# Multiband decomposition of EEG signals

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**Abstract – A method of the distortions evaluation of a digital filtering process is presented in this paper. As an example of an application of the method, an evaluation of the distortions introduced by IIR and FIR digital filtering of the EEG signal is examined.**

## I. INTRODUCTION

An EEG signal is a multichannel electrical signal, which is a recording of brain's bioelectrical activity. Analysis of this signal is a popular method for non-invasive medical diagnosis and therapy. As far, many methods of analysis and classification of the EEG signals have been developed. These methods are based on direct observations of the EEG waves in time domain as well as on observations of a different representations of the EEG signals [1]. In many cases, before the main analysis is perform, it is purposeful to divide the signal to some characteristic bands: delta (0.3-3Hz), theta (4-7Hz), alpha (8-13Hz), beta(14-30Hz) [2], which are connected with the physiological brain activity. This division can be performed using different methods [2][3], but because of the popularity of direct time domain EEG signal observations, FIR and IIR filters are often used [2]. These kinds of filters are also widely used at the preprocessing stage to limit the signal frequency range to desired band (for example: 0.3-30 Hz) [3]. Software which can perform described filtering is offered by many producers of an EEG analysis and biofeedback equipment. In direct analysis of the EEG waves, the distortions introduced by the filters used, should not change the shape of the waves significantly. It is important, because the diagnosis is based on the analysis of the wave shape (for example: location and magnitude of spikes, characteristic frequencies). The following paragraphs present comparison of the selected digital filters from a perspective of distortions introduced to EEG signal by the filtering process. As a measure of distortions an RMS norm was used.

## II. THE PROCEDURE OF DISTORTIONS EVALUATION

The distortions evaluation procedure is briefly presented in fig.1. Discrete testing signal denoted as *x(n)* is filtered simultaneously in a reference filter *H* and the tested filter *G*. As a result of these filtrations two signals are obtained: the reference signal $y_0(n)$ and the filtered testing signal *y(n)*. In the next step these two signals are used to evaluate the distortion measure *D*. The following types of digital filters were chosen for evaluation:

- FIR linear phase filters,
- elliptic (Cauer) IIR filters,
- Butterworth IIR filters.

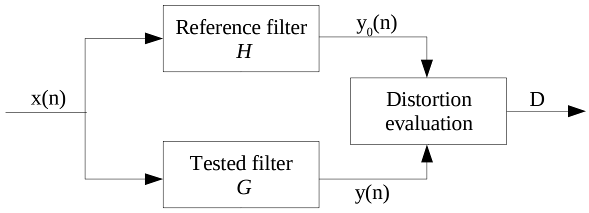


Fig.1. The method of filtration distortions evaluation.

It is not possible to implement an ideal filter [4] (an ideal filter is a filter with unitary gain in the passband and gain equal zero in the stopband and doesn't introduce any phase distortions to the signal), which could be used as a reference filter *H*. To obtain the reference signal $y_0(n)$ it was decided to use the zero-phase filtering technique described in [5] and the same filter for testing and reference channel (*H*=*G*). These technique is based on filtering the signal in both the forward and reverse direction. Because the second filtration is done in the reverse order, the phase distortions introduced by the first filtration are cancelled. Using these method it is possible to obtain a reference signal $y_0(n)$ free of phase distortions and limited to the band characteristic of the *G* filter. The side effect of this process is that (because of the double filtration) the effective filtration order is two times bigger then the filter order. To level the filtration order for both signals: $y_o(n)$ and *y(n)*, the *y(n)* signal is also filtered twice but without reversing it. Both filtering paths are presented in fig.2.

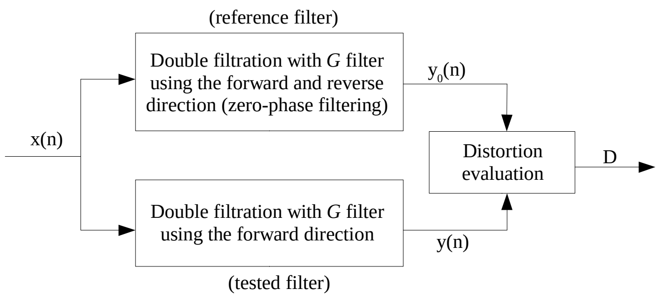


Fig.2. A block diagram of distortion evaluation process.

If the signals: $y_0(n)$ and *y(n)* are obtained using the procedure from fig.2, the difference between these two signals will be connected with phase distortions introduced by the *G* filter. Taking this as a basis, an RMS distortions measure can be proposed:

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$$D=\frac{\sqrt{\frac{\sum_{i=1}^{n}[y(i)-y_0(i)]^2}{n}}}{\sqrt{\frac{\sum_{i=1}^{n}[y_0(i)]^2}{n}}}=\sqrt{\frac{\sum_{i=1}^{n}[y(i)-y_0(i)]^2}{\sum_{i=1}^{n}[y_0(i)]^2}}\,. \qquad (1)$$

RMS distortion measure $D$ defined by the equation (1) is equal zero when signals $y_0(n)$ and $y(n)$ are the same and is the bigger when the difference between $y_0(n)$ and $y(n)$ is bigger. It is important to notice that, additionally to the phase distortions, measure $D$ depends on the dynamical distortions introduced by the tested filter. Influence of this kind of distortions can be evaluated, using as a test signals stationery as well as the nonstationery signals and comparing the results for both signal types.

## V. Example distortion analysis

To illustrate the presented method, an evaluation of beta band filter (14-30Hz) was performed. In the evaluation process five test signals were used. Brief description of these signals is shown in table I.

Table I
THE CHARACTERISTIC OF TESTING SIGNALS

| | |
|---|---|
| **per1** | Unipolar square wave: base frequency=0.2 Hz, amplitude=1, duration=100 s. |
| **x1** | EEG signal from electrode Fz: duration=125 s. |
| **x2** | EEG signal from electrode Cz: duration=125 s. |
| **x3** | EEG signal from electrode Pz: duration=125 s. |
| **per2** | Periodic wave constructed from a slice of x1 signal: base frequency=0.2 Hz. |
| Sampling frequency for all signals is the same and equal 200 Hz. | |

To make possible the evaluation of dynamical distortions introduced by the filter both: the stationery (per1, per2) and nonstationery signals (x1, x2, x3) were used. The latter are real EEG signals of a healthy man. A slice of x1 EEG signal is shown in fig.3.

x1

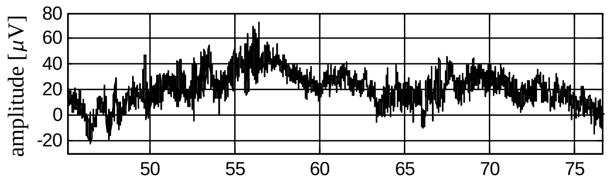


Fig.3. A slice of the x1 testing signal.

Distortions measures $D$ evaluated for each testing signal from table I are presented in fig.4. Relation between measure $D$ and filtration order for Butterworth and elliptic filters is similar. Their values are starting from 1,00 for the filtering order 4 and increasing to 1,45-1,50 for the filtering order 12. For higher filtering orders, measure $D$ for these filters is practically constant. For FIR filters the RMS distortion measure $D$ seems to be constant and independent of the filtering order keeping its value at 1,45.

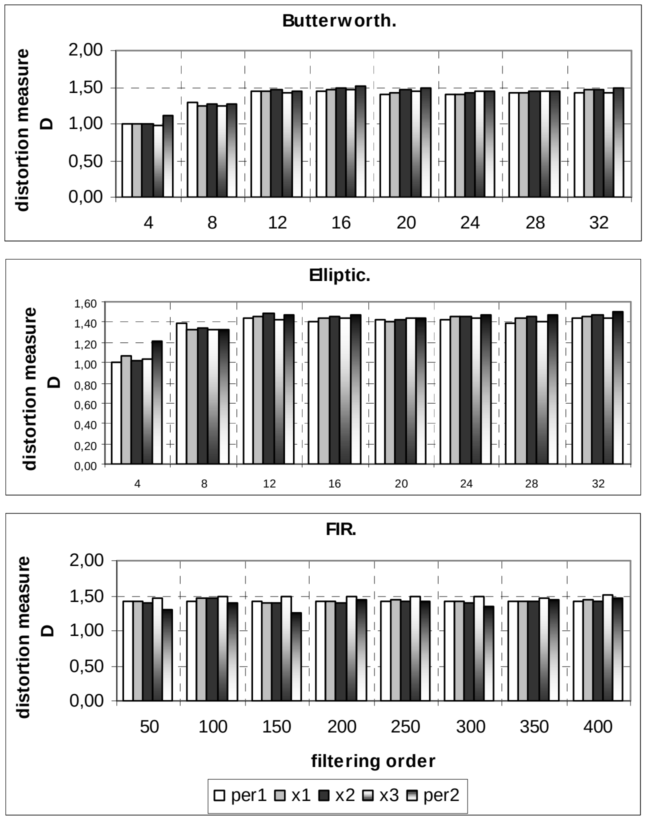


Fig.4. Distortion measure $D$ for the testing signals. Filtering order is two times bigger than the filter order.

Considering the dynamical distortions can be noticed, that distortions measure $D$ is similar for stationery (per1, per2) and nonstationery (x1, x2, x3) signals.

## VI. Summary

Performed distortion analysis showed, that it is possible to asses and compare distortions introduced by different filter types in the meaning of measure $D$. For tested IIR filters measure $D$ was monotonically increasing along with the filtering order and for FIR filters it was constant and independent of the filtration order.

## Literature


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