An Improved Method of Nystagmus Segmentation Using Adaptive Modification of Time-Frequency Signal Representation*

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ABSTRACT

The present work describes an application of adaptative signal filtration in the time-scale domain using a pair of reversible wavelet transformations to the precise delimitation of the nystagmus quick and slow phases in an electronystagmogram. In common used methods the main source of inaccuracies in diagnostics parameters is the imprecision in phases delimitation (nystagmus segmentation) caused by an aggresive low-pass signal filtering. Since the signal is very fragile (typically 5mV/deg) and the acquisition environnement is not stable in time, the need of adaptive filtration appears. The use of reversible wavelet transform of ENG signal, being limited only by uncertainty relation, guarantees the highest possible precision. An improvement in quality of the calculated diagnostic parameters is expressed by a simultaneous occurrence of minimum inaccuracies and a minimum number of interpretation errors.

1. INTRODUCTION

The electronystagmographic (ENG) 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 second group of interferences are particulary difficult to avoid since their souce is often unknown and not controllable for the medical staff. The common used solutions base on constant-characteristics signal filtering, so depending on the applied filters, the interferences (when the cut-off frequency is too high) or the distortions (when the cut-off frequency is too low) markedly influence the precision of nystagmus segmentation and in consequence the quality and accuracy of the diagnostic parameters determined automaticaly. In one of the previous studies we proposed to separate from the signal its undisturbed fragments and then use them as basis for diagnostic parameters calculation, but impossibility to calculate global parameters such as for example the positions of the cumulated nystagmus phases was a disadvantage of that method [1].

By adaptive modification of the time-frequency signal representation it comes possible to cut out the high frequency components only when it is necessary, that means accordingly to the local signal properties defined as a function of time (detection function).

2. DETAILS ON ADJUSTMENT OF THE FILTRATION CHARACTERISTICS

Proposed off-line algorithm of adaptative modification of the time-frequency signal representation consist of two passes:

- Automatic signal analysis and computing of the detection function reflecting the local signal properties (based on general knowledge about the ENG signal) and determining the degree to which the signal

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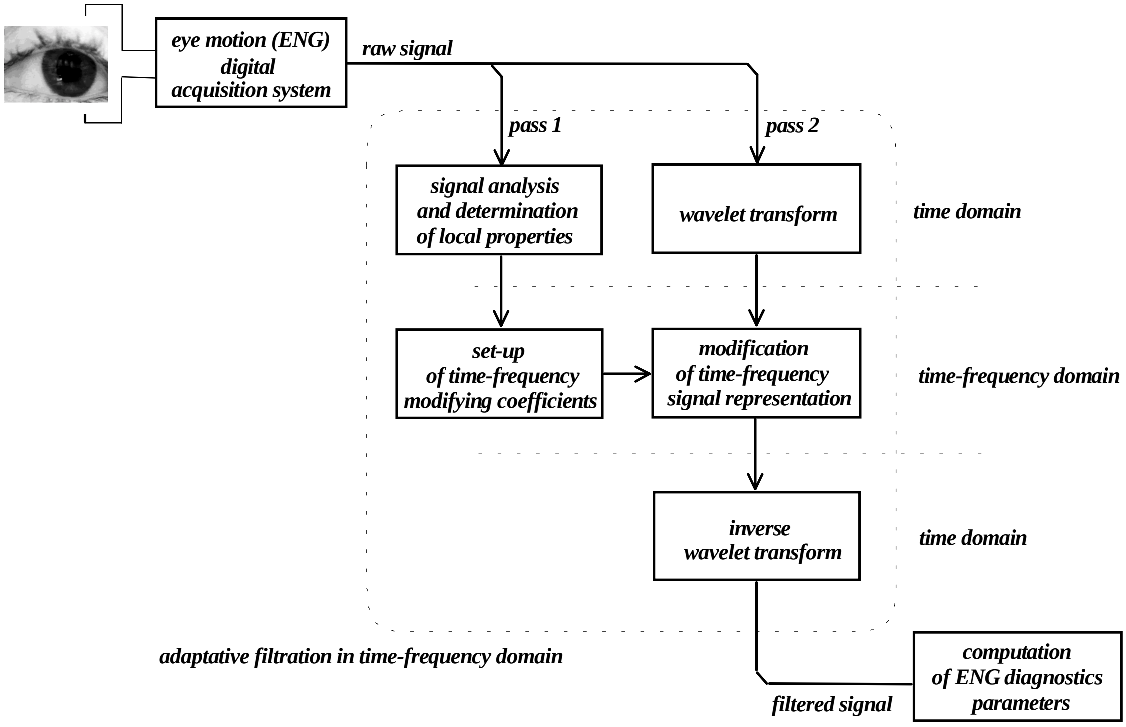

Fig. 1. Diagram of ENG signal processing using adaptative filtration in time-frequency domain

needs to be low-pass filtered. Next the time-frequency modification coefficients vector is obtained by subsampling of the detection function accordingly to the modified frequency ranges (octaves).

- 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 bases on following observations:

- 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 and slow phases duration fill out 70-80% of signal length increasing the interferencing events probability, 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.
- On the other hand, the main source of inaccurate nystagmus segmentation is the smoothness of signal caused by its aggresive low-pass filtering, in effect the slow phase becomes shorter and the fast phase becomes longer than in original signal. In order to guarantee the maximum precision of nystagmus segmentation the sharpness of the fast phases should be keeped, so the low-pass filtration should be avoided.

A computation procedure based on the assumptions mentioned above using the speed of eyeball motion to coarse detection of slow and fast nystagmus phases looks fairly simple:

- The speed of the eyeball motion calculated based on a real, unfiltered signal $s(n)$ as: $v(n) = s(n) - s(n-1)$ is a basis for the modification of the time-frequency signal representation. The speed corresponding to the fast phases is standardized to the <0...1> range. In fact the computed detection function can have any values from the

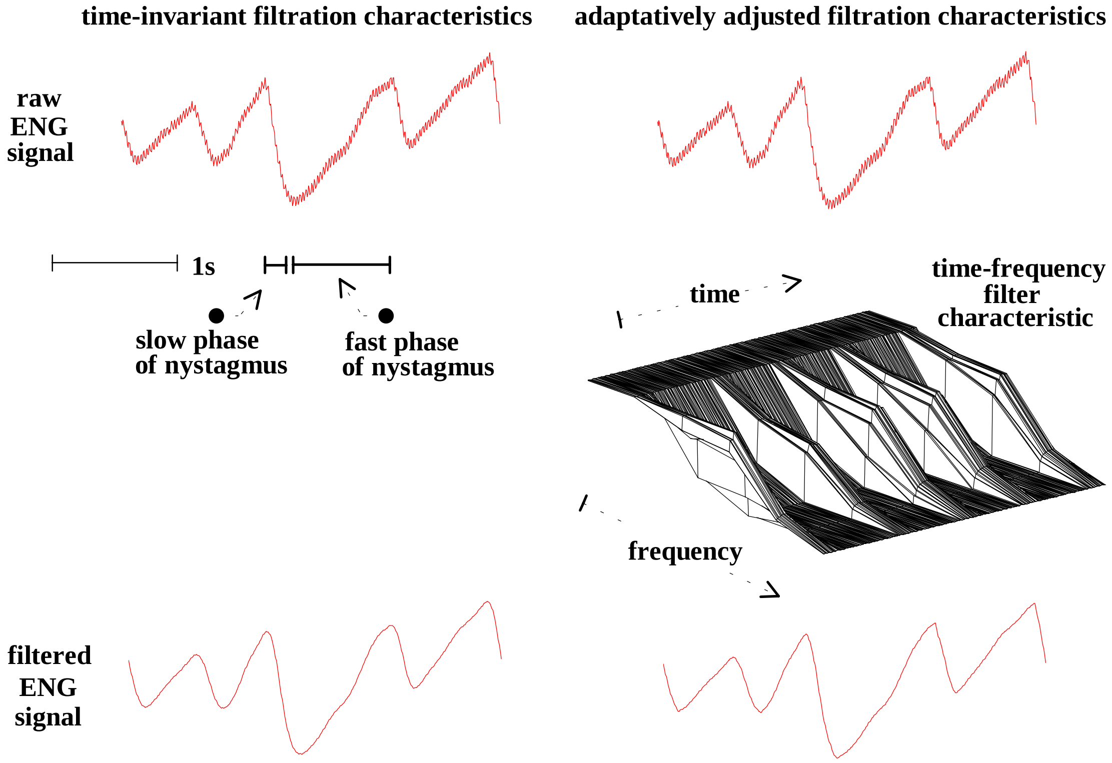

Fig. 2. Comparison of ENG signal filtration with use of time-invariant characteristics (left half) and adaptatively adjusted characteristics (right half). Exemple: 2.5sec of human postcaloric nystagmus.

<0...1> range, so the modification of the filtration characteristics proportionally to the angle speed of the eyeball in the fast phase is possible by simple multiplication.

- Next the detection function is subsampled and modified. It is cancelled out in the highest (first) octave, modified with use of two constant indexes a_j and b_j of values ranging in <0...1> (Tab. 1) in each of the octaves j (j=2, 3, 4) according to the relationship:

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

and finally forced to ones in the lowest frequency ranges including DC. The adaptative characteristics modification is applied only to the frequencies in octaves 2, 3 and 4 (6.3 ... 50 Hz). 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) (Fig. 2).

Tab. 1 Constant index values for octaves 1...5

octave j	frequency range [Hz]	time range [ms]	a_j	b_j
1.	50...100	14.14	0	0
2.	25...50	28.28	0.25	0
3.	12.5...25	56.57	1	0
4.	6.25...12.5	113.1	0.75	0.25
5.	3.12...6.25	226.3	0	1

3. NUMERICAL EXPERIMENTS - COURSE AND RESULTS

Presented approach was verified by a series of numerical experiments. Several alternatives were subjected to numerical testing, using different transformations and various detection functions [2], [3], [5], [6]. During the tests both model and natural signals were used as well.

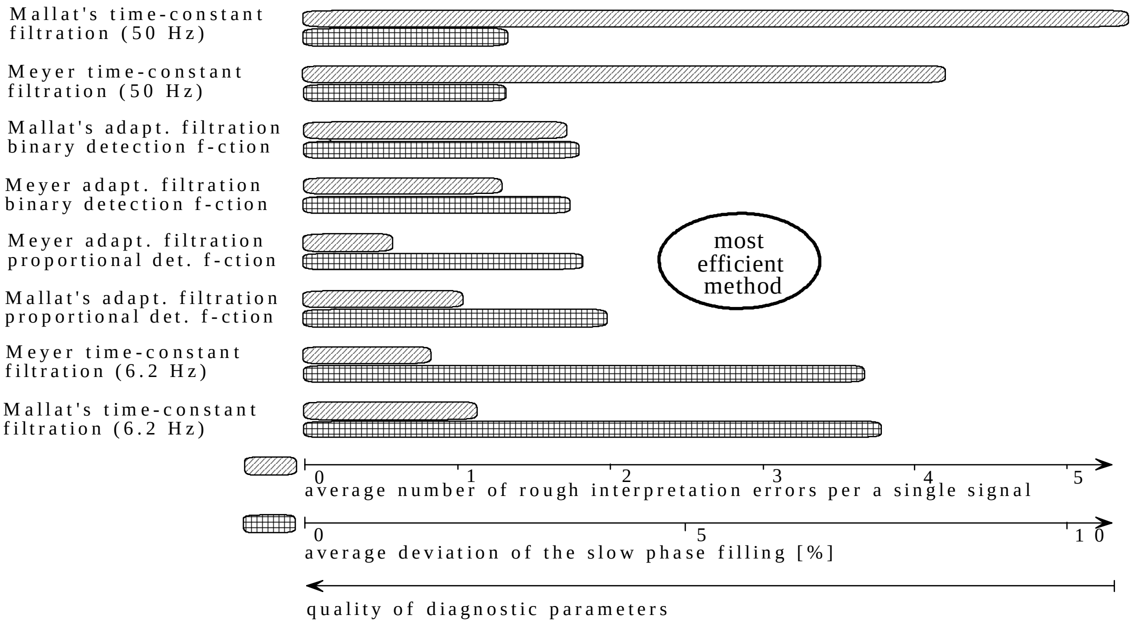

Fig. 3. Graphic interpretation of the quality of electronystagmographic parameters calculated for real signals using various filtration methods. The high quality of the diagnostic parameters is here understood as the smallest deviation of the slow phase filling factor along with the lowest possible number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

In order to compare the filtered and unfiltered signals a meta-parameter called: **slow phase filling factor** has been defined, representing the nystagmus segmentation accuracy and thus the quality of all clinnically used diagnostics ENG parameters. In consequence of the obtained results an improvement in precision of nystagmus segmentation - thanks to adaptative filtration allowing passingthrough of high-frequency components in an extent which is proportional to the speed value - has been demonstrated both for model and real signals (Fig. 3). Obtained results was additionally 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 [4].

The presented approach of filtering fitted to user-defined local signal properties can be interesting as well for other biomedical signals acquired in an unstable environement. The use of reversible wavelet transform guarantees the optimum precision and independant acces to any signal component.

REFERENCES

[1] Arzi M. "Traitement automatique des signaux vestibulo-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] 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.
[5] Mallat S. "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation" IEEE Trans. on Pattern Analysis and Machine Intelligence Vol II, no 7, 1989.
[6] Meyer Y. "Ondelettes et operateurs" I: Ondelettes. Editions Herman 1990.