Determination of primary features of ABR signals in intelligent system aiding the auditory system diagnosis

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Abstract: - The paper presented below contains description of a research study concerning an automated system for objective diagnosis of the human auditory system. In the paper selected aspects have been presented, concerning the detection of characteristic features of ABR signals. Attention has been particularly focused on the detection of those signal parameters, which are most important for the auditory system diagnosis. The paper contains a detailed description of the preliminary processing of ABR signals, as well as the determination of waves I, III and V and their respective latency periods. The presented work should be treated as the first stage in the process of construction of a fully automated, thus objective, system for aiding the diagnostic process, performed by the [medical] staff of audiological institutions.

Key-Words: - ABR Signals, Biomedical Engineering, Human-Machine Systems, Signal Processing

1. Introduction

The auditory brainstem response (ABR) signals are electrical signals of brain activity (EEG), which are generated as a response to an acoustic stimulus. At present they are the basis for the most objective methods of studying the human auditory abilities. The methods is applied particularly in the cases, when the application of classical audiometric methods is difficult or impossible, as the examinations of infants and young children.

Time dependence of a typical ABR signal contains five up to seven waves, denoted by roman numbers I to VII, registered within 10 ms from the occurrence of the acoustic stimulus. In the clinical evaluation of the ABR signals many various parameters, mainly related to the wave V, are taken into account, e.g. the latency period of wave V, the I-IV time distance, absence of some waves, particularly wave V, the amplitude ratio of wave V and wave I [3].

Diagnosis of hearing damages, using the registration of the ABR signals, is based on the analysis of the recording morphology and latency periods of particular waves. The second criterion seems to be much more convenient for formulation as a set of simple rules, which provide a way to check whether a given recording can be classified as a regular one. At present it has been accepted, that the latency periods of particular waves should be contained within the limits, determined in the tests of large number of people with normal hearing abilities. However the determination of the above mentioned limits, with the nonzero probability of error occurrence, requires measurements for large number of samples, what in turn calls for automation of the process of maxima determination in the ABR signals (Fig.1). Because of the considerable individual variety, high level of low-frequency noise and the occurrence of muscular artifacts, the task of latency period determination (localization of the maximum in the ABR recording) for a given wave becomes complicated, particularly for the small amplitudes of the activating signal (< 50 dB). For these cases it is very easy to take a noise bump or an accidental artefact for a real wave and vice versa. Up to date no characteristic features have been defined, which would allow, as for the ECG case, a precise localization of the parameters of particular waves. The scheme proposed below is an attempt of automation for the process of latency period determination for particular waves and it is a results of a heuristic treatment, based on the analysis of large number of samples.

A typical recording of the ABR signal is presented in Fig.1. The recording has been obtained by ABR signal registration from a person with absence of any hearing irregularities. Thus it can be treated as a standard electrical response sequence for acoustic stimuli of various intensities. Each sample is a 1000 element vector, and the sampling period is equal to 10 us.

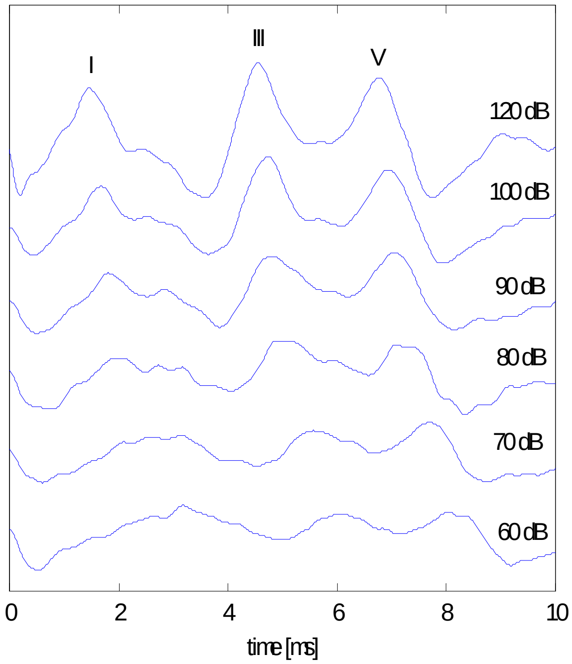

Fig.1 A typical recording of ABR signal, registered from a person with normal hearing abilities. On the right hand side the intensities of the activating signals are denoted. With decreasing intensity of the stimulus the amplitudes of particular waves decrease, while their latency periods increase.

2. Preliminary data processing

Initially the signal is filtered using low-pass FIR-type digital filter, with the cutoff frequency $f_0=0.07$ [10], then the average value and linear trend are removed from each sample and every second data point is selected. Thus the number of data is reduced to n=500. Due to that processing the obtained data sample looks as shown in the figure below (Fig.2).
The signal obtained after such treatment still contains local maxima, which are obstructions in the process of determination of latency periods for particular waves.

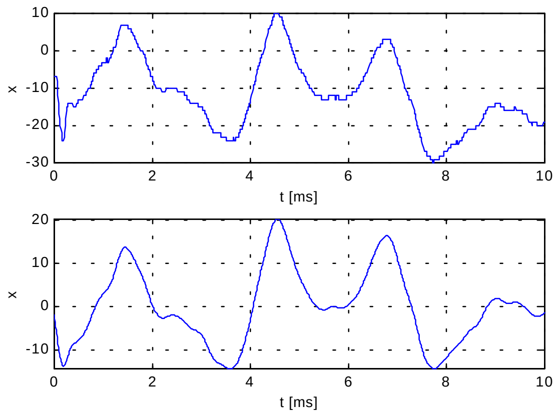

Fig.2 Exemplary sample. The upper plot shows the original data sample. The lower plot - the data sample after filtration, extraction of the average and linear trend, and selection of every second data point.

In order to eliminate the maxima the preprocessed signal is subject to another filtering, described by the following formula:

$$y(k)=\sum_{i} w(i-k)x(i),\ k=1,2,\ldots,n,\ i=1,2,\ldots,n \quad (1)$$

The w(k) function takes the form:

$$w(k)=\frac{1}{\sqrt{2\pi\sigma}}\exp\left(-\frac{k^2h^2}{2\sigma^2}\right), \quad (2)$$

h - denotes the sampling period, the σ parameter determines the cutoff frequency for the filter (1).

As a result of the filtering operation (1) the false maxima are extracted from the original signal (Fig.3).

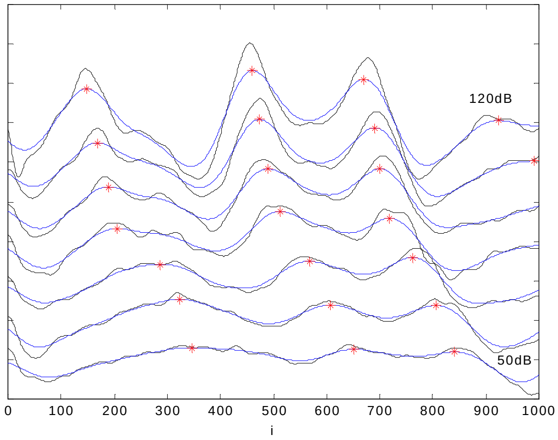

Fig.3 Result of application of the filtering operation (1). The original x(i) (black) and filtered y(i) (blue) data plots are presented.

3. Detection of wave I, III and V

For localization of the maxima a special detection algorithm, dedicated to this particular case, has been applied.

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Data $x(i), y(i), i = 1,...,n$
$k = 1, i=1$

1. Calculate
        $I = (y(i+2) - y(i+1))(y(i+1) - y(i)),$
        $A = (y(i+2) - y(i+1)) - (y(i+1) - y(i)),$

2. If (I<0) and (A<0) then
        $i_{\max}(k) = i,$
        $j_{\max}(k) = \max(x(i_{\max} - p), x(i_{\max} - p + 1),...$
        $..x(i_{\max} - p + 2),...,x(i_{\max} + q))$

        $k = k + 1$ ;

3. $i = i + 1$,
    If (i<n),
        go to 1
    otherwise
        end.
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In the second step of the algorithm the necessary condition is checked for existence of a maximum for the *y(i)* signal. This leads to determination of an approximate maximum location in the *x(i)* signal. Then the maximum value is selected from the set of *x(i)* signal data points, for which the indices belong to the $\{i_{max}\text{-}p,...,i_{max}+q\}$. set. In such a way the maximum location is determined for the *x(i)* signal. The p, q, σ values have been selected experimentally and the actual values are p=10, q=25. The σ values have increased from 8 ms for the 120dB up to 12ms for the activating signal amplitudes less than 70dB. As a result of application of the above algorithm the following data pairs are obtained:

$$(j_{\max}(k), x(j_{\max}(k))), k = 1,2,..,n_{\max}$$

which determine the maximum location and the respective signal data point value. The number of maxima found depends on the shape of the signal recording and the σ parameter. Fig.4 presents the result of the algorithm application for a particular ABR recording.

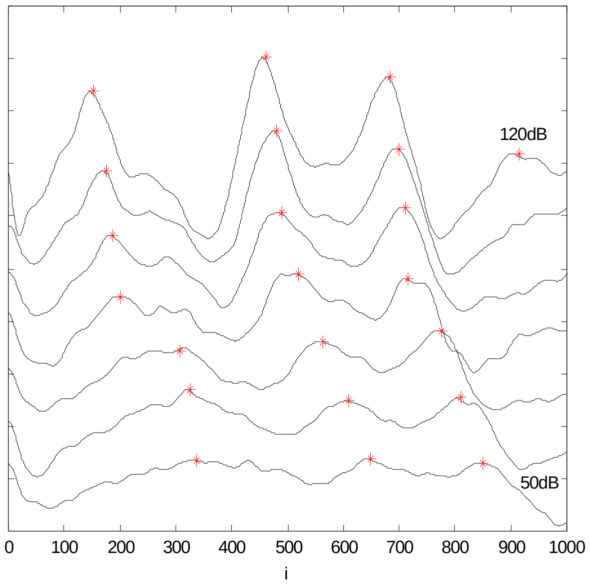

Fig.4 The locations of waves I, III and V determined by the algorithm described above.

4. Determination of standard values and dispersions for latency periods of w`ave I, III, V.

In the following stage the standard values have been determined for the latency periods of wave I, III, V. It is well known that for normal persons the latency periods of particular waves depend on the stimulus type (tone, crackle) and its intensity, as well as the sex and age of the examined person. For the considered case the data have been obtained from normal, healthy man in the age between 30 and 50, and the activating signal was a short pulse with intensity between 50 and 120 dB. In order to determine the distribution of the latency periods for particular waves the following estimator has been used [11]:

$$g(t) = \frac{1}{\sqrt{2\pi} sm} \sum_{i=0}^{m} \exp\left(- \frac{(t - t_i)^2}{2s^2} \right) \qquad (3)$$

where:

t_i - the maximum location, determined using the algorithm constructed earlier, for a given stimulus intensity,

s - parameter (selected from the 0.01-0.5 range) with actual value *s*=0.25

m - the number of isolated maxima

In Figs.5,6 the latency period distributions, obtained from formula (3), are presented. The distributions are multimodal in nature, and the locations of their maxima determine the average values for the latency periods of particular waves. Let t_m^k denotes the average value of the latency period for the k-th wave and let τ^k fulfills the following condition:

$$g(t_m^k + \tau^k) = \alpha g(t_m^k), \alpha \in (0,1)$$

The above equation may exhibit multiple solutions or may have no solution at all. Let's denote the solutions (if they exist) by $\tau_1^k, \tau_2^k, .., \tau_{nk}^k$. The number

$$\delta t_m^k = \min\{\tau_1^k, \tau_2^k, .., \tau_{nk}^k\}$$

can be treated as a measure of dispersion for the latency period of the k-th wave (Fig.5).

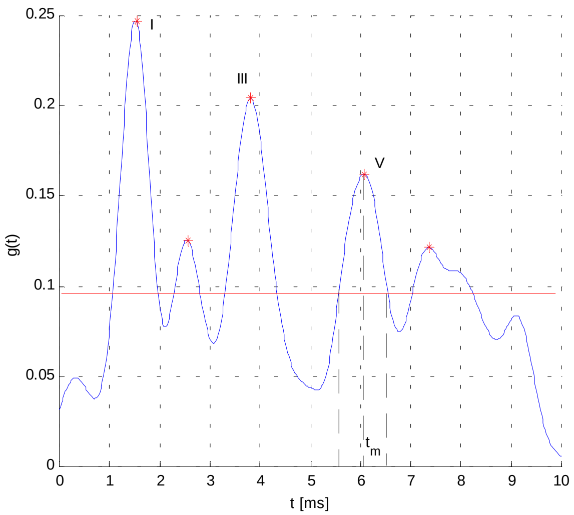

Fig.5 Exemplary distribution of latency periods determined for the stimulus intensity 120dB. The red, horizontal line marks the half value of the wave V amplitude, and the dashed lines denote the solutions of the equation:

$$g(t_m^k + \tau^k) = \alpha g(t_m^k), \alpha = 0.5.$$

The procedure described above has been used for determination of average values of latency periods and their dispersions for 1140 ABR recordings. Fig.7 presents the dependence of latency periods of wave I, III and V on the stimulus intensity, together with their boundary values

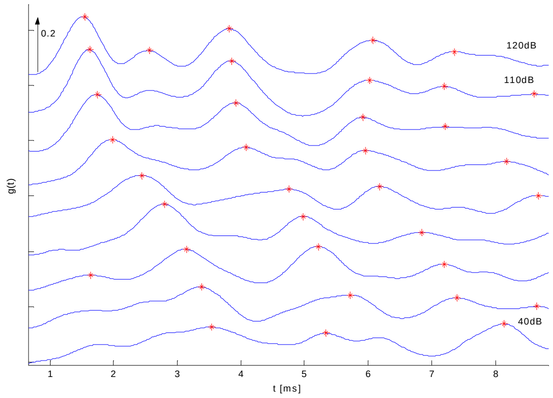

Fig.6 The latency period distributions for particular waves determined for various intensities of the stimulus. It can be noticed that with the decreasing stimulus intensity the dispersion of the distribution increases and the latency periods of particular waves also increase.

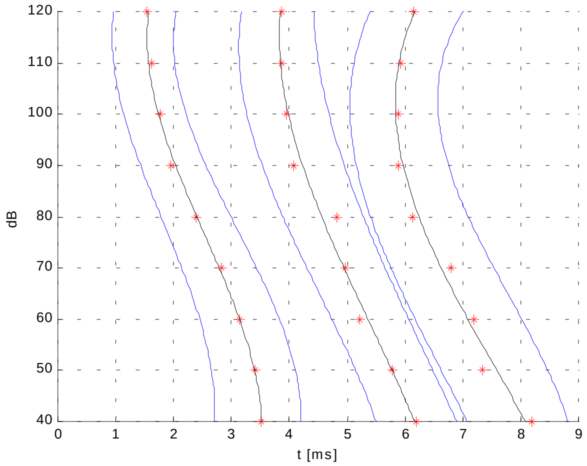

Fig.7 The standard values for latency periods of waves I, III, V, for various intensities of the stimulus.

5. Conclusions

The procedure described above enabled the determination of average values of latency periods and the measure of their dispersion for more than 1000 samples. The results, obtained by application of the method described above, have been compared with the standard values of latency periods for waves I, III and V, determined through empirical observation by the audiologist and full accordance has been founds, what provides a good basis for an optimistic view on the prospects of designed system, for which the main objective is the elimination of unobjective, human factor from the diagnostic process.

References:

[1]. Fortuna Z., Macukow B, Wąsowski J.: Metody numeryczne. WNT W-wa 1993.

[2]. Helwig Z.: Elementy rachunku prawdopodobieństwa i statystyki matematycznej. PWN W-wa 1998.

[3]. Hall J.W.: Auditory Brainstem Response Audiometry College Hill Press Inc., San Diego, 1984.

[4]. Kochanek K.: Rekonstrukcja audiogramu tonalnego w badaniach słuchowych potencjałów wywołanych z pnia mózgu. Otolaryngologia polska, tom XLVIII, suplement nr. 15, 1994.

[5]. R. E. Delgado, O. Ozdmar: "Automated Auditory Brainstem Response Interpretation", IEEE Engineering In Medicine And Biology, April/May 1994

[6]. M.J. Aminoff „Elektrodiagnosis in Clinical Neurology", Churchil Livingstone New York 1986

[7]. Izworski A., Tadeusiewicz R., Pasławski A.: The Utilization of Context Signals in the Analysis of BAEP Potentials by Application of Neural Networks, Lecure Notes in Artificial Intelligence, No. 1810, Springer, Proceedings of 11th European Conference on Machine Learning, Barcelona, Catalonia, Spain, May/June 2000, pp.195-202

[8]. MATLAB documentation: Users Guide, MathWorks, Mass.,

[9]. MATLAB documentation: Neural Network Toolbox Users Guide, MathWorks, Mass., 1999

[10]. MATLAB documentation: Signal Processing Toolbox Users Guide, MathWorks, Mass., 1999

[11]. Parzen. E.: "On Estimation of a probability density function and mode", Ann. Math. Statis., 32, pp. 1065-1076