Artificial Intelligence in Medical Diagnosis of Some Brain Dysfunctions

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***Abstract*—The paper presents an analysis of objective evaluation of speech quality. As an example, the recovering process after stroke for patients with vascular lesion of a central nervous system has been taken into account. Application of neural networks gives possibility for objective evaluation of speech quality of patient suffering from disorder of speech motor.**

***Index Terms*—speech analysis, formant analysis, artificial neural networks, brain dysfunction, stroke, olfactory system**

I. Introduction

AMONG a big number of brain diseases, the paper takes into account only some chosen dysfunctions. Very often it is possible to settle some brain dysfunctions as markers of early symptoms of mental disorder or even as a first early signal before brain stroke. Therefore we have taken into account one from two important brain processes: deterioration of olfactory mechanism and recovering process after ischemic stroke. Inspiration of this paper is a big success of artificial intelligence application in objective method development for the risk stratification of cardiovascular diseases [1]. The elaborated system bases on perceptron neural networks, and it permits to discover a risk of sudden cardiac arrest and, as a consequence, possible sudden cardiac death in an early state. Therefore, the system can be used as an important indicator when the doctor intervention becomes necessary.

In the case of strokes, especially ischemic strokes, almost always disorder of speech motor has been observed. Because it is very difficult to preview such a stroke, an observation of a first slight speech aberration can be used as the stroke marker. It is also important to notice that after stroke, the progress of patient treatment is usually evaluated observing an improvement of speech process [2]. It seems that an objective measurement of the progress of speech recovering can be also made using artificial neural networks (ANN).

Another important area of ANN application is an early recognition of neurodegenerative diseases, like Alzheimer or Parkinson disorders, because there are not specific markers, which can indicate potential risks, that the disease approaches. The acceleration of such researches was made in XXI century when scientists discover the mechanism of human olfactory process. Afterwards, some suggestions concerning relations between early neurodegenerative diseases and malfunction of olfactory nerve responses for typical odors were reported [3].

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In both cases, stroke mechanism recognition and olfactory system deterioration, an ANN can be helpful for an objective discovering early symptoms of such diseases. In [2] the vast analysis of several patient's speech after stroke, illustrating recovery processes, has been performed. It is possible to evaluate in an objective manner the patient state. The results were in a good agreement with subjective observation of phoniatrists, working with patients after stroke. Unfortunately, the proposed method is off-line, time consuming and the final decision concerning patient health state must be taken by qualified medical personnel. The approach proposed in this paper gives possibility to evaluate the recovering process on-line, using ANN classifier.

In the case of electronic diagnosis of human olfactory mechanism, using registration and analysis of EEG signals coming from olfactory and trigeminal nerves, the registration precision is rather small, because of body noises and other artifacts, coming among other from visual and aural nerves. As a consequence, the registration process should be repeated several times, but it is necessary to take into account that increasing the repetition, the sensitivity of human smell mechanism goes down. Therefore, the time necessary for proper registration of olfactory event-related potentials is counted in tens of minutes. A choice of the best diagrams is also important task. Therefore, it is necessary to improve the diagnosis procedures and application of ANN should be helpful.

II. Implementation of Artificial Intelligence

A decision concerning the patient health state belongs always to qualified medical staff. However, due to the rapid development of artificial intelligence methods, based on several mathematical approaches, like automatics, including feedback theory, theory of nonlinear circuits and even wave and quantum physics, it is possible to implement such methods as computer software, helping significantly during medical decision processes. Among several medical oriented algorithms, application of ANN seems to be promising solution.

One can find many other models of classification support algorithms suitable for evaluation of speech quality. One of the basic approach is based on decision trees. Taking into account finite number of speech quality steps, one can build a graph representing the decision tree and according to the measured voice parameters, it is possible to find the path, which indicates the highest probability of the current speech quality.

Comparing ANN with other decision methods, like decision tree, fuzzy logic motor, basic classification models or Bayesian networks, it is necessary to admit that only a Bayesian network has sufficiently high efficiency. Such networks are often used in several medical diagnoses. The Bayesian network is represented by directional graph, where each branch is described by a conditional probability, resulting from a big number of observations providing during medical procedures of treatment. One can easily understand the structure of such network, it is also possible to change easily the probabilities assigned to every branch. Unfortunately, in the case of the change of procedures, resulting for example from improvement of recovery treatment, it is necessary to repeat calculations of all probabilities. To obtain an effective recognition of the health state, simple Bayesian networks are insufficiently, there is still a lack of computer programs for effective design of bigger but useful networks, so it is necessary to do it slowly, step by step. Concluding, the design process of advanced Bayesian network has rather poor design automation support, and also a learning phase for a new data base demands laborious recalculation of several probabilities, so it is time consuming in comparison with automatic processes of ANN learning and verification.

ANN has also two main advantages: the structure is less complicated in comparison with other presented above methods and, what is very important, ANN can discover some hidden dependencies between parameters, which are nor visible neither obvious in other methods.

III. Analysis of Formant Variabilities

A treatment progress after an ischemic stroke is always conjugate with a recovery of normal, standard speech quality. It is possible to establish a lot frequency domain and time domain analyses using recording voice of the patient. One can observe the improvement of speech motor if the process of treatment is advantageous. Since a stroke is almost always an unforeseen occurrence, very often there is no records of the voice before stroke. To solve such difficulties, one can compare the patient speech with the voice of healthy person of the same age and at the same gender, repeating the same utterances.

Analyzing the previous researches [2] concerning speech features during recovery process after ischemic stroke, one can observe significant variability. It is especially visible during formant analysis. A representative example of differences between formants calculated for the same person first day after stroke and just before leaving the hospital, is presented in Fig. 1 [2].

The subjective evaluation of the quality of treatment process depends on the experience of medical staff. To obtain more independent and more objective rating we propose to apply a perceptron ANN. Such approach can be particularly useful if you would like to know an efficiency of completely new method, or if you need to compare several methods of treatment.

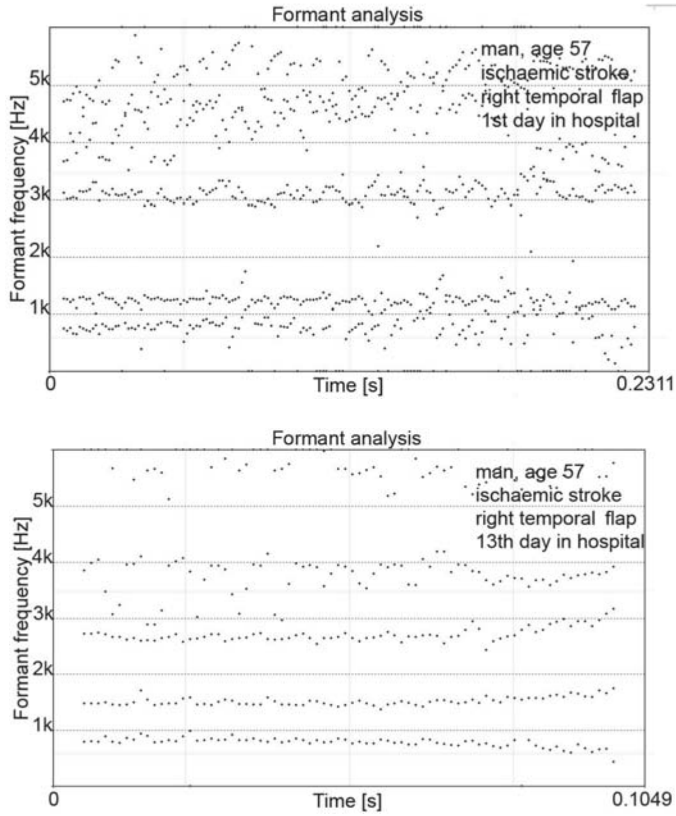

Fig. 1. Formant analysis of the vowel "a" [2].

The formant analysis is based on calculations of short time periodograms $I_N(e^{j\omega})$ for N-point sequences, according to the following equations:

$$I_N\left(e^{j\omega}\right) = \frac{1}{N}\left|X_N\left(e^{j\omega}\right)\right|^2 \qquad (1)$$

where the Fourier transform of the sequence $x[n]$, describing the signal generated by a microphone, can be expressed as

$$X_N\left(e^{j\omega}\right) = \sum_{n=0}^{N-1} x[n]e^{-jn\omega} \qquad (2)$$

It is also important to notice that using several algorithms of formant analysis [4], one can conclude calculation in very short time. Adding even shorter period of ANN analysis, it will be possible to use such analyses on-line during standard medical survey in hospital. Analysis of several speech records of a single vowel [2, 5], for several number of patients (including healthy persons) permits to conclude, that every formant (from 1 to 5) is not a constant value, but it has rather time-period variability when the patient pronounces the vowel "a".

IV. Improvement of Decision Process

The artificial neural network seems to be the most efficient technique for the diagnosis of speech recovery based on expert system, which is a branch of artificial intelligence. Such a system takes into account not only medical suggestions about diagnosis, but also implements human capabilities of reasoning and use of several decision rules and regulations, concerning physical symptoms observed in the past. Frequently it is very difficult to find directly such internal rules, but in the case of ANN it is not necessary. Translation of a hidden knowledge in the explicit rules can lead to significant deterioration including a distortion of the final diagnosis presented at the output of the system. Therefore, the use of neural networks seems to be appropriate, because system designer does not have to understand all the dependencies existing in the given problem.

Even better solution can be obtained combining an artificial neural network and a fuzzy system. Such a fuzzy-neural system permits to combine two important features: adaptive possibilities and a learning function. Such a system has more complicated structure in comparison with perceptron networks and can be realized, for example, as a linear predictor using multi-layer feedforward ANN. Further researches of such system will be investigated in the future, as the next step of ANN development.

Since the time distribution of formants was calculated, in the second step it is necessary to evaluate the current state of the patient using the scale: from “very ill” to “healthful”. To avoid stability problems and to check the possibility of ANN, feed forward architecture of neural network has been used. We were trying to apply the main feature, it means the ANN during teaching processes should discover a hidden dependencies between the quality of the speech and dysfunction state of the brain after stroke. According to the preliminary comparison of voice quality and patient state, resulting from computer analysis of the speech and medical specialists diagnosis of the recovery process, one can find that such dependencies are nonlinear [4, 5].

To check the classification possibility of patient state after stroke, a neural network with two hidden layers has been applied. We have taken into consideration the first four formants, because higher formants are characterized by much bigger variability in time, even for young and healthful person. The example of such network is shown in Fig. 2.

During the test consisting of two phases: learning and checking, a pair consisting of two formants chosen from first four formants, was taken into account. The main idea is to obtain useful tool working in real time conditions, with the possibility to implement them on mobile platform. Therefore, it will be impossible to make analysis for all four or even five formants simultaneously, because both, complexity and also time of calculation increase significantly.

The neural network is designed in such a way, that the output signal of a single output neuron accommodates values from the range 0 – 1. The value 0 denotes that the patient is healthful, while the value equal to 1 denotes that the patient is seriously ill. During the teaching process two kinds of data have been applied: first coming from records of the healthful persons, where the output signal should be equal to “zero”, and the second part of voices recorded first day after stroke, where the output signal was establish as “one”.

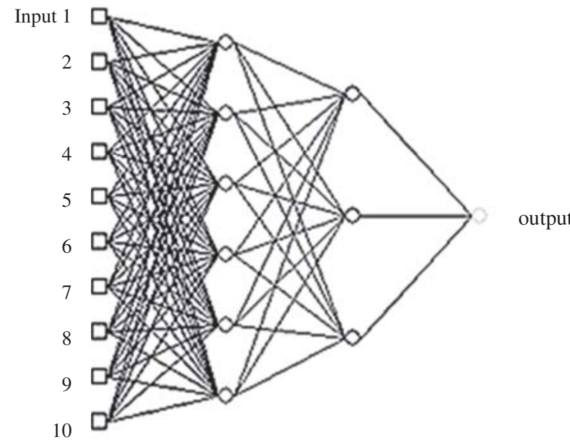

Fig. 2. Example of perceptron neural network with two hidden layers.

The age of the patients and representative healthy persons was from the range of 5 years (from 53 to 58 years old). The final network consisted from 10 neurons according to Fig. 2. After the teaching process, the program was verified using data base created in hospital. The base consists of records of patient’s voice with several comments, like gender, age, recording date and the date of the beginning of stroke, and sometimes following the comment of medical staff concerning the health state of the patient.

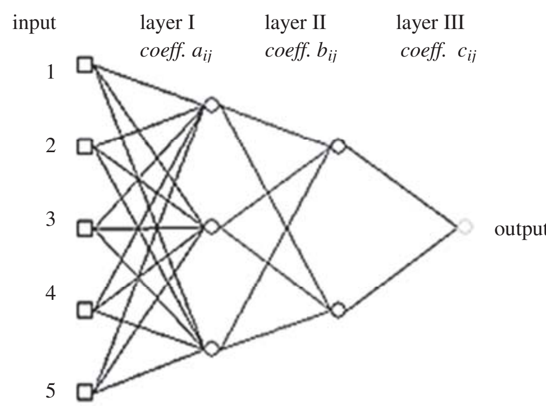

Fig. 3. The structure of ANN for one formant analysis.

After a big number of calculation for different ANN structure for the same learning data, the final structure presented in Fig. 2 was established. Such relatively simple structure containing 10 inputs seems to be the best solution, if it will be implemented in nowadays mobile devices, like Smartphone or palmtop.

An example of analysis using only one formant is presented in Fig. 3. The network contains two hidden layers, five inputs and one output. We chosen fourth formant because it is characterized by relatively high sensitivity with respect to the speech quality and simultaneously it is relatively stable. On the other hand the formant number 5 has higher sensitivity but much lower stability, it means the main frequency of the measured formant depends strongly on the individual person features and also such frequency can sometimes varies randomly for the same person.

EXAMPLE For the fourth formant taken from our data base one can obtain the coefficients (weighs) of all neurons according to the Table I.

TABLE I.
PERCEPTRON COEFFICIENTS

Coeff.	*Value*	*Coeff.*	*Value*
a_{11}	1.58112	a_{51}	-0.31664
a_{12}	-1.09663	a_{52}	0.27508
a_{13}	-2.26617	a_{53}	8.52362
a_{21}	3.22308	b_{11}	-1.51102
a_{22}	1.57812	b_{12}	-1.39172
a_{23}	-21.99018	b_{21}	1.26803
a_{31}	0.38641	b_{22}	1.26623
a_{32}	0.05196	b_{31}	-1.22427
a_{33}	-10.89841	b_{32}	-0.56133
a_{41}	-3.83518	c_{11}	0.53846
a_{42}	0.60034	c_{21}	0.44739
a_{43}	25.82876		

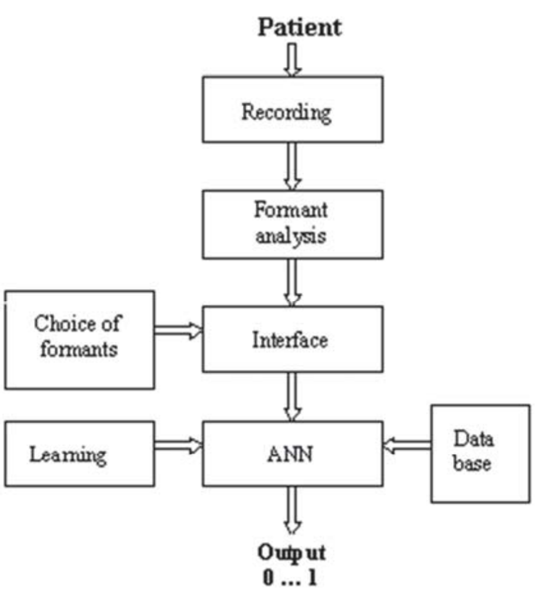

Fig. 4. System for evaluation of patient health state.

The threshold values of neurons had the following values: layer I: 2.70605, 0.52842, 8.34901; layer II: 1.19425, 0.55662, layer III: 0.25346. The average teaching error for the whole network was 0.0094764, it means below 0.01 %.

According to our experiences during verification of ANN, five inputs is the smallest number of input values characterizing the variability of the given formant. In the case of a smaller value of inputs it was impossible to conclude successfully a learning process.

From practical point of view the proper design of the interface, presented as one component in Fig. 4, is also important task of the whole project. Such interface should be intuitive and should have embedded values of parameters describing formants. On the other words, only in some special atypical cases, the user has the possibility to change the formant sequence and parameters, e.g. if the personal experience is in disagreement with output results of our system.

In the case of diagnosis of human olfactory mechanism, only preliminary researches have been done. We are trying to improve the precision of event-related potentials registration. The main tasks is to minimize influence of noise and artifacts for proper registration of responses of signals coming from olfactory and trigeminal nerves. As it was mentioned in [3], the amplitudes of such artifacts have comparable values with useful signals. Therefore, it was necessary to teach ANN how to recognize such noises and artifacts and how to eliminate them from the final records. Such elimination should permit for more precise observation of the increasing of nerve answer latency, which, according to the latest medical hypothesis [7, 8], can be observed in the case of early beginning of Alzheimer's disease.

V. CONCLUSIONS

It is necessary to notice that in our method the quality of the speech is the main factor, which is taken into account for evaluation of recovery process after stroke. The method is based on the assumption that disorder of speech motor is closely connected with a stroke (only ischemic stroke was investigated in this paper) and can be presented as a specific factor of such brain illness, despite the fact that seldom one can find cases of the stroke without disorder of speech process. However, because speech verbal process consists of a big number of brain activities, the majority of brain areas are involved in such complicated process. The most important are five of them: Motor cortex, Auditory cortex, Wernicke's area, Angular gyrus and Broca's area. Therefore, the presented method can be involved as helpful marker in recovering process of speech disorder caused by ischemic stroke and also other neurological disturbances. The main idea is to obtain final algorithm, which can be applied for a mobile device working on line with sufficient precision to recognize improvement or deterioration of voice quality in short time horizon: day after day or week by week. In the paper we concentrated on the part describing a decision process using ANN. The final and real verification of the proposed system can be made only by medical staff during treatment processes.

Efficient diagnosis of speech quality for patient after stroke is inherently a complex task involving human expertise and also should have capability to work in real-time mode. The hardware-software co-design permits to achieve lower cost and higher speed performances in comparison with purely software application.

In the case of high quality speech evaluation it is necessary to take into account noise environment, existing almost always in hospital environment, and nonstationary nature of the voice. To improve the existing results, further researches will be proceeded using nonlinear predictors and recurrent neural networks.

Acknowledgment

The authors thank Prof. Andrzej Klimek and Dr. Bozena Adamkiewicz from Kopernik Hospital in Lodz for cooperation, and for valuable discussions and suggestions.

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