfort, or abnormal head posture. Although the exact cause cannot always be determined with reasonable certainty, strabismus is usually attributable to sensory, organic, anatomic, motor, or innervational causes. Any of these factors alone can result in strabismus; however, strabismus may be the result of multiple factors, which, occurring alone, might not cause the disorder. For some individuals, squint can result in permanent loss of vision. Young children with strabismus often develop amblyopia (lazy eye) and impaired stereopsis (binocular depth perception). Early identification and treatment of strabismic children may prevent amblyopia. The strabismic child with amblyopia has a significantly higher risk of becoming blind by losing vision in the nonamblyopic eye due to trauma or disease.

Remediation of strabismus requires treatment by an eye care practitioner, and the results are usually best when treatment is instituted early. Preservation of vision and binocular function result from proper diagnosis, treatment, and patient compliance. In more serious cases a surgical intervention is needed. The purpose of our work is to design a computer-based system to help in the early detection, measurement and diagnosis of squint. We are developing methods that will help plan the surgical intervention and evaluate its effects.

* IITiS PAN, ul.Bałtycka 5, 44-100 Gliwice, Poland. e-mail: pojdulos@iitis.gliwice.pl

2. MEASUREMENT SYSTEM.

2.1. KNOWN METHODS OF EYE MOVEMENT RECORDING

Several methods have been described in the literature for recording the eye movements. In general, the following techniques can be distinguished:

Movements of the eyes can be measured with a travelling microscope, using blood vessels as reference marks. If the microscope is fitted with a cine camera, permanent recordings of eye movements can be made. With the development of fast cine film it became possible to photograph the whole eye at high speed and thus record rotations about the three axes simultaneously. The time resolution of this method is limited by the speed of the camera and the emulsion, and can hardly be better than 10ms. The eye positions have to be measured from the film and the corresponding directions of the visual axes have to be calculated. This can be very time consuming.

A variety of techniques involve the projection of light onto the eye and a photosensitive device that responds to the light reflected from the eye. For instance, a spot of light can be projected onto the limbus, with a photoresistor arranged to pick up the scattered light. If the reflected light is not all received by the transducer, the quantity of light received by the transducer is approximately proportional to the area of sclera lying under the spot of light. This device can behave linearly over a range of about 10º, with a time resolution of 10ms.

An extension of this method was introduced by Nykiel and Torok (1977); the eye is diffusely illuminated with infrared light and viewed by four photodetectors disposed symmetrically around the orbit. The whole assembly can be mounted on goggles worn by the subject; this eliminates problems related to head movements. This method is an early version of the infrared method used in OBER2 system.

Light reflected on refraction index discontinuities can also be used. Four reflected images can be formed when a bright narrow beam of light traverses the optical surfaces of the eye. These images are called Purkinje images. The first image is formed by the front surface of the cornea. The back of the cornea and the front and back surface of the lens form the second, third and fourth Purkinje image. The center of rotation of the eye is not identical to the center of curvature of the cornea, therefore a device that observes the first Purkinje image can measure eye movements.

A method using the fourth Purkinje image was devised by Cornsweet and Crane (Carpenter, 1977). They use the first and the fourth Purkinje image, because these move in relation to one another on torsional movements. The marked curvature of the cornea makes corneal reflection unduly sensitive to small translations. A plane reflecting device, for instance a mirror mounted on a contact lens, can reduce this sensitivity.

Queré (1981) used electro-oculography (EOG) to study vergence movements. In EOG, movements of the eye are recorded indirectly by periorbital electrodes. The cornea is approximately 1 mV positive with respect to the retina, a situation that creates an electrostatic field that moves with the eye movement. The range of measurement is 1º to 40º with a resolution of 1º. Frequent calibration is essential because of nonlinearity and drift. For quantitative studies direct-current oculography is required, but it is very difficult to solve the problems of baseline drift. For electronystagmography, alternating-current coupled EOG is sufficient, but stationary eye position cannot be recorded in that case.

Robinson (1963) described the scleral search coil in a magnetic field. When the subject is exposed to an alternating magnetic field, eye position may be accurately recorded from the voltage generated in an 8-shaped coil of wire embedded in a scleral contact lens worn by the subject. Horizontal, vertical and torsional eye movements can be measured. A resolution of 15 seconds of arc and a linearity of about 2 % of full scale is claimed. This is the most accurate and most versatile method available, but it is not a contact-free technique which makes it of limited utility when large groups of young people have to be screened.

2.2. DESCRIPTION OF THE OBER2 SYSTEM

The OBER2 is an infrared light eye movement measuring system and it works with IBM PC compatible computers. As one of the safest systems for measuring eye movement it uses very short flashes of infrared light (80 microsecond). The system has an advanced analog-digital controller and converter, which includes background suppression and prediction mechanisms ensuring the elimination of slow changes and fluctuations of external illumination frequency up to 100Hz, with effectiveness better than 40dB. The active measurement axis, sampling rate (25-4000Hz) and measurement start and stop can be set from the PC. By appropriate gain control it is possible to attain high position resolution of 0.5 minute of arc even for large-amplitude eye movement (+/- 20 degree). The whole man-machine interface system can also be driven directly by eye movement in real time.

3. MODEL OF OCULOMOTORIC SYSTEM

3.1. CLASSICAL MODEL

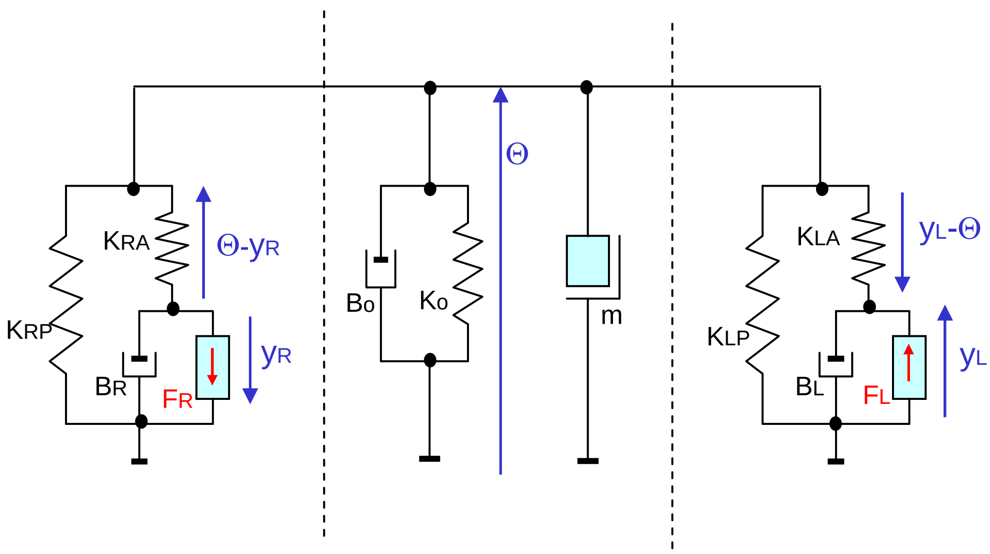

Fig.1 Classical model of oculomotoric system

Modeling of the oculomotoric system is an important area of research in ophthalmology and physiology. One of most known model of eye movements is the Clark and Stark model. [6]

This model describes movements of the eyeball along the horizontal axis. Three active elements are represented. The eyeball, which is described by its mass (*m*), and two muscles, described by the forces exerted on the eyeball (F_R, F_L). The forces are a function of the neural stimulation generated by the brain to control the muscles.

There are some coefficients specified for each element. For the eyeball we need an absorption (*Bo*) and elasticity (*Ko*) of the environment. For the muscle there are two elasticity coefficients. Active coefficients (K_{RA}, K_{LA}) describe the extensibility of the muscle when it is working, and passive coefficients (K_{RP}, K_{LP}) describe the elasticity of the muscle when other muscles affect it. Theta is movement of the eyeball.

For the model shown above we can write the following equations:

$$F_L - B_L \dot{y}_L - K_{LA}(y_L - \Theta) = 0$$

$$-F_R - B_R \dot{y}_R + K_{RA}(\Theta - y_R) = 0$$

$$-J\ddot{\Theta} - K_o\Theta - B_o\dot{\Theta} + K_{LA}(y_L - \Theta) - K_{LP}\Theta - K_{RP}\Theta - K_{RA}(\Theta - y_R) = 0$$

And finally:

$$\frac{dy_L}{dt} = \frac{F_L - K_{LA}(y_L - \Theta)}{B_L};$$

$$\frac{dy_R}{dt} = \frac{-F_R + K_{RA}(\Theta - y_R)}{B_R}$$

$$\frac{d\omega}{dt} = \frac{1}{J}\left(-F_o + K_{LA}(y_L - \Theta) - K_{RA}(\Theta - y_L) - (K_{LP} + K_{RP})\Theta\right)$$

$$\text{where: } \quad \omega = \dot{\Theta} \text{ and } \quad F_o = K_o\Theta + B_o\dot{\Theta}$$

3.2. APPLICATION OF THE CLARK AND STARK MODEL TO THE PLANNING OF EYE MUSCLES SURGERY.

As we said above, the neural activity is the stimulus, or input, for the classical model of the oculomotoric system. This activity controls the forces that are exerted on the eyeball by the muscles.

In electro-oculography the neural activity of the muscles is measured with a system of electrodes connected to the patient's head. Since we want to elaborate a method based on the eye movement signal only, we cannot use the Clark & Stark model directly.

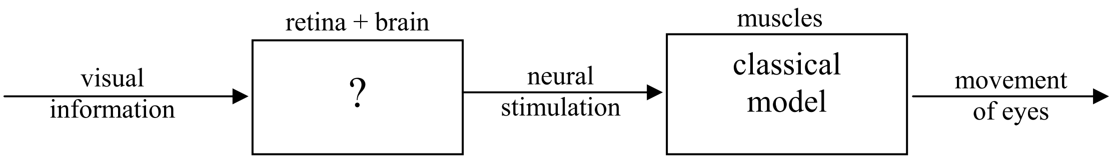

Fig.2 Route of information in eye movements

We need to find a relationship between a visual signal presented on the monitor, and the eye movements registered by the goggles. Or at other way we need to find a relationship between visual stimulation and neural activity, and use the estimated neural impulses to stimulate the classical model (Fig.2).

4. PRINCIPLES OF THE MULTILAYER MODEL

4.1. HOW WE CAN SEE THE WORLD

In order to understand how we can see the world we need to look at the structure of our eyes. And especially at the arrangement of visual receptors. There are about 120 million receptors situated on the retina. Most of them are placed at the central field of retina. So we can see details only if they are placed in the center of our field of vision. Peripheral receptors are arranged irregularly. The spaces between the receptors are large at the edge of the retina, and decrease towards the center. This arrangement of receptors allows us to see fast motion at the peripheral area of the field of vision, and makes possible very fast reactions, like turning our eyes towards the moving object, or stepping out of the way of falling flowerpot.

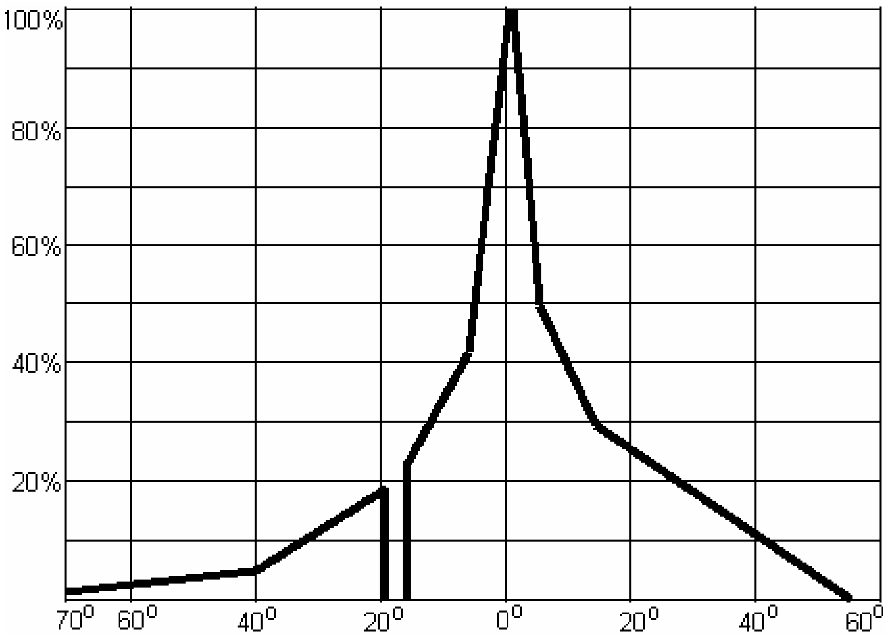

Fig.3 The best sensitivity of vision in the central field of the retina.

So we have three stages of perception: motion detection (in the peripheral field), focussing on the object (at center of field of vision), recognition of the object (in the brain). As we can see, there are similarities to computer vision.

4.2. THREE-LAYERS MODEL

In view of the above we proposed a three-layer model of visual perception. The visual stimulation is converted by the eyes into neural signals. Next the information is transmitted to the brain, and analyzed in its successive levels. At first, in the reflex level, the motion and other fast changes of view are detected. At the second – fixation level, we focus on the object of interest. And finally at the third level – we recognize this object (Fig.4).

From all those levels neural stimulations are transmitted to the muscles of the eyeball. In each layer, a part of the information from one eye is also used to stimulate the muscles of the other eye.

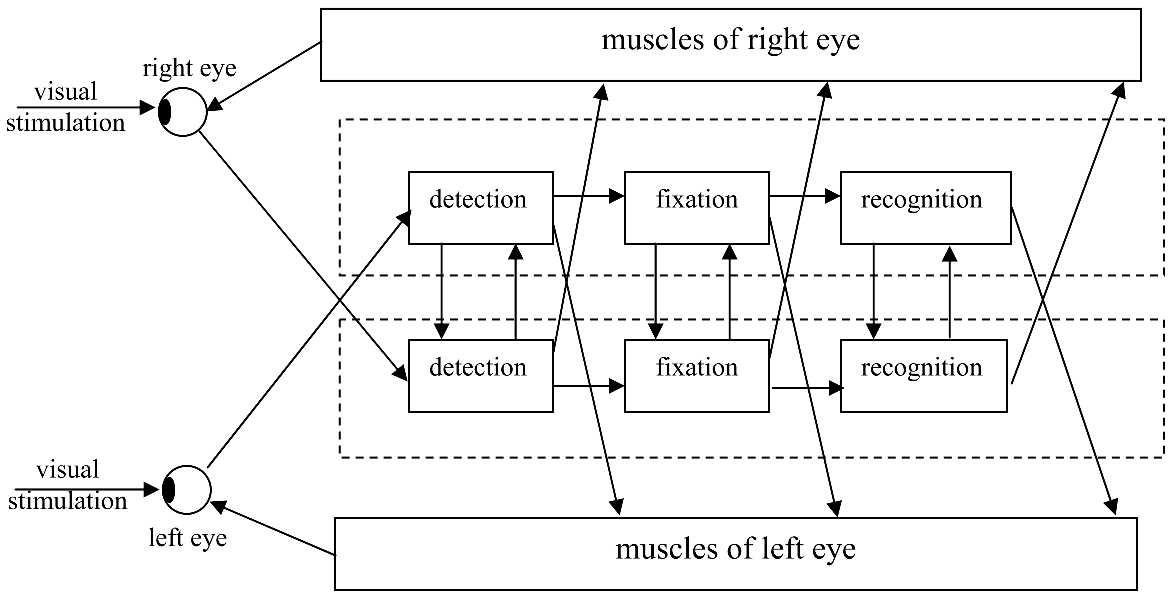

Fig.4 Schematic diagram of the three-layer model of perception

Only the first layer of this model is relevant to our present work. We can observe saccades in reaction to the stimulus presented at peripheral part of the field of vision. We can register the movement of the eyes in a saccade. Under first-level control, both eyes are turned to the object, but only one of them, known as the gaze-leading eye, reaches the correct position. The other eye has to adjust its direction in the second phase, known as the fixation stage (Fig.5).

5. FUTURE WORKS

Our next goal is to implement the model presented above as part of a model of the oculomotoric system. This model will allow us to simulate the functionality of the oculomotoric system in the long saccades, where the eyeball turns towards an object that appeared at the periphery of the field of vision. Analyzing such long movements because is essential for the evaluation of possibly abnormal functionality of the muscles in squint. Such anomalies are usually greatest at the extreme position of the eyeball.

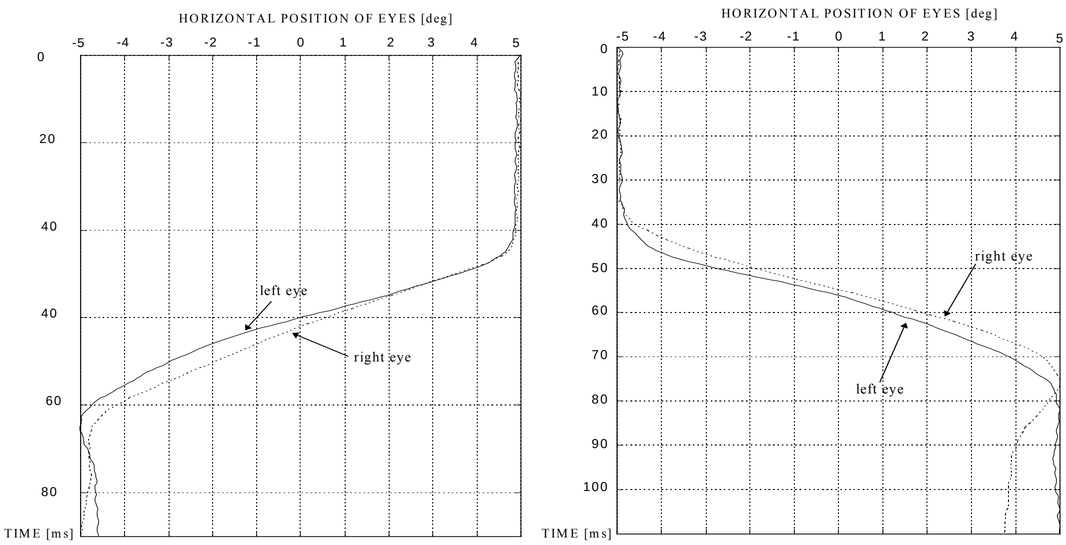

Fig.5 Reaction delay between right and left eye while following a moving target from right to left side of the visual field, and in the opposite direction.

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