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A COMPARATIVE ANALYSIS OF THE RESULTS OF CONVENTIONAL AND COMBINED METHODS OF TRAINING DIRECT PROPAGATION NEURAL NETWORK IN HEALTHY PERSONS TO DETECTING THE DEGREE OF ACTIVITY OF AN AUTONOMOUS NERVOUS SYSTEM

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Abstract

The article deals with a comparative analysis of the efficiency of an artificial neural network (ANN) trained with the help of algorithm back propagation, and of that trained by combining a back propagation algorithm and a variant of Cauchy stochastic training, in detecting the degree of activity of an autonomous nervous system. For the purposes realization of the project has been developed a biotechnical system, including technical device for input electrophysiological information in mode on-line. To evaluate the clinical effectiveness of the classification, records of interpulse intervals in 139 healthy students of Belgorod State University have been analyzed. All of them were part of the same age and social group from 17 to 24 years old. In practice, the ANN training algorithm using the back error propagation method enabled a correct recognition of 96.0% of the samples. The analysis of the clinical effectiveness of combining the back error propagation algorithm with Cauchy stochastic training showed that 100% samples were detected correctly both: as in training statistical samples so and in examination sampling. Classification errors amounted to 0 %.

Keywords: *interpulse intervals; electrophysiological information input block; neurocomputing; neural network classification algorithm; method backward propagation algorithm; Cauchy stochastic training; combined methods of training.*

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INTRODUCTION:

The study of artificial neural networks (ANN) is a contemporary field of research in the mathematical modeling of poorly structured and poorly formalized processes in biomedical systems.

The mathematical description of the assessment of objective conditions of major systems in a patient's body demands processing of a large number of numeric data received via an electrophysiological information input device.

In the technical areas of science, including robotics, neural network algorithms are generally used to optimize decision-making based on fuzzy sets and chaotic dynamics.

In medical practice neuronet technologies have been used for analyzing signals of photoplethysmographic pulse in patients with vascular disease of the lower extremities [1-3].

The level of an autonomic nervous system activity degree can be recognized automatically on the data received from the transducer pulse, allows determining nature of the change of human functional state [4, 5].

This approach allows the construction of scattergrams of inter-pulse intervals and provides automatic differential diagnosis of the clinical outcomes of atrial fibrillation [6].

The classification tasks demand that a new sample should be attributed to a certain group. ANN enables to create decision-making rules in the learning process. Such aims demand a specific collection of data used for training purposes (a training set), which should be previously classified by experts in this field [7].

Models and algorithms of differentiating the types of the functional status of vegetative nervous system based on the back propagation with the purposes of ANN training have been described in [7].

ANN modeling techniques to solve the problem of automatic recognition of the degree of activity of ANS by means of stochastic methods of training have been represented in a number of research works [8,9].

Reference [10] in ANN training describes the approaches based on the use of the back error propagation algorithm.

Research in the evaluation of the efficiency of various ANN training methods plays a major role in solving the problem of classification of functional states of the human body [11].

In the scientific literature were described the translational methods for the development of biotechnical systems for medical diagnostics working on the principles of neuronet technologies [12].

When stochastic training methods are used, modified weight factors take place, which increases the current error value, and are subsequently stored with a certain probability. This approach allows the weight adjustment process to 'escape' from the local minimum point in the search for a deeper global minimum. Decreasing the adjustment rate gradually, it is possible to achieve a sufficient speed of weight ratio change, which will enable the system to "escape" from the local minimum point on its own. Though, this speed will not be sufficient enough for it to "escape" from the global minimum.

Objectives and tasks of the study

The aim of the study is to develop a special module consists of a complex problem-oriented program intended to optimize the decision-making process in medical diagnostics.

The following tasks should be pursued to achieve the stated objective:

- developing a ANN model to solve the classification problem;
- forming a training algorithm based on the back propagation algorithm;
- forming a training algorithm based on the combination of back error propagation and Cauchy stochastic training;
- creating software applications to evaluate the adequacy of the developed models;
- comparing the results of study based on the clinical criteria of the efficiency of the algorithm of ANS activity status detection in terms of sensitivity and specificity.

To solve the stated objectives, the methodology of the system analysis, neurocybernetics, control theory and the theory of modeling has been used. First of all, there has been a comparative analysis of the efficiency of an artificial neural network trained with the help of back error propagation, and of that trained by combining a back error propagation algorithm and a variant of Cauchy stochastic training, in detecting the degree of activity of an autonomous nervous system.

MATERIALS AND METHODS OF RESEARCH:

The model input data of represent a vector of interpulse intervals obtained by using an electrophysiological information input block. The initial time series of interpulse intervals are divided into segments, each of them comprises two signal measurements. Each pair determines the temporal component, namely: the so-called zero adjustment, the accelerating and the decelerating heart rate adjustment.

A random X value is introduced. This value is associated with the duration and with the sign of the adjustment. All the observed values belong to the $(-1{,}55;1{,}55)$ intervals that were passed in increments of 0.05. Thus, the alphabet of the system includes 61 classes of differential histogram of heart rate variability microstructure patterns. Computations are performed from an array of 500 interpulse intervals.

Frequencies of X interval variation series are entered to an ANN input. Network inputs $x_j,\ j=\overline{1,61}$, have been subjected to a process of normalization by means of subtracting the sample mean and dividing by the adjusted standard sample deviation.

The activity of neurons in the $y_k^c,\ k=\overline{1,10}$ hidden layer is calculated with the following formulas:

$$y_k^c = f\left(\sum_{j=1}^{61} w_{kj} x_j\right), \qquad (1)$$

where w_{kj} is the weight ratio between the j-input and the k-hidden layer neuron.

A hyperbolic tangent has been selected as an activation function.

The activity of neurons in the $y_i,\ i=\overline{1,6}$ output layer is calculated with the following formulas:

$$y_i = f\left(\sum_{k=1}^{10} v_{ik} y_k^c\right), \qquad (2)$$

where v_{ik} is the weight ratio between the k-hidden layer neuron and the i-output layer neuron.

The network attributes an input sample to a specific class. The number of the output layer neuron having a maximum activity serves as the class marker. In the training set, the position of the output class is determined by an expert physician. The position of the correct class is marked on the target vector with the value equal to 0.5. The other coordinates of the target vector have the value equal to - 0.5.

The class is recognized based on the maximum neuron output level, which represents one of the six classes in the network, including a sharply pronounced predominance of the sympathetic nervous system (SNS SPP), a pronounced predominance of the sympathetic nervous system (SNS PP), a moderate predominance of the sympathetic nervous system (SNS MPP), the equilibrium state between the sympathetic and parasympathetic nervous systems (Norm), a moderate predominance of the parasympathetic nervous system (PNS MP), a pronounced predominance of the parasympathetic nervous system (PNS PP).

One can consider following Ann Training Methods. ANN training based on the back error propagation algorithm comprises the following steps:

1. Network initialization is performed with random values of weight ratios. All weight ratios have been taking random values from the [-0,3;0,3] interval during network initialization.
2. Current output signals for random input vector selected from the training set were calculated with formulas (1) and (2).
3. Setting up the synaptic weight ratios of the links between the network neurons.

Link weight ratios of links are adjusted towards the anti-gradient of the networks error objective function defined by the formula (3).

$$E(w(n))=\left(\sum_{i=1}^{6}\left(f\left(\sum_{k=1}^{10} v_{ik}(n) f\left(\sum_{j=1}^{61} w_{kj}(n) x_j^{(n)}\right)\right)-t_i^{(n)}\right)^2\right)\Big/2, \qquad (3)$$

where n is discrete time; w and v are the matrix of weight ratios; $x_j^{(n)}$ is the coordinate of the input vector submitted during n; $t_i^{(n)}$ is the i coordinate of the target vector ; $f(\cdot)$ is the activation function of neurons of hidden and output layers.

The adjustment of the synaptic weight ratios is done with formulas (4) and (5).

$$v_{ik}^{N+1} = v_{ik}^{N} - \eta(\delta_i)_l^N \left(y_k^c\right)_l^N, \qquad (4)$$

Here $\delta_i=(y_i-t_i)(1-y_i{}^2)$. In our study, the rate of training is $\eta=0{,}1$.

$$w_{kj}^{N+1} = w_{kj}^{N} - \eta\left(\sum_{i=1}^{p}(\delta_i)_l^N v_{ik}^N\right)\left(1-\left(\left(y_k^c\right)_l^N\right)^2\right)(x_j)_l^N. \qquad (5)$$

Steps 2 and 3 are repeated until an acceptable level of I and II type errors defined in the training set is reached. The outputs of the network during the classification process are calculated with the formulas:

$$y_i(n)= f\left(\sum_{k=1}^{10} v_{ik}(n) f\left(\sum_{j=1}^{61} w_{kj}(n) x_j^{(n)}\right)\right), \qquad (6)$$

The formula includes $i=\overline{1,6}$.

Let us consider the training algorithm compiled by combining the back error propagation training and Cauchy stochastic training. In this case, the step-by-step adjustment of weights during the training process is carried out not only towards the assessment of the objective function anti-gradient, but includes a stochastic component as well.

The recalculation of weight ratios is done with the formulas:

$$v_{ik}^{N+1} = v_{ik}^{N} - \eta\alpha(\delta_i)_l^N \left(y_k^c\right)_l^N + (1-\eta)v_c, \qquad (7)$$

$$w_{kj}^{N+1} = w_{kj}^{N} - \eta\alpha\left(\sum_{i=1}^{6}(\delta_i)_l^N v_{ik}^N\right)\left(1-\left(\left(y_k^c\right)_l^N\right)^2\right)\left(x_j\right)_l^N + (1-\eta)w_c, \quad (8)$$

Where N is a discrete point in time, η - the factor controlling the relative magnitudes of the gradient and the stochastic component weight, α - speed training, $\delta_i = (y_i - t_i)(1-y_i^2)$, v_c and w_c - stochastic changes in the corresponding weights.

The value of the objective function was calculated after adjusting the weight ratios.

If a network error was reduced, the changes of weight ratios were still in place.

Otherwise, the new weight was saved with the "probability" defined by the Cauchy distribution:

$$p(w) = \frac{T(N)}{T^2(N)+w^2}, \quad (9)$$

Where $T(N)$ is artificial temperature, considered as a time function:

$$T(N) = \frac{T_0}{1+N}, \quad (10)$$

Where T_0 is the initial artificial temperature.

The stochastic components of the weight ratio adjustment are calculated with the formula:

$$v_c = w_c = \alpha T(N)\ tg(P(w)), \quad (11)$$

Where $P(w)$ is a "probability" characteristic of the weight change per w_c.

A random number from a uniform distribution on the $(-\pi/2; \pi/2)$ interval was chosen as $P(w)$. The negative part is introduced into consideration for a random determination of the

RESULTS AND DISCUSSION:

The experimental part of the work included a study in the adequacy of the developed models to real electrophysiological processes.

As indicated above, the computer modeling of ANN training by back error propagation algorithm and by a combination of gradient and stochastic methods has been carried out with Lazarus software. To evaluate the clinical effectiveness of the classification, records of interpulse intervals in 139 healthy students of Belgorod State University have been analyzed. All of them were part of the same age and social group from 17 to 24 years old.

In practice, the ANN training algorithm using the back error propagation method enabled a correct recognition of 96.0% of the samples. Only 4.0 % of cases failed to be detected correctly. And all of them were attributed to hypodiagnosis. The algorithm has not allowed for any cases of hyperdiagnosis. The sensitivity of the recognition algorithm was 100.0 % (70.0/70.0 + 0.0), while the specificity of the differential diagnosis equaled to 86.7 % (26.0/26.0 + 4.0).

A test research resulted in 93.0 % cases identified correctly, with only 7.0% failures. Among the latter, cases of hyperdiagnosis amounted to 5.0 % of all cases, and cases of hypodiagnosis amounted to only 2.0 %. The sensitivity of the recognition algorithm was 97.1 % (68.0/68.0 + 2.0), the specificity of differential diagnosis equaled to 83.3 % (25.0/25.0 + 5.0). The neural network algorithm overestimated the class of the ANN degree of activity in 5%, and underestimated in 2% of cases [8].

The analysis of the clinical effectiveness of combining the back error propagation algorithm with Cauchy stochastic training showed that 100% samples were detected correctly both in training sets and in the test sets. Classification errors amounted to 0 %. Thus, the research enabled to find that artificial neural network is the best option of computerized medical systems used for the classification of degree of activity of autonomous nervous system in humans. It should be emphasized that the revealed facts may be used to detect different functional states in patients. This, in its turn, paves the way for developing innovative medical technologies in non-invasive cardiovascular monitoring.

CONCLUSIONS:

In this paper were obtained the following scientific results with a certain degree of novelty:

1. The model of an artificial neural network comprising the hidden layer and output layer was developed for solving the problem of medical classification. A distinctive feature of this network is that a hyperbolic tangent is taken as the activation function of the neurons in the hidden and output layers.
2. The algorithm of training has been compiled by means of the mathematical method of back propagation algorithm. In this case, the step by step adjustment of the weight ratios in the training process is carried out only towards the assessment of the objective function anti-gradient.
3. A training algorithm has been developed by means of combining the mathematical method of back propagation algorithm and Cauchy stochastic training. This method is aimed at the elimination of the drawbacks algorithm of backward propagation of the error associated with the interruption of the training process in local minimums of error and re-training network. The distinguishing feature of this algorithm is the ability to optimize the neural network training through the implementation of the mechanism of adjusting the probability weight ratios in the range from the local to the global minimum.

4. The computer applications have been created for the evaluation of the adequacy of the developed models. A special module consists of a complex problem-oriented program intended to optimize the decision-making process in medical diagnostics. Criteria to evaluate the effectiveness of diagnostics by means of created neural network algorithms have been elaborated. These criteria were computed in terms of sensitivity and specificity. Distinctive features of the criteria relate to the low level of errors of the first and second kind.

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