Identification of object on an emitted signal based on matrixes of a bispectrum and indicator characteristics of Fourier spectrum

R A Krupchatnikov¹, M V Artemenko² and N M Kalugina²

¹Kursk State Agricultural I.I. Ivanov Academy, 70, Karl Marx Street, Kursk, 305021, Russia
²Southwest State University, 94, October 50 let Street, Kursk, 305040, Russia

E-mail: artem1962@mail.ru

Abstract. The article considers the urgent problem of identifying the state of an object in order to improve the quality of management. To identify the state of the object, a new method is proposed for analyzing the characteristics of the spectral power of a signal recorded during monitoring, which is characterized by the application of convergent decision production rules of a classification type. It is proposed to carry out convergence based on the analysis of the bispectrum of the acoustic signal emitted by the object and the correlation matrix of the characteristics of the amplitude spectral function. The first approach allows to investigate autocorrelation functions of a signal. The second approach allows to study structure of the organization of a signal. The following are considered: the mathematical apparatus and algorithms for determining specific correlation matrices and the methodology of the decision rules system. Results of synthesis of convergent decisive rules for diagnostics of statuses of an organism at standard forms of bronchitis are given. It is noted that the convergence of decision rules allows to increase the accuracy of identification of the state of the observed object by an average of 5-6% compared to private decision rules and by 10% compared with the classification by an expert person. A distinctive feature is the analysis of not only spectral characteristics, but also the functional relationship between them, which allows us to identify new properties and take into account the states that characterize the change in the functioning of the internal control system as a reaction to external influence as a whole. The obtained research results can be used in the construction of smart expert systems that are part of facility management systems whose state is characterized by emitted acoustic signals.

1. Introduction

Entity management systems are based on application of the adjusting influences. At biotechnical systems there is couple "object subject": the person acts as the subject (the operator in an ergatic system [1], the driver of the vehicle [2, 3], the patient [4, 5], the doctor [6], etc.). Identification of a status of a managed object is a classification task and is carried out on the basis of measurement of values of the certain indicator variables allowing an object status to a certain cluster. A certain part of the registered variables is reaction of an autonomous system of management [7] of an object to influence of a management system of measuring instruments. Let's notice that the autonomous system of management in a human body, as a rule, functions within the concept of indistinct regulation of haemo static statuses.
As a rule, as process of measurement in automated control systems is carried out continuously, there is a selection problem from the registered signal of components on the basis of which specific indicator indicators (variables) are formed.

Methods of the amplitude-frequency analysis of the registered signals (are applied to permission of the specified problem at an auskultation – acoustic frequency range) on a basis: Fourier transforms or Walsh [8], velyet-analysis [9], applications of a bispectrum (threefold autocorrelation function) [10, 11], and other methods of "blind analysis" [12]. Methods of accurate and indistinct management [13], the mnogoagentny analysis [14], artificial neural and immune networks [15, 16], different methods of selection of informative signs [17, 18, 19, 20], the analysis of a phase portrait are applied [21].

The specified methods were applied at the solution of specific objectives and had different values of quality characteristics of classification a status of objects. At the same time the quality in many respects depended on experience of the researcher and the applied specific methods. In this regard, recently, bigger attention began to be paid to application of synergy approach at signal analysis [22], a system image reflecting the happening self-organizational processes in an object during registration of a signal [11, 12]. In this case characteristic changes of structures and parameters of autocorrelation functions, (specific) to certain statuses of an object (or others) the registered signal are analyzed.

A variety of forms of the signals radiated by an object results in need of application of different concepts of the analysis, methodologically and gnoseological, differing from each other. Increase in accuracy of identification of a status of an object and, therefore, quality of management process (correction) causes need of convergence (association) of results of different methods of processing and the analysis of an emitted signal [23]. For coordination the procedures of the expert analysis designed to carry out optimum convergence [11], as a rule, are used.

Considering relevance of a problem of high-quality identification of a cluster of a status of an object of control and the existing means and technologies of artificial intelligence, the purpose of the real work is development and a research of classification opportunities of methodology of convergence of results of different ways of the analysis of the signal radiated by an object.

As an object of researches two new methods of selection of the indicator variables from an emitted audible tone based on conversions of matrixes were considered: a bispectrum and correlation communications of characteristics of an amplitude spectrum of Fourier with the information frequency ranges. As natural data signals of the acoustic noise registered in the course of an auskultation of lungs at different forms of bronchitis were used.

2. Theory and methodology

Let the object of a research emit an audible tone \( x(t) \) on the basis of which control of its status is exercised (the signal is provided a digital format with a certain sampling rate (the satisfying theorem Kotelnikov – Nyquist – Shannon). It is required to create from this signal the indicator variable (sign, an indicator) allowing to classify with acceptable quality (to identify) an object status for further high-quality management of a trajectory of its three-dimensional motion of statuses.

For the solution of the specified task it is offered to use convergence of two decisive rules. One is formed on the basis of a bispectrum of the registered signal \( x(t) \). Let's call this rule - BISPrule. The second rule is synthesized on the basis of the analysis of a matrix of the pair correlation relations between various characteristics of an amplitude spectrum of Fourier of a signal \( x(t) \) (and the calculated secondary functions from it – differential and integral) with the selected informative frequency ranges. Let's call this rule – MKORrule. We will designate the convergent decisive rule as CONVrule. We will present the decisive rule CONVrule in the products form:

\[
IF A_l \text{ THEN } C_l \text{ with confidence } CCR_l,
\]

where: \( A_l \) - antecedent, \( C_l \) – consequens, \( CCR_l \) – coefficient of confidence in application of this decisive rule, the identifying \( So \) object status as \( W_l \) cluster; \( C_l \equiv (So \in W_l) \); \( l=0.1.,L \) – the index of the identified cluster.

The private decisive rules BISPrule and CONVrule are presented in the form:
\textit{BISPrule}: "IF ABIS} \_i \text{ THEN } C_l \text{ with confidence } CCRBIS} \_l \text{"}, \hspace{1cm} (2)

\textit{MCORrule}: "IF ACON} \_i \text{ THEN } C_l \text{ with confidence } CCRCONV} \_l \text{"}, \hspace{1cm} (3)

where: \textit{ABIS} \_i \text{ and } ACON} \_i \text{, CCRBIS} \_l \text{ and } CCRCONV} \_l \text{ - respectively, antecedents of the rules } BISPrule \text{ and } CONVrule \text{, coefficients of confidence in results of application of these rules.}

The following algorithm of convergence \textit{BISPrule} \_l \text{ and } \textit{MCORrule} \_l \text{ is offered.}

1. The initial set of discrete outgoing audible tones \( \{x(t)\}^N \) (\( N \) – quantity of discrete steps) is subdivided into training \( \{x(t)\}^{N1} \) and examination \( \{x(t)\}^{N2} \) subsets: \( \{x(t)\}^N = \{x(t)\}^{N1} \cup \{x(t)\}^{N2} \), \( N = N1+N2 \).

2. On a subset \( \{x(t)\}^{N1} \) synthesize the rules \textit{BISPrule} \_l \text{ and } \textit{MCORrule} \_l \text{ (components of rules – the antecedents and the consequents are defined).}

3. The quantity of recursions of quality check of classification of an object by the decisive rules \textit{BISPrule} \_l \text{ and } \textit{MCORrule} \_l \text{ - } NQC > 10 \text{ is set.}

4. In each recursion by the Monte Carlo method for all alternative classes, examination subsets \( \{x(t)\}^{N1} \) are formed, on which the matrix of qualification coefficient efficiency factors (accuracy) \textit{BISPrule} \_l \text{ and } \textit{MCORrule} \_l \text{ - } \{AC\}_{NQC-L2} \text{ is set.}

5. The value of the Kendall concordance coefficient (Wbc) is calculated using the \( \{AC\}_{NQC-L2} \) matrix (similar to the Kendell coefficient in expert analysis).

6. Values are accepted to coefficients of confidence of private decisive rules:

\begin{align*}
\mu_{i,\text{bis}} = \frac{AC_{l,1}}{k} = \frac{NQC-1, NQC \cdot L + NQC-1}{L}, & \quad \text{for } l = 0, L-1, L \text{ – number of clusters}, \hspace{1cm} (4) \\
\mu_{i,\text{acon}} = \frac{AC_{l,2}}{k} = \frac{NQC-1, NQC \cdot L + NQC-1}{L}, & \quad \text{for } l = 0, L-1, L \text{ – number of clusters}. \hspace{1cm} (5)
\end{align*}

7. Components of convergent decisive rules (1) identification of a status of an object are synthesized (correlation to a cluster \( l \)):

\begin{align*}
A_l = \text{ABIS}_l \lor \text{ACON}_l \text{,} \hspace{1cm} (6) \\
CCR_l = (CCRBIS}_l + \text{CCRCONV}_l \cdot (1 - CCRBIS}_l) \cdot \text{Wbc} \text{.} \hspace{1cm} (7)
\end{align*}

The following algorithms for the synthesis of private decision rules are proposed: identification of the state of the control object (assignment to a specific cluster) \textit{BISPrule} \_l \text{ and } \textit{MCORrule} \_l \text{ for the subsequent application of the synthesis of convergent decision rule (1).}

\subsection*{2.1. Synthesis algorithm of the decisive rule MCORrule}

The correlation matrix is considered as the graph connectivity matrix: the vertices correspond to the indicator variables (attributes) of the object, and the arcs correspond to pair correlation coefficients. A theoretical consideration of the application of system analysis and graph theory in the processing of various information about the analyzed object and a description of the practical application of various methods are given, for example, in [24, 25].

Let there be \( N \) clusters of states of the control object \( W_0 \), ..., \( WN \) in the hyperspace of direct and latent indicator variables. A matrix reflecting the correlants between features will be called specific for the cluster \( W_l \) if it corresponds only to the cluster \( W_l \). Denote these matrices by \( SE \).

Modifying the algorithm offered in [26] for a correlation matrix we receive:

1. For signals \( x(t) \) characteristic of different clusters, the set of informative signs \( \{X\} = \{x_1, x_2, ..., x_M\} \) is formed. On experimental material the training matrix \( x_{ij} \) which each element represents value of sign of \( j \) for object \( i \) is formed. The last column of a matrix \( (M+1) \cdot y \) represents the identifier of an alternative cluster of \( W_i \).

2. In a set \( \{X\} \) are selected training \( \{x\}^{N1} \) and examination \( \{x\}^{N2} \) subsets: \( \{x\}^N = \{x\}^{N1} \cup \{x\}^{N2} \), \( N = N1+N2 \) (\( N1 \) and \( N2 \) – quantity of objects examples in the corresponding sets).

3. On the training sample \( \{x\}^{N1} \), matrices of pairwise connected coefficients of \( RR \) are determined:

4. The formation of specific matrices \( ER \):
\[ ER_{i,j} = \begin{cases} 0, & \text{if } R_{i,j} = R_{k,j} \forall l \neq k \\ R_{i,j}, & \text{otherwise} \end{cases} \]

where: \( l, k \) are indexes of a cluster; \( R_{i,j} = \begin{cases} \left[ (K \cdot \tanh\left( \frac{I_{RR,i,j}}{Rp} \right) - 1) \right] + 1, & \text{if } I_{RR,i,j} > Rp \Rightarrow RR_{i,j} = \text{coefficient of pair correlation of Spirmen between signs of } i \text{ and } j \text{ in cluster } W_l; \\ 0, & \text{otherwise} \end{cases} \)

of pair correlation of Spirmen between signs of \( i \) and \( j \) in \( W_l \) cluster; \( K \) – the coefficient defining a quantizing level of values of a matrix of \( RR \) (in fact) is the alphabet of representation of values of elements of matrices of \( R_l \in [-9, 9] \) is recommended by \( R = 9 \); \( Rp \) is threshold value for a correlation coefficient at the level of an error of first kind no more than 0.1 (\( Rp > 0.3 \) is recommended).

5. "Reference" matrices for each cluster are defined \( W_l: SER_l = ER_l^{-1} \).

6. Pairwise regression matrices for clusters \( W_1 \) are determined define:

\[ SGER_l = GER_l^{-1}, \]

where: \( GEN_{i,j} = \begin{cases} 0, & \text{if } ER_{i,j} = 0 \\ b_{i,j}, & \text{otherwise} \end{cases} \)

\( b_{i,j} \) – parameter of regression of signs of \( i \) and \( j \) in a cluster \( W_l: x_i = a + b \cdot x_j \)

7. Are defined as indicator variables:

\[ IDK_l^i = \frac{\sum_{j=1}^{M} MC_{i,j} - M}{M^2}, \]

\[ IDK_l^k = \frac{\sum_{j=1}^{M} MR_{i,j} - M}{M^2}. \]

where: \( M \) is the number of features in \( \{X\} \), the matrices \( MC \) and \( MR \) are the products of the standard matrices \( SER_l \) and \( SGER_l \) and the corresponding matrices calculated for a particular object.

8. Sets the number of recursions \( NN \). Points 2-5 are repeated \( NN \) times and are formed:

- on the training samples, the \( DK_l \) and \( DR_l \) ranges, which include the values of the indicators \( IDK_l \) and \( IDR_l \);

- on the examination, \( CCRCONV_l \) values are determined as the average values of the diagnostic (qualification) effectiveness of the application of decision rules «IF \( (IDK_l^i \in DK_l^i) \&(IDR_l^i \in DR_l^i) \) THEN \( C_l \)» (see a formula (1)). Here: \( IDK_l^i \) and \( IDR_l^i \) - corresponding values of indicator variables \( IDK_l \) and \( IDR_l \).

9. Decision rules of the form \( MCOReule_l \) are generated according to the formula (3):

\[ ACONV_l = (IDK_l^i \in DK_l^i) \&(IDR_l^i \in DR_l^i). \]

2.2. Synthesis algorithm of the decisive rule \( BISPrule \).

1. Signals \( x(t)_n \) are registered \( (m=1, ..., M, l \in M) \) – quantity of objects in a cluster \( W_l \); to basic cluster there corresponds \( l=0 \). Training and examination sets are formed for all alternative clusters: \( \{x(t)\}_N = \{x(t)\}_{N1} \cup \{x(t)\}_{N2}, N1/N2=N/N1, N=N1+N2 \).

2. Using randomly selected signals from the cluster \( W_0 \), the values of the amplitude spectral function are calculated. These values form (analytically or visually) the vector of time steps \( k \) and \( l, k=(k_1, k_2, ..., k_10), l=(l_1, l_2, ..., l_10) \). If there is no additional information, then \( l_i=k_i \). The indices correspond to the maxima of the averaged values of the spectral functions (recommended by the first ten).
3. From the set of signals of the cluster $W_0$ a signal is randomly selected $x(t)_p$.

4. For $x(t)_p$, the matrix $Rx_0$ is calculated by the formula: 
   $$\hat{R}_r(k,l) = \sum_{t=0}^{N_w-1} x_p(t) \cdot x_p(t+k) \cdot x_p(t+l)$$
   \(N_w\) – the "temporary window" selected by the researcher in a signal; instead of $k$ and $l$ - value of vectors $kt$ and $lt$, respectively.) Values of array elements $Rx_0$ smaller on module 0.3 are nullified. If as a result of the procedure of zeroing in a matrix there are less than 9 (10%) not zero elements out of the main diagonal of a matrix, then the threshold value 0.3 is recommended to be reduced gradually with a step 0.25. The reference matrix is defined $R_y = Rx_0^{-1}$.

5. Procedures of item 4 repeat for all signals of training sets of a cluster of $W_l$, forming matrixes $Rx_{ij}$ (l – the index of a cluster, j – the index of an object in a cluster).

6. Indicator matrixes of a type are calculated: $IR_{i,j} = R_{x_{i,j}} \cdot R_y$. Are defined a vector of root mean square deviations from an identity matrix:
   $$SR_i = \left( \sum_{j=1}^{10} \sum_{n=1}^{10} IR_{i,j} - 10 \right) / 100 .$$

   Variable $SR_{i,j}$ is accepted as the indicator.

7. On the training sample diagnostic intervals are determined by this indicator - $dSR_i$.

8. Confidence coefficients $CCRBIS_i$ are determined, which are taken as the values of diagnostic (classification) efficiencies of using confidence intervals in $ABIS_i$ on examination samples of $W_l$ clusters.

3. Results of a research and discussion

The offered approach was approved on the system of breath of the person. Possibilities of diagnosing on an audible tone of respiratory noise of the main forms of the bronchitis registered in the course of auscultation were investigated.

As registration of a sound signal $x(t)$ might contain sections with artifacts, according to the recommendations of medical specialists registration time when forming of the training samples was 30 seconds. Latent records were in addition originated: $dX(t)$ and $sX(t,T)$ – the first a derivative and integral for T interval. Volumes of the training examples for the considered clusters were (bronchial breath was listened and registered): $W_0$("healthy") - 54 examples of an audible tone of respiratory noise (bronchial breath was listened), $W_1$ (chronic bronchitis) – 82 examples, $W_2$ (an acute bronchitis) – 58 examples. The training and examination samples (subsets) were in a random way created by volume ratios [27, 28]: the training sample for $W_0$ – 33 examples, for $W_1$ - 51 examples, for $W_2$ - 36 examples. From records sections of a period of time in 20 seconds were selected. Each record in samples was set by identifier $x(t)_{ik}$ (l - "number" of a cluster, k is number of record in a cluster). All signals for respect for purity of an experiment were filtered and digitized with a sampling rate of 2.8 kHz. The following information frequency ranges were selected: $d_1$ - 5-120 Hz, $d_2$ - 400-900 Hz, $d_3$ - 800-1300 Hz. Note: the technique of "floating window" in 10 discrete steps and total – 60 was applied to calculation of matrixes of correlation communication between informative signs of a range of power of an audible tone of the respiratory noise registered in the course of auscultation (it is representative according to recommendations [29]).

Initial the ensemble of signs included 126 elements - candidates for indicator variables: $min(Z(t))$, $max(Z(t))$, $M(Z(t))$, $\sigma(Z(t))$, $As(Z(t))$, $Ex(Z(t))$ and their arithmetic combinations - respectively, the minimum, maximum, standard deviation, asymmetry and excess of the signal $Z(t)$ and their various relationships ($Z(t)$ - the analyzed signals $x(t)$, $dx(t)$ and $Sx(t,T)$ in the selected informative frequency ranges).

The carried-out analysis of correlation of frequency ranges allowed to reveal that: among themselves correlate $d_1$ and $d_3$, $d_2$ and $d_3$, $d_1$ and $d_2$ ranges on a signal $x(t)_{ik}$ and to signals $dx(t)_{ik}$ u $sX(t)_{ik}$, $d_1$ and $d_2$ to $sX(t)_{ik}$. It is revealed that at low frequencies it is preferable to analyze directly registered audible tone $x(t)$, on higher – its differential (high-speed) and integrated properties.
After use of prospecting correlation analysis and a research of a linear regression, the required set of informative signs decreased twice and was 63 elements: \( s_{i,j,m} \) (i=1,…,7; j=1,2,3 – numbers of the selected frequency ranges; m=1 – related to the signal \( x(t)_{j,k} \), m=2 – \( dx(t)_{j,k} \) and m=3 – \( sx(t,T)_{j,k} \),

\[
\begin{align*}
\sigma_{s_{i,j,m}} &= \frac{\sum_{j=1}^{J} \sigma_{sp_{f_{i,j,d_{j}}}}(z(t))}{F} , & \sigma_{s_{2,j,m}} &= \frac{\left( \sum_{j=1}^{J} \sigma_{sp_{f_{i,j,d_{j}}}}(z(t))-\sigma_{s_{1,j,m}} \right)^{2}}{F} , & \sigma_{s_{3,j,m}} &= \frac{s_{2,j,m}}{s_{1,j,m}} , & \sigma_{s_{4,j,m}} &= \ln(s_{2,j,m}) ,
\end{align*}
\]

\[
\begin{align*}
\sigma_{s_{6,j,m}} &= \frac{\max(\sigma_{sp_{f_{i,j,d_{j}}}}(z(t)))-\min(\sigma_{sp_{f_{i,j,d_{j}}}}(z(t)))}{s_{6,j,m}} , & \sigma_{s_{8,j,m}} &= \sigma_{sp_{f_{i,j,d_{j}}}}(z(t)) , & \sigma_{s_{9,j,m}} &= \text{Ex}(\sigma_{sp_{f_{i,j,d_{j}}}}(z(t))) ,
\end{align*}
\]

Here - \( \sigma_{sp_{f_{i,j,d_{j}}}}(z(t)) \) - the spectral signal power of \( z(t) \) in \( d_{j} \) range corresponding to a range discrete step \( f_{i,j} \), \( F_{d_{j}} \) – quantity of frequency discrete steps in the range \( d_{j} \); \( \sigma_{s} \) and \( \text{Ex} \) – respectively, skewness and kurtosis.

Examples of specific matrixes are given in table 1. Comparative results of quality of use of decisive rules (convergent and private types) and results of diagnostics of a status of a respiratory system in the considered clusters are given by the health worker in table 2 (the coefficient of a concordance of private rules calculated analytically made \( W_{bc}=0.87 \)).

| Table 1. Specific correlation chains of a correlation matrix (fragment). |
|-----------------------------|-----------------------------|-----------------------------|
| cluster | Specific chains | m | d |
| W₀ | \( s_{1,d,j,m} - s_{2,d,j,m} - s_{5,d,j,m} \) | 1 | 2, 3 |
| W₀ | \( s_{1,d,j,m} - s_{6,d,j,m} \) | 2 | 1, 3 |
| W₁ | \( s_{2,d,j,m} - s_{5,d,j,m} - s_{6,d,j,m} \) | 3 | 1, 2 |
| W₁ | \( s_{4,d,j,m} - s_{5,d,j,m} \) | 1 | 2, 3 |
| W₂ | \( s_{5,d,j,m} - s_{6,d,j,m} \) | 2 | 1, 3 |
| W₂ | \( s_{2,d,j,m} - s_{3,d,j,m} \) | 3 | 1, 2 |

| Table 2. Quality of diagnosis of bronchitis at auscultation (efficiency of AC) |
|-----------------------------|-----------------------------|-----------------------------|
| Decisive rule | Cluster W₀ | Cluster W₁ | Cluster W₂ |
| BISP rule | IF \( SR^{*} \in [0,2;1,2] \) THEN \( So \in W_{0} \) with confidence 0.9; \( AC=0.9 \) | IF \( SR^{*} \in [1,1;10] \) THEN \( So \in W_{1} \) with confidence 0.88; \( AC=0.88 \) | IF \( SR^{*} \in [8;40] \) THEN \( So \in W_{2} \) with confidence 0.94; \( AC=0.92 \) |
| MCOR rule | IF \( ( IDK^{*}_{i} \in [0,6;1,4] \) \) & \( IDR^{*}_{i} \in [0,5;4] \) THEN | IF \( ( IDK^{*}_{i} \in [1,6;12] \) \) & \( IDR^{*}_{i} \in [3,5;30] \) THEN | IF \( ( IDK^{*}_{i} \in [10;80] \) \) & \( IDR^{*}_{i} \in [26;120] \) THEN |
| CONV rule | IF \( ( SR^{*} \in [0,2;1,2] \) \) or | IF \( ( SR^{*} \in [1,1;10] \) or | IF \( ( SR^{*} \in [8;40] \) or |
( \( IDK_i^* \in [0,6;1,4] \) \& \( IDR_i^* \in [0,5;4] \) ) \& THEN \( So \in W_0 \) with confidence 0,83

( \( IDK_i^* \in [1,6;12] \) \& \( IDR_i^* \in [3,5;30] \) ) \& THEN \( So \in W_1 \) with confidence 0,84

( \( IDK_i^* \in [10;80] \) \& \( IDR_i^* \in [26;120] \) ) \& THEN \( So \in W_2 \) with confidence 0,87

Therapist AC=0,86

Notes: \( W_0 \) cluster was chosen as the base one; if none of the rules is followed, then an additional examination of the respiratory system is required, involving expert experts; the intersection of intervals emphasizes the lack of clear boundaries between the clusters in question.

4. Conclusion
The convergence of decision rules allows to increase the accuracy of identification of the state of the observed object by an average of 5-6\% compared with private decision rules and by 10\% compared with classifications by an expert person. This helps to improve the quality of management (in this case, the treatment of bronchitis). The obtained values of diagnostic quality indicators (efficiency of use) allow us to conclude that the decision rules are acceptable for use in the control system — in this case, the regulation of the respiratory system using control (corrective) therapeutic or preventive measures.

The results can be used to build smart expert systems that are part of control systems that allow timely and adequate correlation of an object to a specific cluster by the emitted acoustic signal. A distinctive feature is the analysis not of spectral characteristics, but of their functional connection, which allows us to identify new properties and take into account the states characterizing the change in the functioning of the internal control system as a reaction to an external action (control or disturbing).

Acknowledgement
This work was carried out as part of the federal target program "Research in priority areas for the development of the scientific and technological complex of Russia for 2014-2020" and with the support of grant # 13801 GU / 2018 of the "Fund for Assistance to the Development of Small Forms of Enterprises in the Scientific and Technical Field".

References
[1] Muhin I E, Dvornikov M V and Koptev D S 2017 Subsystem of monitoring physiological state of pilot as any of the links of the biotechnical system of the erguic type "pilot - airplane - environment" *Proceedings of Southwest State University Series Control, computer engineering, information science. Medical instruments engineering* 4 (25) 59-69
[2] Korneev N V and Grebennikov A V 2016 Intelligent control system for vehicle *Information technology* 1 312-5
[3] Alpatov A V and Kirjuhin A V 2015 Driver assistance system based on analysis of pulse and vehicle motion parameters *Biomedical Engineering* 49 (0) 102-7
[4] Geger E V and Fedorenko S I 2016 Information systems as means of control augmentation of medical treatment facility *Proceedings of Southwest State University Series Control, computer engineering, information science. Medical instruments engineering* 2 (19) 39-45
[5] Dubovsky V A 2014 A biotechnical system for improving human motor function: Functional model and technical implementation *Actual problems in machine building Proceedings of the International Scientific and Practical Conference* Vol 3 pp 259-62
[6] Afonichkin A I, Pivovarov I V 2016 The analysis of use of systems of the automated uperavleniye by medical institutions *Vestnik of Volzhsky after V.N. Tatischev* 2(3) 82-6
[7] Zhdanov A A 2009 Autonomous artificial intelligence *BINOM Laboratory of knowledge (Moscow)* p 359
[8] Stepanov M F and Stepanov A M 2016 *Principles, methods, automation equipment of*
development and research of control algorithms (Saratov) p 215

[9] Petropulu A P 2017 Higher-Order Spectral Analysis The Biomedical Engineering Handbook: Second Edition, Boca Raton: CRC Press LLC 368

[10] Smolencev N K 2017 Bases of the theory of veylet. Veylet in MATLAB (Saratov) p 628

[11] Burmaka A A, Shatalova O V and Korovin E N 2018 Impedance Models in Anomalous Electrical Conduction Zones Forming by In-Vivo Experiments for Intelligent Systems of Socially Important Diseases Diagnostic In 2018 International Russian Automation Conference (RusAutoCon) IEEE pp 1-4

[12] Krupchatnikov R A, Artemenko M V, Kalugina N V and Rybochkin A F 2018 Experience of convergence of methodologically various decisive rules for improvements of quality of identification of complex objects on analog signals ISPCIET'2018 IOP Conf. Series: Vattrials Science and Engineering p 441

[13] Kravchenko V F 2007 Digital processing of signals (Moscow: FIZMATLIT) p 544

[14] Egupov N D 2002 Methods of robustny, neuro and indistinct and adaptive management (Moscow) p 744

[15] Sijuart R and Piter N 2006 Artificial intelligence: modern approach (Moscow: Vityaz publishing house)

[16] Cain G 2017 Artificial Neural Networks: New Research Nova Science Pub Inc (NY USA) p 243

[17] Michersky R M 2017 Classification of data with the use of the artificial immune system “Programmye produkty i sistemy” (Software & Systems) 1 (1) 99-03

[18] Artemenko M V, Chernetskaia I E, Kalugina N M and Shekina E N 2018 Bootstrap and counter-bootstrap approach for formation of the cortege of informative indicators by results of measurements Journal of Physics: Conference series 998 012002

[19] Artemenko M V, Podvalnyy E S and Starcev E A 2016 Integrated assessment methods and selection of informative features composition in problems assessment biotechnical systems Biomedical Radioelectronics 9 38-44

[20] Artemenko M V, Kalugina N M and Dobrovolsky I I 2016 The formation of a set of informative features based on the functional relationships between the data structure field observations European Journal of Natural History 6 43-8

[21] Filist S A, Shatalova O V & Petrunina E V 2019 Intellectual Systems with Virtual Flows in Predicting Cardiovascular Complications International Russian Automation Conference (RusAutoCon) IEEE pp 1-5

[22] Zaran M, Savastru R S and Savastru D M, Synergetic use of geospatial and in-situ data for earthquake hazard assessment in Vrancea area Proceedings of SPIE - The International Society for Optical Engineering 4. "Fourth International Conference on Remote Sensing and Geoinformation of the Environment, RSCy 2016"

[23] Shatalova O V 219 Associations of decision modules in intellectual prediction systems of cardiovascular diseases System analysis and management in biotechnical systems 18 (2) 153-62

[24] Al-Kasasbeh R T, Korenevskiy N, Filist S, Shatalova O V, Alshamasin M S, & Shaqadan A A (2019). Biotechnical monitoring system for determining person's health state in polluted environment using hybrid decisive rules. International Journal of Modelling, Identification and Control 32(1) 10-22

[25] Zakharov A, Zhiznyakov A 2015 Synthesis of three-dimensional models from drawings based on spectral graph theory Applied Mechanics and Materials 756 598–603

[26] Dobrovolskij I I, Krupchatnikov R A, Artemenko M V and Kalugina N M 2017 Formation of decisive rules for systems of support of decision-making on the basis of diagnostic indicators of quality of informative characteristics and the count of correlations between them Proceedings of Southwest State University Series Control, computer engineering, information science. Medical instruments engineering 3(24) 78-90

[27] Li R Y M, Fong S and Chong R W S 2017 Forecasting the reits and stock indices: grooup method
of data handling neural network *Pacific Rim Property Research Journal* 23 (2) 123-60

[28] Pyatakovich F A, Mevsha O V, Yakunchenko T I, Makkonen K F 2016 Biotechnical system of automatic classification scattergrams and evaluation of atrial fibrillation outcomes *International Journal of Pharmacy and Technology* 8(2) 14129-36

[29] Shakhgeldian K I, Geltzer B I, Gmar D V, Krivelevich EB, Teuk K A & Trankovskaia L V 2018 The problems of analysis of medical statistics data *Problems of social hygiene, health care and history of medicine* 26 (3) 132-6