Determination of the Diagnostic Parameters of an Electronystagmogram Using Signal Filtration in the Time-Frequency Domain and Adaptatively Selected Characteristics

Piotr Augustyniak[1]

[1]Institute of Automatics, University of Mining and Metallurgy,
al. Mickiewicza 30, 30-059 Kraków

ABSTRACT

The present study introduces the application of adaptative signal filtration in the time-frequency domain using reversible wavelet transformations for the determination of the electronystagmogram diagnostic parameters.

A significant improvement in quality of the calculated diagnostic parameters has been achieved, expressed by a simultaneous occurrence of minimum inaccuracies and a minimum number of interpretation errors.

1. INTRODUCTION

As conclusion of comprehensive literature investigations and own expertise accumulated by the author during many years of the electronystagmographic signal analysis (both clinical and laboratory), it has been stated that the signal is highly sensitive to interferences and that those interferences (and the distortions generated during their filtration) markedly influence the quality and accuracy of the diagnostic parameters determined based on the signal. As result of previous investigations it has been demonstrated that filtration of the signal in the frequency domain, hence improving its resistance to interferences -leads to signal distortions - that in consequence ends up with significant inaccuracies in the calculated diagnostic parameters. In one of the previous studies it has also been proposed to separate from the signal its undisturbed fragments (the procedure has been called "identification") [1], and then using them as basis for diagnostic parameters calculation. However processing an unfiltered signal is an advantage of the method, a disadvantage arises, resulting from the impossibility to calculate global parameters such as for example the positions of the cumulated nystagmus phases.

2. IDEA OF SIGNAL FILTRATION IN THE TIME-FREQUENCY DOMAIN

Having remarked that the "identification" process is in fact a kind of time-filtration of the signal, a thesis has been formulated that assumes the possibility of nystagmus diagnostic parameters improvement using signal filtration in the time-frequency domain (Fig. 1) [3]. The verification of this thesis was the main goal of the presented studies and experiments. Signal filtration in the time-frequency domain, with adaptatively selected characteristics created hope for joining the advantages and eliminating the disadvantages of both previously known methods. Confirmation of these hopes required a series of numerical experiments, aiming to investigate the properties of the proposed method of filtration. Preparation of the main part of the experiments required selection of the signal time-frequency filtration and designing an algorithm for the adaptative selection of filtration characteristics. The precedential character of the performed investigations and therefore a complete lack of published guidelines in this field lead to an alternative formulation of solutions to the above problems. In consequence, four alternatives of signal filtration in the time-frequency domain with adaptative characteristic selection were subjected to numerical testing, using different transformations and various detection functions [2], [4], [8], [9], [10]. The preparation work also included setting-up a set of test signals including both model and natural signals. The criterion of signal selection was the susceptibility of the resulting diagnostic parameters to particular types of interferences tested in a given phase of the experiment.

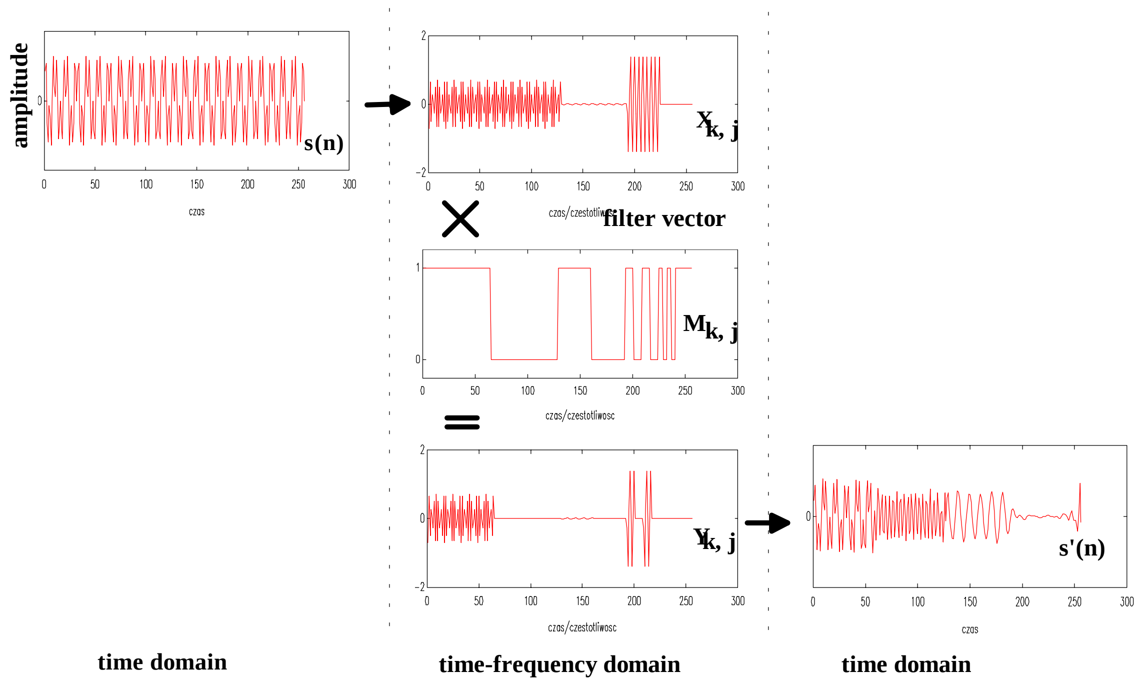

Fig1. Idea of signal filtration in the time-frequency domain

3. PROPORTIONAL SELECTION OF THE FILTRATION CHARACTERISTICS

Proposed off-line method of signal filtration in the time-frequency domain with adaptive characteristics selection consist of two stages:
Automatic signal analysis and computing of filter vector based on the presumptions and general ENG signal knowledge.
Filtration of the signal by modifying its time-frequency representation and with use of the reversible wavelet transform.

filtration of the ENG signal using a proportional detection function is a method of automated construction of the filter vector $M_{k,j}$ (Fig. 1), based on the following remarks and properties of the signal:

- speed of the eyeball motion, which can be calculated based on the ENG signal $s(n)$ as: $v(n) = s(n) - s(n\text{-}1)$. Its values have opposite signs in the slow and fast phases. The sign of the eyeball speed can be a basis for initial separation of the nystagmus phases
- the speed of the eyeball motion calculated based on a real, unfiltered signal cannot be considered as diagnostic parameter because of the presence of high-frequency interferences and noise, but it can successfully be a basis for the modification of filtration characteristic
- the ENG signal should be filtered in a more aggressive way on sections representing the slow nystagmus phase rather than on parts representing the fast phase
- within the roughly determined slow phases of the nystagmus, the filtration characteristic is not modified; in the fast phases sections, the filtration allows passingthrough of high-frequency components in an extent which is proportional to the speed value. It results from the fact that higher speed values in the fast phase indicate the existence of significant high-frequency components. Their passing-through allows to maintain the ENG signal distortions and by the same diagnostic inaccuracies at the minimum level.

Based on the above assumptions an algorithm for proportional selection of filtration characteristics has been proposed and divided into the following stages (Fig. 2):

- Based on the electronystagmographic signal $s(n)$ (Fig. 2a) a detection function $f_d(n)$ is created referring to the commutation of the speed directions in the slow and fast phases. Phase detection and instantaneous eyeball speed calculations are thus performed based on an unfiltered signal
- Then, the speeds corresponding to the detected free phases are canceled, and the speeds corresponding to the fast phases - standardized to the <0...1> range. The such created detection function can have any values from the <0...1> range (Fig. 2c). Therefore it is possible to modify the filtration characteristics proportionally to the angle speed of the eyeball in the fast phase.
- Modification is independent for each of the modified octaves but in a way to perform stronger filtration of the signal within the slow phase than in the fast one. "Within the fast phase" should be understood in this case also as such time sub-ranges of the detection function, in which it reaches non-zero results. Of course the time subranges are additionally modified by the time resolution of the transformation in a given frequency range (an octave). Each of the octaves j has

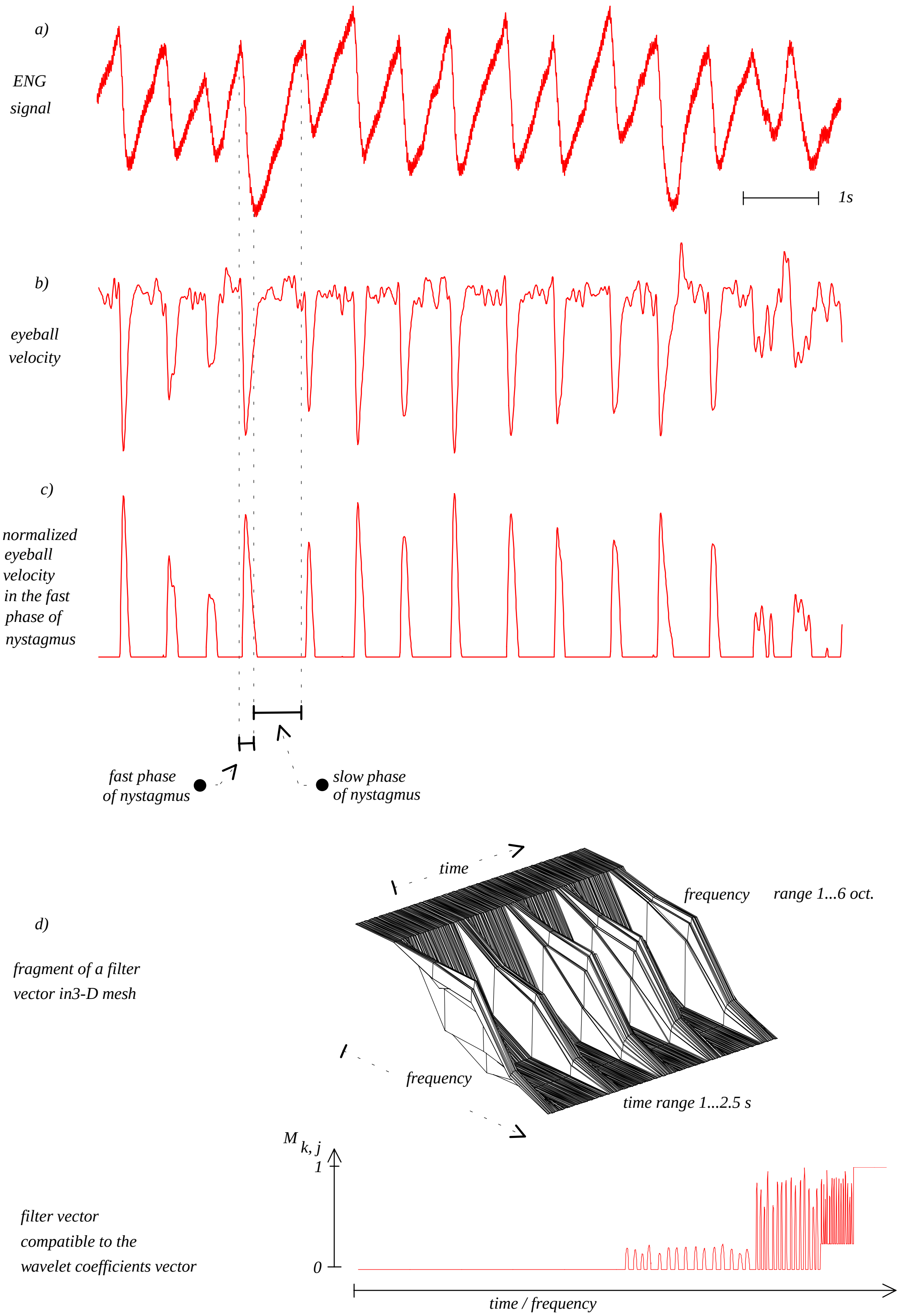

Fig. 2. Scheme of an algorithm for proportional selection of filtration characteristics according to the eyeball velocitity in fast phase of nystagmus

two constant indexes a_j and b_j of values ranging in <0...1>, being proportional modficators of the detection function $f_d(n)$ in this octave during construction of the filter vector $M_{k,j}$ (Fig. 2d) according to the relationship:

$$M_{k,j} = a_j * f_d(n) + b_j \qquad (1)$$

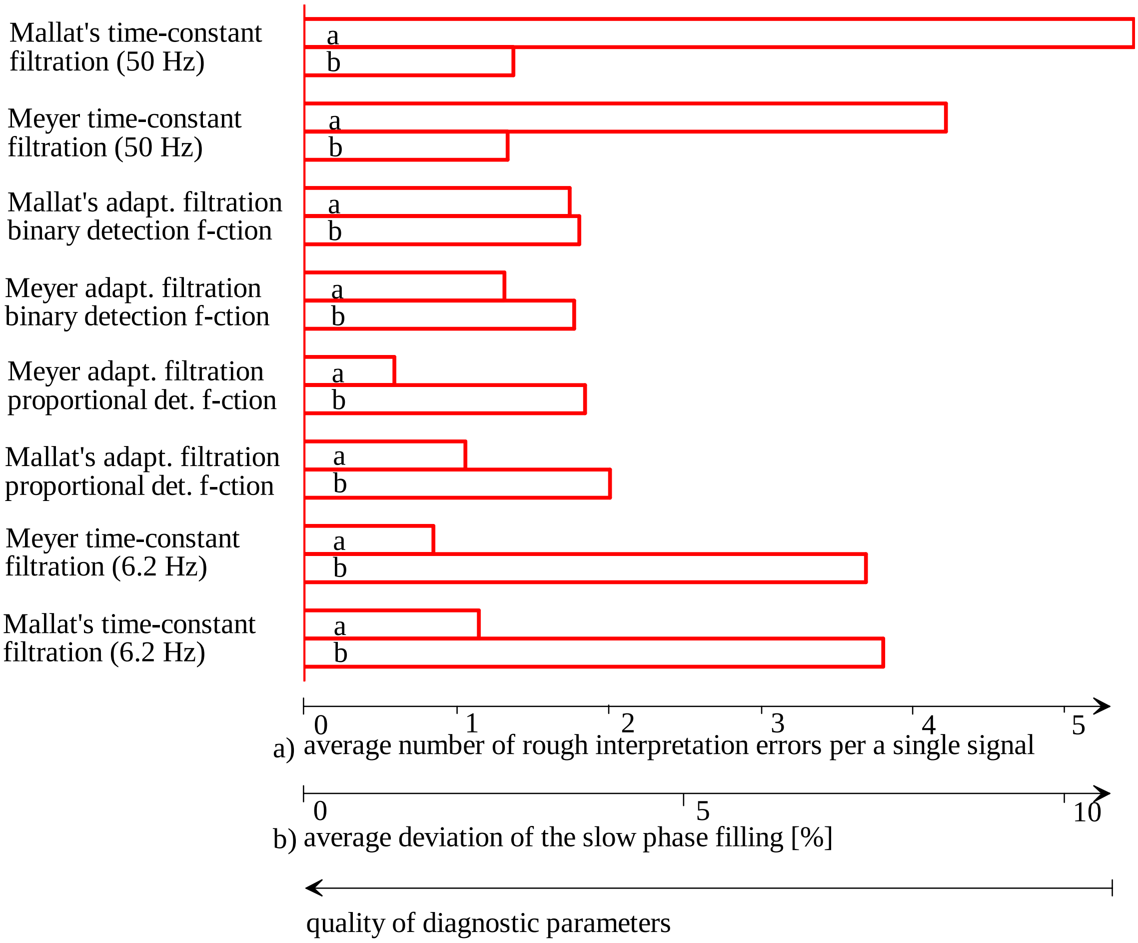

Fig. 3. Graphic interpretation of the quality of electronystagmographic signals calculated for real signals using the described filtration methods. The high quality of the diagnostic parameters is here understood as the smallest deviation of the filling factor of the slow phase along with the lowest possible number of rough interpretation errors.

4. NUMERICAL EXPERIMENTS - COURSE AND RESULTS

The next stage of the work was to perform a series of numerical experiments and he interpretation of obtained results. The interpretation has been done through detailed analysis of the diagnostic parameters (obtained after signal filtration) and through comparing the parameters obtained from the tested frequency-filtration methods with unfiltered signals [5], [6], [7]. In consequence of the obtained results an improvement in quality of the calculated diagnostic parameters has been demonstrated both for model and real signals (Fig. 3).

In addition, the analysis of the numerical experiment results also lead to the determination of directions to follow for the eventual future investigations, aiming to further improve the quality of diagnostic parameters. These are investigations leading to a detailed analysis of influence of the following factors on the diagnostic parameters:

- the time-frequency transformation employed
- the detection function employed
- the employed values of the filter characteristic modificators

Proposing an optimum method for adaptative selection of the time-frequency signal filtration characteristics seems to be the most important current problem. Filtration of the elctronystagmographic signal in the time-frequency domain with adaptative selection of the characteristics is a new and promising method, in the same time a method with still unexploited possibilities. The performed experiments brought a new light on the discussed issue and opened a new field of applications for modern techniques of numerical signal processing in biomedical sciences.

REFERENCES

[1] Arzi M. "Traitement automatique des signaux vwsibulo-oculaires et optocinetiques" These INSA de LYON nr 86ISAL0025 1987

[2] Battle G. "A Block Spin Constuction of Ondelettes - Part I: Lemarie Functions" Commun. Math. Phys. Vol 110 pp. 601-615, 1987.

[3] Bertrand O. Bohorquez J. Pernier J. "Analyse et filtrage de signaux numeriques par transformations en ondelettes discretes" INSERM-U280 LYON 1989.

[4] Combes J. M. Grossman A. Tchamitchian eds. "Wavalets, Time-Frequency Methods And Phase Space" proc of the International Conference Marseille, December 1987, Berlin, Springer Verlag 1988.

[5] Jongkees J. B. W Acta Otolaryng. (Stoc.), 1961, 159

[6] Juhola M., Jantti V., Pyykko I. "Effect of Sampling Frequencies on Computation of the Maximum Velocity of Saccadic Eye Movements" Biological Cybernetics 53, 67-72, 1985.

[7] Latkowski B. "Podstawy elektronystagmografii" PZWL Warszawa 1976.

[8] Mallat S. "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation" IEEE Trans. on Pattern Analysis and Machine Intelligence Vol II, no 7, 1989.

[9] Meyer Y. Jaffard S. Rioul O. "L'analyse par ondelettes" Pour la Science, Paris Sept. 1987, pp 28-37.

[10] Meyer Y. "Ondelettes et operateurs" I: Ondelettes. Editions Herman 1990.