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Application of Artificial Neural Networks for Analysis of Pathologies in Blood Vessels

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Abstract: The aim of this work is to study the possibility of using artificial neural networks to identify and characterize pathologies in blood vessels. The studies carried out to analyze the results of Doppler ultrasound of the arteries of the lower extremities and to find the position and characteristics of atherosclerotic plaques in the longitudinal section of the carotid artery. Because of the study, models of neural networks were designed that can solve the assigned tasks with an error of no more than 9%.

Key words: neural networks, pathologies in the vessels, ultrasound doppler.

Introduction

Formulation of the problem

In modern medicine, information technologies are widely used in the diagnosis and treatment of various diseases. The main task of creating such systems is to improve the quality indicators of diagnosis and treatment. Therefore, works aimed at finding new solutions for the creation of such systems are relevant. Despite all the advantages of neural networks, there are many difficulties in their implementation in medicine. This is because the neural network does not provide any documentary justification for why it considers this particular diagnosis to be correct. In addition, doctors can only literally “trust the machine”, which does not quite suit them.

Analysis of the literature

Continuing interest in neural network methods that observed recently explained by the fact that they are very successfully applied in various fields - where it is required to solve problems of forecasting, classification and control. Neural networks have the ability to nonlinear modeling in combination with a relatively simple implementation and this is what makes them indispensable for solving complex multidimensional problems, including medical ones [1]. With the advent of the first computers, humankind strives to shift the solution of most tasks onto their shoulders. One of the most difficult and most important medical problems is the problem of correct diagnosis based on the analysis of numerous parameters of the human body. In addition, of course, it attracts the very opportunity to automate this process so that the result (the diagnosis

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itself) is not influenced by the so-called "human factor", since its influence can be not only positive, but also negative. A positive effect is the medical experience gained over the years of medical practice, and a negative one is the doctor's poor health. Currently, many medical decision systems are known, but serious methodological difficulties stand in the way of developing such systems. Indeed, how to systematize knowledge if different specialists understand the same disease in different ways and this is a typical situation in medicine? How to accurately characterize a rather complex clinical situation using logical rules? Finally, and this is the main, most important difficulty, the necessary knowledge at the time of system development may not exist at all. For example, modern medicine does not have effective capabilities to detect cancer diseases in advance, and there is insufficient knowledge about the pathogenesis of atherosclerosis, hypertension and heart rhythm disturbances. In addition, this list could be continued for a very long time. Therefore, attempts are being made to create a system that would know more than its creators [3]. Ideally, the diagnostic method should have one hundred percent sensitivity (do not let sick people pass) and, at the same time, one hundred percent specificity (do not refer healthy people to sick people). Typically, high sensitivity results in low specificity. This is because not all people go beyond the established norm for a certain parameter to mean a disease. Here the individual characteristics of the human body come into force. Ideally, the “sick / healthy” line should be drawn for each person individually. Increasing the sensitivity of the method without decreasing its specificity allows neural networks, which are nonlinear systems that allow much better data classification than the commonly used linear methods. Neural networks turned out to be able to make decisions based on hidden patterns in the data that they identified. They are not programmed - they do not use any inference rules to make a diagnosis, but learn to do this by example. This is the main difference between neural networks and expert systems. Another advantage of neural network technologies is that they are able to carry out classification, generalizing previous experience and applying it in new cases [3]. In the beginning, it was assumed that the neural network should function like the human brain. A huge number of neurons and their connections are responsible for maintaining the unique abilities of the human body. The brain is able to process huge streams of information almost instantly when it itself consists of slow-acting cells. However, even the very first networks had little resemblance to it and their capabilities were very limited. With the further development of neural network technologies, developers are forced to create artificial networks with properties that are not possible in living nature [4]. Neural network methods can be used independently or serve as an excellent addition to traditional methods of statistical analysis, as will be seen from the next part of the article [6]. In the modern world, doctors can use the capabilities of neural networks for the correct diagnosis, cleaning biological signals from noise, separating useful data

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from the variety of data available according to certain criteria [2]. In addition, these are far from all the possibilities that can be implemented using ANN. As an example of large systems, one can cite centralized systems of medical diagnostics, in which the number of classified diseases reaches many tens, and the number of symptoms exceeds several hundred. Such systems consist of several levels, at each of which, because of the work of local recognition systems, symptoms are determined, which are used at subsequent levels of the system to determine more complex symptoms.

Neural network technologies are designed to solve difficult-to-formalize problems, to which, in particular, many problems of medicine are reduced. This is primarily because the researcher is often provided with a large amount of heterogeneous factual material for which a mathematical model has not yet been created. In addition, it is necessary to present the analysis results in a form that is understandable to a specialist in the application field. One of the most convenient tools for solving such problems is artificial neural networks - a powerful and at the same time flexible method for simulating processes and phenomena. Neural networks are different in structure and shape, but they have a few things in common. At the core of every neural network are simple elements called artificial neurons that mimic the way neurons in the brainwork. A distinctive feature of neural networks is their ability to learn based on experimental data from the subject area. With regard to medical topics, experimental data are presented in the form of a set of initial signs or parameters of an object and a diagnosis based on them. Neural network training is an interactive process, during which the neural network finds hidden nonlinear relationships between the initial parameters and the final diagnosis, as well as the optimal combination of weight coefficients of neurons connecting adjacent layers, at which the error in determining the image class tends to a minimum [4]. In the learning process ("with a teacher"), a sequence of initial parameters is fed to the input of the neural network along with the diagnoses that these parameters characterize. Careful formation of the training sample determines the quality of work, as well as the level of error of the neural network.

A number of difficulties are associated with the use of neural networks in practical tasks. One of the main problems in the application of neural network technologies is the previously unknown degree of complexity of the designed neural network, which will be sufficient for a reliable diagnosis. This complexity can be prohibitively high, requiring more complex network architecture. It is known, for example, that the simplest single-layer neural networks are capable of solving only linearly separable problems [10]. This limitation can be overcome by using multilayer neural networks. This study describes the experience of using multilayer neural networks of various architectures for finding the position and characteristics of atherosclerotic plaques in a longitudinal section of the carotid artery, as well as analyzing the results of Doppler

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ultrasound of the arteries of the lower extremities. Let us compare the neural network approach with statistical methods. Statistical methods (regression analysis, multiple correlation, etc.) are widely used in medicine when making a diagnosis. However, real data are often fuzzy, with gaps, and dependencies on the input data can have strong non-linearity. All these problems, including fast retraining, can be solved by using artificial neural networks. The neural network can also reduce the dimension of the input data space, leaving the most essential ones. Nevertheless, statistics and neural network technologies should not exclude, but complement each other, especially since there is powerful software for statistical methods.

Application of artificial neural networks for analysis of the results of ultrasonic dopplerography of the arteries of the lower limbs

The severity of ischemic syndrome of the lower extremities in occlusive diseases of the abdominal aorta and its branches is due to peripheral circulatory failure and depends on the localization of the stenosis [1]. Doppler diagnosis not only confirms the presence of stenosis, but also determines its localization and length. When making a diagnosis of stenosis in the lower extremities using Doppler ultrasound, both direct and indirect signs play a role [1]. Direct signs are determined by analyzing the blood flow of the femoral, popliteal and posterior tibial veins. An indirect criterion of deep vein obstruction is an increase in blood flow velocity in the superficial veins. Only a combined assessment of both criteria allows for an accurate diagnosis. All these signs are revealed by comparing the blood flow in the veins at symmetrical points of the opposite lower limb. The analysis of Doppler blood flow signals during examination of the arteries of the lower extremities is characterized by the identification of parameters that, with a certain experience, provide a reliable opportunity for the location and differentiation of normal and pathological vessel signals [7]. The task is to determine the diagnosis of the presence of stenosis in the examined extremities based on the parameters revealed after Doppler scanning with a certain degree of reliability.

To solve the problem, a two-layer feed forward neural network model was chosen. Neural networks consisting of two or more layers have several distinctive features [11]:

- Each neuron in the network has a non-linear activation function; - the network contains one or more hidden layers of neurons that are not part of the input or output of the network; - the network has a high degree of connectivity. The nonlinear logistic activation function most widespread in multilayer perceptrons was chosen as the activation function for the neurons of the network (Fig. 1). The logistic (sigmoid) function is determined by the formula

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$$f(S)=\frac{1}{1+e^{-S}},$$

where S is the weighted sum of the neuron input signals. The presence of nonlinearity plays an important role, since otherwise the "input - output" mapping of the network can be reduced to an ordinary single layer perceptron, which is not capable of solving nonlinear problems [10].

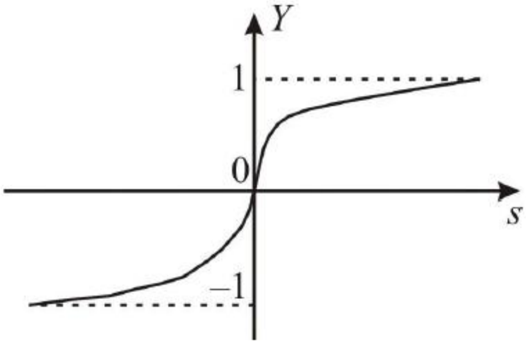

Figure: 1. Logistic activation function, where S is the weighted sum of the input signals of the neuron, Y is the value of the activation function

The input layer of the neural network, which performs the task of transferring input values to the hidden layer, consisted of 36 neurons, which corresponded to the number of considered initial parameters for making a diagnosis. The number of neurons in the hidden layer is usually selected experimentally [5]. As a result of the experiments, a hidden layer was selected, consisting of 16 neurons, while the output layer consisted of 2 neurons, which correspond to the probabilities of finding an atherosclerotic plaque in the studied vessels. It is believed that if the error in the operation of a neural network with data that is not involved in the learning process is within the established norm, then the network has a good learning ability. One of the factors that determine the generalizability of a neural network is the size and representativeness of the training sample. The training sample is usually formed from examples, each of which is the result of a domain experiment with a specific answer. As a training sample, 1000 initial parameters of blood flow Doppler sonographer were compiled with the corresponding diagnosis, which corresponded to the real data encountered in practice [8]. A neural network of a given architecture was trained and tested. Testing was carried out on a sample composed of blood flow Doppler sonographer parameters not involved in neural network training. The error in determining the diagnosis on the test data was ≈ 8%.

Application of artificial neural networks to find the position and characteristics of atherosclerotic plates in the longitudinal section of the carotid artery

Unlike the first approach, in which a neural network processes numerical data, this approach analyzes a graphic object directly, such as a photograph. The task is to find the

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position of the atherosclerotic plaque on the longitudinal section of the carotid artery (Fig. 2) [6], the image of which was obtained using an ultrasound diagnostic apparatus. Neural networks that solve pattern recognition problems require a large number of similar instances representing a certain class of objects. In this study, such specimens are images of vessels with impaired patency and with a narrowed lumen, expressed in the presence of atherosclerotic plaques on various vessel walls, as well as vessels with intact patency and a normal state of the lumen. The first step to solving the problem was the formation of a volumetric training sample, consisting of images of vessels with lesions in the form of atherosclerotic plaques, and vessels without such lesions. The images were transformed into models (Fig. 3) for the convenience of presenting them as an input to the neural network. The vascular patterns as well as the location and shape of the lesions are consistent with [3, 6]. All images had the same dimension m × n, where m is the horizontal size of the image and n is the vertical

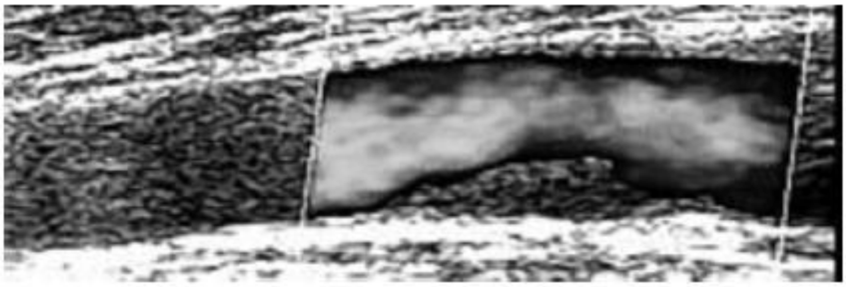

Figure: 2. Image of an atherosclerotic plaque in the carotid artery

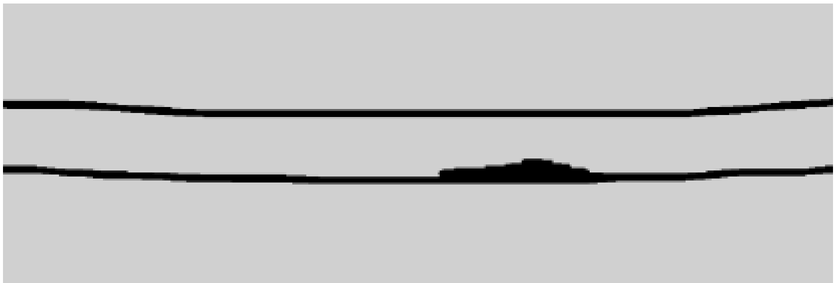

Figure: 3. An example of a model of an artery with an atherosclerotic plaque

There are several ways to represent the original image as an input sequence of a neural network: - an n × m image is written as a vector m · n; - additional processing of the image is carried out in order to fix the most informative sections and transform them into some array of numbers. The first method is most widespread, its advantage is that it does not require additional image processing, which in some cases can turn into a rather capacious task [10]. However, the disadvantage of this method is that a large amount of memory is required to form such vectors, and the learning rate of the neural network drops significantly. To solve the problem, the second way of representing the image as an input vector of the neural network was chosen. The most informative areas of the image in this case were such indicators as the geometry of the vessel,

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patency, wall thickness, diameter and state of the lumen. As a result, the training sample was obtained using the formula

$$V = \bigcup_{i=1}^{l} V_i$$

where l is the number of input images, Vi is the input vector of the i-th image, V is the training sample. The output of the neural network, or the result of its work, was considered the coordinates of the location of the stenosis on the model image of the vessel. If stenosis was not observed, then the sequence returned, signaling this. As the architecture of the neural network, a two-layer feed forward neural network model was chosen. The dimension of the input layer of the neural network corresponded to the dimension of the input vector and was equal to 3600 neurons. As a result of experiments with the number of neurons in the hidden layer, the following tendency was observed: - when using a hidden layer consisting of 1200 neurons or less, the learning process slows down proportionally to the decrease in the number of neurons, and the learning error increases; - when using a hidden layer, consisting of more than 1200 neurons, the learning process was performed in less time, but due to the complexity of the network architecture, it needed to perform more computational operations, which also reduced the learning rate, and the learning error practically stopped decreasing. A hidden layer consisting of 1200 neurons was chosen as the optimal one. The dimension of the output layer was also determined by 1200 neurons. A logistic nonlinear function was chosen as the activation function for the neurons of the network (see Fig. 1). The general architecture of the neural network is shown in Fig. 4. A detailed description of the symbols used in fig. 4 is in [5].

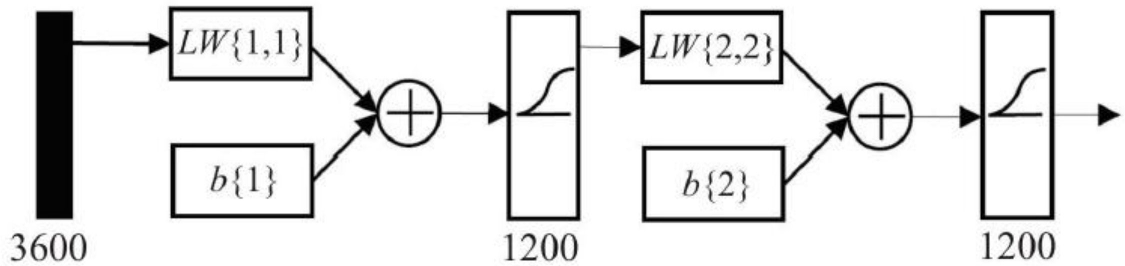

Figure: 4. Neural network architecture, where b {i} is the displacement vector of the i-th layer, LW {i, j} is the matrix of weights from layer i to layer j

The neural network was trained on a sample consisting of 500 images of vessels in which stenosis was observed, as well as from vessels in which it was not. The neural network was trained by one of the most popular algorithms for training multilayer neural networks - the error backpropagation algorithm [7]. This algorithm is based on error correction, when synoptic weights are adjusted in order to maximize the output of the network to the desired in the

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statistical sense [7]. Learning continued for 500 epochs, after which the error level reached its minimum value and learning was stopped [2]. Testing of the trained neural network was carried out on a testing sample consisting of 100 elements. The error of the neural network on the testing data was calculated by the formula

$$S_i = \frac{\left|Y_i^{\exp} - Y_i\right|}{Y_i^{\exp}} 100\%$$

where Si is the error of the i-th result, n is the amount of testing data, i are the numbers 1, n, Yi is the result of the neural network, Yi exp is the expected result.

Conclusions

In this paper, two different ways of using artificial neural networks for the analysis of pathologies in blood vessels were considered. In one of the approaches, the neural network worked with the initial parameters to determine the diagnosis, which were represented as a set of numbers, while the other approach involved using a direct graphic image of the vessel. In both cases, neural networks of the same topology were built, but differing in the number of neurons involved in different layers of the neural network. The results of training and testing the performance of the designed neural networks show their successful application for solving the assigned tasks and the ability to find complex patterns and relationships between various objects belonging to the same data class. It can also be assumed that when using more capacious and diverse training samples, the errors in the operation of neural networks will decrease. Once trained, the network becomes a reliable and inexpensive tool for analyzing pathologies in blood vessels.

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