Interpretation of the Biomedical Signals using the RBF-Type Neural Networks

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Abstract: -The paper described determination of parameters of Brainstem Evoked Auditory Potentials (BAEP) registration using computational intelligence methods. In the research on the system of automated diagnosis of the patient's auditory system the Radial Basis Functions (RBF) neural networks have been applied. The authors have also presented an interpretation of the determined network's weight coefficients, which leads to an easy evaluation of the required characteristics of the BAEP registration. Diagnostic systems based in the analysis of BAEP signals are currently a dynamically developing field of objective research concerning the human auditory system. The physician's interpretation usually includes only the amplitudes and latency periods of characteristic waves, the presence and time location of which, provides a basis for diagnosing the patient's hearing abilities. Because of great diversity of signals, which in general depend on the age, sex and also on the stimulus intensity, the evaluation and elaboration of a unanimous diagnosis becomes quite difficult for inexperienced physicians. Therefore the authors of the present paper make an attempt of constructing a diagnostic system, which could be able to eliminate the uncertainty element from the process of evaluation of hearing abilities, and would be able to provide a fully autonomous operation, based on clear, predefined criteria.

Key-Words: Computational Intelligence**,** RBF Neural Networks, Brainstem Evoked Auditory Potentials, Biomedical Signal Processing

1 Introduction

The BAEP signals registered by the surface electrodes are derivatives of bio-electric activity of the brain and auditory cortex. Elaboration of the BAEP registration and analysis technique offered the audiologists a possibility of common application of objective, electro-physiological methods for diagnosing the human auditory system. Those methods have become irreplaceable, particularly in the instances, where direct cooperation between the patient and the physician is not possible, like in the examinations of newborns or malingerers.

The examination of the hearing threshold using the ABR comprises registration of a sequence of responses for stimuli of varying intensities and frequencies and then the determination of the wave V detection threshold. The primary problem of the ABR threshold studies during analysis of the registered material is determination of the wave V threshold. The result of that determination is highly dependent on the experience of the person evaluating the examination results.

Typical registration of BAEP signal, being a subject of audiological analysis, usually consists of several response signals obtained for acoustic stimuli of various intensities [Fig.1]. Diagnosing of the hearing impairment is usually based on the analysis of the recording's morphology and the amplitudes and latency periods of particular waves in the recording. The last two measures seem to be much easier for formulation in the form of simple rules, which allow a direct conclusion, whether a given recording can be classified as regular. At present it is assumed that the amplitudes and latency periods of particular waves should be contained within standard limits, determined from examinations of considerable number of people with full hearing abilities. [4,5].

It has been assumed that the values:

$$y_i^j = f(x_1, x_2) \qquad (1)$$

where:

x_1 - time [ms], x_2 - intensity of the stimulus [dB],

x_{1i} - i-th time value i = 1,2....n,

x_{2j} - j-th intensity of the stimulus j =1,2,...,m

y_i^j - i–th sample of the BAEP recording, attributed to the x_{2j} intensity,

have been obtained from measurement of discrete values of unknown function, representing a three-dimensional structure of the intensity series. Additionally, this function can be described merely by specification of the latency periods and amplitudes of its component signals.

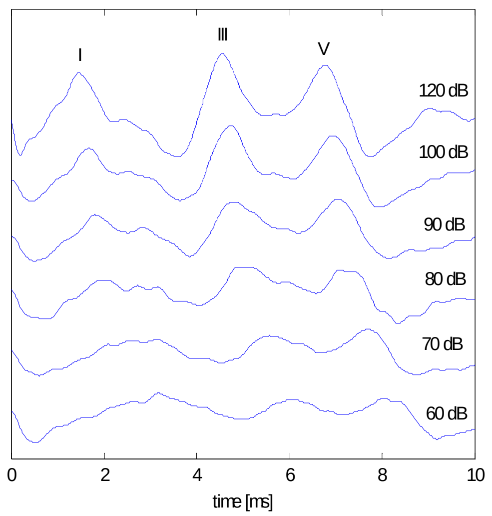

Fig. 1. Typical BAEP signal recording registered for a patient with normal hearing. On the right hand side the intensity of the stimulating signal has been marked. With decreasing intensity of the stimulus the amplitudes of individual waves decrease, while their latency periods increase.

2 Modeling of the BAEP Signal by Application of RBF Neural Networks

Radial Basis Functions (RBF) neural networks [6] provide a universal tool for function approximation. In the case described the weight coefficients obtained as a result of the RBF network's learning process contain the information about amplitudes and latency periods of particular waves.

An RBF network of index *j* is described by the following formula:

$$\left.\begin{aligned} y_{rb}^j(x_1) &= \left[\sum_{k=1}^{5} w_k^j \varphi_k(x_1 - v_k^j, \sigma_k^j)\right] + w_0^j, \\ \varphi(\xi,\sigma) &= \exp\left(-\frac{\xi^2}{2\sigma^2}\right), \end{aligned}\right\} \qquad (2)$$

The learning goal for the j-th RBF network is:

$$\min_{W_j, V_j, S_j, w_{0j}} \left\{ \frac{1}{2} \sum_{i=1}^{n} \left(y_{rb}^j(x_{1i}) - y_i^j \right)^2 \right\}, \; j = 1,..,m \qquad (3)$$

while:

$$W_j = \left[w_1^j, w_2^j, \ldots, w_5^j\right]^T,$$

$$V_j = \left[v_1^j, v_2^j, \ldots, v_5^j\right]^T,$$

$$S_j = \left[\sigma_1^j, \sigma_2^j, \ldots, \sigma_5^j\right]^T.$$

The network has been learned by the Levenberg-Marquardt algorithm. The network learning is started from the sample recorded for the highest intensity of the stimulus (e.g. 120 dB). The W_j, V_j, S_j, w_{0j}, coefficients provide a starting point for the next iteration, i.e. for the learning the network with index *j+1*. When the W_j ,V_j , S_j, w_{0j} coefficients are known it is easy to determine the latency periods and amplitudes of particular waves. The latency period of the 1-st wave in the j-th iteration is given by:

$$L_l^j = v_l^j, \qquad (4)$$

and its amplitude is given by:

$$A_l^j = \left[\sum_{k=1}^{5} w_k^j \varphi_k(v_l^j - v_k^j, \sigma_k^j)\right] + w_0^j. \qquad (5)$$

Therefore a following operation algorithm can be proposed:

a) Present the input data
j = 1,

x_{1i} - i-th time value i = 1,2....n,

x_{2j} - j-th intensity of the stimulus j = 1,2,...,m,

y_i^j - i–th BAEP recording sample, attributed to the x_{2j} intensity,

w_{0j} ,

$$W_j = \left[w_1^j, w_2^j, ..., w_5^j\right]^T,$$

$$V_j = \left[v_1^j, v_2^j, ..., v_5^j\right]^T,$$

$$S_j = \left[\sigma_1^j, \sigma_2^j, ..., \sigma_5^j\right]^T.$$

where the numbers:

V_1 = [1.5 2.5 4.5 5 6.5], S_1 = [0.2 0.2 0.2 0.2 0.2],
W_1 = [12 14 40 30 37],

$$w_{01} = \frac{1}{2n}\sum_{i=1}^{n} y_i^1 .$$

have been selected on the basis of medical data obtained from the database of Institute of Physiology and Pathology of Hearing, Warsaw, Poland.

b) Solve the problem of learning the j-th RBF network

$$\left\{\hat{W}_j, \hat{V}_j, \hat{S}_j, \hat{w}_{0j}\right\} = \arg\left\{\min_{W_j, V_j, S_j, w_{0j}} \left\{\frac{1}{2}\sum_{i=1}^{n}\left(y_{rb}^j(x_{1i}) - y_i^j\right)^2\right\}\right\}$$

c) for l = 1...5 determine

$$L_l^j = \hat{v}_l^j,$$

$$A_l^j = \left[\sum_{k=1}^{5} \hat{w}_k^j \varphi_k(\hat{v}_l^j - \hat{v}_k^j, \hat{\sigma}_k^j)\right] + \hat{w}_0^j .$$

d) If $j = m$ STOP, otherwise substitute:

$j \leftarrow j+1,$

$$W_{j+1} = \hat{W}_j,\ V_{j+1} = \hat{V}_j,\ S_{j+1} = \hat{S}_j,\ w_{0,j+1} = \hat{w}_{0j}.$$

The execution of the algorithm provides sets of numbers determining the latency periods and amplitudes of particular waves as functions of the stimulus intensity. The numbers are conveniently written in the matrix form:

$$L = \begin{bmatrix} L_1^1 & \cdots & L_5^1 \\ \vdots & \ddots & \vdots \\ L_1^m & \cdots & L_5^m \end{bmatrix}, A = \begin{bmatrix} A_1^1 & \cdots & A_5^1 \\ \vdots & \ddots & \vdots \\ A_1^m & \cdots & A_5^m \end{bmatrix}$$

for which the superscripts describe the stimulus intensity, and the subscripts denote the wave number. The required functional dependencies of the amplitude and latency period values on the stimulus intensity can be approximated by third-order polynomial functions [Fig.2,3,4].

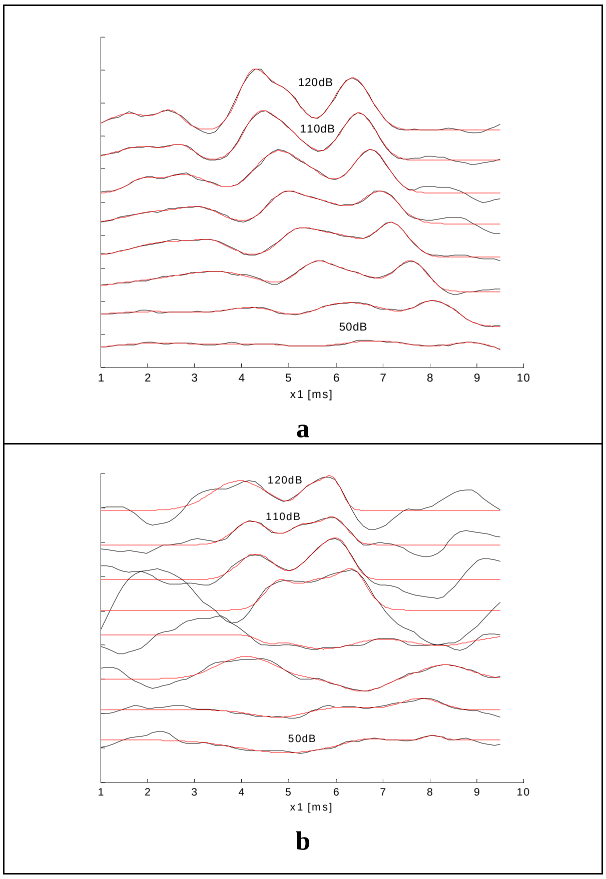

Fig. 2. Approximation of BAEP signal recording obtained by using RBF networks (red lines), experimental data (black lines). a – recording for patient with normal hearing b- recording for a patient with hearing impairment.

The analyzed signals, obtained both from the patients with normal hearing and with hearing pathologies, have been subject to preliminary processing, which removed the linear trend and the average value, and then the signals have been fed as input data to the algorithm described above.

Full procedure has been implemented in the MATLAB environment and it has been tested on 107 BAEP recordings obtained from patients with hearing impairments and 53 recordings from patients with normal hearing abilities.

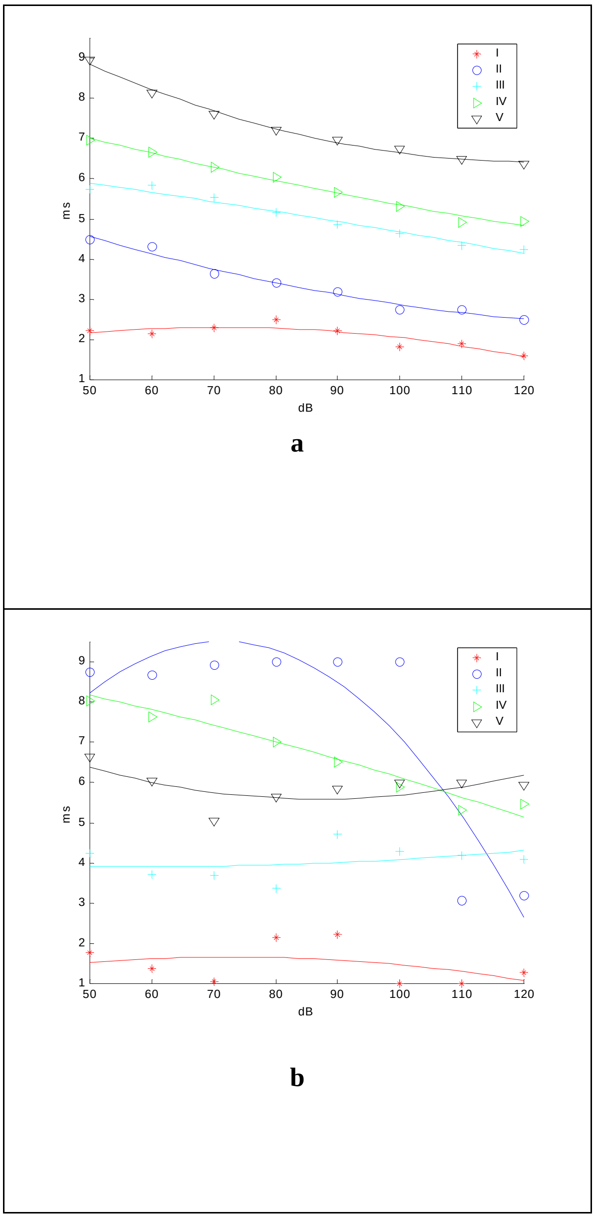

Fig. 3. Latency periods of particular waves as a function of stimulus intensity, determined by the algorithm (marker) and the third-order polynomial approximation (continuous line). a – recording from a patient with normal hearing, b - recording from a patient with hearing impairment.

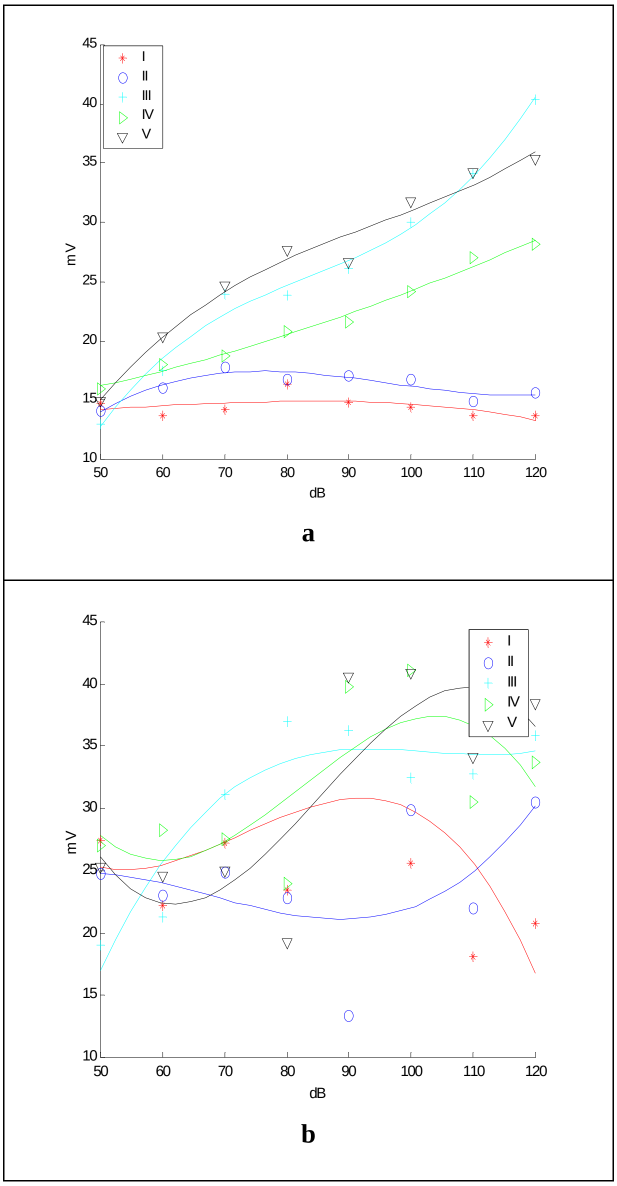

Fig. 4. Amplitudes of particular waves as a function of stimulus intensity determined by the algorithm (marker) and third-order polynomial approximation (continuous line). a – recording from a patient with normal hearing, b - recording from a patient with hearing impairment.

3 Conclusions

After completing the whole study it has been found the proposed algorithm ensures rapid convergence of the required parameters to the values estimated by a specialized physician (97%) for patients with normal hearing abilities. For the patients with pathologies the algorithm did not provide a unique parameter attribution, however it was always possible to find out, that the pathology was present. For those cases the concordance with the medical classification was also quite high (85%). Therefore the described algorithm can be used for estimation of the hearing standard limits and for preliminary data processing for the needs of classifications of hearing impairments.

The obtained values of latency periods and wave amplitudes allow a reduction in the number of input data required for neural networks performing a context analysis of the shape and morphology of an BAEP signal recording. The obtained preliminary results, described in the present paper, should be considered as promising. The next stages of the study will include construction of networks, which will be working on the input data supplemented by additional information, regarding the personal characteristics of the patient.

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