JOURNAL OF MEDICAL INFORMATICS & TECHNOLOGIES Vol. 19/2012, ISSN 1642-6037

ENG signal,
optokinetic nystagmus,
signal averaging

Tomasz PANDER[1], Robert CZABAŃSKI[1], Tomasz PRZYBYŁA[1],
Dorota POJDA-WILCZEK[2]

THE POSSIBILITIES OF OPTOKINETIC NYSTAGMUS CYCLES AVERAGING

The analysis of eyes movements is a crucial part of eyes examination performed by clinicians. One of the characteristic type of eyes movements is a saccade. Its accurate detection is the base for further processing including the estimation of saccade parameters such as velocity, amplitude and duration. This paper presents averaging of optokinetic nystagmus (OKN) cycles that allows comparing and detecting different types of nystagmus phenomena. In order to average the OKN cycles the ENG signal needs to be processed. The saccade detection function is used to find the location of saccades in OKN waveform allowing the ENG signal to be divided into cycles. The resulting cycles are aligned using the Fourier shift method and then averaged providing the OKN cycle model, which can be used for evaluating the eyes at different movement conditions.

1. INTRODUCTION

Eyes are photosensitive sensory organs being an essential part of human visual system. Its primary function consists in focusing the light entering the eye from the visual field onto the retina, conversion of the incident light into nerve impulses, and transmission of nerve impulses (information) towards the brain [9]. Eyes can be monitored in order to detect the weariness or diseases of a person based on the results of observation of eyelids, pupils or the character of gazes. The analysis of eyes movements is a crucial part of eyes examination performed by clinicians. Different methods can be used to record or/and analyze eye movements [9]. In ophthalmology, the optokinetic nystagmus (OKN) is regarded as one of the important phenomena to be evaluated as it provides a large amount of information about condition of eyes. OKN is a visually driven eye movement whose purpose is to stabilize the retinal image during global movement of the visual field [5].

The electronystagmography (ENG) signal can be applied for investigation of nystagmus. Nystagmus is a type of eye movement produced as a response to stimuli which activate the vestibular and/or the optokinetic systems [12]. There are two types of nystagmus being distinguished: congenital (CN) and optokinetic (OKN). Congenital nystagmus is an ocular motor oscillation that usually appears in early infancy. It is characterized by involuntary, conjugated, bilateral to and from ocular oscillations. CN is predominantly horizontal, with some torsional and, rarely, vertical motion. In CN patients, a clear and stable vision of the world is corrupted by rhythmical oscillations, which result in rapid movements of the target image in the retina [11]. Unfortunately, the pathogenesis of CN is still unknown [1, 11]. The optokinetic nystagmus is characterized as an involuntary eye movement response when moving stimulus is presented in a large visual field [2, 13]. The OKN cycle consists of a slow phase which relates to tracking of the moving object and the fast phase in the opposite direction corresponding to saccade movement [4, 8]. Figure 1 presents an example of optokinetic nystagmus cycles corrupted with spontaneous blinks and the baseline drift.

[1] Silesian University of Technology, Institute of Electronics, Akademicka Str. 16, 44 100 Gliwice, Poland.
[2] Department of Ophthalmology, Medical University Of Silesia, Ceglana Str. 35, 40-952 Katowice, Poland.

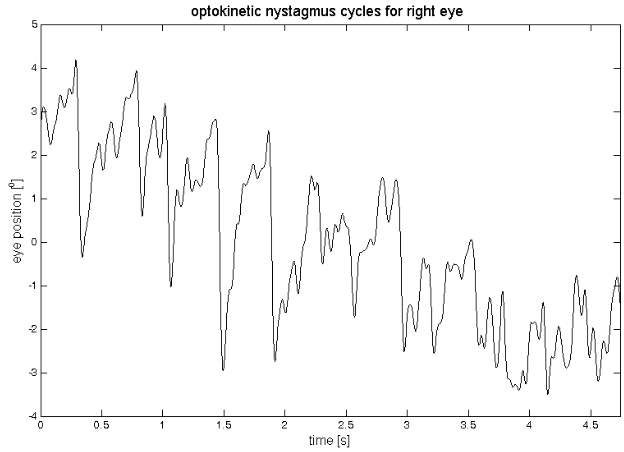

Fig. 1. Example of horizontal ENG signal for the nystagmus cycles corrupted with the baseline drift.

The quasi-periodic nature of ENG signal with characteristic OKN waveforms whose repetition rate varies over time allows their averaging in time domain. The signal averaging aggregates information from individual cycles of the periodical signal [7]. The application of the arithmetic mean is the simplest method of noise reduction with minimal risk of the signal distortion. Under the assumption that the noise is stationary, with zero mean and not being correlated with the signal [7] the noise-reduction factor is equal to $\sqrt{N}$, where N is the number of averaged signals.

This paper presents a method of OKN cycles averaging, which provides models of OKN for both eyes, allowing for the comparison and detection of differences in eyes movement as well as the recognition of the nystagmus type.

2. OKN CYCLES EXTRACTION METHOD

The first step of the OKN nystagmus processing consists in saccades detection in the ENG signal. It is based on the detection function described in [10], which can be applied for each eye separately. In the figures 2 and 3 two cases of OKN cycles determination are presented. The first (Fig. 2), represents typical ENG signal where all saccades were correctly determined. In the second (Fig. 3), only the first two saccades were correctly detected and OKN cycles were determined without any mistake. The erroneously appointed cycles should be disregarded and not taken into account when creating a model of the averaged cycle. Therefore, before averaging the correctness of OKN cycle should be checked. For that reason we apply a simple triangle model of OKN cycle with slow and fast phase recognition.

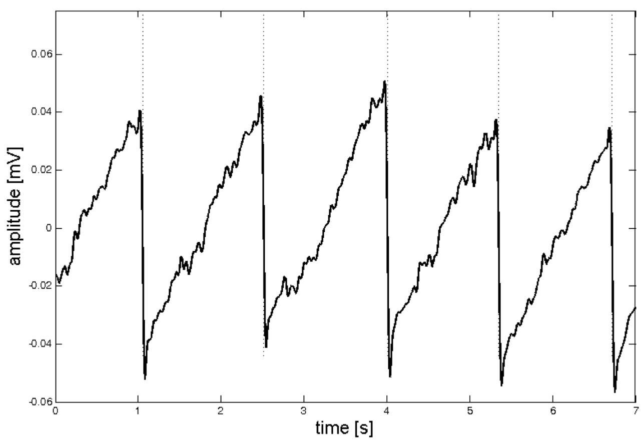

Fig. 2. An example of the ENG signal with detected saccades determining the OKN nystagmus cycles.

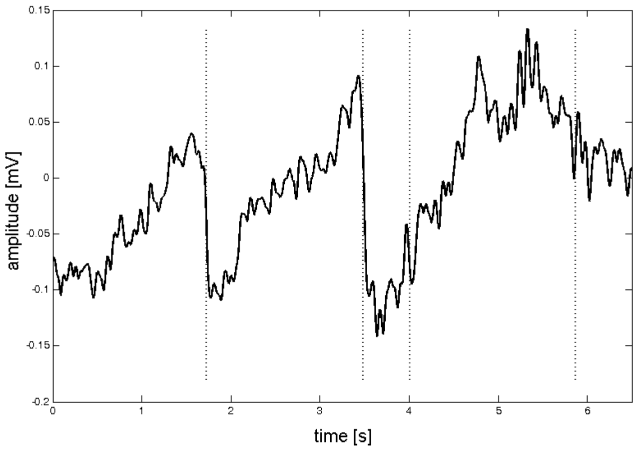

Fig. 3. An example of the ENG signal with problematic saccade detections.

The identification of each phase of OKN cycle is not a simple task due to random changes in beating directions, different waveform types and the noise presence [11]. As stated in [11], variability of eye position and foveation time are key features in CN visual acuity estimation. Hence, a correct and robust measure of both those parameters is crucial to obtain reliable results. In this paper we assume a linear model of nystagmus cycle. This assumption causes a necessity for estimation of two lines: the first line defines the slow phase of nystagmus cycle, while the second the fast (saccadic) phase of the cycle. The most important parameter is the slope *a*:

$$y = a \cdot t + b \tag{1}$$

where *t* denotes time. The slope determines the speed of slow (a_1) and fast (a_2) eye movements. To calculate the OKN cycle parameters we used a method based on a mean gradient of samples in the specified range. In order to calculate the slopes of nystagmus phases, firstly the characteristic points should be determined. The locations of these points are presented in the figure 4.

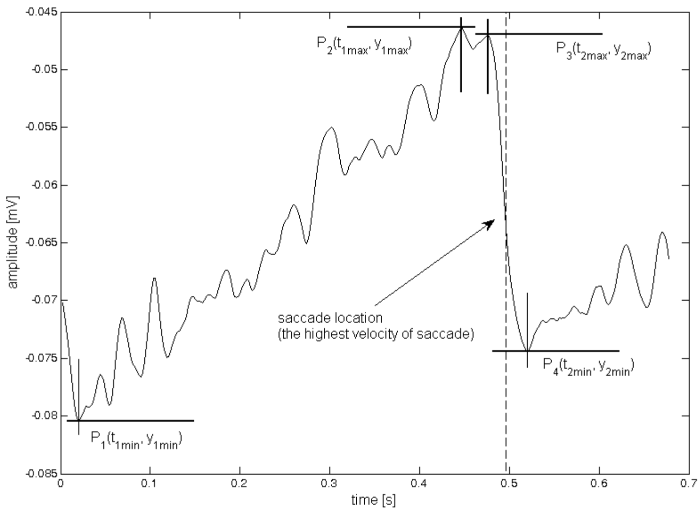

Fig. 4. An example of the single OKN cycle with detected saccade (dashed line) and the locations of characteristic points in OKN nystagmus cycle that are needed for the cycle description.

The position of the *i*–th saccade is denoted as T_i, $i = 1,\ldots, N$ where *N* is the total number of detected saccades. For the OKN cycle the following four points should be determined $P_1(t_{1\min}, y_{1\min})$, $P_2(t_{1\max}, y_{1\max})$, $P_3(t_{2\max}, y_{2\max})$ and $P_4(t_{2\min}, y_{2\min})$. The section between points P_1 and P_2

corresponds to the slow phase. These two points belong to the range from T_{i-1} to T_i. In order to find P_1 and P_2 the following conditions should be fulfilled:

$$y_{1\min}\Big|_{t1\min} = \min_{T_{i-1}\le n\le T_i} y(n), \tag{2}$$

and

$$y_{1\max}\Big|_{t1\max} = \max_{T_{i-1}\le n\le T_i} y(n). \tag{3}$$

The second stage consists in determination of the section between points P_3 and P_4 that corresponds to saccade movements. These points are searched in the range from T_i to T' where $T'=T_i + \varepsilon(T_{i+1} - T_i)$, where ε is the correction factor (in this work ε = 0.4). Such correction is necessary in order to protect algorithm against finding the maximum of the next nystagmus cycle. The point P_3, with coordinates ($t_{2\max}$, $y_{2\max}$), is a point for which the previous amplitude of the signal sample is lower than $y_{2\max}$. Similarly, P_4 is the point for which the next signal sample is greater than $y_{2\min}$. This requirements guarantee that fast phase of nystagmus cycle is strictly related to the saccade.

The slope a can be calculated directly from coordinates of points P_i, $i \in \{1, 2, 3, 4\}$ using the gradient method. The concept of a slope is crucial to differential calculus. For non-linear functions, the rate of change varies along the curve. The derivative of the function at a point is the slope of the line that is tangent to the curve at the point, and consequently, it is equal to the rate of change of the function value at this point. If we denote Δt and Δy as the distances (along the t and y axes, respectively) between two points on a curve, then the slope is given as:

$$a_1^{(n)} = \frac{\Delta_{(n)} y(n)}{\Delta t}, \tag{4}$$

where: $\Delta t=1/f_s$, $\Delta_{(n)}y(n)=y(n) - y(n-1)$ and $t_{1\min} \le n \le t_{1\max}$. Then the slopes $a_1^{(n)}$ are averaged:

$$a_1 = \frac{1}{t_{1\max} - t_{1\min} - 1}\sum_n a_1^{(n)}. \tag{5}$$

Similarly, the slope a_2 of fast phase of OKN cycle is calculated. Such defragmentation is required to make cycle averaging possible.

The parameters a_1 and a_2 are used for the selection of OKN cycles to be averaged. For the correct cycles classification we defined the ratio a_2/a_1 which, according to our experiments, should be greater than 5 to guarantee that all deformed and erroneously detected OKN cycles are rejected.

3. AVERAGING CYCLES OF OPTOKINETIC NYSTAGMUS

Signal averaging is a signal processing method allowing the repeated or periodic waveforms, which are contaminated by noise, to be enhanced. By summating noisy waveforms the random components (the noise) are decreased while the deterministic components (the desired signal) remain unchanged. The following requirements must be fulfilled for temporal averaging to work effectively [3]:

- the signal of interest must be repetitive or invariable,
- signal of interest must be time locked to a fiducial point,
- noise must be random with uncorrelated to the fiducial point.

In our method, we defined the fiducial point as P_3 (Fig. 4). The detected and separated OKN cycles have the standardized length which was defined as the nearest value of the power of 2 that is greater than real length of OKN cycles. This requirement is needed for the applied alignment method in time domain. However, before the alignment in time domain the alignment in amplitude domain is performed. The OKN cycles are aligned according to the amplitude of the last sample of the last OKN cycle in the set of OKN cycles to be averaged. The procedure is presented in the figure 5.

The next step is the alignment in time domain. In our work, we applied the Fourier Shift Method (FSM) presented in [6], ensuring the high accuracy of the alignment. In FSM method one of the correct signal cycles is selected as the reference for the alignment process. The other cycles are shifted in time domain:

$$y_d(n) = x(n - d). \tag{6}$$

The $x(n)$ and $y_d(n)$ signals correspond to subsequent periods of the aligned cycles $x^{(i)}(n)$ and $x^{(i+1)}(n)$. Using discrete Fourier transform (DFT) we get:

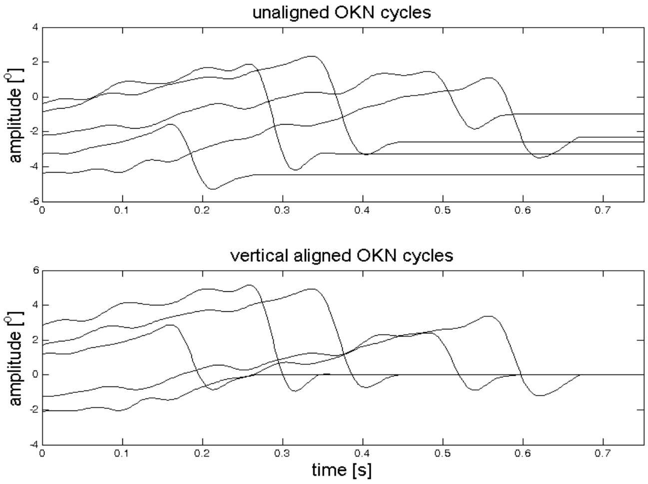

Fig. 5. The alignment OKN cycles in amplitude domain.

$$X(k) = \sum_{n=0}^{N-1} x(n+1) e^{-\frac{2\pi nk}{N}}; \quad k = 0,..., N-1. \tag{7}$$

The equation (7) can be written also as:

$$X(k) = F\{x(n)\}. \tag{8}$$

For signal $y_d(n)$ which is shifted in time domain with d samples we get the following form of the equation (8):

$$Y_d(k) = F\{x(n-d)\}. \tag{9}$$

On the basis of the Fourier transform properties we get:

$$Y_d(k) = X(k) e^{-\frac{2\pi kd}{N}}. \tag{10}$$

The error of signals matching is defined as:

$$e_{xy}(d) = \sum_{n=1}^{N} [y_d(n) - x(n)]^2 = \sum_{n=1}^{N} [x(n-d) - x(n)]^2. \tag{11}$$

Using the fact that the aligned signals are real and applying the Parseval's theorem we obtained:

$$e_{xy}(d) = \frac{2}{N}\sum_{k=1}^{\frac{N}{2}-1}\left| Y_d(k) - X(k)\right|^2. \qquad (12)$$

The shift of the signal $y_d(k)$ is determined as the result of the minimization process:

$$d_{xy} = \min_d e_{xy}(d). \qquad (13)$$

The Newton-Raphson method is used to find an argument for which the error function $e_{xy}(d)$ reaches the minimum value [6]. The FSM method allows us to determine the time shift with accuracy greater than the sampling period.

4. EXPERIMENTS

In order to evaluate of the optokinetic cycles averaging method, the ENG signal was recorded with BIOPAC MP-36 system for each eye separately in the horizontal eye movement plane using six Ag/AgCl electrodes. The frequency sampling was 500 Hz. The optokinetic nystagmus was induced by rotating the black and white alternating stripes with the width of 6 mm and the rotating speed 0.86 cycle/cm. An example of the averaged OKN cycles (21 OKN cycles were averaged for the right and 16 OKN cycles for the left eye) is presented in the figure 6.

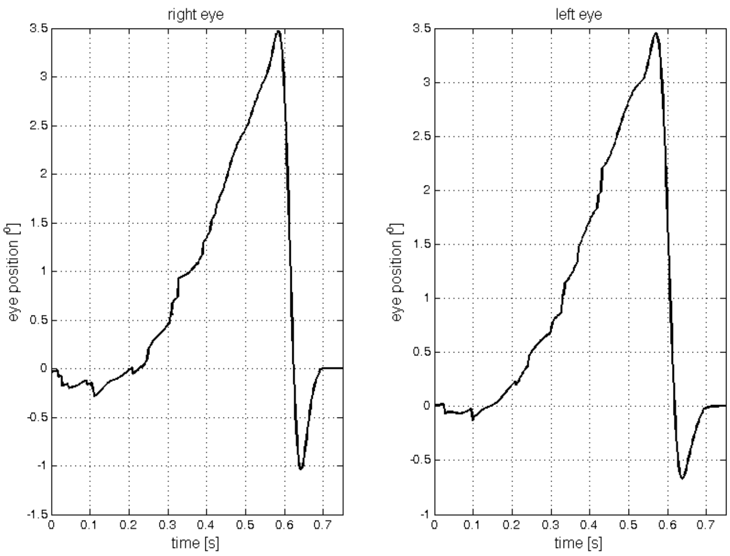

Fig. 6. An example of averaged OKN cycles for the right and left eye.

On the basis of the averaged cycles, the basic parameters (the duration of cycle phases and eye velocity during the cycle) of the optokinetic nystagmus can be measured. The values of the parameters for the averaged OKN cycles presented in the figure 6 are shown in the Table 1.

Table 1. Parameters of the averaged OKN cycles

	a_1 [°/sec]	a_2 [°/sec]	T_{slow} [sec]	$T_{saccade}$ [sec]
Right eye	6.00	-75.31	0.58	0.06
Left eye	6.05	-58.96	0.57	0.07

5. CONCLUSIONS

In this paper a new approach for analysis of optokinetic nystagmus was presented. A simple linear model of the OKN cycles was applied. It requires the definition of two lines that correspond to slow and fast phase of the cycle. The slope parameters correspond to the velocity in changing the eyes position. The proposed criterion on the slopes ratio allows for selecting the cycles to be averaged. The Fourier shift method was used for accurate alignment of the OKN cycles in time domain. The averaged cycles and their parameters can be used in evaluating the eyes mobility at different movement conditions. The proposed method is the starting point for the future investigations of the eye electrophysiology.

BIBLIOGRAPHY

[1] CLEMENT R.A., WHITTLE J.P., MULDOON M.R., ABADI R.V., BROOMHEAD D.S., AKMAN O., Characterisation of congenital nystagmus waveforms in terms of periodic orbits, Vision Research, 2002, Vol. 42, pp. 2123-2130.

[2] GARBUTT S., HAN Y., KUMAR A.N., HARWOOD M., HARRIS CH.M., Vertical optokinetic nystagmus and saccades in normal human subjects, Investigative Ophthalmology & Visual Science, 2003, Vol. 44, No. 9, pp. 3833-3841.

[3] HASSAN U., ANWAR M.S., Reducing noise by repetition: introduction to signal averaging, Eur. J. Phys. 2010, Vol. 31, pp. 453.

[4] KIM K.G., KO J.S., PARK B.R., A new measuring method of slow component velocity for OKN signal, IEEE 5th Inter. Conference on Power Electronics and Drive Systems, 2003, pp. 973-977.

[5] KNAP CH.M., GOTTLOB I., MCLEAN R., PROUDLOCK F., Horizontal and vertical look and stare optokinetic nystagmus in healthy adult volunteers, Investigative Ophthalmology & Visual Science, 2008, Vol. 49, No 2, pp. 581-588.

[6] ŁĘSKI J., A new possibility of non-invasive electrocardiological diagnosis, Politechnika Śląska, Zeszyty Naukowe, 1994, No. 1233, Gliwice.

[7] ŁĘSKI J., Robust weighted averaging, IEEE Trans. on Biomedical Engineering, 2002, Vol. 49, No. 8, pp. 796-804.

[8] MICHAELS D.L., TOLE J.R., A microprocessor-based instrument for nystagmus analysis, Proceeding of the IEEE, 1977, Vol. 65, pp. 730-735.

[9] NIEMENLEHTO P.H., Constant false alarm rate detection of saccadic eye movements in electro-oculography, Computer Methods and Programs in Biomedicine, 2009, Vol. 96, pp. 158-171.

[10] PANDER T., CZABAŃSKI R., PRZYBYŁA T., JEŻEWSKI J., POJDA-WILCZEK D., WRÓBEL J., HOROBA K., BERNYŚ M., A New Method of Saccadic Eye Movement Detection for Optokinetic Nystagmus Analysis, EMBS Conference, San Diego 2012, paper accepted.

[11] PASQUARIELLO G., CESARELLI M., ROMANO M., LA GATA A., BIFULCO P., FRATINI A., Waveform type evaluation in congenital nystagmus, Computer Method and Programs in Biomedicine, 2010, Vol. 100, pp. 49-58.

[12] SHETH N.V., DELL'OSSO L.F., LEIGH R.J., VAN DOREN CL., PECKHAM H.P., The effects of afferent stimulation on congenital nystagmus foveation periods, Vision Research, 1995, Vol. 35, pp. 2371-2382.

[13] WANG C., YANG Q., WEI M., SUN W., LI Z., SUN F., Open-loop system of optokinetic nystagmus eye movement in human, IEEE Inter. Conference on Systems, Man and Cybernetics, 2004, pp. 2664-2668.