Application of the Kohonen neural network for monitoring tissue oxygen supply under hypoxic conditions

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Abstract. The article presents the results of application of the Kohonen artificial neural network (KANN) in assessing the oxygen status of human tissues, as well as for studying the adaptive-compensatory response of the body to functional load. In the experiment, the registered digital oxygen images of the tissue of 31 subjects were distributed into three classes using the KANN. Each group is characterised by different resistance of the organism to hypoxia. The research results have shown the effectiveness of using an artificial neural network structure and the possibility of its implementation for recognition of the functional state of a person under conditions of metabolic hypoxia; it seems relevant and has theoretical and practical significance in the framework of ecological physiology.

1. Introduction
In the modern world, there is a constant deterioration of the ecological situation [1-10]. Deterioration of the environment has a negative impact on human health [11-16]. For this reason, it is required to pay increased attention to the control of health at different time intervals, especially in moments of poor health [17-23]. In this situation, the development of devices for express diagnostics of the state of human health, as well as support systems for making medical decisions is extremely relevant [21-28].

During the operation of such systems, a number of problems arise [21, 22, 25-27, 29, 30], one of which is associated with obtaining a large amount of unstructured data, which often require automated processing. One of the possible options for solving this problem is the intellectualization of information processing using data mining methods: cluster analysis algorithms and artificial neural networks [31-35]. The task of data mining is to identify latent rules and patterns in data sets, and data mining methods are a direction that complements classical statistical research methods. To date, algorithms built on the basis of neural networks show decent results in various fields of human activity and fields of science [15-18, 20, 33, 34, 36]. In addition, ANNs have many advantages over traditional computational methods. The advantages of neural networks, which include the ability to solve problems with unknown patterns, high resistance to noisy data, low error rate, potentially high speed, continuous improvement and optimization of various network learning algorithms, make neural networks an increasingly promising direction in data mining.

Today there are many different artificial neural networks, differing in many parameters for learning, generalization, abstraction. One of the popular classes of neural networks is the Kohonen neural network in the form of Self-organizing Kohonen maps (SOM). Self-organizing process is a learning process without a teacher. With such training, the training set consists of the values of the input variables, and in the training process there is no comparison of the outputs of neurons with the desired values. Self-organizing Kohonen maps are used for visualization, forecasting, searching for patterns in large data sets, identifying independent
features and reducing the dimension of the feature space. In particular, the capabilities of SOM can be used to solve a wide range of non-formalized problems in the field of medical diagnostics, as well as for clustering and classification of various medical indicators [37, 38].

Most of the known diseases are directly or indirectly associated with oxygen deficiency in the organs and tissues of the body. Hypoxia is one of the main biologically significant factors that a person encounters throughout his life. Oxygen deficiency can occur in tissues due to dysfunction of the cardiovascular and respiratory systems, and negatively affect the development of various pathological processes in the human body. In this regard, the assessment of the oxygen supply of tissues with oxygen is of great importance both in express diagnostics of the general functional state of the human body and in the therapy of critical conditions.

The proposed work describes the application of an artificial neural network of the SOM for the analysis of oxygen digital tissue images containing information about the oxygen status of human tissues and recorded using the developed optical non-invasive complex, in order to project data into a space of lower dimension, identify the cluster structure and classify them.

2. Method

Registration of oxygen digital tissue images, which contain information about the oxygen status of tissues, was carried out using the developed non-invasive optical medical diagnostic complex [37]. The complex is based on a six-channel analyzer of optical spectra of the visible range, which detects backscattered light in tissues. The principle of operation of the instrumental complex is based on the ability of hemoglobin to absorb light of a certain wavelength, while the degree of light absorption depends on the percentage of oxyhemoglobin in the blood. Each oxygen digital tissue image represents the readings of the optical sensors of the diagnostic system, recorded at different points in time during the functional load. Operations related to system control, recording of results, processing and analysis of the obtained data are performed by the information module of the developed optical complex.

The obtained measurement results are analyzed using Kohonen Self-Organizing Maps. SOM are one of the various neural network algorithms. This algorithm solves clustering problems, and during training, the unsupervised learning method is used, that is, the training result depends only on the structure of the input data. An important feature of the algorithm for the functioning of self-learning maps is that all neurons are ordered into a certain structure (two-dimensional grid). At the same time, in the course of training, not only the winning neuron is modified, but also its neighbors in a certain radius, albeit to a lesser extent. Before starting training the map, it is necessary to initialize the weights of the neurons. Initialization occurs with random values, when all weights are given small random values. Self-organizing Kohonen maps are trained by the method of successive approximations using iterations in which neurons-vectors are corrected. At each iteration, one vector is randomly selected from the initial sample, and then a search is made for the vector of neuron coefficients most similar to it. The neuron most similar to the input vector is declared the winning neuron. As a criterion for the proximity and determination of the winning neuron, the criterion of the minimality of the Euclidean distance between the points specified by the coordinates of the vectors was chosen:

$$\|x - w_{ij}\| = \sqrt{\sum_{t=0}^{t_n} \left| x(t) - w_{ij}(t) \right|^2}$$

$$d = \min_{i,j} \|x - w_{ij}\|$$

where, $x$ is the input vector, $t$ is the current iteration, $x(t)$ is the input vector’s instance at iteration $t$, $w_{ij}(t)$ is the weight of the connection between the nodes $i,j$ in the grid, and the input vector’s instance at the iteration $t$, $d$ is the distance between vectors $x$ and $w$. 
After that, all the weights of the neural network are corrected, so that the winning neuron and its neighboring vectors in the grid are shifted towards the input vector, and both the winning neuron and its neighbors are modified. The weighting coefficients of the winning neurons and neurons lying in its vicinity are corrected by the following formula:

\[ w_{ij}(t + 1) = w_{ij}(t) + \alpha_i(t) \cdot \beta_{ij}(t) \cdot \left( x(t) - w_{ij}(t) \right) \]  

(3)

where, \( \alpha_i(t) \) is the learning rate, decreasing with time in the interval [0,1], to ensure the network converges, \( \beta_{ij}(t) \) is the neighbourhood function, monotonically decreasing and representing a node \( i, j \)'s distance from the winning neuron.

Thus, the change in the value of the weighting coefficient of the \( i \)-th neuron is the less, the further this neuron is located from the winner's neuron. If the neuron does not belong to the neighborhood \( S_w(t) \), then its weighting coefficient will not change. The execution of the algorithm will continue until the output values appear on the feature map. After the final organization of neurons into a specific structure, the resulting map is displayed, which is an n-dimensional grid. Further, for each cell, statistical characteristics are determined, which make it possible to assign certain color to a cluster of cells.

To assess the stability of a cluster solution, one can compare the clustering result that was obtained using SOM with the results of solutions obtained using other clustering algorithms (non-hierarchical, hierarchical).

In an experimental study, 31 healthy young people took part on a voluntary basis. All subjects performed the proposed functional load, which was holding the breath for the maximum possible time. During all periods of functional load (before breath holding, during breath holding and after breath holding), the readings were recorded using a non-invasive optical diagnostic system. During the measurements, each subject was in a sitting position; measurements were taken on the cyst of the left hand. The obtained oxygen digital images of each subject were multivariate data, which were further processed using SOM.

3. Results

To process the oxygen digital images of subjects obtained as a result of the study using SOM, the software environment R was used. The analysis used the readings that were recorded 4 minutes after the functional load (the recovery period after holding the breath). Prior to the application of the Kohonen neural network, the readings of each sensor were standardized with respect to the readings of each sensor, which were recorded before the functional load (resting state). As a result of using the neural network, the subjects were divided into 3 clusters. The result of grouping nodes of the Kohonen map is shown in figure 1.

![Figure 1](image)

Figure 1. Cluster nodes of the Kohonen map with the distribution of subjects by nodes.

Node clusters are highlighted in different colors: yellow, green, and blue. Each node contains a different number of objects (test subjects).
In addition, to assess the stability of the cluster solution, the same data was processed by the hierarchical clustering method. The created cluster solution coincided with the result of clustering by the hierarchical complete-linkage clustering method (figure 2), which indicates the statistical significance and stability of the cluster solution.

Figure 2. The result of cluster analysis using the complete-linkage clustering with splitting the tree into three groups.

Each cluster is characterized by both a different level of the body's resistance to hypoxia and a different general functional state of the subjects. Each cluster contains 20, 4 and 7 people, respectively. The results obtained are confirmed by independent biomedical research.

4. Conclusion
Thus, evaluating the result obtained using the network, we can conclude that self-organizing Kohonen maps can be used to solve the problem posed by us. The proposed approach to assessing the oxygen status of human tissues and recognizing the general functional state of a person has shown prognostic ability and can be used to create an intelligent information system for express diagnostics.

Acknowledgments
The study was carried out within the framework of State Assignment No. 075-00280-21-00 SU NIR 0074-2019-0013.

References
[1] Davydov V V, Cheremiskina A V, Velichko E N and Karseev A Yu 2014 Journal of Physics: Conference Series 541(1) 012006
[2] Kozlova E S and Kotlyar V V 2014 Computer Optics 38(1) 132-138
[3] Kuzmin M S and Rogov S A 2019 Computer Optics 43(3) 391-396
[4] Smirnov K J and Batov Y V 2019 Journal of Physics: Conference Series 1368(2) 022073
[5] Smirnov K J, Glagolev S F, Rodygina N S and Ivanova N V 2018 Journal of Physics: Conference Series 1038(1) 012102
[6] Gryznova E, Batov Y and Myazin N 2020 E3S Web of Conferences 140 09001
[7] Gryznova E, Grebenikova N, D. Ivanov D and Bykov V 2019 IOP Conference Series: Earth and Environmental Science 390(1) 012044
[8] Nikitina M, Grebenikova N, Dudkin V and Batov Y 2019 IOP Conference Series: Earth and Environmental Science 390(1) 012024
[9] Davydov V V 1999 Russian Physics Journal 42(9) 822–825
[10] Myazin N S and Yushkova V V 2019 Environmental Research, Engineering and Management 75(2) 28–35
[11] Davydov V V, Velichko E N, Dudkin V I and Karseev A Y 2014 Measurement Techniques 57(6) 684–689
[12] Davydov V V, Dudkin V I and Karseev A Y 2015 Technical Physics Letters 41(4) 355–358
[13] Davydov V V, Dudkin V I and Karseev A Y 2015 Technical Physics 60(3) 456–460
[14] D’yachenko S V and Zhernovoi A I 2016 Technical Physics 61(12) 1835–1837
[15] Myazin N S, Yushkova V V and Dudkin V I 2019 Journal of Physics: Conference Series 1400(6) 066008
[16] Rukin E V, Myazin N S and Dudkin V I 2019 Journal of Physics: Conference Series 1368(4) 042011
[17] Neronov Y I 2021 Biomedical Engineering 54(5) 333–336
[18] D’yachenko S V and Zhernovoi A I 2016 Technical Physics 61(12) 1835–1837
[19] Davydov V V, Dudkin V I and Karseev A Y 2015 Instruments and Experimental Techniques 58(6) 787–793
[20] Makeev S S, Grevtzeva A S, Glinushkin A P and Matorin D N 2020 Journal of Physics: Conference Series 1695(1) 012112
[21] Myazin N S, Yushkova V V and Taranda N I 2019 Journal of Physics: Conference Series 1410(1) 012130
[22] Marusina M Y and Karaseva E A 2018 Asian Pacific Journal of Cancer Prevention 19(10) 2771–2775
[23] Marusina M Y, Fedorov A V, Prokhorovich V E, Tkacheva N V and Mayorov A L 2018 Measurement Techniques 61(3) 297–302
[24] Myazin N, Neronov Y, Dudkin V and Petrov A 2019 IOP Conference Series: Materials Science and Engineering 497(1) 012111
[25] Davydov R V, Mazing M S, Yushkova V V and Stirmanov A V 2019 Journal of Physics: Conference Series 1410(1) 012067
[26] Grevtzeva A S, Smirnov K J, Greshnevikov K V and Glinushkin A P 2019 Journal of Physics: Conference Series 1368(2) 022072
[27] Grevtzeva A S, Smirnov K J, Davydov V V and Rud V Yu 2018 Journal of Physics: Conference Series 1135(1) 012056
[28] Myazin N, Neronov Y, Dudkin V and Yushkova V 2018 MATEC Web of Conferences 245 11013
[29] Myazin N S 2018 Journal Physics: Conference Series 1124(1) 031004
[30] Myazin N S 2018 Journal Physics: Conference Series 1135(1) 012061
[31] Logunov S E, Davydov V V, Glinuchkin A P, Podkovyrov I Yu and Rud V Yu 2019 Journal of Physics: Conference Series 1410(1) 012113
[32] Tuckova J 2013 11th International Workshop of Electronics, Control, Measurement, Signals and their application to Mechatronics (IEEE), p. 1-6
[33] Logunov S E, Rud V Y, Davydov R V, Moroz A V and Smirnov K J 2019 Journal of Physics: Conference Series 1326(1) 012024
[34] Grevtzeva A S, Davydov V V and Rud V Yu 2020 Journal of Physics: Conference Series 1697(1) 012079
[35] Valov A P, Davydov R V, Rud V Y and Grevtzeva A S 2019 Journal of Physics: Conference Series 1326(1) 012040
[36] Davydov V V, Logunov S E and Fadeenko V B 2018 Russian Journal of Nondestructive Testing 54(3) 213–221
[37] Mazing M S, Zaitceva A Y and Kislyakov Y J 2021 Springer Proceedings in Physics 255 233–239
[38] Mazing M S, Zaitceva A Y, Kislyakov Y Y, Avdyushenko S A and Davydov V V 2020 International Journal of Pharmaceutical Research 12 1974–1978