ADVANCED METHOD OF NYSTAGMUS-PHASE SEPARATION USING ADAPTIVE MODIFICATION OF TIME-FREQUENCY SIGNAL REPRESENTATION

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ABSTRACT

The present paper introduces an advanced method of adaptative signal filtration in the time-frequency domain using reversible wavelet transformations for the precise delimitation of the nystagmus quick and slow phases in an electronystagmogram. In widely used automated ENG systems, the imprecision in phases delimitation - caused by constant-characteristics signal filtration - is the main source of inaccuracies in diagnostics parameters. The adaptive modification of filtration characteristics allows to cut-out the highest frequency components only when necessary, that means accordingly to the local signal properties. The use of reversible wavelet transform of ENG signal makes possible to modify each "atom" of signal independently.
A significant improvement in phases separation has been achieved both for model and real signals.

1. INTRODUCTION

The electronystagmographic signal is highly sensitive to interferences of different nature: technical (i. e. noise, electrodes contact etc.) and physiological (i. e. oculomotoric and eyelid muscle activity etc.). The so-called physiological interferences are particulary difficult to avoid since their souce is out of control and often unknown. In common used automated ENG systems the interferences and the distortions generated during their low-pass filtration markedly influence the quality and accuracy of the diagnostic parameters determined based on the signal. In absence of high frequency components on the nystagmus-phases transients they loose the sharpness, slow phase becomes shorter and quick phase becomes longer than in unfiltered signal. In early 90-ties the alternative method was developped, based on preliminary separation from the signal its undisturbed fragments (the procedure has been called "identification"), and then calculation of ENG diagnostic parameters on the unfiltered fragments. However processing an unfiltered signal is an advantage of the method, a disadvantage arises, resulting from the impossibility to calculate some global parameters of high clinical importance (i.e. the positions of the cumulated nystagmus phases).

By adaptive modification of the time-frequency signal representation we expected to joining the advantages and eliminating the disadvantages of both previously known methods.

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2. MATERIAL AND 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:

- choice of reversible wavelet transform - discrete Meyer's C^∞ base [1] and Mallat's B-spline based pyramidal decomposition [2] were used, but are not the only possible.
- selection of the time-frequency filtration - it concerns only the 2, 3 and 4 octave (6.3 ... 50 Hz frequency range).
- developping an algorithm for the adaptative selection of filtration characteristics - the filtration depends on detection functions, both: binary and proportional (analogue) functions were used.
- setting-up a set of test signals including both model and natural signals (total: 74 signals).

Four alternatives of signal filtration in the time-frequency domain with adaptative characteristic adjustment were subjected to numerical testing, using different T-F transformations and various detection functions. All parts of experiment including wavelet transforms and ENG diagnostic parameters computation procedures were implemented in Matlab®. The most efficient method is detailly described hereafter.

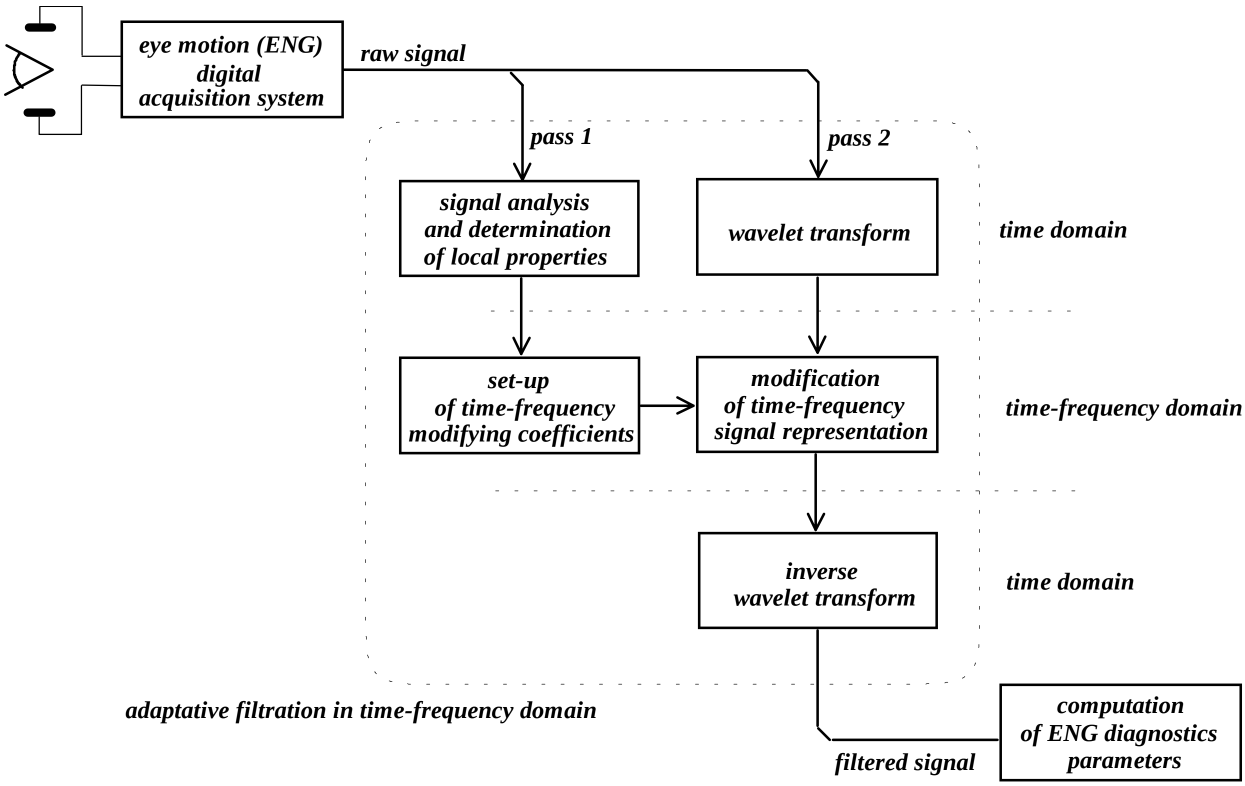

Fig. 1. Diagram of ENG signal processing using adaptative filtration in time-frequency domain

3. PROPORTIONAL ADJUSTMENT OF THE FILTRATION CHARACTERISTICS

Proposed off-line method of adaptative modification of the time-frequency signal represen- tation consist of two passes:

- **pass 1**: Automatic signal analysis and computing of time-frequency modification coefficients based on the presumptions and general ENG signal knowledge.
- **pass 2**: Filtration of the signal by modifying its time-frequency representation obtained with use of the reversible wavelet transform.

The coefficients modifying the time-frequency representation of ENG signal are computed as result of preliminary automatic signal analysis, accordingly to the local properties of the signal. The proposed algorithm for proportional adjustment of filtration characteristics proceeds as follows:

- In the slow phases of nystagmus the signal is more sensitive to interferences than in the fast phases. Since the main source of rough interpretation errors are the false positive detections of slow-to-fast phase transients, the ENG signal should be filtered in a more aggressive way on parts representing the slow nystagmus phase rather than on parts representing the fast phase.
- The speed of the eyeball motion can be calculated based on the ENG signal $s(n)$ (Fig. 2a) 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 (Fig. 2b), but it can successfully be a basis for the modification of the time-frequency signal representation. The speed corresponding to the fast phases is then standardized to the <0...1> range. Since the such created detection function can have any values from the <0...1> range (Fig. 2c) , it is possible to modify the filtration characteristics proportionally to the angle speed of the eyeball in the fast phase.

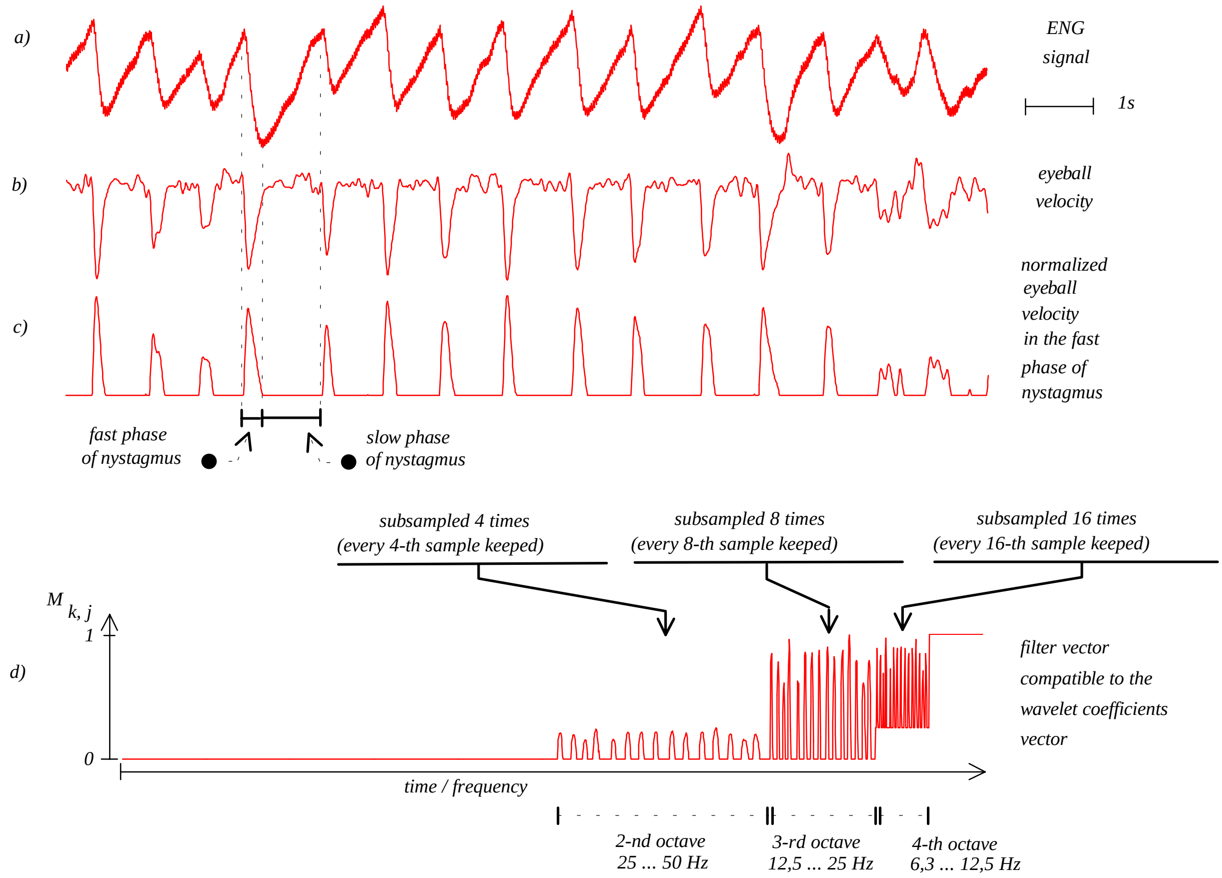

Fig. 2. Details of an algorithm for proportional adjustment of filtration characteristics according to the eyeball velocitity in fast phase of nystagmus. An original human post-caloric nystagmus signal is presented as an exemple.

- in the roughly determined slow phases of the nystagmus, the time-frequency signal representation is cancelled out (replaced by zeros) in octaves 1, 2, 3 and 4 (6.3 ... 100 Hz), while in the fast phases sections, the time-frequency signal representation is multipied by corresponding modification coefficients in octaves 2, 3 and 4 (6.3 ... 50 Hz) and cancelled out in the highest (first) octave. Each of the octaves j (j=2, 3, 4) has 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:

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

Of course the time subranges (fast and slow phases) are additionally modified by the time resolution of the transformation in a given frequency range (an octave).

That 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.

4. 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 frequency-filtration methods with unfiltered signals.. Since (as mentioned above) the inaccuracies of

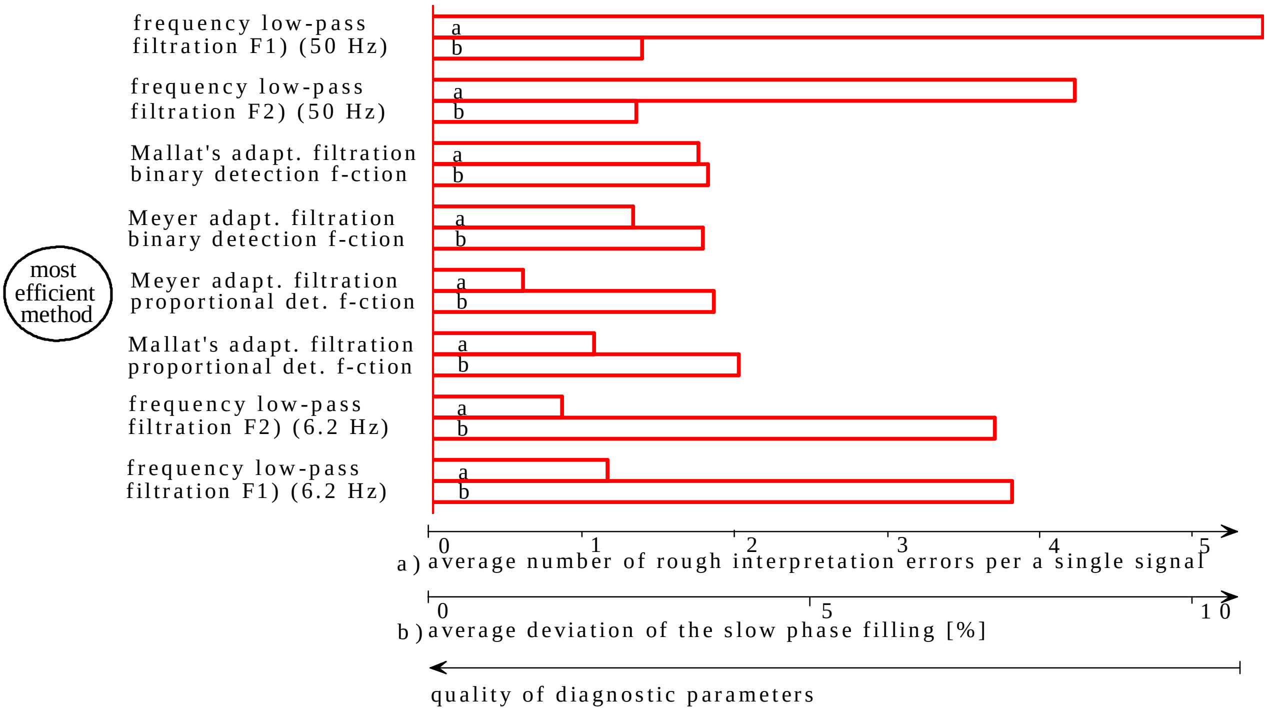

Fig. 3. Graphic interpretation of the quality of electronystagmographic signals calculated for real signals using the described filtration methods. The high quality of the diagnostic parameters is here understood as the smallest deviation of the filling factor of the slow phase along with the lowest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

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). 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.

Proposing an optimum method for adaptative selection of the time-frequency signal filtration characteristics seems to be the most important current problem.

Adaptative filtration of the electronystagmographic signal in the time-frequency domain 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 the obtained results may be interesting for a future applications of numerical signal processing in biomedical sciences.

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