Computer System for Recognition and Interpretation of the Auditory Brainstem Response Signals

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Abstract: - One of the most important challenges in the contemporary audiology is the early detection and diagnosis of hearing impairments in newborn children. In practice such an objective can be achieved only by application of objective methods. The most important is the study of auditory brainstem response signals (ABR). Unfortunately for that method the prospects for automation of the examination are not very promising. It is easy to elaborate an algorithm for automated acquisition and stimulation, it is however much more difficult to construct an algorithm for automated analysis of the results. The objective of the project is the construction of a unified acquisition technique for ABR signals and elaboration of a processing method capable of their automated analysis and understanding. In the final stage the combination of the present research topic with remote access to the database will lead to creation of a diagnostic advisory system.

Key-Words: Pattern Analysis and Machine Intelligence, Computerised Signal Processing, Neural-based pattern recognition, Feature extraction, Web-based information system, ABR signals

1. Introduction

Due to elaboration of extracranial registration techniques for ABR signals, which present a derivative of bioelectrical processes taking place at the brainstem and auditory cortex, it has become possible to construct objective diagnostic and research methods, which are able to provide a comprehensive assessment of functioning of the whole auditory system. Results of that research are currently widely applied in clinical assessment of the hearing organs, and the progress in registration techniques and analysis of the ABR will probably lead to even wider dissemination of that technique, also in outpatients examinations.

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.

Elaboration of a practical algorithm and detection procedure for wave V and its threshold is of great importance for persons with low/modest experience. Recently the number of early diagnostic centers, which implement the ABR method, has increased considerably. Further systematic growth of their number can be also expected, because of introduction of a massive program of auditory screening tests for newborn infants into clinical practice. Therefore construction of an automated method of wave V detection, which could be implemented into devices presently used by those centers, seems particularly useful.

The aim of the described project is the organization of a countrywide system for analysis of ABR signals registered during the screening tests and diagnostic examinations. Therefore the realization of the project requires the following:

- Elaboration of methods for acquisition, preliminary processing and analysis of ABR signals,
- Construction of the space of distinctive features, describing the signals,
- Elaboration of techniques for both classification and automated recognition of ABR signals,
- Elaboration of unified methods for collection and visualization of ABR data for the whole country

In the present paper the results for items from the above “to-do” list has been described. At present the methods for ABR data storage and visualization are being prepared, which should enable the collection and distribution of both raw and processed data for the needs of scientific research in the fields of neuroacoustics and social medicine. The development and testing of electromedical equipment, creation of standards and test sets, as well as training and improvement of the medical staff at all levels also takes place.

2. System for Recognition and Interpretation of ABR Data

The objective of the system for acquisition and automated recognition of ABR is to offer a service of remote monitoring and evaluation of a registered intensity series of ABR signals. The system consists of three main components:

- mobile devices for ABR acquisition
- computer system for processing, collection and automated assessment of ABR
- optional advisory service of medical experts

In the basic assumption the product offered by the system is the service itself. Mobile device for ABR signal acquisition is used for registration of time dependent ABR signals. The device transfers the ABR data to the system using the Internet. The data undergo preliminary analysis by the software, and if the analysis exhibits any ABR shape irregularities the respective information is sent to the medical consultant, who can proceed with the detailed signal analysis. The result of the analysis is also sent back to the user.
The program layer of the system offers the system users a set of functions, dependent on the user type. Three types of system users can be distinguished:

- client --- a person making use of the service offered by the system
- consultant --- a person analyzing the ABR data
- administrator --- the person responsible for the system maintenance

Additionally another user type is defined, called "potential client". This is a person, who may be willing to use the system service. Potential client is offered access to the WWW page of the system, which can be used for attracting the client, as the source of information and as a "call-center" for the service requests.
A registered client owns the ABR acquisition device and is entitled to make use of the system services, which include the ABR measurement, transfer of the data to the system, data analysis by the computer system (original software) and reaction of the medical consultant if any deviations from the standards are observed. The consultant is given access to the restricted part of the system, in which the patient's data sets can be browsed. The consultant is also given access to additional system functions, like modification of the communication settings, messages, reminders etc. The system administrator is given access to the control functions of the system, which allow the maintenance of the system as well as report preparation, data archiving etc.
Personalized system homepage is intended as a central contact points for the clients, which includes all possible interaction between the client and the system.

3. Methods of hearing examinations

Examination of the hearing threshold by analysis of ABR signals comprises registration of a series of responses for stimuli of various intensities and frequencies and the determination of the wave V threshold, which, as shown by clinical studies, correlates to the highest level with the hearing threshold values determined by the audiometric methods. The primary problem in the ABR threshold studies is the determination of the wave V threshold by analysis of the ABR recordings. The result of such analysis is highly dependent on the experience of the person evaluating the examination results. In order to make the determination of the wave V threshold easier the

ABR signals are registered according to a intensity series procedure i.e. from the highest down to the lowest intensities (Fig.1). If the recordings exhibit the required quality then for the evaluating person with proper experience the determination of the hearing threshold is not a serious problem. Much greater problem is the correct determination of the wave V peak in the recordings done for single intensities, as it is the case in the auditory screening tests for newborns.

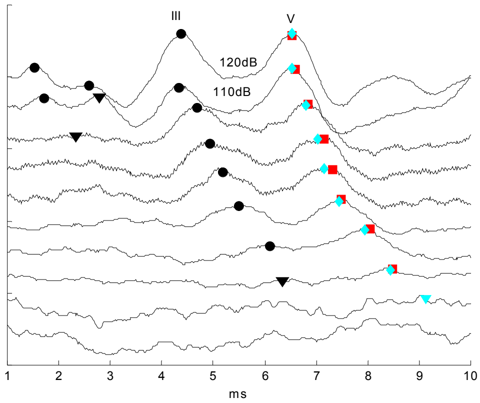

Fig. 1. Typical ABR signal recording obtained from a person with normal hearing abilities. With the decreasing intensity of the stimulus the amplitudes of particular waves decrease, while their latency periods increase.

The elaboration of a practical algorithm of data acquisition and preprocessing is of great importance for medical staff with modest experience. In the recent years the number of audiological early diagnosis centers, in which the auditory brainstem response signals are employed, has increased several times. It can be also expected that a further systematic increase in the number of these centers will take place, because a wide program of screening examinations of hearing abilities for newborns is being introduced into clinical practice. It is also worth mentioning that most of the Polish audiologic centers are equipped with devices, in which the methods presented below can be implemented in the most natural way.

For determination of the latency periods for particular waves an original algorithm has been used, allowing the maxima detection in the ABR signal recording. The solutions applied for data acquisition and preliminary processing will be the topic of a separate publication [1].

4. The Context Classification

In the task of automated recognition of the ABR potentials artificial neural networks have been applied, learned by the error backpropagation methods. The implemented neurons exhibited a unipolar, sigmoidal activation function. The applied neural networks included one or two layers of hidden neurons.

No	Neural network architecture	No of epochs	RMS error	Accuracy of the classification [%]	
				Learning set	Test set
1	1000 × 12 × 1	260	0,63	100	83.12
2	1000×7×2 ×1	325	3,70	92.11	85,71
3	100 × 8 × 1	479	0,09	100	85,71
4	100 × 7 × 2 × 1	414	2,00	97.37	85,71
5	25 × 7 × 1	310	1,25	98.68	83,01
6	25 × 7 × 1	288	2,01	96.05	82,31

Table 1. Results obtained for classification of signals 1000, 100 and 25 points in size

In Table 1 selected results are shown of the automated classification of the ABR signals obtained in the previous research stages, oriented towards recognition of isolated signals by the artificial neural networks.

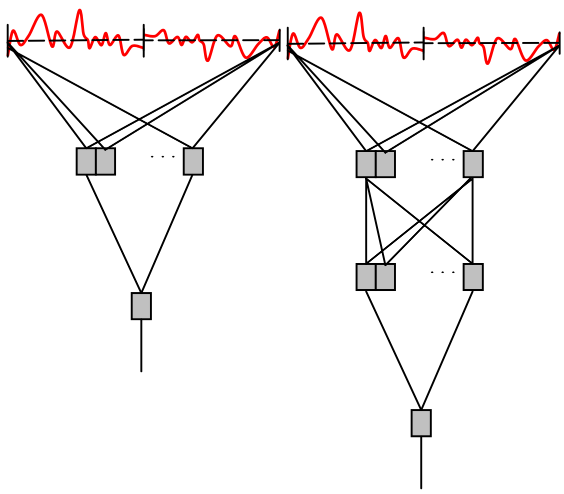

Fig. 2. The double and triple layer neural networks, in which the neurons are connected according to the "full connection" rule, doublets of signals are fed to the network's input

The network's input has been fed with a signal describing the analyzed ABR recording (it was a uniformly sampled set of momentary values of the signal of the normalized size of 100 points) and the expected network's output consisted of a single logical-type signal was expected, indicating the presence or absence of the wave V in the input signal.

The studied network architectures exhibited the 100-n-1 structure (where n denotes the size of the optimized hidden layer) or alternatively 100-n-m-1 structure, for the cases when networks with two hidden layer were applied.
In order to take the context into account in the described study two signals have been fed at the same time to network's input: the presently analyzed ABR signal and the previous, accompanying signal, obtained for the higher intensity of the acoustic stimulus. This goal could have been achieved using a simple multi-layer neural network, but additional attempts have been made to use in the recognition process neural networks of some more complicated architecture, modified according to the specific features of the considered task. Therefore several various neural network structures have been proposed and studied. Their architectures will be presented and discussed below. The input vectors necessary for the context studies have been constructed in such a way, that each of the ABR signals has been appended in front by the preceding signal, obtained in the same measuring sequence but for the higher amplitude of the acoustic stimulus. So the pairs of signals were created: 80 and 70dB, 70 and 60dB, etc. The length of such input vectors was of course 200 points.
The simplest architecture (Fig.2), which offers the possibility to make use of the context during the recognition of signals of auditory response is a neural network to the input of which two signals are fed in sequence (i.e. vectors consist of consecutive values of time samples of the considered signals), what leads the situation that the considered networks make use of the input vector being 200 points in size.
The network architecture described above have been later modified in such a way, that the first hidden layer has been split into two parts, and then two component signals of the input vector have been fed separately to each of the layers (Fig.3.). Due to such a procedure the split layers of the hidden layer preliminary process the signal to be recognized and its context signal, working independently.

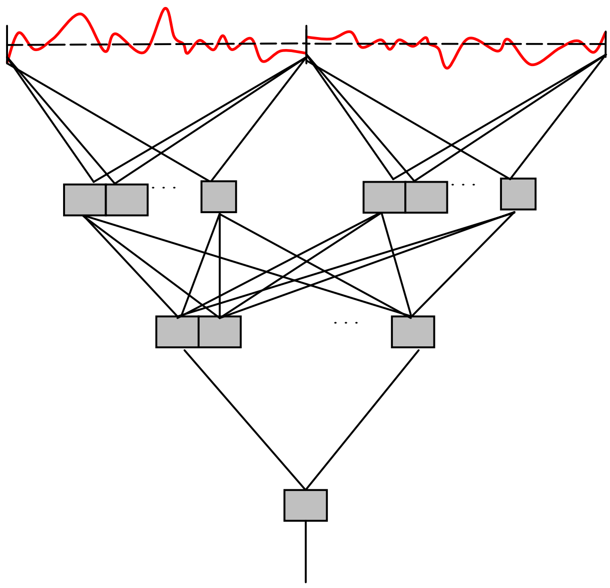

Fig. 3. Triple-layer network, the first hidden layer has been split, so that two consecutive ABR signals are fed separately to the network

In the course of the simulation the network's architecture has been optimized in order to provide the best results of the recognition. In Table 1 several best results are shown (for comparison), obtained from the classification of single input signals. These results have already been published. The Table 2 below shows the new results for the study of recognition of the ABR signals making use of the context signals.

Table 2. Selected best results of the classification for the networks presented in Fig.1 and 2

No	Neural network architecture	No of epochs	RMS Error	Accuracy of the classification [%]	
				Learning set	Test set
1	200 × 10 × 1	330	1.98	96,05	87,01
2	200 × 8 × 1	395	1.24	96,05	89,61
3	200 × 8 × 1	365	1.43	97,37	88,31
4	200 × 7 × 2 × 1	1049	3.94	94,74	85,71
5	(100+100) × (4+4) × 2	2080	3.87	94,74	87,01
6	(100+100) × (3+3) × 2	1794	3.88	94,74	87,01
7	(100+100) × (3+3) × 2	2250	3.87	94,74	88,31

After comparing the learning results, obtained during a several tens of simulation runs, quite a lot can be said about the influence of including the context and application of various network structures on the quality of ABR signals recognition results. From the completed research it follows that including the context has the strongest positive influence on the classification quality for the networks including one hidden layer, for which the improvement of the ABR recognition results was about 4-5%. The conclusion, that can be drawn, states that appending the recognized signal by the information regarding only the classification of the signal preceding the analyzed signal leads to much worse effects than addition of the whole context signal.

5. Conclusions

The aim of the presented project was the creation of a unified technique for acquisition of ABR signals and elaboration of a method for their automated analysis. In further development the automation of ABR signals analysis was oriented towards the detection of wave V in the ABR signal, what is of key importance for the assessment of hearing abilities of the examined patients (mainly infants). The automated classification of ABR signals has been carried out by application of artificial neural networks of various architectures. Good results have been obtained only after application of neural networks with architectures allowing the utilization of context information. Main efforts will be focused on the construction of visualization and distribution rules (in the countrywide scale) for the collected data together with their interpretation. The collected data will also allow the execution of several analyses assessing the health condition of the population subject to the screening tests. In the long run, due to the combination of that facility with the remote database access, it will be possible to create a decision support system, similar to an expert system, covering the area of whole Poland and providing the prospects for a considerable degree of unification and objectiveness of the ABR examinations.

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