IMPROVE THE QUALITY OF DIAGNOSTIC PARAMETERS OF AN ELECTRONYSTAGMOGRAM USING SIGNAL FILTRATION IN THE TIME-FREQUENCY DOMAIN AND ADAPTATIVELY ADJUSTED CHARACTERISTICS*

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ABSTRACT

The present study introduces the application of adaptative signal filtration in the time-frequency domain for the determination of the ENG (electronystagmogram) diagnostic parameters. In common used methods, the imprecision in phases delimitation - caused by constant-characteristics signal filtration - is the main source of inaccuracies in diagnostics parameters. Since the signal is very fragile and the acquisition conditions are not stable in time, the need of adaptive filtration seems to be evident. The use of reversible wavelet transform of ENG signal makes possible to modify each "atom" of signal independently. 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 authors during many years of the electronystagmographic (ENG) signal analysis (both clinical and laboratory), it has been stated that the signal is highly sensitive, particulary to the "physiological" interferences (like oculomotoric and eyelid muscle activity etc.). Those interferences (and the distortions caused during their filtration) markedly influence the nystagmus-phases separation and thus 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 attenuating the 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 been also 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 was an advantage of that method, a disadvantage arises, resulting from the impossibility to calculate global parameters such as for example the positions of the cumulated nystagmus phases.

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

Having remarked that the "identification" process is in fact a kind of time-domain 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) [2]. Adaptative modification of the time-frequency signal representation (accordingly to the local signal properties) 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 adjustment 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 T-F transformations and various detection functions [3], [4]. The preparation work also included setting-up a set of test signals including both model and natural signals.

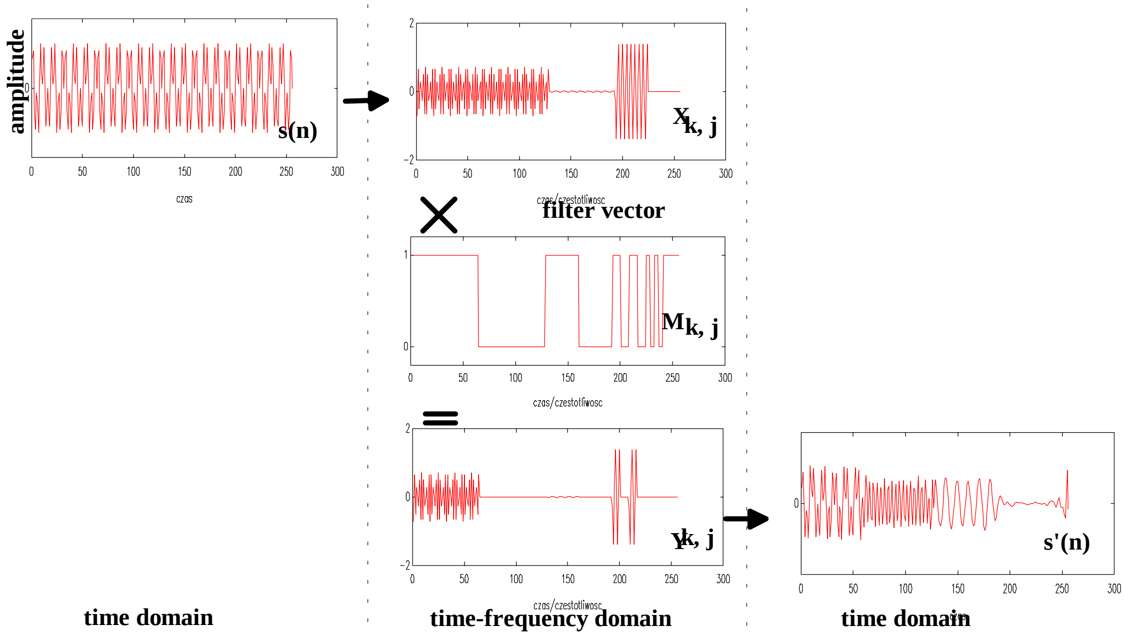

Fig1. Idea of signal filtration in the time-frequency domain

3. PROPORTIONAL ADJUSTMENT OF THE FILTRATION CHARACTERISTICS

Proposed off-line method of signal filtration in the time-frequency domain with adaptive adjusted characteristics consist of two stages:

- Automatic signal analysis and computing of filter vector based on the presumptions and general knowledge about the ENG signal.
- Filtration of the signal by modifying its time-frequency representation and with use of the reversible wavelet transform.

The filter vector, used to modify the time-frequency representation of ENG signa,l is computed as result of preliminary automatic signal analysis, accordingly to the local properties of the signal:

- During the slow phases of nystagmus the signal is more sensitive to interferences than in the fast phases. The main source of rough interpretation errors are the false positive detections of slow-to-fast phase transients. So 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.
- The values of speed of the eyeball motion 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 be successfully a basis for the modifications of filtration characteristic.
- Within the roughly determined slow phases of the nystagmus, the filtration characteristic is not modified - it cancels out all high-frequency components to avoid the false positive detections of slow-to-fast phase transients.
- 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):

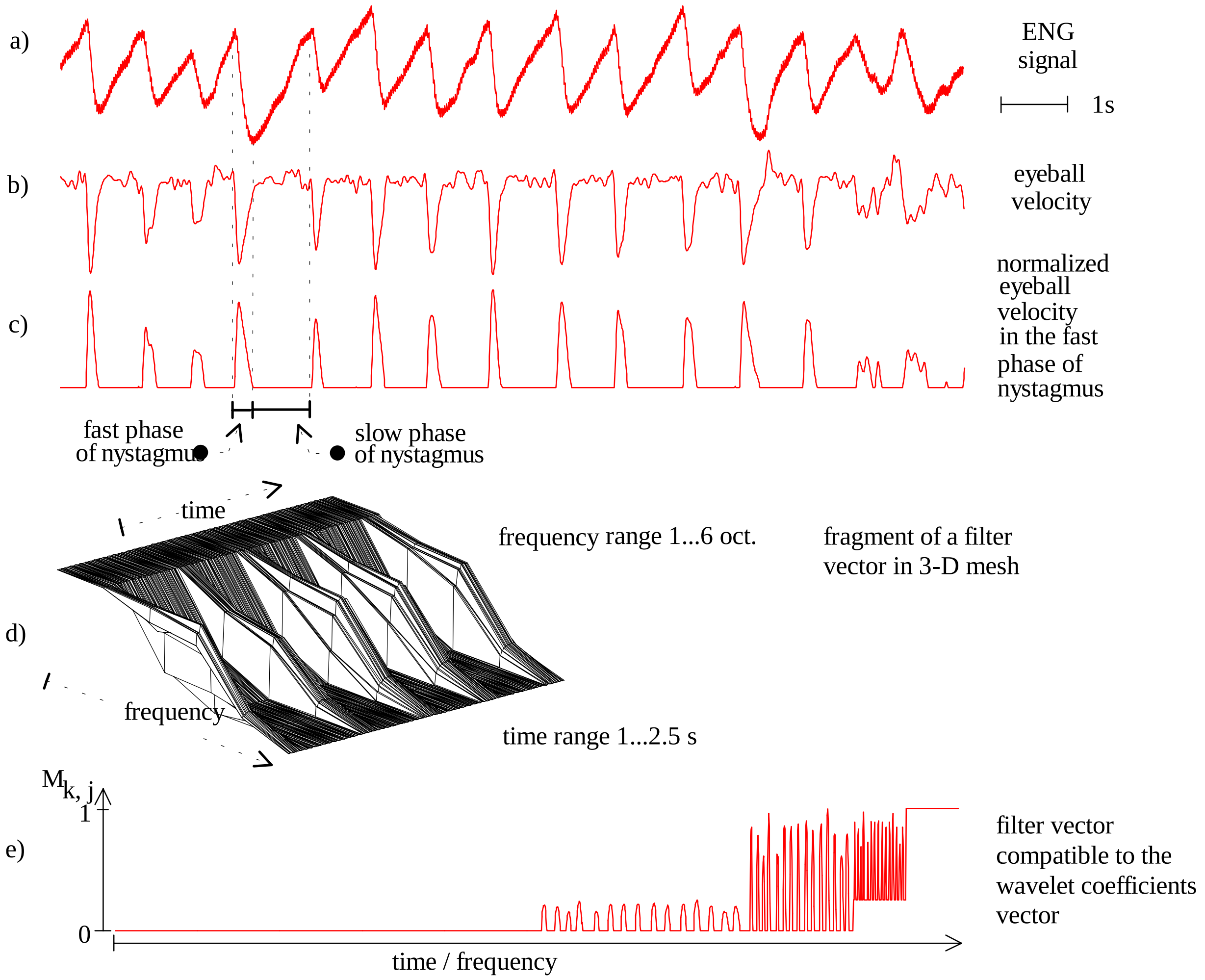

Fig. 2. Scheme of an algorithm for proportional adjustment of filtration characteristics according to the eyeball velocity in fast phase of nystagmus

- Based on the electronystagmographic signal $s(n)$ (Fig. 2a) a detection function $f_d(n)$ is created referring to the sign of the eyeball speed $v(n)$ directions in the slow and fast phases. Phase detection and instantaneous eyeball speed calculations (Fig. 2b) are thus performed based on an unfiltered signal.

$$v(n) = s(n) - s(n-1)$$

- Then, the speeds corresponding to the detected slow 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 by simple multiplication.
- 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 as such time sub-ranges of the detection function, in which it reaches non-zero results and with regards to the time resolution of the T-F transform in a given frequency range.
- For each of the octaves j (j = 2, 3, 4) two constant indexes a_j and b_j of values ranging in <0...1> have been assigned. They are proportional modficators of the detection function $f_d(n)$ in octave j during construction of the filter vector $M_{k,j}(n)$ according to the relationship (Fig. 2d, e):

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

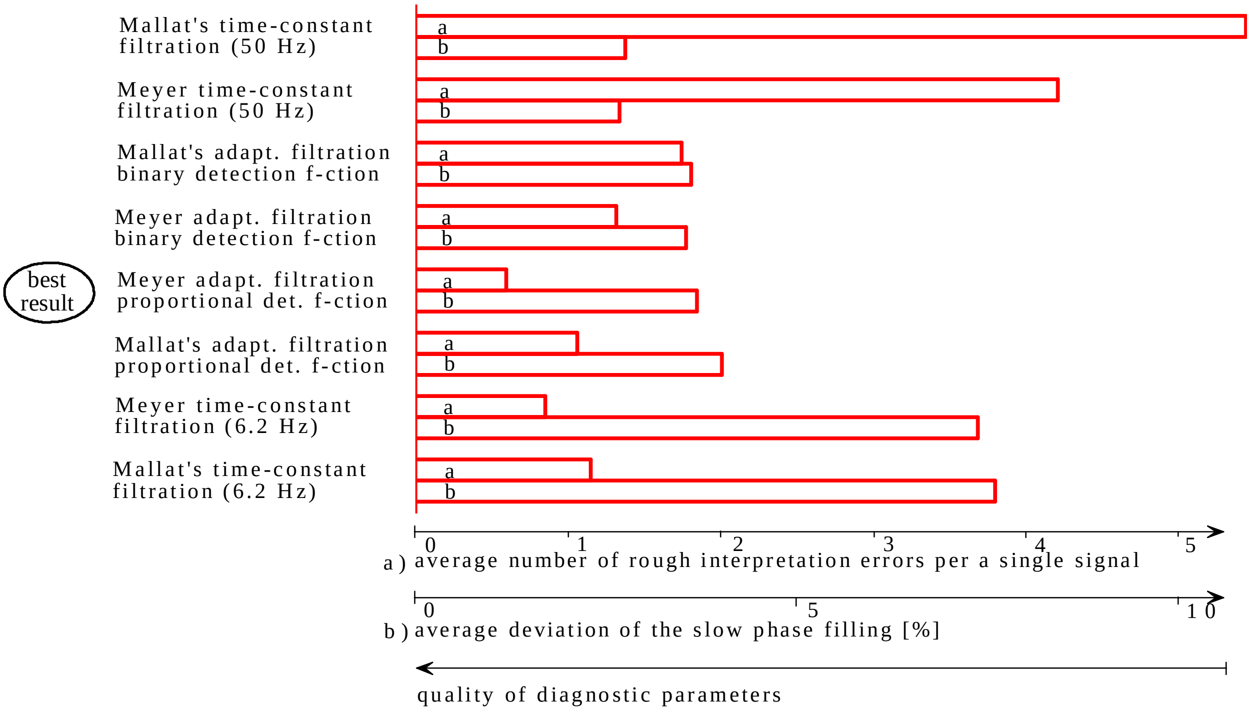

Fig. 3. Graphic interpretation of the quality of electronystagmographic signals calculated for real signals using the described filtration methods. The high quality of the diagnostic parameters is here understood as the smallest deviation of the filling factor of the slow phase along with the lowest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

4. NUMERICAL EXPERIMENTS - COURSE AND RESULTS

Presented approach was verified by a series of numerical experiments. Obtained results was interpreted through detailed analysis of the diagnostic parameters (obtained after signal filtration) and through comparing the parameters obtained from the tested T-F-filtration methods with those based on frequency- filtered and unfiltered signals. Since the inaccuracies of diagnostic parameters are mainly caused by imprecise separation of nystagmus phases, in order to compare the filtered and unfiltered signals we defined meta-parameter called: **slow phase filling factor** representing all the clinically used diagnostics parameters of ENG. 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).

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. Proposing an optimum method for adaptative adjustment of the time-frequency signal filtration characteristics seems to be the most important current problem. Filtration of the electronystagmographic signal in the time-frequency domain with adaptative adjustment 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.

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