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ARTICLE

NEURAL NETWORK MODEL AND SOFTWARE COMPLEX TO DETERMINE PERSON'S FUNCTIONAL STATE

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ABSTRACT

This article deals with the definition of an intoxicated person functional state. They performed the analysis of pupillary response peculiarities to illumination changes. It is proposed to use the method of pupillometry for the analysis of pupillary reactions. They concluded that it is necessary to evaluate the values of the papillo gram parameters on the basis of the neuro net approach. The task was to develop a mathematical model and software to determine the functional state of a person's intoxication. The solution of this problem is carried out on the basis of neural network collective, formed according to the bootstrapping method. They proposed the methods to collect and prepare the initial data for analysis, to develop a neural network model, as well as the method and the algorithm to optimize the composition of the input and the number of hidden neurons of its neural networks. ROC analysis is used to find an optimal clipping point for solution classes generated at the output of neural network models. They provided the description of the neural network model, the developed software package, as well as the results of the research conducted on its basis. For the purpose of approbation, the problem of a person's intoxication is solved during a pre-trip medical examination. The conclusion is made about material, technical and time cost reduction during the survey conduct using the proposed approach, as well as the possibility and the effectiveness of its practical use in other areas.

KEY WORDS
functional state, neural network, pupillometry, diagnostics, ROC analysis, bootstrapping, reduction, genetic algorithm, pre-trip medical examination.

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INTRODUCTION

At present, the task of a person functional state (FS) determination acquires an urgency in various subject areas. A number of works are devoted to this problem solution. The change of mammal pupil size under the influence of light flashes was recognized as a reliable marker of brain activity, including human brain [1,2]. In addition to brightness change adaptation, the changes of a pupil diameter correlate with a person's excitation, attention, and perception changes [3-5]. Such diagnostic methods based on the evaluation of the pupillary response of a person refer to the methods of pupillomimetry. In [6] they proposed to use this method to determine the FS of athletes.

There are different classes of human FS [7]: normal, borderline, pathological ones. Among the latter they determine the FS, characteristic of alcohol or drug intoxication. In most cases, intoxication leads to a human visual system disorder. This feature allows you to identify human FS in medical diagnostic systems. Many scientists have been involved in this area research [8-11]. However, diagnostic systems, including those based on the methods of pupillometry, require the participation of qualified experts, the creation of special conditions and significant material, technical and time costs. These features of pupillometry method application in medical diagnostics reduce the possibility of its use in other areas.

The pupillometry allows to obtain the data, according to the analysis of which it is possible to classify the human FS. This problem should be solved on the basis of the neural network approach [12,13], which proved its effectiveness in diagnostic systems [14,15] and decision making support [16,17]. Many scientists contributed to the development of neuro cybernetics and the development of decision making support systems [18, 19]. However, they did not study completely the issues of neural network (NS) use in the determination of human FS based on pupillometry. This actualizes the need to develop new neural network models, the methods and the algorithms that can solve the task effectively. Thus, in order to determine the human FS according to the analysis of its pupillary response to light impulse, it is necessary to develop mathematical model and software based on the neural network approach.

METHODS

One of the criteria that affect the quality of a person's life is his FS, in particular the state of intoxication (alcoholic or narcotic). In this state, the intensity of pupillary reaction decreases, and the pupils are narrowed or widened as much as possible.

Pupillometry is an effective method of intoxication state diagnostics. In this method, the dynamics of a pupil size change is represented in the form of a time series - the pupillogram [Fig. 1].

The following parameters are indicated on the figure: ID - initial diameter, FD - final diameter, HCD - half constriction diameter, MD - minimum diameter, LRT - latent reaction time, HCT - half constriction time, HET - half expansion time, CT - constriction time, AC - the amplitude of constriction, and ET - the expansion time. Pupillometry also uses such parameters as the rate of narrowing (CC) and the rate of expansion (CP), calculated according to the initial data. Thus, each set of parameter values can be associated with the state of "norm" or "deviation". The totality of such values is the data to develop a model for a person intoxication state determination.

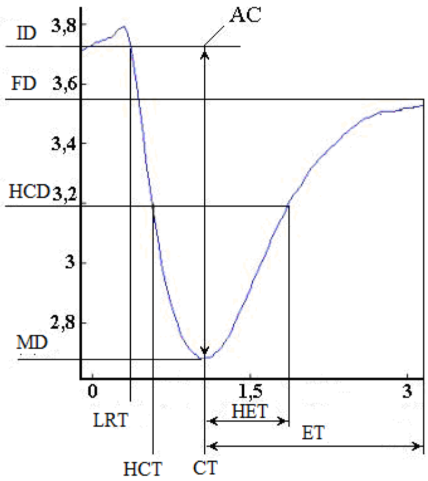

Fig. 1: Example of a pupillogram and its parameters.

The solution of time series problem analysis from pupillometry results is based on various methods. Discrete transformations are widely used in pupillometry. It is proposed to use a transient Fourier transformation in [20] to estimate the mental load. The parabolic and elliptic Haf transformations are used to recognize and measure a pupil size obtained from web camera data [21]. Wavelet transformations are used to analyze the results of pupillometry in [22]. Discrete Walsh transformations and their generalizations can be used effectively during the solution of time series analysis problems in the methods of pupillometry [23, 24].

At present, statistical methods are used to solve the problem under consideration: parametric, linear-discriminant, clustering, etc. The effectiveness of their use depends on data quality. At low detail of an image, the accuracy of the diagnosis is reduced. Therefore, in order to analyze the values of the pupillogram parameters under the specified conditions and to develop the binary classification model, it is important to use the methods of data analysis, in particular the NN, whose effectiveness is conditioned by their universal approximating ability, which allows them to solve practical problems with a high degree of accuracy.

Thus, in order to determine the state of a person intoxication on the basis of a neural network approach, the following developments are required:

1) the methods for the collection and preparation of baseline data for analysis;
2) the neural network model and the methods of its development;
3) the numerical method and neural network model algorithm reduction to increase the efficiency of its practical use;
4) software complex implementing the proposed methodologies, model, method and algorithm.

The methodology has been developed in order to collect and prepare data for analysis, consisting of the following steps:

1) the collection of initial data in changing illumination conditions;
2) the evaluation of source data quality;
3) source data cleaning;
4) the calculation of pupillogram parameter values;
5) the development of the initial data table with the calculated values;
6) quality assessment, data table cleaning and obtaining for analysis.

To implement the first stage, they developed the laboratory stand that includes a video camera and software to record and analyze the images of human eyes. All images were recorded for 3 seconds with a light pulse provision. The obtained data include noise, anomalous and missing values [25]. Therefore, during the second and the third stage of the methodology, the data quality is assessed and its cleaning takes place [26].

During the fourth stage, they calculate the values of the pupillogram parameters. Let us have the pupillogram P = {(t0, D0),..., (ti, Di),..., (tk, Dk)}, where t0 is the initial time moment (0 seconds), tk is the

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final time moment (3 seconds), D0 is the initial diameter of a pupil, Dk is the final diameter of the pupil. Then the values of the parameters will be calculated by the following formulas:

- $D_{\min} = \min(D_i), i = \overline{0, k}$ – MD;
- $t_s = t_i \mid D_i = D_{\min}$ – CT;
- $D_{ps} = \dfrac{D_0 + D_{\min}}{2}$ – HCD;
- $t_{ps} = t_i < t_s \mid D_i = D_{ps}$ – HCT;
- $t_{pr} = t_i - t_s \mid D_i = D_{ps}, t_i > t_s$ – HET;
- $t_r = t_k - t_s$ – ET;
- $A_s = D_0 - D_{\min}$ – AC;
- $V_s = \dfrac{A_s}{t_s}$ – CC;
- $V_r = \dfrac{D_k - D_{\min}}{t_r}$ – CP;
- $t_l = \min(t_i) \mid D_i < D_0$ – LRT.

During the fifth stage, the obtained values are reduced to the table showing the class of the human FS. During the sixth stage, quality assessment, purification and the obtaining of a ready-made data table for analysis are performed see [Table 1].

Table 1: Data fragment to develop a neural network model

№	D_0	D_{min}	D_{ps}	D_k	A_s	V_s	V_r	t_l	t_s	t_r	t_{ps}	t_{pr}	Class
1	5,4	4	4,7	5,2	1,4	2,6	0,5	0,2	0,5	2,4	0,2	1,1	0
2	5,5	4,1	4,8	5,4	1,5	2,8	0,6	0,2	0,5	2,3	0,2	1	0
3	5,4	4,1	4,7	5,2	1,2	2,2	0,5	0,2	0,6	2,2	0,2	1	0
4	5,5	4	4,7	5,1	1,5	2,8	0,3	0,2	0,5	2,2	0,2	1,1	0
5	2,6	2,6	2,6	2,6	0,1	0,1	0,1	0,3	0,3	2,4	0,1	1,1	1
6	2,6	2,6	2,6	2,6	0,1	0,2	0,1	0,2	0,4	2,4	0,1	1,1	1
7	7,1	6,7	6,9	6,9	0,3	0,6	0,1	0,2	0,5	2,2	0,2	1	1
8	7,3	6,7	7,1	7,1	0,6	1,1	0,2	0,3	0,5	2,2	0,2	1	1

In order to develop a neural network model based on the analysis of the obtained data, the following procedure was developed:

1) To form the structure of the NN on the basis of Arnold-Kolmogorov-Hecht-Nielsen theorem for the whole set of input parameters [18];
2) To develop an initial neural network model of the given structure, to find an optimal cut-off point for class solution by the ROC-analysis method and to estimate the model error by bootstrapping method [26];
3) in order to increase the accuracy and to reduce the dimension of an original model structure, to reduce it by clarifying the composition of the input and the number of hidden neurons based on the genetic algorithm.

In order to solve this problem, the perceptron model NS was developed. The number of its hidden neurons is determined by the corollary of the Arnol'd-Kolmogorov-Hecht-Nielsen theorem on the basis of the following expression [18]:

$$N_h \le 2 \times N_{in} + 1, \quad (1)$$

where Nh is the number of hidden neurons, and Nin is the number of input neurons.
Thus, taking into account (1), the initial model consists of 12 input neurons, 25 hidden neurons and one output neuron.

In order to select an optimal clipping point to cut off solution classes in the neural network model, the ROC analysis method was used. The criterion for an optimal cut-off point $Cutt\_off_o$ selection is the reduction of errors of the first kind according to the rule:

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$$Cutt\_off_o = Cutt\_off_k \Big| Se = \max_{k=1,K}(Se_k) \;\&\; k = \max[1, K]$$

[Fig. 2] shows the example of cut-off point selection rule.

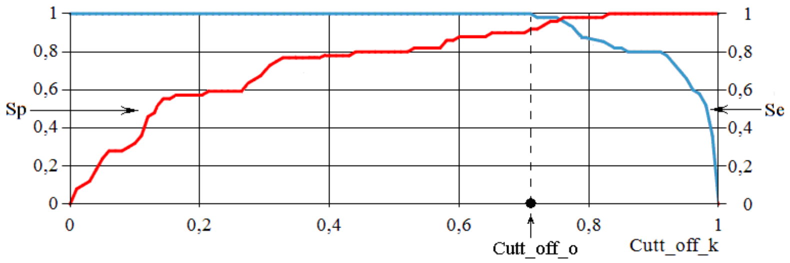

Fig. 2: Example of cut-off point selection.

Therefore, among the set of all cut-off points K, the optimal point should be on the right side of the maximum sensitivity range (Se) boundary, at which the specificity (Sp) is maximum.

In order to estimate the model error, the bootstrap method is used to form N random sets of training and test samples with the calculation:

- $\varepsilon_{train} = \dfrac{n_{train}}{N_{train}}$ – model error in learning, where n_{train} is the number of correctly classified learning examples, N_{train} is the volume of the training sample;

- $\varepsilon_{test} = \dfrac{n_{test}}{N_{test}}$ – model error in testing, where n_{test} is the number of correctly classified test cases, N_{test} is the volume of the test sample.

After the i-th (i = 1..N) iteration, the error is calculated: $\varepsilon_i = 0{,}632 * \varepsilon_{testi} + 0{,}368 * \varepsilon_{traini}$.

Final model error: $\varepsilon = \dfrac{\sum_{i=1}^{N} \varepsilon_i}{N} \times 100\%.$

Thus, during bootstrapping, the team of N NS of the same architecture is developed. The result of the classification is the aggregation of all NN decisions on the basis of voting see [Fig. 3].

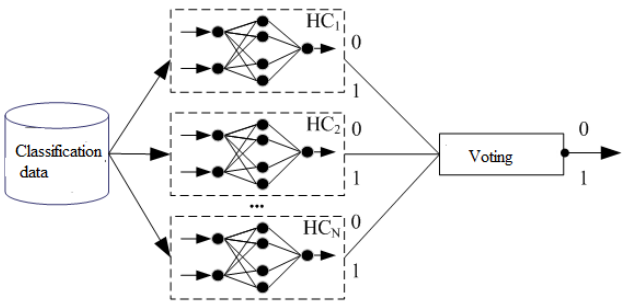

Fig. 3: NN collective model application scheme.

Typical results of bootstrapping at N = 7 are presented in [Table 2].

Table 2: Typical bootstrapping results

Item №	ε_{train}	ε_{test}	ε_i	ε, %	Model accuracy
1	0,04	0,09	0,07	6,8	91%
2	0,06	0,05	0,05		
3	0,03	0,02	0,02		
4	0,04	0,11	0,08		
5	0,08	0,09	0,09		
6	0,03	0,12	0,08		
7	0,04	0,09	0,07		

According to the presented results, the adequacy of the initial model is not high. The accuracy of the model can be improved by the elimination of its constituent redundancy. To solve this problem, the method and the algorithm for genetic optimization has been developed to reduce the number of input and hidden neurons. Let the set $N^{in} = \{N_1^{in}, N_2^{in}, \ldots, N_{m_1}^{in}\}$ contains the neurons of the input layer $N_j^{in}, j = \overline{1, m_1}$ (m1 – the number of input neurons), and the set $N^{hid} = \{N_1^{hid}, N_2^{hid}, \ldots, N_{m_2}^{hid}\}$ are the neurons of the hidden layer $N_l^{hid}, l = \overline{1, m_2}$ (m2 – the number of hidden neurons). Let's encode the input layer of the network in the form of the chromo some $H_i^{in} = \{h_{ij}^{in}\}$, where the single gene h_{ij}^{in} means the presence of the input layer neuron, and the zero gene is its absence. The hidden layer of the network is encoded as the chromosome $H_k^{hid} = \{h_{kl}^{hid}\}$ with a similar representation of the gene h_{kl}^{hid}.

The examples of chromosome encoding of the input and hidden layers:

H_k^{hid}	0	1	1	1	0	0	1	...	1
	N_1^{hid}	N_2^{hid}	N_3^{hid}	N_4^{hid}	N_5^{hid}	N_6^{hid}	N_7^{hid}	...	$N_{m_2}^{hid}$

H_k^{hid}	0	1	1	1	0	0	1	...	1
	N_1^{hid}	N_2^{hid}	N_3^{hid}	N_4^{hid}	N_5^{hid}	N_6^{hid}	N_7^{hid}	...	$N_{m_2}^{hid}$

The creation of the initial population of chromosomes of the input layer (volume m1) is performed by the inclusion of the parent chromosome in the population from single genes and a set of descendants obtained as the result of random mutation of its genes with the probability of 0.5. The reduction of NN structure is reduced to the search for chromosomes of the input and hidden layers, under which the final model error and the number of elements of its structure are minimal.

The fitness function is determined as follows:

$$F(H_{ik}) = \frac{\sum_{b=1}^{N} 0{,}632 * \varepsilon_{test_b}^{ik} + 0{,}368 * \varepsilon_{train_b}^{ik}}{N} \to \min_{\forall H_{ik}}, \quad (2)$$

where $H_{ik} = H_i^{in} + H_k^{hid}$ – the chromosome for NN structure coding.

Let's consider the implementation of genetic operators. At the first stage, according to the formula (1), the NN generation is performed corresponding to the initial chromosomes of the input layer. The following is performed for each network:

1.1) the creation of the initial chromosome population of the hidden layer (volume m2) in the following composition: the parent chromosome from single genes and the set of descendants obtained as the result of random mutation of its genes with the probability of 0.5;
1.2) the estimation of all chromosome fitness according to the formula (2);
1.3) the selection of 2 parent chromosomes based on the roulette wheel method;
1.4) the crossing of the parent chromosomes to obtain 2 descendants;
1.5) the mutation of offspring by the inversion of their genes with the probability of 0.02;
1.6) the evaluation of descendant fitness according to the formula (2);

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1.7) the reduction of the 2 worst chromosomes to form a new population.

The steps 1.3-1.7 are performed until chromosomes with better fitness appear. After that, the chromosome $H_i \Leftrightarrow \min F(H_k^{hid})$ is selected. Adaptability of input layer chromosomes:

$$F(H_i^{in}) = F(H_i) = \min F(H_k^{hid}).$$

The second stage is the search of a set corresponding to the NN with a minimum classification error. To do this, the steps similar to the first step are performed. This stage is repeated until chromosomes with better fitness appear. The best one determining the structure of the desired NN is chosen from the final set of chromosomes.

[Fig. 4] shows the desired NN collective model, obtained after the reduction of its constituents.

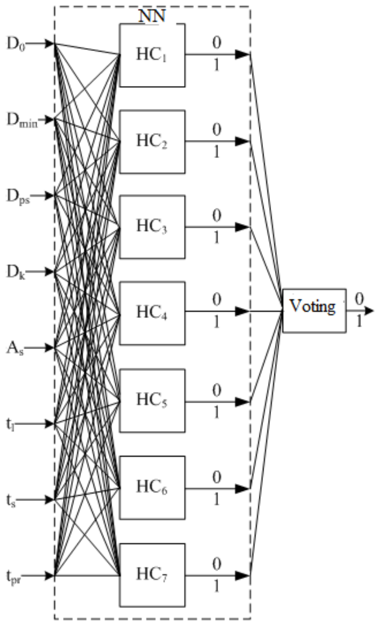

Fig. 4: NN collective model.

The desired model consists of 7 reduced NN with 10 hidden neurons and 8 input neurons, whose composition is determined by the following parameters: D0, Dmin, Dk, Dps, As, tl, ts, and tpr. After the reduction, the accuracy of the model made 96.7%, which corresponds to the error of 3.3%. Since the error makes no more than 5%, the obtained model is adequate.

RESULTS AND DISCUSSION

Based on the proposed methodologies, method and algorithm, the software package was implemented in Microsoft Visual Studio environment via C# language. This complex consists of three programs see [Fig. 5].

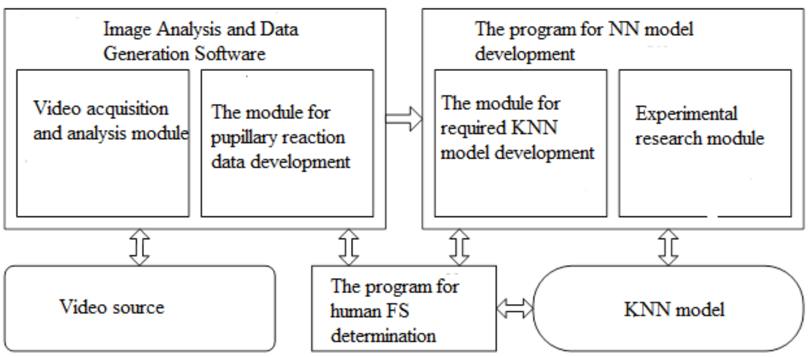

Fig. 5: Software complex structure.

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The first program consists of two modules responsible for video image obtaining and analysis and pupil response data generation. The second program consists of the modules for neural network model development, the evaluation of their adequacy, the reduction and the conduct of studies to assess the impact of various parameters on the NN collective model adequacy. The third program is used to determine the human FS.

Let us consider the results of the studies on the evaluation of method effectiveness and NN reduction algorithm see [Table 3].

Table 3: NN reduction results

№	Input parameters of the model	Amount: In. neuron	Amount: Hidden neuron	Model accuracy, %	Stage number $ГA_1$ / $ГA_2$	Reduction time, in min.
1	D_0, D_{min}, D_{ps}, V_s, t_l, t_s, t_{ps}, t_{pr}	8	11	96,2	20/492	40
2	D_{min}, D_{ps}, A_s, t_l, t_s, t_r, t_{pr}	7	4	94	20/490	36
3	D_0, D_{min}, D_{ps}, V_r, t_l, t_s, t_{ps}, t_{pr}	8	8	96,2	28/716	71
4	D_0, D_{min}, D_{ps}, D_k, t_l, t_s, t_{pr}	7	7	94,2	20/480	30
5	D_0, D_{min}, D_{ps}, D_k, A_s, t_l, t_s, t_{pr}	8	10	96,7	24/758	59
6	D_0, D_{ps}, D_k, A_s, t_l, t_s, t_r, t_{pr}	8	7	94,7	21/505	49
7	D_{ps}, D_k, V_s, t_l, t_s, t_r, t_{pr}	7	5	95,6	20/438	38
8	D_0, D_{min}, t_l, t_s, t_r, t_{pr}	6	3	96,4	24/660	59
9	D_{min}, D_{ps}, D_k, A_s, t_l, t_s, t_r, t_{pr}	8	5	95,3	24/726	67
10	D_0, D_{ps}, D_k, A_s, t_s, t_{ps}, t_{pr}	7	5	96,1	24/682	69

During the fifth experiment, the set of model parameters was obtained, which achieves the accuracy of 96.7%. At that, each NN in the model structure consists of 8 neurons of the input layer and 10 neurons of the hidden layer.

Let us consider the results of the proposed approach approbation to intoxicated man FS definition using the example of pre-trip medical examination procedure passing by a driver see [Fig. 6].

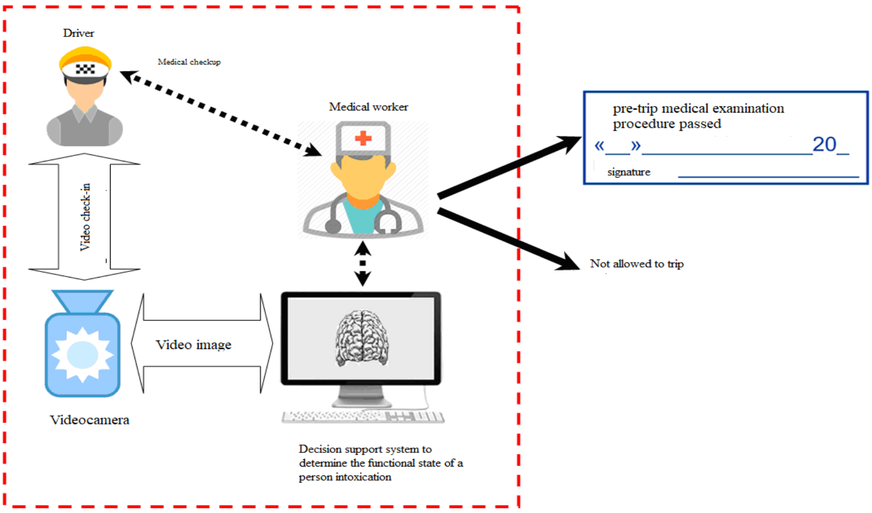

Fig. 6: Pre-trip medical examination passing scheme.

In this scheme the software complex is used in the form of a decision support system to determine whether drivers have medical restrictions for vehicle driving. A medical worker makes the conclusion on the admission of drivers to drive a car based on the results of the medical examination and taking into account the driver's FS assessment by neural network (sober / drunk).

The developed system was put into trial operation in the trucking industry of the city of Kazan. They performed the estimation of its efficiency from the point of view of material, technical and time expenses reduction see [Table 4].

By approbation results it is possible to draw the conclusion about the effectiveness of the developed software. Its use to determine the state of a person intoxication in the procedure of pre-trip medical examination allows to reduce material and technical (no less than 90%) and time (no less than 10 times) costs.

Table 4: Evaluation effectiveness results from the system use

Item №	Cost indicators (per driver)	Costs	
		Prior to introduction	After introduction
1	Material-technical	consumables for alcohol level testing (~ 20 rubles per test) and the presence of psychoactive substances (~ 195 rubles per test)	Consumables for alcohol level testing
2	Time	no less than 10-15 minutes	no more than 1 minute

CONCLUSION

Thus, the developed neural network model is an effective tool to determine human FS. In particular, its use is effective when the drivers of motor vehicles undergo pre-trip medical examinations. The great advantage of the neural network model use in the framework of the described technology, as compared with the classical papillometric survey, is the absence of stringent requirements for laboratory and special technical support. Besides, there is no need to put an expert diagnostician in each area of medical examination, since the role of the expert is performed by NN.

The conducted researches have shown a high efficiency of neural network model and the possibility of its use in various spheres of human activity. First of all, the definition of intoxication FS is relevant in the sphere of public safety to identify potentially dangerous people whose abnormal condition is a threat to society, economy and the state. In order to develop a scientific trend concerning the definition of human FS, it is advisable to improve the mathematical model and software, as well as to develop, implement and use new applied intelligent decision support systems in various subject areas.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None

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