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METHOD OF OPTIMAL EXTRAPOLATION OF VECTOR RANDOM SEQUENCES REALIZATIONS ON THE BASIS OF NONLINEAR CANONICAL DECOMPOSITION

Annotation.*The given work is devoted to the solving of important scientific and technical problem of the method development of the optimal (in mean square sense) extrapolation of the realizations of vector random sequences for any quantity of the known values, used for forecasting, and for any order of nonlinear stochastic relations. Forecasting model is synthesized on the basis of polynomial canonical decomposition of vector random sequence. There is obtained the formula for determination of the mean square error of extrapolation that allows to estimate the solution accuracy of the forecasting problem with using the proposed method. Taking into account the recurrent character of the estimationprocesses of the future values of investigated sequence the method is quite simple in calculating respect. The developed method of extrapolation as well as the vector canonical expansion assumed as its basis don't put any essential limitations on the class of prognosticated random sequences (linearity, Markovian property, stationarity, scalarity, monotony etc.).*

Keywords:*optimal nonlinear extrapolation, vector random sequences, polynomial canonical decomposition.*

Introduction.

The peculiarityof a wide range of applied problems in different science and engineering fields is the probabilistic nature of an investigated phenomenon or presence of random factors influence on the investigated object, therefore the process of its state changing also has a probabilistic nature. The objects of such class are the objects with randomly changing conditions of operation and they are investigated in such applications as: the technical diagnostics, radiolocation, plane-to-plane navigation, predictive control of reliability, information security, synthesis of the models of chemical kinetics, technological objects control etc.

The specific peculiarity of mentioned problems is the presence of preliminary stage of gathering the information about the investigated object. Random character of external influences and coordinates (input and output) of the objects with randomly changing conditions of operation at sufficient volume of statistic data determines the necessity and reasonability of applying the deductive methods [1] of random sequences forecasting.

Analysis of the latest investigations and publications. It is known thatthe most general extrapolation form for the forecasting problems solving is the mathematical model in the form of Kolmogorov-Gabor polynomial [1, 2]. Such model permits to take into account any number of measurements of a random sequence and the order of exponential nonlinearity. But its practical application is limited by significant difficulties, associated with the formation of a large number of equations for the extrapolator parameters determination. The existing optimal methods, that are used for the applied problems solving, are obtained for certain classes of random sequences, in particular, Kolmogorov's [3] and Wiener's [4] methods – for stationary processes, Kalman's filter-extrapolator [5] – for markovian random sequences, Pugachev's [6] and Kudritskyi's [7-8] methods – for non-stationary Gaussian sequences etc. It should be mentioned that their application permits to obtain the optimal results only for the sequences with certain a priori known characteristics.

Thus there are exist the theoretically grounded solutions of random sequences forecasting problem but the known methods and models are based on the use of appropriate restrictions which don't permit to obtain the maximal extrapolation accuracy.

The purpose of the paper. The creation of the method of vector random sequences extrapolation at the most general assumptions concerning the stochastic qualities of investigated sequence (with use for forecasting any degree of nonlinear stochastic relations and measurements number).

Mathematical problem statement. Vector random sequence $\left\{\vec{X}\right\} = X_h(i),\ h=\overline{1,H}$, describing the time variation of H interdependent parameters of some object with a randomly varying operating conditions, fully specified in a discrete number of points $t_i,\ i=\overline{1,I}$ by moment functions $M\left[X_l^{\nu}(i)\right],\ M\left[X_l^{\nu}(i)X_h^{\mu}(j)\right],\ i,j=\overline{1,I};\ l,h=\overline{1,H}\ \nu,\mu=\overline{1,N}$. It is necessary to obtain the best estimations $\overset{*}{x}_h(i), i=\overline{k+1,I}, h=\overline{1,H}$ of future values of the investigated random sequence for each of its components $X_h(i)$ under the stipulation that the values $x_h^{\mu}(j),\ j=\overline{1,k},\ \mu=\overline{1,N},\ h=\overline{1,H}$ of the first k observation points are known.

Main material statement. The most universal approach to the solution of the formulated problem from the viewpoint of the restrictions,

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imposed on the random process, consists of using the canonical decompositions [6-8]. For the vector case such decomposition with taking into account stochastic relations $M\left[X_l^{\nu}(i)\right], M\left[X_l^{\nu}(i)X_h^{\mu}(j)\right],\ i,j=\overline{1,I}$ has the form [9]:

$$X_h(i)=M\left[X_h(i)\right]+\sum_{\nu=1}^{i-1}\sum_{l=1}^{H}\sum_{\lambda=1}^{N}W_{\nu l}^{(\lambda)}\beta_{l\lambda}^{(h,1)}(\nu,i)+$$

$$\sum_{l=1}^{h-1}\sum_{\lambda=1}^{N}W_{il}^{(\lambda)}\beta_{l\lambda}^{(h,1)}(i,i)+W_{ih}^{(1)},\ i=\overline{1,I}, \qquad (1)$$

$$D_{l,\lambda}(\nu)=M\left[\left\{W_{\nu l}^{(\lambda)}\right\}^2\right]=M\left[X_l^{2\lambda}(\nu)\right]-M^2\left[X_l^{\lambda}(\nu)\right]-$$

$$-\sum_{\mu=1}^{\nu-1}\sum_{m=1}^{H}\sum_{j=1}^{N}D_{mj}(\mu)\left\{\beta_{mj}^{(l,\lambda)}(\mu,\nu)\right\}^2-\sum_{m=1}^{l-1}\sum_{j=1}^{N}D_{mj}(\nu)\left\{\beta_{mj}^{(l,\lambda)}(\nu,\nu)\right\}^2- \qquad (2)$$

$$-\sum_{j=1}^{\lambda-1}D_{lj}(\nu)\left\{\beta_{lj}^{(l,\lambda)}(\nu,\nu)\right\}^2,\ \nu=\overline{1,I};$$

$$\beta_{l\lambda}^{(h,s)}(\nu,i)=\frac{M\left[W_{\nu l}^{(\lambda)}\left(X_h^s(i)-M[X_h^s(i)]\right)\right]}{M\left[\left\{W_{\nu l}^{(\lambda)}\right\}^2\right]}=$$

$$=\frac{1}{D_{l\lambda}(\nu)}(M\left[X_l^{\lambda}(\nu)X_h^s(i)\right]-M\left[X_l^{\lambda}(\nu)\right]M\left[X_h^s(i)\right]-$$

$$-\sum_{\mu=1}^{\nu-1}\sum_{m=1}^{H}\sum_{j=1}^{N}D_{mj}(\mu)\beta_{mj}^{(l,\lambda)}(\mu,\nu)\beta_{mj}^{(h,s)}(\mu,i)- \qquad (3)$$

$$-\sum_{m=1}^{l-1}\sum_{j=1}^{N}D_{mj}(\nu)\beta_{mj}^{(l,\lambda)}(\nu,\nu)\beta_{mj}^{(h,s)}(\nu,i)-\sum_{j=1}^{\lambda-1}D_{lj}(\nu)\beta_{lj}^{(l,\lambda)}(\nu,\nu)\beta_{lj}^{(h,s)}(\nu,i),$$

$$\lambda=\overline{1,h},\ \nu=\overline{1,i}.$$

The random sequence $X_h(i), i=\overline{1,I}; h=\overline{1,H}$ is represented with $H\times N$ arrays $\{W_l^{(\lambda)}\},\ \lambda=\overline{1,N};\ l=\overline{1,H}$ of centered uncorrelated random coefficients $W_{\nu l}^{(\lambda)},\ \nu=\overline{1,I};\ \lambda=\overline{1,N};\ l=\overline{1,H}$. Each of these coefficients contains information about corresponding value $X_l^{\lambda}(\nu)$, and coordinate functions $\beta_{l\lambda}^{(h,s)}(\nu,i)$ describe the probability connections of $\lambda+s$ order between the components $X_l(i)$ and $X_h(i)$ in sections t_ν and t_i. On Fig. 1 the algorithm block-diagram of the canonical model (1) parameters determination is represented.

The forecasting model, based on the canonical decomposition (1) of random sequence, has the form [10]:

$$m_{x;j,h}^{(\mu,l)}(s,i)=\begin{cases} M\left[X_h(i)\right], \text{ at } \mu=0, \\ m_{x;j,h}^{(\mu,l-1)}(s,i)+\left(x_j^l(\mu)-m_{x;j,j}^{(\mu,l-1)}(l,\mu)\right)\beta_{j,l}^{(h,s)}(\mu,i), \text{ at } l>1,\ j<H, \\ m_{x;j,h}^{(\mu,N)}(s,i)+\left(x_{j+1}(\mu)-m_{x;j,j+1}^{(\mu,1)}(N,\mu)\right)\beta_{j+1,1}^{(h,s)}(\mu,i), \text{ at } l=1,\ j<H, \\ m_{x;H,h}^{(\mu,N)}(s,i)+\left(x_1(\mu+1)-m_{x;H,1}^{(\mu,N)}(N,\mu+1)\right)\beta_{1,1}^{(h,s)}(\mu+1,i), \text{ for} \\ l=1,\ j=H, \end{cases} \quad (4)$$

were

$m_{x;j,h}^{(\mu,l)}(1,i)=M\left[X_h(i)/x_\lambda^n(\nu),\ \lambda=\overline{1,H}, n=\overline{1,N}, \nu=\overline{1,\mu-1};\ x_\lambda^n(\mu),\ \lambda=\overline{1,j}, n=\overline{1,l}\right]$ – optimal (in the root mean square sense) estimation of future values of the investigated random sequence at the assumption that for forecasting it is applied a posteriori information $x_\lambda^n(\nu), \lambda=\overline{1,H},\ n=\overline{1,N}$, $\nu=\overline{1,\mu-1};\ x_\lambda^n(\mu),\ \lambda=\overline{1,j},\ n=\overline{1,l}$.

The diagram in Fig. 2 represents the distinctions of the calculation process of determination of a random sequence future values at using the extrapolation algorithm (4). The equation for the root mean square error of the extrapolation with using the forecasting model (4) according to known values $x_j^n(\mu),\ \mu=\overline{1,k};\ j=\overline{1,H};\ n=\overline{1,N}$ has the form

$$E_h^{(k,N)}(i)=M\left[X_h^2(i)\right]-M^2\left[X_h(i)\right]-\sum_{\mu=1}^{k}\sum_{j=1}^{H}\sum_{n=1}^{N}D_{jn}(\mu)\left\{\beta_{jn}^{(h,1)}(\mu,i)\right\}^2, \quad (5)$$

$$i=\overline{k+1,I}.$$

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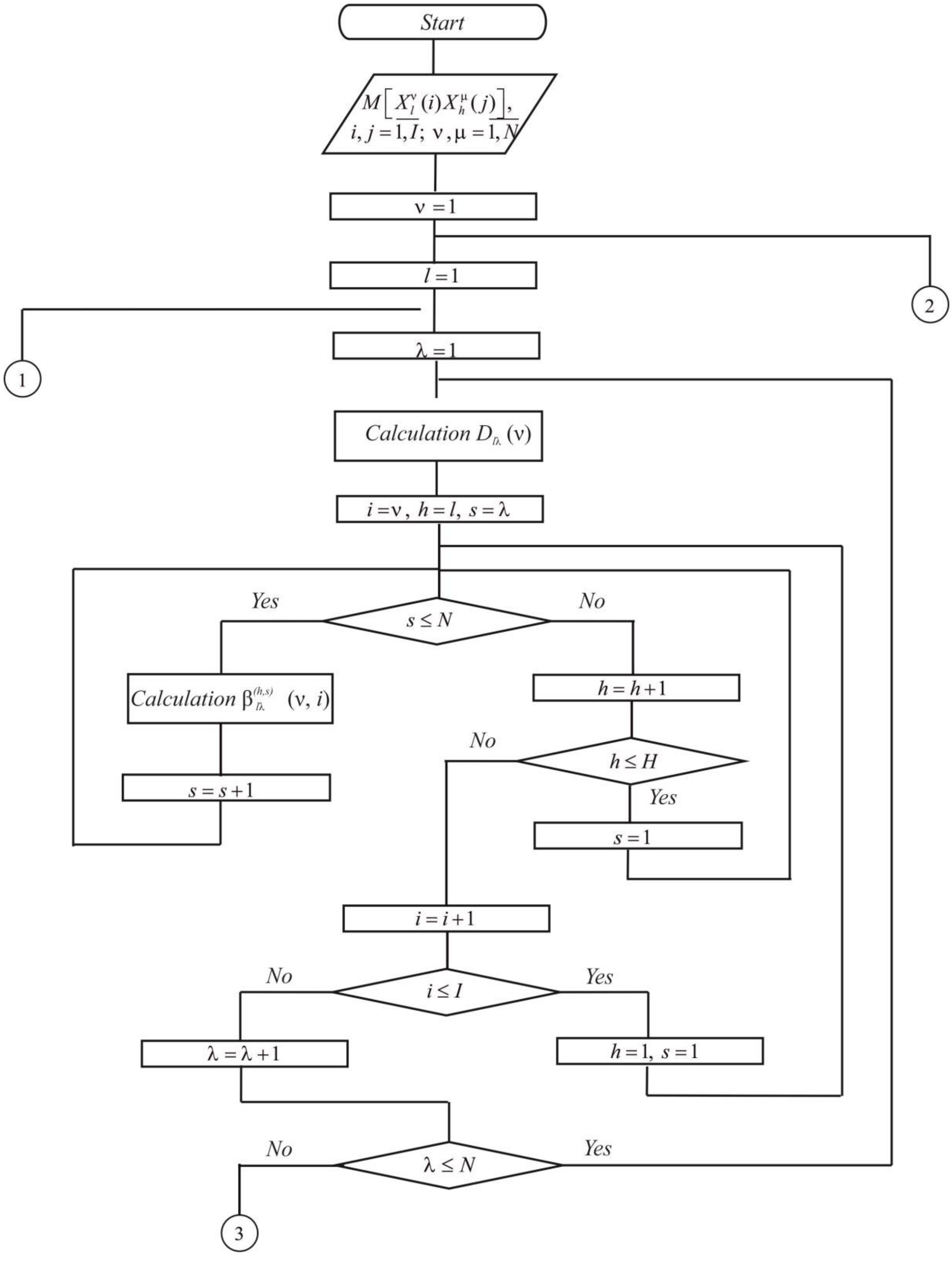
Start
$M\left[X_l^{\nu}(i)X_h^{\mu}(j)\right]$,
$i, j = \overline{1, I}$; $\nu, \mu = \overline{1, N}$
$\nu = 1$
$l = 1$
$\lambda = 1$
Calculation $D_{l\lambda}(\nu)$
$i = \nu$, $h = l$, $s = \lambda$
Yes
$s \le N$
No
Calculation $\beta_{l\lambda}^{(h,s)}(\nu, i)$
$s = s + 1$
$h = h + 1$
No
$h \le H$
Yes
$s = 1$
$i = i + 1$
No
$i \le I$
Yes
$\lambda = \lambda + 1$
$h = 1$, $s = 1$
No
$\lambda \le N$
Yes
1
2
3

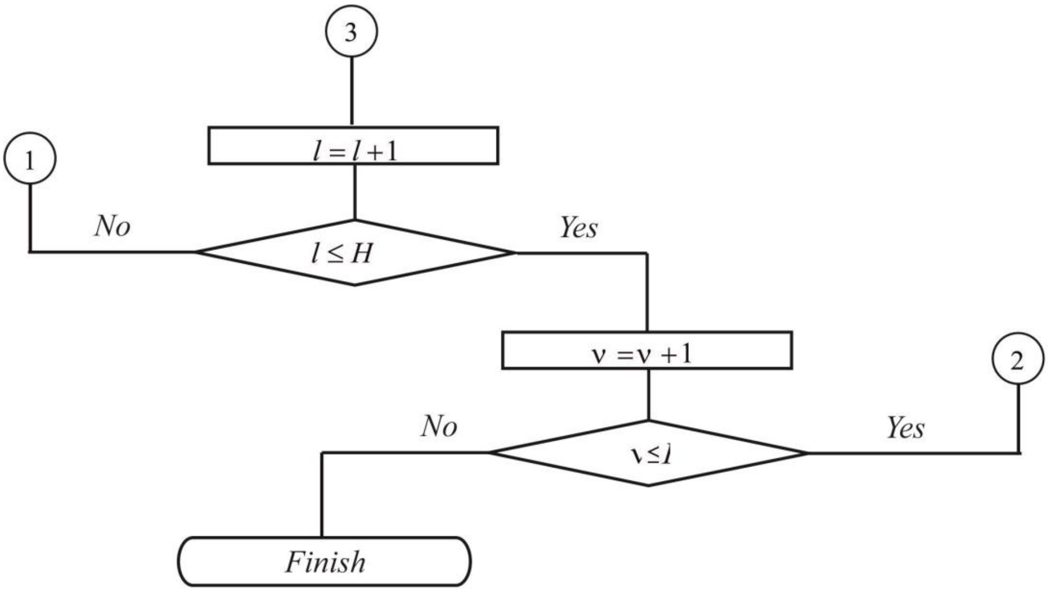

Fig.1. The algorithm block-diagram ofcalculatingthe parameters $D_{l,\lambda}(\nu)$,

$\beta_{l\lambda}^{(h,s)}(\nu,i)$ of vectorcanonicaldecomposition (1)

The root mean square of extrapolation $E_h^{(k,N)}(i)$ error is equal to the dispersion of a posteriori random sequence

$$X_h^{(k,N)}(i) = X\left(i / x_l^{\nu}(j),\ \nu = \overline{1,N},\ j = \overline{1,k}, l = \overline{1,H}\right) = m_{H,h}^{(k,N)}(1,i) +$$

$$+ \sum_{\nu=k+1}^{i-1} \sum_{l=1}^{H} \sum_{\lambda=1}^{N} W_{\nu l}^{(\lambda)} \beta_{l\lambda}^{(h,1)}(\nu,i) + \sum_{l=1}^{h-1} \sum_{\lambda=1}^{N} W_{il}^{(\lambda)} \beta_{l\lambda}^{(h,1)}(i,i) + W_{ih}^{(1)},\ i = \overline{k+1,I}.$$

The use of developed method of random sequences extrapolation on the basis of forecasting model (4) requires the implementation of the following stages:

Step 1: Collection of the statistics data about the investigated random sequence;

Step 2. Estimation of the moment functions $M\left[X_l^{\nu}(i)\right]$, $M\left[X_l^{\nu}(i) X_h^{\mu}(j)\right]$, $i, j = \overline{1,I}; l,h = \overline{1,H};\ \nu,\mu = \overline{1,N}$ on the basis of the accumulated realizations of the random sequence;

Step 3. Formation of canonical decomposition (1) for the investigated vector random sequence in accordance with the algorithm, represented on Fig. 1;

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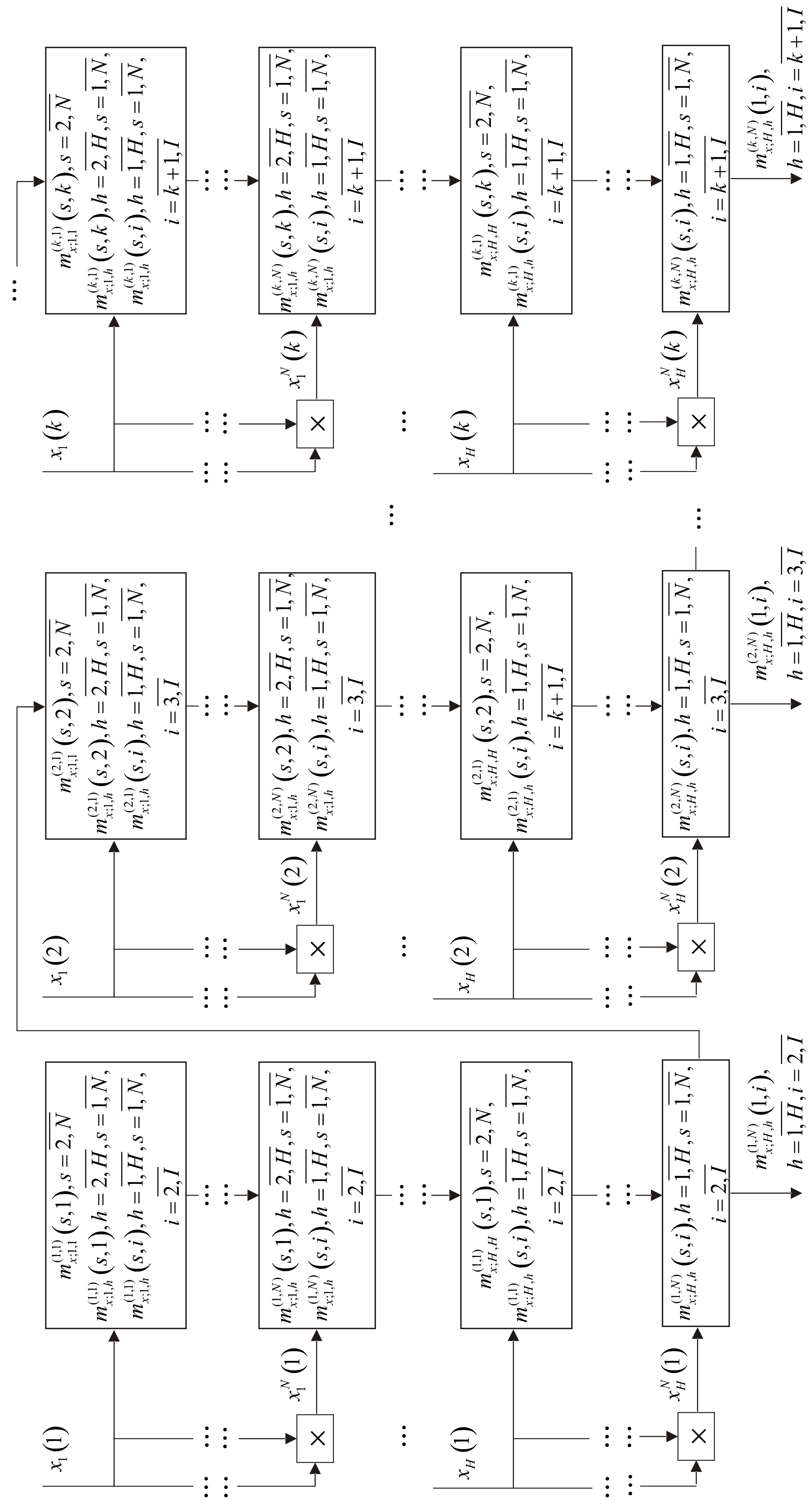

Fig.2Schematicprocedureof formation ofthe future values ofa random sequenceusing the algorithm(4)

Step 4: Calculating the estimates of future values of extrapolated realization on the basis of forecasting models (4) in accordance with the scheme on Fig. 2;

Step 5: Assessment of problem solution quality of investigated sequence forecasting with using equation (5).

At absence the stochastic relationships between the components the forecasting model (4) can be simplified to H equations [11–12] for scalar sequences extrapolation.

The method was tested for forecasting the random sequences, describing the average monthly air temperature changing in Odessa and Kiev. As statistics data have been used [13] the values of average (from January to December) temperature during hundred years (1910–2009 y.y.).

The Fig. 3 shows the diagrams of mathematical expectations of the investigated random sequences ($X_1(i),\ i=\overline{1,12}$ – random sequence of average monthly temperature changing in Odessa, $X_2(i),\ i=\overline{1,12}$ – a random sequence of average monthly temperature changing in Kyiv).

Numerical experiment was organized in the following way. On the basis of 99 realizations of random sequences $X_1(i), X_2(i)\ i=\overline{1,12}$ were determined the model's (4) parameters for $N=5$ and linear extrapolator (in model (4) used only correlations). For the remaining realization from a hundred existing statistical database the estimation of the future values was calculated and the forecasting error was determined. The procedure was performed a hundred iterations and forecasted realization was removed from the training sample, and in its place was placed the investigated in the previous experiment realization.

As a result of numerical experiments the standard deviations (SD) and the mean square errors of extrapolation of random sequences realizations $X_1(i), X_2(i)\ i=\overline{1,12}$ were obtained thought the linear algorithm and developed method based on the model (4) (Fig. 4, Fig. 5).

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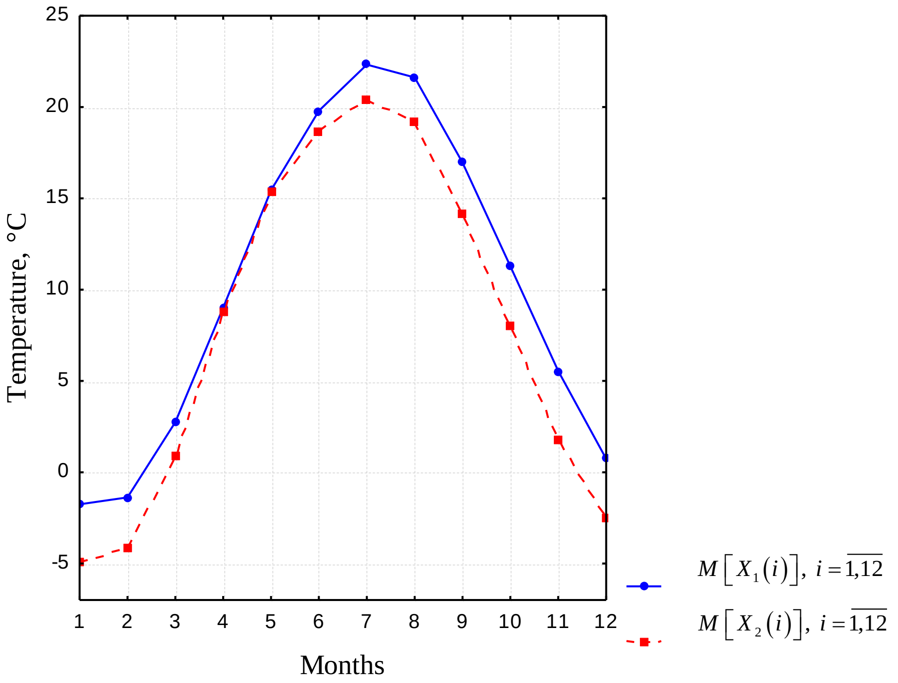

Fig. 3. The diagrams of mathematical expectations of random sequences of the average temperature in Odessa ($M\left[X_1(i)\right],\ i=\overline{1,12}$) and Kyiv ($M\left[X_2(i)\right],\ i=\overline{1,12}$)

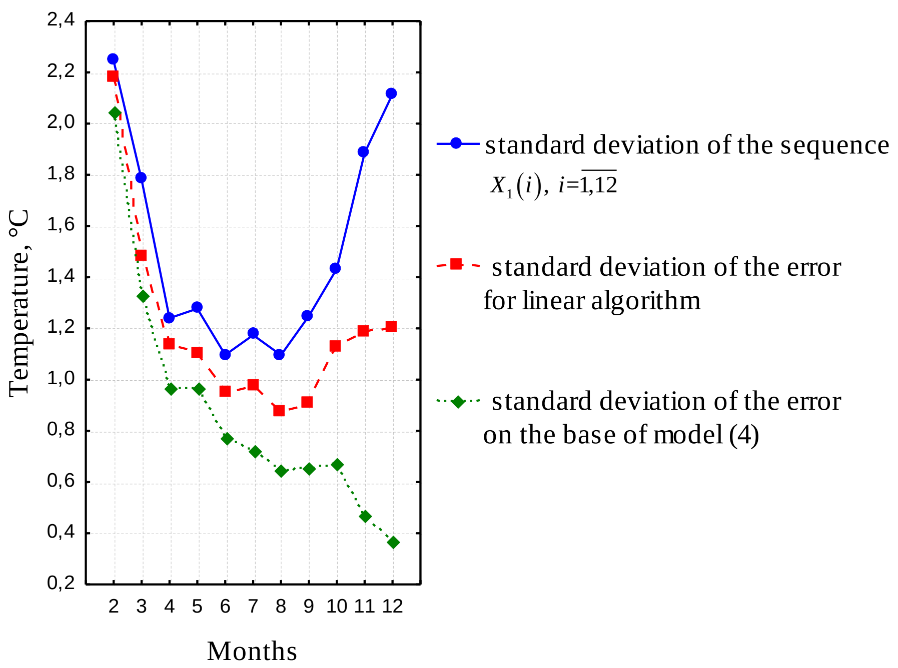

Fig. 4. The root mean square error of sequence realizations extrapolations using the linear algorithm on the basis of model (4)

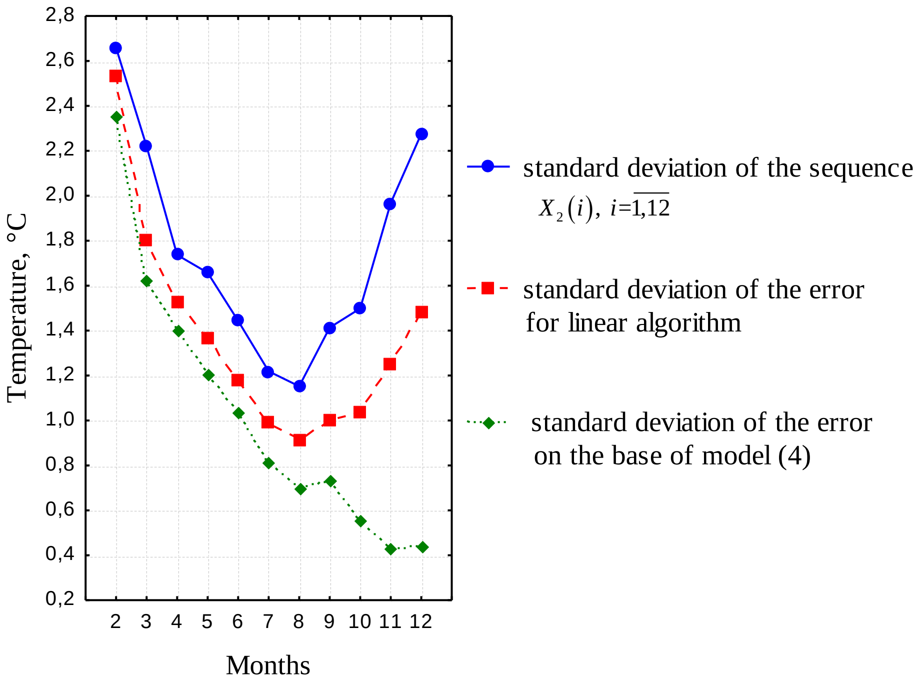

Fig. 5. The extrapolation root mean square error of sequence realizations $X_1(i),\ i=\overline{1,12}$ with using the linear algorithm and on the basis of the model (4)

Forecasting results show on the significant advantage in an extrapolation quality through using the nonlinear stochastic relations in forecasting model.

Conclusions.

There was developed the method of nonlinear extrapolation of vector random sequences, that do not impose any significant restrictions on the class of investigated sequences: stationarity, Markovian property, linearity, monotonicity, etc. The universality of the obtained solution is determined by the fact that there is a canonical decomposition and accurately describes in the discreteness points any random process with finite dispersion. The method is optimal in the sense of mean-square criterion and it allows the use of stochastic connections of any non-linearity order and any measurements number. Taking into account the recurrent nature of the extrapolator parameters calculations, its implementation on a computer is enough simple. The numerical experiments results shown high efficiency of the proposed method.

Since the most of investigated physical, technical, economic or other real processes are stochastic, the proposed method has the wide range of applications at solving the control problems in various fields of science

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and engineering: forecasting control of technical devices reliability, medical diagnostics, radiolocation, technological objects control etc.

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LINGUISTIC MODELS OF FRACTAL DATA SERIES

Abstract. *The properties of construction linguistic models of dynamic processes time series. In the article the theoretical bases of linguistic models of dynamic processes. Attention is paid to the peculiarities of forming patterns with fractal properties.*

Keywords: *linguistic model, linguistic modeling, time series, fractal grammars.*

Formulation of problem

Standing detection task fractal properties of time series generated by dynamic processes, and building linguistic models using fractal formal grammars.

Analysis of recent research and publication

Linguistic modeling [1,2] based on the following mathematical theory known as the theory of time series, interval mathematics[3,4], mathematical tools of hidden Markov models, structural approach to pattern recognition, the theory of formal grammars[5].

Task of investigations

Research objective is offer linguistic modeling as a universal mechanism for time series modeling of dynamic processes with having fractal properties for further analysis and forecast.

Main part (the results of theoretical and experimental research)

We give a definition of linguistic modeling and linguistic model.

Linguistic modeling - a complex of methods, techniques and algorithms that use numerical arrays process of converting information into linguistic sequences on which resumed formal grammar. Linguistic model - is based on a set of linguistic modeling symbolic (linguistic) sequences for the chosen parameters of the process of transformation and restored on the basis of its formal grammar. Linguistic modeling should be considered as a specific kind of mathematical modeling to handle data in a character (not numerical) form.

In this paper we considerate main principles of new kind mathematical modeling, linguistic modeling, and formalisms, which released its.

At begin we will be done definition of linguistic model. The linguistic model is formal system that consists of four elements:

$$<D,I, L,G>$$

where D - set of input data(for example, time series);

I - rules of input data intervalization;

L – isomorphism from set interval to symbol set (alphabet);

G – formal grammar was restored by linguistic chains set given .

The linguistic modeling may be used to practice solving of different problems: time series forecasting; pattern recognition (sound, voice, emotion statement etc.); user's authentication by hand motions; early diagnose of skeleton-muscle diseases and other.

Now we will be discussed main procedures for realization of intervalization rules.

The linguistic model building process consist of next steps:

- data preprocession (first calculation of the time series of differences of various orders etc.) $\Delta^1 = x_{i+1} - x_i$;
- definition of the field values of the time series and its frequency characteristics;
- intervalisation values set (special kid of quantification);
- process of converting numerical series to symbolic form, which we named “linguistisation”;
- formal grammar restoring with HMM.

Of course that the simplest linguistization scheme power corresponding alphabet must be much smaller than the coherence time series.

Let we have two partially ordered sets X and Y. The set, which asked the relevant procedure is called ordered if the order relation defined for any two of its elements, and partially ordered otherwise. Partially ordered set is called a structure, if any two-element subset that it has the exact upper and lower limit, and a complete structure, if each of its non-empty subsets has the exact boundaries.

Each of the sets and we assume conditional structures and mark S(X) and S(Y). The ratio of the order is denoted by ≤.

If we have a,b∈S(X) and a≤b, then the set $I(a, b) = [a, b] = \{x \in X, a \leq x \leq b\}$ set will be named an interval on S(X). The set of all intervals on the structure of S (X) denote $\mathcal{J}_{S(X)}$.

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Thus, if $X = R^1$- set of real numbers, then $\mathcal{I}_{R^1}$- the set of closed intervals on the line of real numbers. In this case, $\mathcal{I}_{R^1}$ is called interval number.

Returning to the procedure of partitioning the set of values into intervals, we note that basically we consider intervals that are not degenerate. In this case, the simplest linguistization method could bring everything to the fact that all the values of the time series (or differences) is a degenerate interval and other intervals not.

We are interested in certain cases that reflect the following types intervalization: 1) when the intervals are equal; 2) logarithmic intervals; 3) when equal probability intervals; 4) intervals for a specific probability distribution (normal, beta distribution, Poisson, Dirichlet, etc.).

To construct intervals according to the selected distribution we use interval mathematics. For example, we have $[a_{3,}a_6] = [a_{3,}a_4] + [a_{4,}a_5] + [a_{5,}a_6]$ for $v_{3,6} = v_{3,4} + v_{4,5} + v_{5,6}$ (see fig.1).

When partitions on equal intervals of the N-level set X, we have $\omega(a_1, b_1) = \omega(a_2, b_2) = \cdots = \omega(a_N, b_N)$, where $\omega(a_i, b_i) = b_i - a_i$ is width of the interval $I[a_i, b_i]$.

When equally (or equifrequent) set partitioning values into intervals we have $dim\{I[a_1, b_1]\} = dim\{I[a_2, b_2]\} = \cdots = dim\{I[a_i, b_i]\} = \cdots = dim\{I[a_N, b_N]\}$.

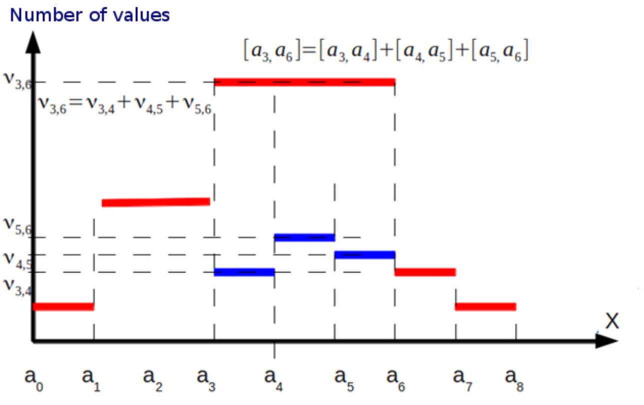


Fig. 3. Construction intervals using the rules of interval mathematics

Calculating frequency response range is in accordance with a distribution.

For example, the calculation parameters for beta distribution we can find the average m and variance s by difference time series. And then we have a beta distribution expression

$$a = -(m \cdot s + m^3 - m^2)/s$$

$$b = ((m-1) \cdot s + m^3 - 2 \cdot m^2 + m)/s$$

We have an alphabet $\mathcal{A} = \{e_i\}_{i=\overline{1,N}}$, the set of elements e_i, which also imposed ratio procedure $e_1 \ll e_2 \ll \cdots \ll e_N$, which we call lexicographic order for the alphabet $\mathcal{A}$. We have a time series $X = \{x_1, x_2, \dots, x_M\}$, which is consistent with the set of intervals I, ie, all the values of a number of values between $a_1$and b_N. The operation resulted intervalizatsiyi time series X is a sequence of intervals, which include elements of the time series, $(X) = I_X = \{I^1, I^2, \dots, I^M\}$, $I^j \in I, j = 1,2, \dots, M$. In fact, you can write $\mathcal{J}(x_j) = I^j, j = 1,2, \dots, M$.

Defined mapping $\mathfrak{L}: I \to \mathcal{A}$, morphism, which puts each interval $I_i \in I$ element alphabet $\mathcal{A}$.

At the stage of converting numerical values of the time series by using reflection $\mathfrak{L}$, it replaces elements x_i to $e_{j=}\mathfrak{L}(I_j)$, if $x_i \in I_j$.

As a result of this operation, we obtain a sequence of linguistic elements of a set of alphabet $\mathcal{A}$: $\mathfrak{L}(\mathcal{J}(X)) = \mathfrak{L}(I_X) = \{\alpha_1, \alpha_2, \dots, \alpha_M\}$, ie $\alpha_j = \mathfrak{L}(I^j), j = 1,2, \dots, M$.

In converting the results we obtained material (linguistic chain), which subsequently can be used to restore formal grammar (see fig.2,3).

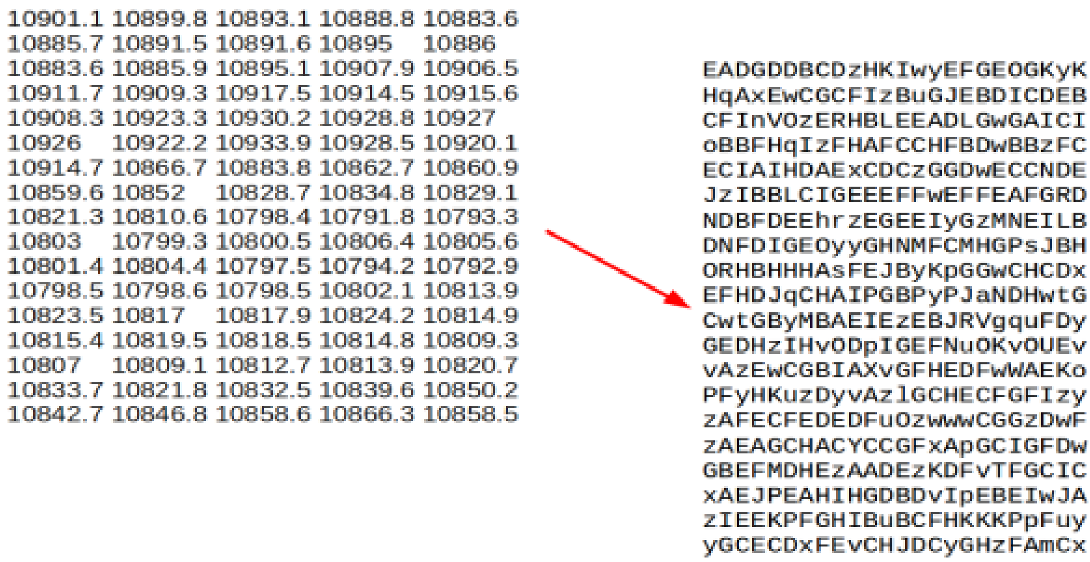
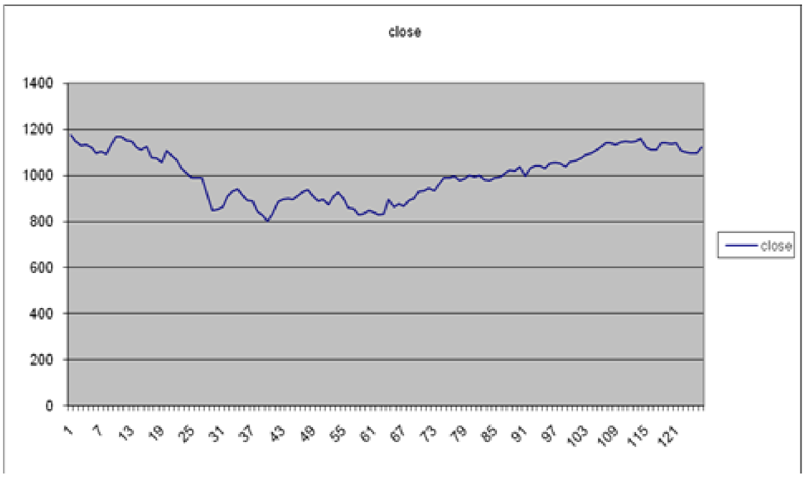


Fig. 2. Numerical series convert to a linguistic chain



IEvCHuDhlxEyHCsQyEeGEMFExyXZvtgqtHGzOEIkfswAspvHGv
FlqHNAHwsACwaKsBovlwtCmoxuFutAvEytwssyrMluxBpwzDowtsutsrx
BtwyxtLBylyzvKBzyn

Fig. 3. Linguistic chain of time series

One of the possible options to solve this problem - the use of mathematical tools hidden Markov models for constructing probabilistic formal grammars. Example transition probability matrix will be show in fig.4.

	r	s	t	u	v	w	x	y
p	0	0	0	0	0,007874015	0,007874015	0	0
q	0	0	0,007874015	0	0	0	0	0
r	0	0	0	0	0	0	0,007874015	0
s	0,007874015	0,007874015	0	0,007874015	0	0,007874015	0	0,007874015
t	0	0,015748031	0	0	0	0,015748031	0	0
u	0	0	0,015748031	0	0	0	0,007874015	0
v	0	0	0,007874015	0	0	0	0	0
w	0	0,015748031	0,015748031	0	0	0	0	0,007874015
x	0	0	0,007874015	0,007874015	0	0	0	0,007874015
y	0,007874015	0	0,007874015	0	0	0	0,007874015	0
z	0	0	0	0	0,007874015	0	0	0,007874015
A	0	0,007874015	0	0	0,007874015	0	0	0
B	0	0	0,007874015	0	0	0	0	0,007874015
C	0	0,007874015	0	0	0	0,007874015	0	0
D	0	0	0	0	0	0	0	0
E	0	0	0	0	0,007874015	0	0,007874015	0,015748031

IEvCHuDhlxEyHCsQyEeGEMFExyXZvtgqtHGzOEIkfswAspvHGv
FlqHNAHwsACwaKsBovlwtCmoxuFutAvEytwssyrMluxBpwzDowtsutsrx
BtwyxtLBylyzvKBzyn

Fig. 4. Transition probability matrix of linguistic chain HMM

Fractal dimension in the classic sense is a number that describes quantitatively how an object, process fills the space. There are many ways of calculating fractal dimension. They are based on the calculation of volume or area of fractal formation in the same space where there is education.

Consider the time series $\{x_i\}_{i=\overline{1,N}}$ that describes a dynamic process. If the levels of a series x_i of independent, it is easy to see the lack of bright trends and dynamic behavior of the process will be more likely to resemble "white noise". In this case, the fractal dimension will be directed to the magnitude of topological dimension plane, that is. If the value of the time series are not independent, the fractal dimension is much smaller than 2. Contents of this is that our time series dynamic process has memory, that there are certain time intervals varying quality trends that change the times of uncertainty.

A completely different situation when we deal with linguistic links.

At the ordered $A = \{\alpha_1,..,\alpha_M\}$ alphabet introduced a measure $\mu(\alpha_i) = f(i)$ where f - a function of the elements of the alphabet (the Index).

The notion of distance between elements of the alphabet $R[\alpha_i, \alpha_j] = \begin{cases} \mu(\alpha_i) - \mu(\alpha_j), \ if\ i > j \\ \mu(\alpha_j) - \mu(\alpha_i), \ if\ j > i \end{cases}$.

While similar numerical series, introducing indicators fractal linguistic series.

$$\mathcal{L}_H = 2 - \mathcal{H},$$

$$\mathcal{H} = \frac{log\left(\frac{\mathcal{R}}{\mathcal{S}}\right)}{log\left(\frac{N}{2}\right)},$$

where $\mathcal{R} = max\{\mu(\alpha_i)|\alpha_i \in \mathcal{A}\} - min\{\mu(\alpha_i)|\alpha_i \in \mathcal{A}\}$ and $\mathcal{S}$ is the mean linguistic deviations of linguistic series.

Conclusions and prospects for further research

The article was the analysis to identify fractal properties of linguistic dynamic process chains. Features of the application of linguistic modeling to build models of dynamic processes with fractal properties.

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UDK 506+510

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MODELING SUSTAINABLE DEVELOPMENT PROCESSES

Abstract*. The paper contains the description of the feasible approach to modeling and forecasting of ecological processes that are the component of the sustainable development paradigm. The suggested mathematical apparatus is based on the statistical methods and comprises hidden Markov models with the linguistic modeling.*

Keywords*: hidden Markov models, linguistic model, linguistic modeling.*

Formulation of problem

We propose the mathematical apparatus that might be used for the modeling and forecasting of the environmental processes of the sustainable development paradigm. The common problem of the statistical methods is the lack of the historical information.

Analysis of recent research and publication

According to the definition suggested by the Centre “For our common future” (“За наше спільне майбутнє”), that has been working in Geneva since 1988, and the United Nations Conference in Rio de Janeiro (1992), the sustainable development is understood as the kind of development that “satisfies the current needs, but does not compromise the abilities of the future generations to satisfy their own needs”, or that provides “the high quality of environment and the healthy economy for all nations”. Therefore, the problem of the sustainable development is the problem of the mankind salvation from the consequences of its own activity that, by the end of the 20th century, have become critical and manifested themselves in desertification, pollution of the atmosphere, oceans and soil, rapid population growth, poverty, starvation, dangerous diseases, etc. The issues of scientific knowledge and education, industry and innovation technologies, ecological, social and medical problems, international relations and political events and many other phenomena of modern life have intertwisted into the single interrelated unit. The consciousness of the situation and the search of the reasonable solutions to the problem have become an urgent matter. It requires focused attention not only on a global, but also on a national, regional and local basis. [1]

Usually, the sustainable development paradigm is presented in the following way (fig.1).

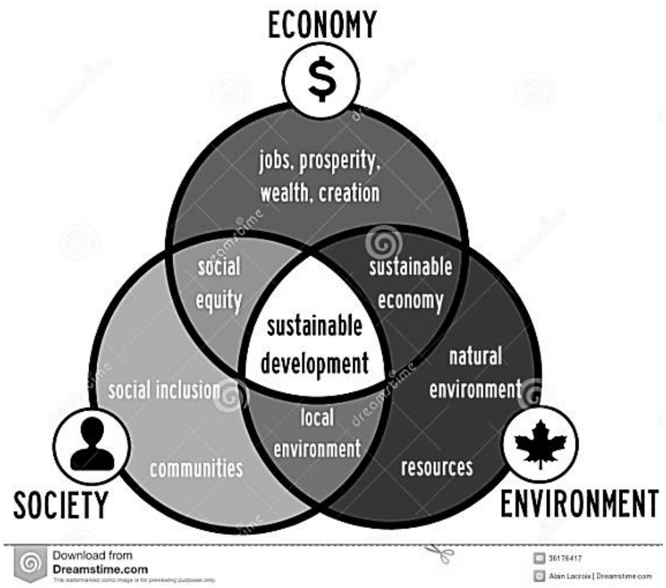

Fig. 1 The triune concept of the sustainable development

The growing rate of exploitation of natural resources, economic decline of the economies in transition raise up the risk of the technogenic disasters, keep the countries from spending considerable efforts and resources necessary for the implementation of measures to reduce the environmental impact.

To accomplish the purpose of the sustainable development the specific mechanisms for its implementation are required. The development and application of the "environmental assessment" system for the assessment of the transition to the sustainable development is of considerable significance in the world practice. The most important are the two of its modes (local and strategic) that nowadays are the well-established mechanisms of revelation and prevention of the environmental consequences of the human induced activity (refer to fig.2) [2].

However, for better understanding of the ecological component of the sustainable development paradigm, it is necessary to analyze some natural phenomena and biospheric processes and their interaction in the "man-environment" system. We will pay careful attention to environmentally hazardous processes.

The task of time series analysis in technical, medical or economical processes where the quality of decision-making to a large extent depends on the prediction of trends in the dynamic process. One of the sub-tasks of such trends is a search for the available templates.. We propose an approach to solve this problem using a hybrid model of a special kind - the "hidden Markov model - a linguistic model.". The principles of hidden Markov models (HMM) was described Baum and his colleagues in the late 60's [6-8]. In the early 70th Baker, Dzhelinek and their colleagues first used HMM for speech recognition [9, 10]. The linguistic modeling has been for almost the 20th century, especially in the works of Markov A.A. [11,12], Apresian Yu.D.[13], Fu K.S[14]. Andrey Markov produced the first results (1906) for these processes, purely theoretically. In 1913, he applied his findings for the first time to the first 20,000 letters of Pushkin's Eugene Onegin. The main principles of linguistic modeling was described in works [15,16].

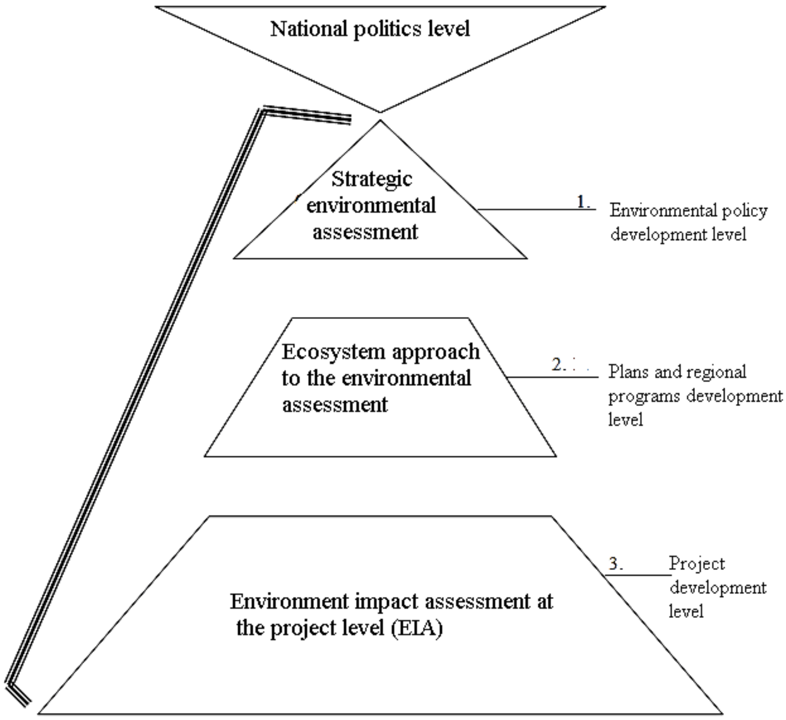

Fig.2. Environmental assessment system (EA)

Task of investigations

Proposed to build a hybrid model of the time series based on hidden Markov models and linguistic modeling (HMM-LM). The article provides a classification of existing hidden Markov models and ways of constructing a hybrid model HMM-LM.

Main part (the results of theoretical and experimental research)

Environmentally hazardous processes are generally understood as exogenous and endogenous (anthropogenic), short-term and long-term impacts on the ecosystem as a whole or on its particular element, leading to the violation or problems of its performance that in its turn disrupts the man-environment balance.

1. Endogenous (anthropogenic) are caused by anthropogenic activity (pollution by harmful organic and non-organic substances of all kinds of the environment: the atmosphere, surface waters, water-saturated underground layers, soil, animate environments; noise and electromagnetic pollution of the atmosphere; light pollution; flooding of soils and slopes; ozone depletion and creating conditions for the greenhouse effect). They may be controlled and, in some cases, reduced or even prevented.

2. Exogenous are the manifestations of the outer space and internal geological processes and changes (solar cycles, hurricanes, tropical cyclones, monsoons, volcanic activity, global warming as a result of the precession of the Earth's axis, and finally, the asteroid hazard). They are purely objective, cannot be controlled, but may be observed and forecasted. Therefore, it is possible to develop a set of measures to minimize the damages or mitigate the consequences.

It becomes clear from the mentioned earlier that the environmentally hazardous processes are of various nature and types. Also, it is evident that “not everything depends on a man”.

In fig.3 there is a schematic classification of the environmentally hazardous processes. [3]

The solar activity (fig.4) is a special type of an exogenous impact on the geological and biochemical processes taking place on Earth. The index for the solar activity characteristics, so called Wolf number, Zurich number or the relative sunspot number is calculated by the following formula:

$$R = k\,(f + 10g),$$

where R is the Wolf number; f is the total number of sunspots on the visible sun hemisphere; g is the number of sunspot groups; k is the multiplier (<1) that takes into account the total contribution of observing conditions, the telescope type and that is observed by the standard Zurich numbers.

According to the observation data for the last 304 years, the cycle length in actual practice varies from 8.5 to 14 years between the proximate minimums and from 7.3 to 17 years between the proximate maximums. The connection between the solar cycles and the increased occurrence of land slides has been proved. The most adverse impact is on that of the innovate technology effects, high-frequency operating devices, such as mobile communications, satellites (and also the related navigational safety problems), etc. Solar radiation is the source of the motion in the atmosphere-ocean system. The force, that the solar radiation generates, produces buoyancy – the source of motion in the atmosphere. It determines the nature of hurricanes, tornadoes, tsunamis and other destructive processes. Also, the solar activity influences the proliferation of some diseases, increases the frequency of traffic accidents, etc.

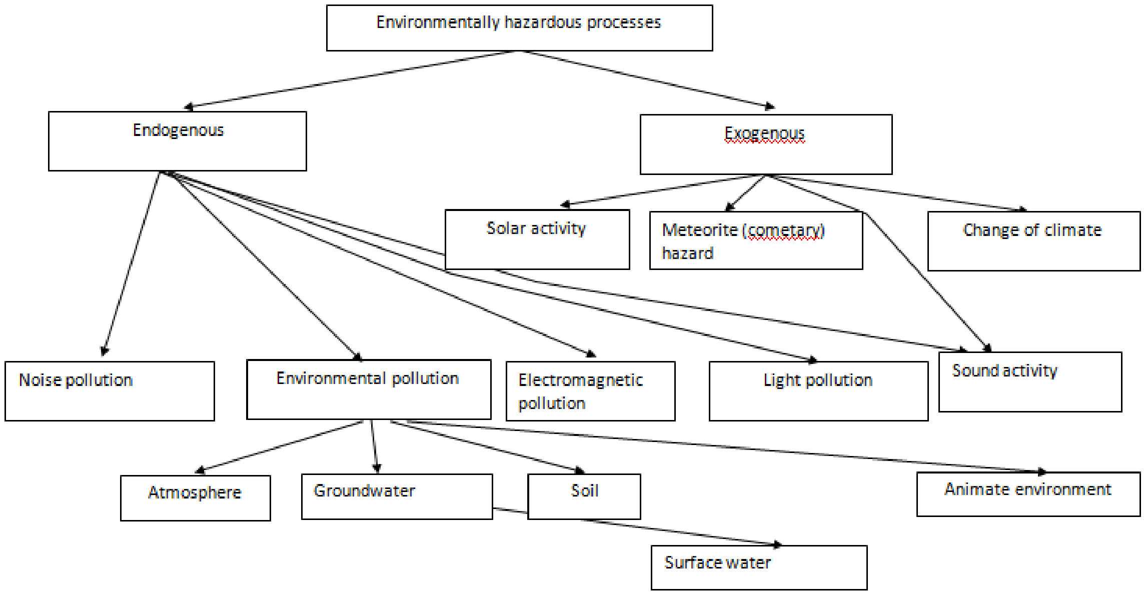

Fig. 3 Environmentally hazardous processes classification

According to the data of US National Centre for Environmental Information

(http://www.ngdc.noaa.gov)

The climate change caused by the global warming is not only the result of increased greenhouse gases concentrations (especially, carbon dioxide) in the atmosphere, but also the result of the next cycle of the precession of the Earth's axis, thus it has an exogenous cause and it will be intensified in the near future. Although, according to Kh.Y. Shelnhuber [4], Antarctic and Greenland's ice sheet, Sahara desert, Amazonian rainforest, Asian monsoon system, Gulf Stream and six more "weak spots" of Earth influence the climate, and in the case of at least one of them undergoing changes, the ecological disaster (of the continental level) will be inevitable, the risk may be decreased by reducing the emission rate of gases mentioned earlier.

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Considering the literature [3], we can define two principal directions and accordingly, two methodological approaches to the mathematical modeling of the dynamics of the environmentally hazardous processes of various nature. The first approach comprises dynamic-computed approaches based on computational methods for solving various kinds of differential equations that describe the basic laws of physics, and also atmospheric and hydrodynamic processes. They are focused on solving the following basic problems of the most important spatiotemporal patterns of the current natural processes:

- Exposure of the current spatiotemporal interrelations between various atmospheric processes in the observation dynamics;
- Natural processes modeling for the forecasting of their development dynamics.

The second approach, comprising empirical dynamic-statistical approaches based on the use of the long-term field measurement statistics, belongs to the international system for the analysis and forecasting of the ecosystem components. They are focused on the exposure of the basic spatiotemporal patterns typical of the atmospheric processes over decades. The main purpose of these approaches is, in fact, the establishment of deep spatiotemporal correlations between various natural processes based on the long-term statistics. Depending on the purposes of the study it is necessary to perform the development of the mathematical apparatus for the analysis of the dynamics of the environmentally hazardous processes based on either dynamic-computed or dynamic-statistical approaches, taking into account the specific peculiarities and properties of the processes.

Besides, there is the third type of processes that cannot be modeled with the help of dynamic-computed methods, and due to the absence of a peculiar particular periodicity (daily, monthly, annual or another permanent periodicity) they are difficult to describe using empirical-statistical methods. Therefore, the problem of the development of the process analysis and the development of the forecasting methods of such processes for the information support of the environmental situation control and monitoring system is relevant.

To sum up, the conducted analysis allows for the conclusion that the environmentally hazardous processes are characterized by the complex interrelations, interdependencies and interactions of various factors and causes. They have the following characteristic properties and peculiarities:

• The heterogeneousness and diversity of causes and factors and an activity that causes them;

• The spatial distribution of the triggering events, temporal and spatial uncertainty of the growth dynamics and their impact on the eco-surroundings;

• The nonstationarity of properties and ambiguity of their characteristics.

These properties and peculiarities determine the practical relevancy of studying of all the variety of characteristics, interrelations, interactions, interdependencies of the diverse factors and causes of the environmentally hazardous processes on the basis of the single systematic approach from the perspective of achieving the globally defined objective of the environmental situation management – early prevention and (or) minimization of the adverse effects of their action. However, the analysis shows that nowadays the various types of natural and technogenic environmental processes, their causes, progress, consequences and the sphere of the action are studied separately, without regard to interrelations, interdependencies, and interactions.

Such an approach does not consider some factors of primary importance that influence the active processes, their adverse impact level, the possibility and effectiveness of its prevention.

Considering all of the above-mentioned, we propose the feasible mathematical apparatus that may be used for the forecasting of the environmental processes of all three types.[5]

Hidden Markov models

A hidden Markov model (HMM) is a statistical Markov model in which the system being modeled is assumed to be a Markov process with unobserved (hidden) states. In a typical Markov model is visible observer, so the probability of transitions - a single option. In HMM, we can monitor only variables that are affected by this condition. Each state has a probability distribution among all possible output values. Therefore, the sequence of characters generated HMM provides information about the sequence of states.

We now turn directly to the classification of HMM. In a broad sense HMM can be classified into the following general classes [12]:

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- hidden semi-Markov model;
- classic HMM;
- hybrid Markov model.

Hidden semi-Markov model (HSMM) is a generalization of the HMM, which allows a more general distribution of residence time. The basic structure HSMM is shown in Figure 1. Arrows from $\overline{S_1}$ to $X_1,\ldots, X_{d_1}$ and from $\overline{S_2}$ to $X_{d_1+1},\ldots, X_{d_1+d_2}$ indicate conditional dependence of observations on the hidden states.

Hidden semi-Markov model consists of a pair of random processes with discrete time $\{S_t\}$and $\{X_t\}$. As HMM the observed process $\{X_t\}$is associated with a hidden state semi-Markov process $\{S_t\}$with conditional distribution.

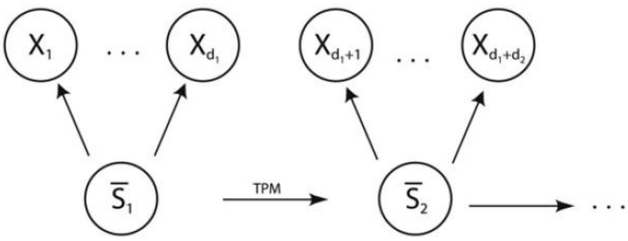

Fig. 4. Basic Structure of HSMM

Classic HMM divided in the following classification criteria by:
- number of states (1);
- number of levels (2);
- temporal characteristics (3);
- type of probability distribution that underlie the HMM (10);
- parametric property (11);
- type of topology (4);
- homogeneity (5);
- linearity (6);
- dynamic properties (7);
- structure of matrix transitions (8);
- connectivity graph transitions (9).

The general classification of classic HMM showed in fig.5. Number in parentheses corresponds to the diagram.

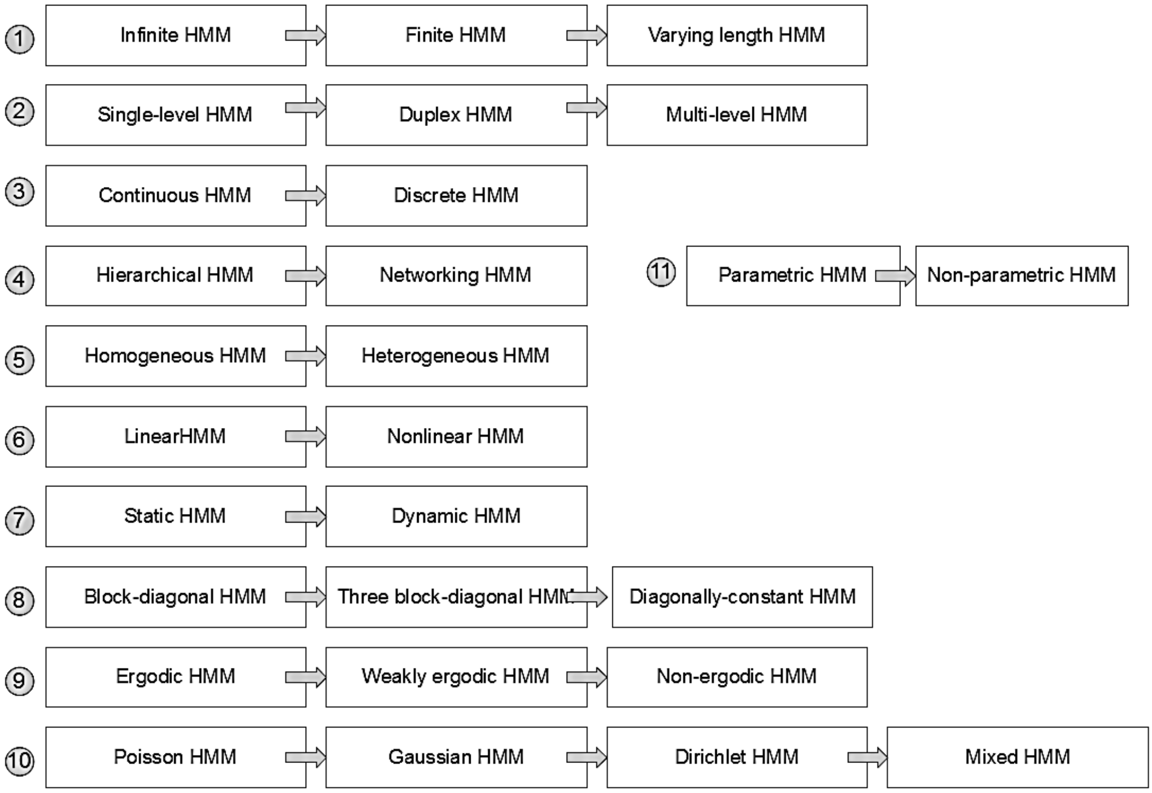

Fig. 5. The general scheme of classification of classical hidden Markov models.

Conclusions and prospects for further research

Thus, we proposed the mathematical apparatus that might be used for the modeling and forecasting of the environmental processes of the sustainable development paradigm. The common problem of the statistical methods is the lack of the historical information. However, the mankind is engaged in the monitoring of the environment, observation of the weather and natural processes throughout the life. Therefore, the use of the statistical methods in particular is fully justified.

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F.E. Geche

IMPLEMENTATION OF BOOLEAN FUNCTIONS BY ONE GENERALIZED NEURAL ELEMENT

Summary. *Present article considers the neural elements (NE) with generalized threshold activation function and represents criterion of Boolean functions implementation on such neural elements.*

Keywords: *characteristic vector, neural element, activation function, vector structure, recognition, spectrum, character of group.*

Introduction

Developmentofsuitablemethodsforprocessingandsolvingtheproblemof digital signals and images recognition is actual and practically important task. As we know [1-5], selectionofbasisforrepresentationof discrete signals and images is an important stage during their processing and formation of indicators for recognition problem.

Surfaces which are defined by neural elements with conventional threshold activation functions andareusedforseparationofobjectsclasses, arebuiltbymeansofhyperplanes. Neural elements with generalized threshold activation function define nonlinear surfaces andbymeansofthesesurfacesthe complex surfaces are generated, whichcanbesuccessfullyusedforsolving problems of classification and recognition of objects, defined by sets of Boolean vectors.

Thus, developmentofeffectivemethodsverifyingtheimplementationoflogicalgebra functionsby one neural element with generalized threshold activation function is actual and important while solving problems connected with objects recognition and data compression.

Neural elements with generalized threshold activation function

Let $H_2 = \{-1,1\}$ – isa cyclic group of 2-ndorder, $G_n = H_2 \otimes \ldots \otimes H_2$ – isa direct product of n cyclic group H_2 and $X(G_n)$ – is a group of characters [6-8] of group G_n over the field of real numbers R. Letsdefinefunctionon the set $R \setminus \{0\}$:

$$Rsign\,x = \begin{cases} 1, & if\ x > 0, \\ -1, & if\ x < 0. \end{cases} \qquad (1)$$

Let $i \in \{0,1,2, \ldots, 2^n - 1\}$ and $(i_1, \ldots, i_n)$ – is its binary code, that is $i = i_1 2^{n-1} + i_2 2^{n-2} + \ldots + i_n$, $i_j \in \{0,1\}$. The value of character χ_i on element $g = ((-1)^{\alpha_1}, \ldots, (-1)^{\alpha_n}) \in G_n$ ($\alpha_j \in \{0,1\}, j = 1,2,\ldots, n$) is defined as follows:

$$\chi_i(g) = (-1)^{\alpha_1 i_1 + \alpha_2 i_2 + \ldots + \alpha_n i_n}.$$

Let us consider 2^n-dimensional vector space $V_R = \{\varphi \mid \varphi : G_n \to R\}$ over the field R. Elements χ_i $(i = 0,1,2, \ldots, 2^n - 1)$ of group $X(G_n)$ form orthogonal basis of space V_R [6]. Booleanfunctioninthealphabet $\{-1,1\}$ sets definiteindication $f : G_n \to H_2$, that is $f \in V_R$. Consequently, arbitrary Boolean function $f \in V_R$ definitely could be written as follows:

$$f(g) = s_0\chi_0(g) + s_1\chi_1(g) + \ldots + s_{2^n-1}\chi_{2^n-1}(g).$$

Vector $s_f = (s_0, s_1, \ldots, s_{2^n-1})$ isnamedthe spectrum ofBooleanfunctionin system of characters $X(G_n)$ (in system of basis functions of Walsh-Hadamard [9]).

Fromdifferentcharacters $X(G_n)$, exceptthemainone, wewillbuild m-element set $\{\chi_{i_1}, \ldots, \chi_{i_m}\}$ and relating the chosen systems of characterswe will consider the following mathematical model of neural element:

$$f(x_1(g), \ldots, x_n(g)) = Rsign(\sum_{j=1}^{m} \omega_j \chi_{i_j}(g) + \omega_0), \tag{2}$$

wherevector $w = (\omega_1, \ldots, \omega_m; \omega_0)$ isnamedasvectorofneural element structureand $g \in G_n$.

Let $w(g) = \omega_1\chi_{i_1}(g) + \ldots + \omega_m\chi_{i_m}(g) + \omega_0$. If $w = (\omega_1, \ldots, \omega_m; \omega_0)$ isavectorofNEstructurerelatingtosystemofcharacters $\{\chi_{i_1}, \ldots \chi_{i_m}\}$ of group G_n over R, which implements Booleanfunction $f : G_n \to H_2$, then from (1) and (2) immediately follows that

$$\forall g \in G_n \quad w(g) \neq 0. \tag{3}$$

Furtherwewillconsideronlysuch neural elements, vectorstructuresofwhich satisfy the condition (3). Setofallsuch $m+1$-dimensional real vectors that satisfy the condition (3), we will mark by means of $W_{m+1} = W_{m+1}(\chi_{i_1}, \ldots \chi_{i_m})$.

Itisobvious, thatthe neural element relatingtothe system of characters $\{\chi_1, \chi_2, \chi_4, \ldots, \chi_{2^{n-1}}\}$ coincides with the threshold element [10].

Theorem 1. *Boolean function* $f : G_n \to H_2$ *isimplementedbyoneneuralelement relating to system of characters* $\{\chi_{i_1}, \ldots \chi_{i_m}\} \subset X(G_n)$ *with vector of structure* $\mathrm{w} \in W_{m+1}$ *only in case, when*

$$\forall \mathrm{g} \in G_n \quad f(\mathrm{g})w(\mathrm{g}) = |w(\mathrm{g})|, \tag{4}$$

where $|x|$ *– when module of number* $x \in R$.

The proof follows immediately from (2) and from equality: $(Rsign x) \cdot x = |x|$, where $x \in R \setminus \{0\}$.

Theorem 2. *Boolean function* $f : G_n \to H_2$ *isimplementedbyoneneuralelement relating to system of characters* $\{\chi_{i_1}, \ldots \chi_{i_m}\} \subset X(G_n)$ *with vector of structure* $\mathrm{w} \in W_{m+1}$ *only in case, when*

$$\sum_{\mathrm{g} \in G_n} f(\mathrm{g})w(\mathrm{g}) = \sum_{\mathrm{g} \in G_n} |w(\mathrm{g})|. \tag{5}$$

Proof. Sufficiency. Indeed, when function f is not implemented by one NE relating $\{\chi_{i_1}, \ldots, \chi_{i_m}\}$, then such elements exist $\mathrm{g}_1, \ldots, \mathrm{g}_k \in G_n$ for which the equality (4) is not true, that is:

$$\forall \mathrm{g}_j \in \{\mathrm{g}_1, \ldots, \mathrm{g}_k\} \quad f(\mathrm{g}_j)w(\mathrm{g}_j) = -|w(\mathrm{g}_j)|$$

and

$$\sum_{\mathrm{g} \in G_n} f(\mathrm{g})w(\mathrm{g}) = \sum_{\mathrm{g} \in G_n \setminus \{\chi_{i_1}, \ldots, \chi_{i_m}\}} |w(\mathrm{g})| - \sum_{j=1}^{k} |w(\mathrm{g}_j)|. \tag{6}$$

Henceon the basisof (5) we have

$$2\sum_{j=1}^{k} |w(\mathrm{g}_j)| = \sum_{\mathrm{g} \in G_n} |w(\mathrm{g})| - \sum_{\mathrm{g} \in G_n} f(\mathrm{g})w(\mathrm{g}) = 0.$$

Consequently, $\forall \mathrm{g}_j \in \{\mathrm{g}_1, \ldots, \mathrm{g}_k\} \quad w(\mathrm{g}_j) = 0$, that contradicts the condition $\mathrm{w} \in W_{m+1}$. The necessity follows directly from theorem 1.

Let us write the left side of equality(5) in expanded form:

$$\sum_{g \in G_n} f(g) w(g) = \sum_{g \in G_n} f(g)(\omega_1 \chi_{i_1}(g) + \ldots + \omega_m \chi_{i_m}(g) + \omega_0) =$$

$$= \omega_0 \sum_{g \in G_n} f(g) + \sum_{j=1}^{m} \omega_j \left(\sum_{g \in G_n} f(g) \chi_{i_j}(g) \right) = \omega_0 b_0 + \sum_{j=1}^{m} \omega_j b_{i_j} \ ,$$

where $\mathrm{b}_f(X) = (b_{i_1}, \ldots, b_{i_m}; b_0)$, $\left(b_{i_1} = 2^n s_{i_1}, \ldots, b_{i_m} = 2^n s_{i_m}, b_0 = 2^n s_0 \right)$ – is a characteristicvector of Booleanfunction f relating to the system of characters $X = \{\chi_{i_1}, \ldots, \chi_{i_m}\}$.

Usingtheconceptofcharacteristicvectorof Booleanfunction f relatingtothe system of characters $X = \{\chi_{i_1}, \ldots, \chi_{i_m}\}$ theorem 2 could be written as follows:

Theorem 3. *Boolean function $f : G_n \to H_2$ is implemented by one neural element relating to the system of characters $X = \{\chi_{i_1}, \ldots \chi_{i_m}\} \subset X(G_n)$ with vector of structure $\mathrm{w} \in W_{m+1}$ only in case, when its characteristic vector $\mathrm{b}_f(X)$ satisfies the condition*

$$(\mathrm{w}, \mathrm{b}_f(X)) = \sum_{g \in G_n} |w(g)|,$$

where $(\mathrm{w}, \mathrm{b}_f(X))$ – is a scalar product of vectors w and $\mathrm{b}_f(X)$.

Conclusions

It derives from theorem 3 that Booleanfunction, which is implemented by one neural element relating to system of characters $X = \{\chi_{i_1}, \ldots \chi_{i_m}\} \subset X(G_n)$, is definitely determined by its $m+1$-dimensional characteristic vector $\mathrm{b}_f(X) = (b_{i_1}, \ldots, b_{i_m}; b_0)$, and functions, which are not implemented by one neural element, are definitely determined in spectral region only by its spectrum $\mathrm{s}_f = (s_0, s_1, \ldots, s_{2^n - 1})$. Consequently, compression coefficient of Boolean function f, which is implementedbyoneneuralelement in spectral area is set by the ratio $2^n / (m+1)$. This means that characteristic vectors of such Boolean functions could be successfully used for data compression. Maximization of data compression coefficient is reduced to minimization of parameter

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$m = m^*$, that is to finding out such minimum system of characters $X^* = \{\chi_{i_1}, \ldots \chi_{i_{m^*}}\}$ relating to which the coresponding functions of logic algebra are implemented by one neural element.

If neural element with vector of structure $\mathrm{w} \in W_{m+1}$ relating to system of characters $X = \{\chi_{i_1}, \ldots \chi_{i_m}\}$ implements the Boolean function f, then from theorem 3 and equality (6) follows that for Boolean function $h : G_n \to H_2$ $(h \neq f)$ the following inequality is true

$$(\mathrm{w}, \mathrm{b}_f(X)) > (\mathrm{w}, \mathrm{b}_h(X)).$$

The last inequality could be used for construction of iterative procedure of neural elements synthesis with generalized threshold activation function relating to system of characters X.

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UDK 004.931

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SHADOW DETECTION AND REMOVAL FROM VERY HIGH RESOLUTON SATELLITE IMAGE

Abstract: *Shadows cause hindrance to correct feature extraction of image features like buildings, towers etc. in urban areas it may also cause false color tone and shape distortion of objects, which degrades the quality of images. Hence, it is important to segment shadow regions and restore their information for image interpretation. This paper presents an efficient and simple approach for shadow detection and removal based on HSI color model in complex urban color remote sensing images for solving problems caused by shadows. In the proposed method shadows are detected and compensated using the infrared channel.*

Keywords: *satellite images, shadow, multichannel, high resolution, algorithm, detecting, compensating.*

Introduction

Many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. The choice of specific techniques or algorithms to use depends on the goals of each individual project [1, 2]. Remote sensing data can be used in circumstances where it is impossible terrestrial research methods, such as fires and floods. One of the most common types of error encountered in remotely sensed data is shadow. This problem is a major source of confusion and misclassification in extracting land cover information from remote sensing data. The presence of shadow can also lead to misleading results if change detection is applied to a ground surface because of changes in the shadows, depending on the time and season. Space images of the town infrastructure, as a rule, contain many shadows cast by tall objects (buildings, bridges, towers, etc.) when the scene is lit by the sun. Shadows are a substantial obstacle in recognition of objects because they make it difficult to determine boundaries of those objects. On the other hand, a shadow is a deciphering feature making it possible to learn a lot about the shape, location and other properties of an object casting it. In object recognition, an important step is detection and compensation of shadows, as well as reconstruction of the scene in the shadowy area.

Paper overview

At the moment, there are classical algorithms of image processing for detection and selection of shadows, namely, contour, cluster, and frequency algorithms [3-5]. A variety of image enhancement methods have been proposed for shadow removal, such as histogram matching, gamma correction, linear correlation correction and restoration of the color invariance model [7,8]. The main shortcoming of these algorithms is formation of false outlines, which is caused by the substantial difference of brightness of the shadow and surrounding background and, subsequently, by a sharp change of brightness at the boundary of the shadow with the background and the object, which substantially complicates the stage of reconstruction of objects in the shadowy area [9].

Formulation the problem

There is a necessity to improve the algorithm of detection and compensation of shadows in the multichannel satellite images.

The basic material

In this work, an improvement of the algorithm for detection and compensation of shadows, the foundations of which include:

1. The preliminary processing stage, increase of the information capability on the base of ICA and Wavelet transforms [2].
2. Selection of the vegetation component.
3. Determination of the optimal binarization threshold.
4. Selection of the outlines of the objects.
5. Segmentation of the shadow area.
6. Compensation of the shadow area.

The structure chart of the improved algorithm is represented in Figure 1. The proposed method has been examined with variety of high resolution satellite images obtained under dissimilar illumination conditions in urban areas. The paper investigates satellite images from Worldview-2, the original size of the panchromatic image is 4600x4604 and 1150x1151 multichannel. The multichannel bands (Band1 = Coastal, Band2 = Blue, Band3 = Green, Band4 = Yellow, Band5 = Red, Band6 = Red Edge, Band7 = Near-Infrared 1, Band8 = Near-Infrared 2) cover the spectral range from 400 nm - 1050 nm at a spatial resolution of 1.84 m, while the panchromatic band covers the spectrum from 450 nm – 800 nm with spatial resolution 0.46 m. Figure 2 represents images obtained after each stage of work of the algorithm.

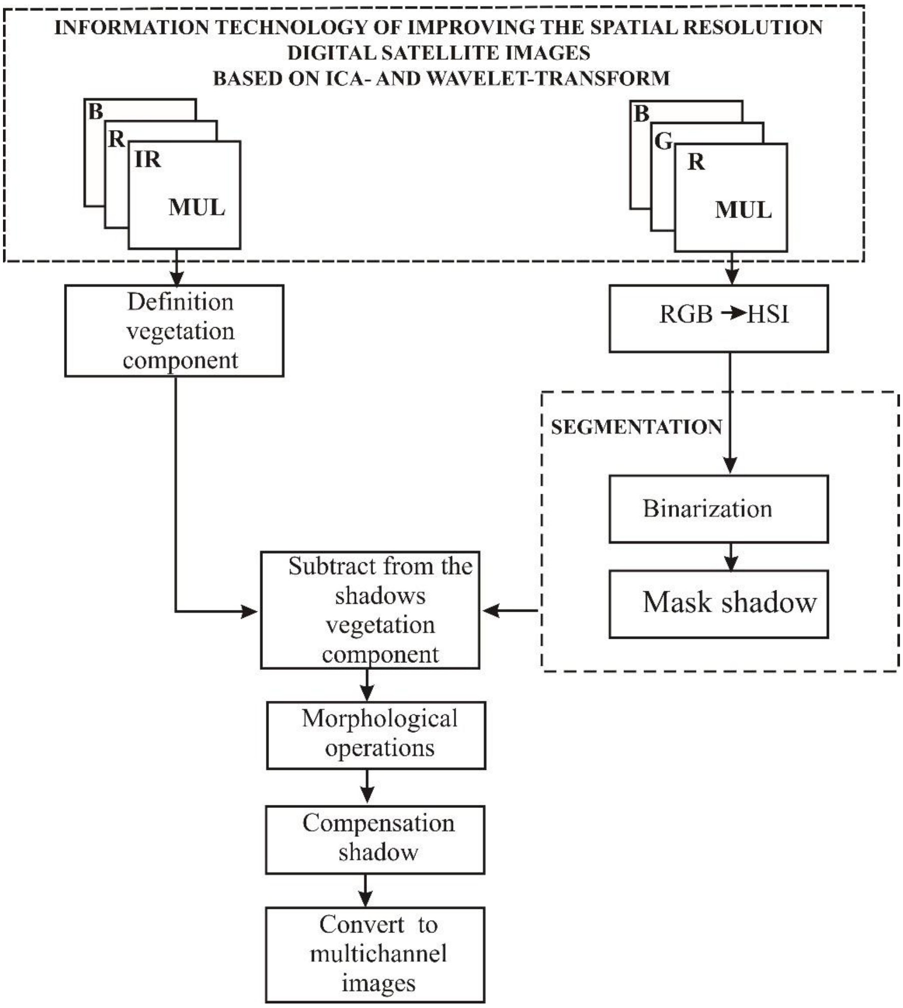

Figure 1. Algorithm scheme

We proposed to select the vegetation component with the use of the infrared channel. As the R channel, we select the IR, second and third (G and B, respectively). This operation is represented by this expression:

$$NDI = \frac{IR - R}{IR + R} \tag{1}$$

where IR - infrared channel, R - red channel.

Suppose R, G, and B are the red, green, and blue values of a color. The HSI intensity is given by the equation:

$$I = (R + G + B)/3. \tag{2}$$

Now let m be the minimum value among R, G, and B. The HSI saturation value of a color is given by the equation:

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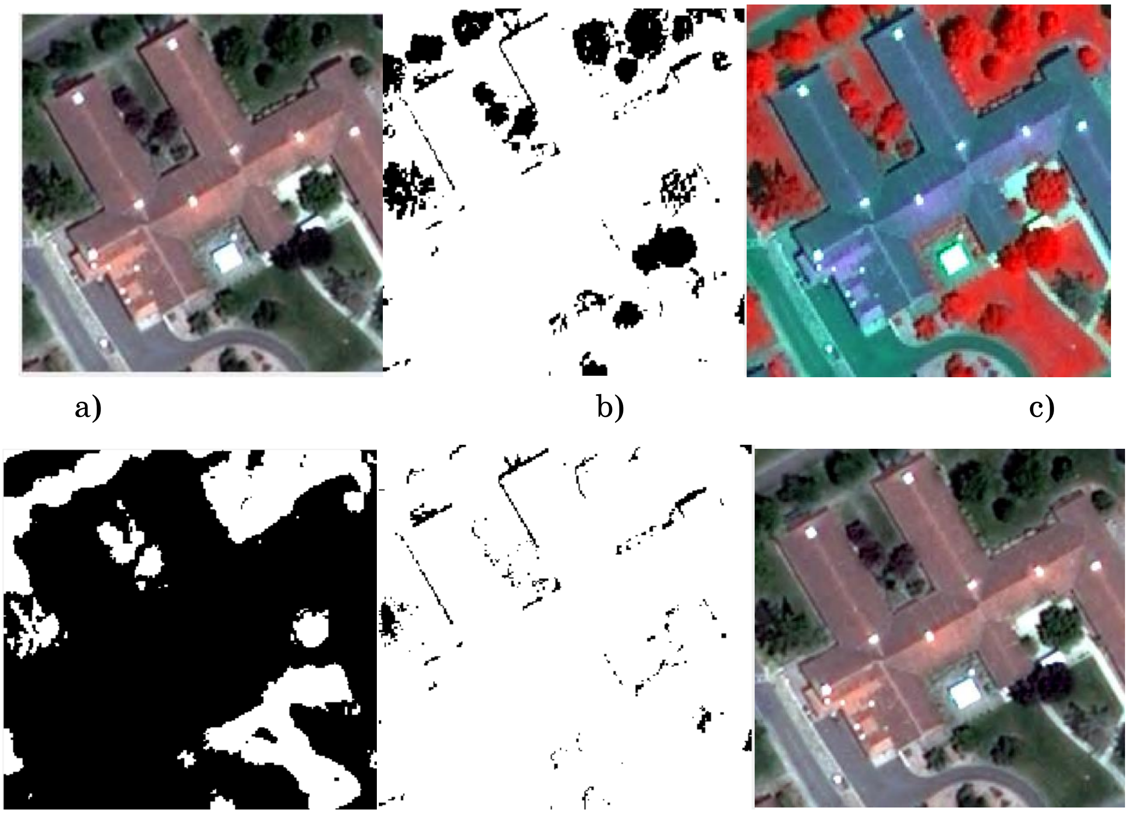
$$S = 1 - m/I \; if \; I > 0, \; or$$
$$S = 0 \; if \; I = 0 \qquad (3)$$

To convert a color's overall hue, H, to an angle measure, use the following equations:

$$H = cos^{-1}\left[\frac{(R - ½G - ½B)}{\sqrt{R^2 + G^2 + B^2 - G - RB - GB}}\right], \; if \; G \geq B, \; or \qquad (4)$$

$$H = 360 - cos^{-1}\left[\frac{(R - ½G - ½B)}{\sqrt{R^2 + G^2 + B^2 - RG - RB - GB}}\right], \; if \; B > G, \qquad (5)$$

where the inverse cosine output is in degrees.



a) b) c)

d) e) f)

Figure 2. Algorithm scheme:

a) original image (R G B); b) binary image showing shadows; c) original image (IR R B); d) binary image showing vegetation; e) subtraction of vegetation component from shadow; f) result image

The task of segmentation of the image is implemented on the base of the two-level hierarchical pyramidal algorithm, which allows us to use various color and texture difference of areas. As the criterion of homogeneity, the evaluation of closeness of the elements and areas of the image in the combined texture and color space of features. In the process of segmenting, the image transformed into HSI color model underwent binarization with selection of the optimal threshold. As a result of binarization, shadow areas were set to 1, and areas without shadows were set to 0 (Figure 2 (e)). Then the mask is applied to the obtained image, and we get segmented of shadow areas.

On the next stage of the algorithm, we carry out the operation of subtraction of the vegetation component out of the shadow one, which allows us to leave out only shadowy areas in the image. Compensation of shadow pixels is done owing to the increase of the brightness component for those pixels, the brightness component of which is below the threshold value [8].Then we convert the obtained image from the HSI color space back into RGB. To convert hue, saturation, and intensity to a set of red, green, and blue values, you must first note the value of H .

Conclusion

In the paper, an improved algorithm is proposed for detection and compensation of shadows in multichannel satellite images with increased information capacity on the base of ICA- and wavelet transforms. As the source, a multichannel image with an IR channel is used, which makes it possible to reliably determine the vegetation component, as well as shadows cast by the vegetation. In order to get a shadow detection result, image segmentation considering shadows is applied. The shadow removal method based on brightness component matching can effectively restore the information in a shadow area. The parameters calculated by using the radiation difference between inner and outer homogeneous sections can retrieve a shadow very effectively. In the future, we will explore more feature information to estimate more accurate the shadow coefficient, and obtain better result of shadow removal.

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PECULIARITIES OF RISKS ASSESSMENT BASED ON FUZZY MODELS

Abstract: *The article describes the methodology for the risk assessment based on fuzzy models. In the models of risk management, triangular norms can extend the probabilistic models to fuzzy models and thereby make possible their use in conditions of poor statistics. The effectiveness of this methodology for the design of fuzzy controllers, decision support systems based on fuzzy models of risk assessment was shown. There are some practical examples that demonstrates that fuzzy measures and integrals are good techniques to solve different complex problems.*

Keywords: *risks assessment; fuzzy models; fuzzy measures; fuzzy integrals.*

Introduction

Nowadays, risk management is seen as a key direction of applied management, so much attention is paid to researching of risk areas and the main types of risks, finding effective methods of their evaluation, control and monitoring. Efficient solving of any problems mainly depends on the accuracy and validity of decisions at all stages of problem solving and, regardless of the complexity of tasks, impossible without risk.

The general scheme of risks management is presented on figure 1.

The first phase is the collection of data, usually denoted as Risk Analysis, i.e. identification of hazards present in the workplace and work environment as well as the exposed workers, and identification of potential consequences of the recognized hazards – risks, i.e. the potential causes of injury to workers, either a work accident or an occupational disease. This is followed by the Risk Assessment phase, which includes the risk evaluation, the ranking of the evaluated risks and their classification in acceptable or unacceptable. At the end of this phase, the unacceptable safety and health risk situations are identified. The last phase is Risk Control that includes designing/planning safety control measures to eliminate or at least to reduce risks, followed by the implementation of safety control measures. Part of the risks could be transferred to insurance companies [1].

The main cause of risk is the uncertainty of the environment, which is caused by factors such as lack of full and reliable information on the environment; limited capabilities for processing information about the process or system; chance of occurrence of adverse events; conflicts; breach of contractual obligations; political decisions.

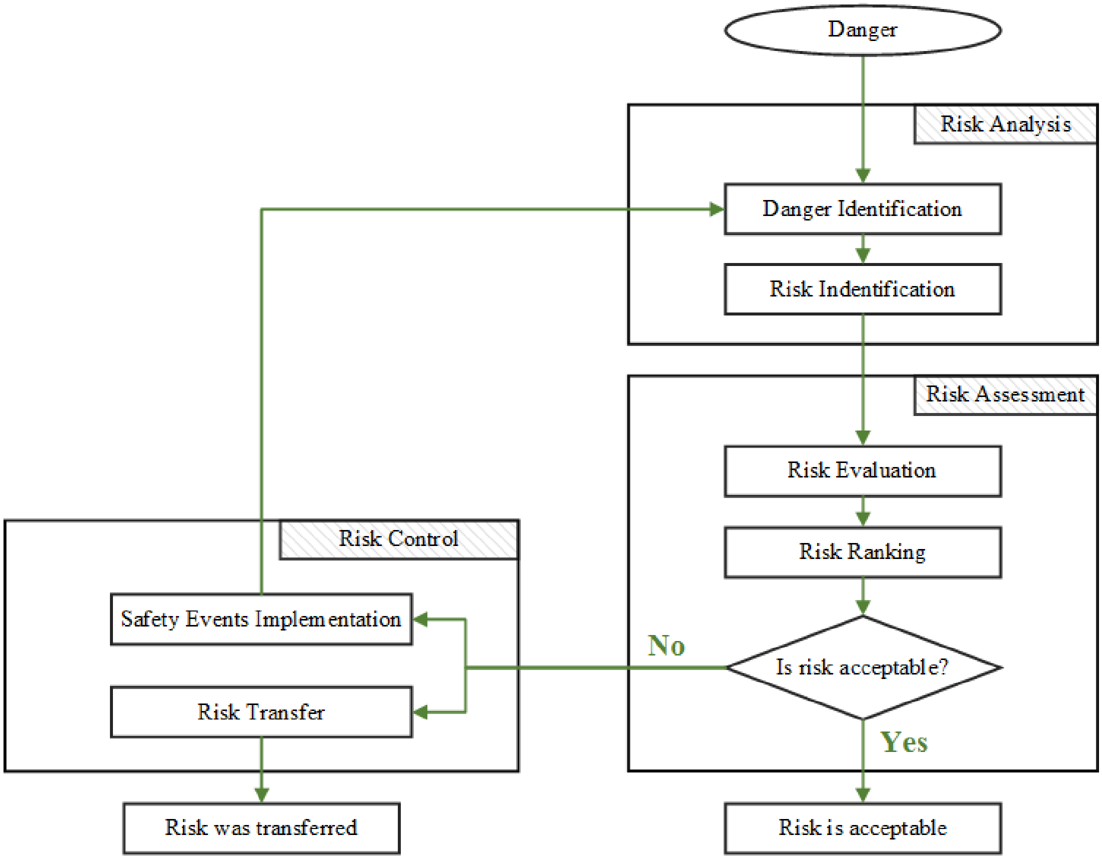

Fig. 1. General Scheme of Risk Management

On this basis, all planning decisions are divided into three groups:

–taken under certainty;

–taken under probabilistic certainty (based on risk);

–taken in complete uncertainty (unreliable).

Decision making under probabilistic certainty based on statistical decision theory. Incomplete and unreliable information are supplemented by examining random events and processes that may occur. The behavior of random objects is described by probabilistic characteristics. Themselves probabilistic characteristics are not random, and they can be used to find the optimal solution as well as with deterministic characteristics. General criteria for finding the optimal solution is a medium risk.

However, in most cases, decision-making and risk assessment take place in conditions of uncertainty and incomplete information, because the application of probability as the classic characteristics of mass processes is impossible. One of the promising areas of modern high-tech is fuzzy modeling, due to the trend of increasing complexity and formal mathematical models of physical systems and management processes related to the desire to increase their adequacy and consider set of different factors that influence the decision-making processes.

The uncertainty (lack of) information makes risk common with situation of decision making under non-determined parameters. Given the need for a quantitative risk assessment, it is reasonable to define risk through a combination of the event value (the consequences of the event) and possibility of its occurrence [2]. In practice, to get a point value of risk, the product of their numerical values is used.

However, the measure of the possibility of an event is usually chosen as probability of its occurrence P. The consequences of unwanted event A can be assessed by various specific parameters – from the economic to the ethical or political. Hence the risk is

$$R = A \cdot P . \quad (1)$$

The biggest problems arise whenthere are two (or more) types of threats at the same time. In this case the risk can be represented in vector form with various types of threats corresponding coordinate axes:

$$R_X = A_X \cdot P_X . \quad (2)$$

This view assumes that the variables do not interact with each other. In practice, as a rule, this assumption is not satisfied. For example, the risk of health is directly related to the risk to the environment. Therefore, for proper risk assessment is necessary to develop adequate mathematical apparatus [2].

1 Fuzzy Models

In many cases, the risk is a function of statistical parameters as well as fuzzy parameters. Due to differences in the theories used to describe these two types of parameters (probability theory, for example), the problem of aggregation becomes non-trivial. To solve it, you need to convert the parameters to the same type. This involves transforming a probability density distribution P into distribution of opportunities R, or, conversely, R into P. Moreover, in such transformations the amount of information (uncertainty) must be kept in the distributions P and R.

Fuzzy models assume a wide range of options for aggregation of event values and measure of its occurrence possibility. There are possible options for the generalization of such models [2].

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Aggregation is used in fuzzy inference and recognition, multi-criteria decision-making problems. The operator of aggregation is often called a function on N variables (criteria) that has some desired properties and is defined on the unit interval. The range of values of this function is a unit interval. Fuzzy measure expresses a subjective weight or importance of each subset of criteria.

Using of T-norms for the assessment of confidence in the validity of the formula.

The formula for risk (1) can has non-strict nature because the value of the probability P and damage A may not be known for sure, but with some degree of confidence $x(P)$ and $y(A)$. The degree of confidence $z(R)$ in the validity of the formula may depend on the degrees of confidence $x(P)$ and $y(A)$ as follows [2]:

–as their minimum – $z(R)=T_M\left[x(P),y(A)\right]=x(P)\wedge y(A)$ – Zadeh's T-norm;

–as their product – $z(R)=T_P\left[x(P),y(A)\right]=x(P)\times y(A)$ – probability T-norm;

–other T-norms.

Replacement of A and P values by fuzzy numbers (linguistic variables), and products – by expanded (on basis of generalization) product of fuzzy numbers.

In this case, the formula (1) will look like [2]:

$$R=A\otimes P\Leftrightarrow \mu_R(z)=\vee\left[\mu_A(x)\wedge\mu_P(y)\right]$$

$$z=x\times y$$

Here R,A and P – fuzzy numbers; $\mu_R(z)$, $\mu_A(x)$ and $\mu_P(y)$ – membership functions characterizing the degree of belonging to the elements of fuzzy sets R,A and P respectively; $\otimes$ – operation of expanded product of fuzzy numbers; $\wedge$ – operation minimum (disjunction); $\vee$ – operation maximum (conjunction). It should be noted that there are some other approaches to expansion. Their consideration is usually associated with the problems of "interaction" and "compensation" variables.

Replacement of A and P values by fuzzy relationship, and products – the composition of these relations.

Fuzzy relation is called a fuzzy set in the Cartesian product of base sets [2].

$$\mu_R(x,y)=\mu_{A\times P}(x,y)=min\left[\mu_A(x),\mu_P(y)\right]$$

The formula (1) can be rewritten using the composition operation as follows:

$$R(x,y)=A(x,y)\circ P(x,y)$$

Here $R(x,y), A(x,y)$ and $P(x,y)$ – some fuzzy relationships, and $\circ$ – the operation of the composition. Among the known composition transactions often used max-min and max-product operations, i.e.:

$$\mu_R(x,y)=\vee\left[\mu_A(x,y)\wedge\mu_P(x,y)\right]$$

and

$$\mu_R(x,y)=\vee\left[\mu_A(x,y)\cdot\mu_P(x,y)\right]$$

respectively.

We can also use a max-T composition of fuzzy relations, where T – parametric norm. The relationships $R(x,y), A(x,y)$ and $P(x,y)$ can be interpreted as the ratio of modeling, that is $X=(x_1,\ldots,x_N)$ – a universe that may be normalized, $X_{norm}=[0,1], x_1,\ldots,x_N\in[0,1]$; $Y=(y_1,\ldots,y_K)$ – the name (s) of elements of term-set of linguistic variables that express fuzzy values of R, A and P. Normalization X (converting to universal scale) made special monotonic transformation $F:\ X\rightarrow[0,1]$, in the simplest case $F(x)=\frac{x}{|X|}$ [2].

Compile formula using fuzzy integrals.

Expanding formula (1) using parametric T-norms leads to fuzzy interpretation of the formula through convolution of T-norm from distribution of the possible consequences of unwanted event A – μ_A and probability measure P [2]:

$$R(x)=\int T\left[\mu_A(x),P(x)\right]dx$$

The concept of fuzzy measure and fuzzy integral taken from classical set theory, fuzzy set theory and measure theory. Fuzzy measure and fuzzy integrals have some important properties – they may reflect the importance of certain criteria and represent the interaction between criteria. These properties make fuzzy measure and fuzzy integrals most rational for the risk assessment.

Fuzzy integral can be represented by the expression

$$FI=\int h\circ\mu$$

where FI –fuzzyintegral; h–measurable function(membership function); $\circ$– composition (the most often is usedmax-mincomposition); μ–fuzzymeasure.

It is also possibleto useSugenoandChoquetintegrals as afuzzyinterpretationof the formula (1).

Let $X=(x_1,\dots,x_N)$ and P – fuzzy measure on X. Then risk can be defined as Sugeno integral of the function A: $X\to[0,1]$ with respect to the measure P [2]:

$$R(x)=(S)\int A\circ P=\bigcup_{i=1}^{N}\left[A\left(x_{(i)}\right)\wedge P\left(A_{(i)}\right)\right]$$

Here (i)means that the indices are arranged, so that $0\le A\left(x_{(1)}\right)\le\ldots\le A\left(x_{(N)}\right)\le 1$ and $A_{(i)}=\left\{x_{(i)},\dots,x_{(N)}\right\}$.

Risk can also be defined as the Choquet integral of the function A: $X\to R$with respect to the measure P:

$$R(x)=(C)\int AdP=\sum_{i=1}^{N}\left[A\left(x_{(i)}\right)-A\left(x_{(i-1)}\right)\right]\cdot P\left(A_{(i)}\right)$$

with the samesymbolsthatweredescribed above and $A\left(x_{(0)}\right)=0$.

Risk membership function μ_R fully characterizing the risk as fuzzy value. It provides defuzzified risk value, such as its most possible value, and variations of the risk values [2].

The main types of relationships between the criteria in the context of aggregation by using Choquet integral were described by Marichall in [3]. A positive (negative) correlation and interdependence (replacement) of criteria are formalized using fuzzy measure by the sign and the index of interaction $I(i,j)$. With a positive correlation and criteria substituting, the index $I(i,j)$ is taken as negative, and with the negative correlation and substituting – as positive. Preferred dependence of the criteria and its opposite – preferred independence of the criteria – are types of dependencies between criteria that well known in the utility theory [2].

Analysis of the literature showed that the fuzzy integrals (Sugeno and Choquet) have special properties that are suitable for a variety of data merge criteria [4]:

–Sugeno and Choquet integrals are idempotent (i.e. repeated action over the object does not change it), continuous monotonically nondecreasing operators;

–Choquet integral with respect to the additive measure μ coincides with the weighted arithmetic average where weights w_i are $\mu(\{x_i\})$;

–Choquet integral is stable for positive linear transformations. Sugeno integral does not have this feature, but it fulfills a similar property with min and max replacement of selection and sum. Choquet integral is suitable for the basic aggregation, while the Sugeno integral, more suitable for the progressive aggregation;

–Sugeno and Choquet integrals containing all ordinals statistical characteristics, in particular, min, max and mean;

–Weighted minimum and maximum are special cases of Sugeno integral.

The disadvantage of fuzzy integral is the complexity of definition of fuzzy measures.

There also some difficulties of practical application of fuzzy integrals. According to Grabish [5] "With the introduction of fuzzy integrals, as aggregation operators it is implied that nonadditivity of fuzzy measures should allow to model the preferred dependence of the criteria. However, an apparatus that allows doing it strictly formal, is still not developed as well as the phenomenon of dependence of the criteria was studied poorly". If fuzzy measure is additive, the criteria do not interact with each other and interaction indexes of these criteria are equal

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to zero. Therefore, if in expert's opinion the criteria are mutually preferably independent, the corresponding indexes of interaction are equal to zero. If the expert believes the preferred dependence of the criteria, it can only be formalized by a partial order on a set of criteria implementations X (training set).

2 Applications of Fuzzy Measures and Integrals

To apply Choquet integral, fuzzy measure must first be identified based on experts' knowledge. This identification is difficult with exponentially increasing complexity in the sense that it is necessary to set the measure value for each subset of criteria. The choice of all 2^N coefficients of fuzzy measure $P\left(X_{(i)}\right)$ for relevant 2^N subsets of set of criteria indexes A is very difficult and even impossible for expert. Note that in case of even three criteria for determining the fuzzy measure we need to get $2^3=8$ coefficients [6]. Despite this complexity, Choquet integral can still be applied in practice. In order to do this, Grabish proposed the concept of fuzzy measure of k-order or k-additive fuzzy measures, where the order k is less than the number of aggregated criteria, or $k<|X|=N$ [12]. The essence of the concept is that in order to simplify the specifying of fuzzy measures, dependencies among more than k criteria are excluded from consideration. According to the concept of fuzzy measure of k-order in most practical cases it is possible to use Choquet integral of fuzzy measure of 2nd order, or Choquet integral of 2nd order, because it allows you to simulate the interaction between the criteria, while remaining relatively simple [6].

In addition to increasing complexity, there is also the problem of understanding the meaning of the coefficients of the expert fuzzy measure [5]. To solve this problem Grabish [7] proposed the idea of a graphical interpretation of the Choquet integral of 2nd order. The point of this interpretation is to build on the coordinate plane the restriction lines for interaction index values and Shapley indices for two criteria. This idea was developed in [8], in which the methods of fuzzy measure identification by using a hierarchical diagram of paired comparisons (in the form of "diamond"), based on the interpretation of Grabish where analyzed.

With the implementation of this approach to work with an expert in the process of formalizing its knowledge, we should choose a mathematical method for fuzzy measure identification based on formalized knowledge. These methods differ in the type of information that is required as input. Overview of methods applied to utility theory is given in [9]. The method of least squares is not well suited for solving practical problems because it involves for expert to know the desired values of aggregation result on the training sample of criteria implementations. The method based on the maximum separation is suitable for recognition problems as it involves maximizing the minimum difference between the results of the aggregation on the training set. The expert describes an instance of each class, and ranks them by using non-strict order that serves as input to the method. Method based on the minimization of the variance of fuzzy measures, or what is the same thing as maximizing the entropy of fuzzy measures, is the most appropriate to solve many practical problems [6]. It is based on the principle of maximum entropy. With regard to the construction of the aggregation operators, this principle involves the use of all available information about the aggregation criteria, but the most open-minded attitude towards the not available information.

The following practical examples briefly discussed the application of fuzzy measures and fuzzy integrals, in particular, the assessment of the properties of interfaces, technical diagnostics, and navigation.

The authors of [10] offered a solution to the problem of determining the degree of convenience of a software interface to the user. This assumes direct specifying by experts of fuzzy measures by filling special tables for multiple criteria (about four). Direct assignment of fuzzy measures is very time-consuming, and in the case of even a slight increase of the number of criteria is impossible. However, this example showed that using of fuzzy measures could improve the accuracy of estimation convenience interface.

Another practical example of the application is the analysis of the technological processes based on fuzzy expert knowledge [6]. On the first level of state analysis, the values of the membership functions of diagnostic parameters of fuzzy sets corresponding to the terms of reference of linguistic variables are determined. On the second level, by aggregating valuesof the membership function by using fuzzy measures and fuzzy integrals, the membership values of the current state of the process are obtained and corresponds to a particular class of fuzzy states such as class of the health status and the proper functioning of equipment. Identification of fuzzy measures carried out based on minimizing the variance by involving the rendering engine [6]. This example also confirms the possibility of increasing the reliability of technical diagnostics by using the fuzzy integrals.

Another example illustrates the use of the fuzzy measures in [11], which describes the navigation system for pedestrians. The inputs to this system are the subjective evaluation of various characteristics of the routes, in particular, distances, road surface quality, noise level, etc. All of these criteria are related to each other in a nontrivial way. Therefore, the aggregation of such criteria is conveniently carried out using Choquet integral [6]. As a method for identifying fuzzy measures the method of least squares is used. Despite the relatively high labor intensity of implementation, this example points to the flexibility of the Choquet integral as an aggregation operator of such subjective criteria.

In [12, 13] proposed fuzzy-probabilistic model to assess the risk of transportation of important cargoes in view of possible terrorist attacks. The value is a function of many factors (parameters) of "technical" nature: the number of ways, arrows, bridges etc., as well as the "human factor". In addition, the value depends on the possible risk of terrorist attacks. The possibility of these actions influenced by the proximity of the highways to the forests, human settlements; the presence and quantity of the accompanying protection, the ability to call reinforcements and time of arrival etc. Some factors have statistical nature and can be quantified from the available information using traditional statistical methods based on probability theory. Other factors have a fuzzy nature and can not be properly described as part of a probabilistic approach. Some of them can be described using linguistic variables, such as expert judgment. In this regard, more urgent task is aggregating of the information, including information of a different nature. Another important issue – correct assessment of the possible values spread of the risk with illegible source data. These problems are solving using "soft computing" – using not only the methods of probability theory, but also the fuzzy sets theory, possibility theory et al [14]. This approach yields the distribution function of risk, taking into account distributions of parameters influencing in a different nature, and therefore make an adequate risk assessment and its possible spread. Moreover, this variation corresponds to the real uncertainties (vagueness) of the original data.

As an example, in the task of creating optimal portfolio of investment project the objective function $f(x) \to max$ with restrictions $\varphi_i(x) \leq 0$ where $i = 1, \ldots, m$ and $x \in X$, where X – the set of alternatives; $f : X \to R^1$ and $\varphi : X \to R^1$ are known functions. There are various integrated performance counters which used as the parameters of the objective function $f(x)$. However, despite of some advantages and disadvantages of each of the indicators, many scientists think that net present value (NPV) is the most preferred parameter of the objective function. NPV has the additivity attribute that gives an opportunity to assess the profitability of the entire investment project portfolio as the sum of profitability of investment projects, which form the present portfolio. There are different versions of the task of forming the optimal portfolio [15].

Usually, the economic meaning of the objective function $f(x)$ is the maximization of economic benefits from investment activity, and the meaning of the restrictions $\varphi_i(x) \leq 0$, which imposed on the set of feasible solutions of the problem, shows the limited funds with considering the possibility of different budget constraints for each of the time intervals of the project life.

Strategic decisions, including those related to the formation of the optimal investment projects portfolio, aimed at the long term and therefore inherently connected with significant uncertainty, and have subjective component, so the using of fuzzy mathematical programming to solve the problem of forming optimal project portfolio has many benefits.

As an example, we can consider a situation in which the set of feasible alternatives (investment projects) is a collection of various ways of resource allocation that decision maker is going to invest in order to create an optimal investment portfolio. Obviously, that it is inappropriate beforehand to introduce a strict distinction for many acceptable alternatives (e.g., strict limits on the size of the investment budget of the company during the period t). In some cases, it may happen that the allocation of resources lies beyond this limit, which shows the effect of

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exceeding of small desirability (e.g., the size of the investment costs) of these distributions for decision maker. Thus, fuzzy description is more appropriate in reality than arbitrarily adopted a strict description of the problem.

Fuzzy description forms of initial information in tasks of decision-making may be different; hence, there are differences in the mathematical formulation of relevant tasks of fuzzy mathematical programming [15].

Discussion and Conclusions

Fuzzy logic has been used to handle uncertainty in human-centered systems (e.g., ergonomics, safety, occupational stress) analysis, as a way to deal with complex, imprecise, uncertain and vague data. In the models of risk management, triangular norm can extend the probabilistic models to fuzzy models and thereby make possible their use in conditions of poor statistics.

The issues of practical application of fuzzy measures and fuzzy integrals where reviewed the difficulties that arise and possible ways to overcome them were analyzed. The main obstacle to practical use of these tools is the complexity of working with an expert to formalize his knowledge in the form of coefficients of fuzzy measures. The area of research related to fuzzy measures and integrals is intensively developing.

In sum it should be noted, that fuzzy sets theory is the most promising and adapted mathematical apparatus that allows implement scientific task of developing methods for assessing individual risks in terms multifactor and uncertainties. Due to the large dynamic range of factors involved in the formation of risks, in order to develop a new method based on fuzzy sets theory for assessing individual risks, it is advisable to implement on the universe of variables that have a wide range of values, such as the likelihood of accident and risk.

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THE OPTIMIZATION OF POWER CONSUMPTION OF MOBILE ROBOTS

Annotation. *In this article the analysis of factors affecting on battery life consumption of mobile robot for phytomonitoring of plants in the greenhouse and usage of variation calculus method for optimization of energy consumption have been conducted.*

Keywords: *energy consumption, optimization, linear velocity, calculus of variations.*

Modern robotic systems have many advantages over traditional: high efficiency, reduced costs for human resources; the possibility of upgrading. Their main drawback is limited energy resource, because of the relatively small capacity of the battery, especially of mobile robots. The following problem can be solved by increasing the battery life, or reduce energy consumption. Our research aimed at reducing power consumption during the process of robot moving [1].

Energy saving is achieved if the robot moves with optimal speed (the speed with constant acceleration and speed has infrequent changes in the conditions of the robot straight line moving).

To formulate the optimization problem we accept that the mobile robotic system for electrical phytomonitoring is nonholonomic system with symmetrical structure, as set in motion by two identical DC motors [2].

Let the work of the position (coordinates and angle) as the $P(t) = [x(t)\ y(t)\ и(t)]^T$, linear velocity - v, angular velocity - w. Then kinematic equations to describe will be shown in expression:

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{и} \end{pmatrix} = T_p \begin{pmatrix} v \\ w \end{pmatrix},\ T_p = \begin{pmatrix} \cos\theta & \sin\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}^{\mathrm{T}}. \tag{1}$$

To simplify the calculations, we assume that both engines have identical: anchor resistance - R_a, anti-EMF - K_b, torque - K_t and gear ratio - n. If we will mark the battery voltage as V_s, then engine balance equation will look like:

$$R_a i = V_s u - K_b n w, \tag{2}$$

where $i = [i^R i^L]^T$ - anchor current vector, $w = [w^R w^L]^T$ - vector of angular speed of wheels and $u = [u^R u^L]^T$ - normalized input vector of control. Indices R, L correspond to the left and right engine respectively.

Dynamic dependence between the angular speed and current of the engine, considering inertia and friction for the engine it is possible to write down as:

$$J\frac{dw}{dt} + F_v w = K_t n i, \tag{3}$$

where F_v - coefficient of friction, J – matrix moments of engine inertia.

From the expressions (2) and (3) we can get next differential equation:

$$\dot{w} + Aw = Bu, \tag{4}$$

where $A = \begin{pmatrix} a_1 & a_2 \\ a_2 & a_1 \end{pmatrix} = J^{-1}\left(F_v + \frac{K_t K_b n^2}{R_a}\right)$, $B = \begin{pmatrix} b_1 & b_2 \\ b_2 & b_1 \end{pmatrix} = J^{-1}\frac{V_s K_t n}{R_a}$.

We define a state vector as $z = [v \ \ w]^T$, associate w and v *with* w^R and w^L in expression:

$$z = \begin{pmatrix} v \\ w \end{pmatrix} = T_q \begin{pmatrix} w^R \\ w^L \end{pmatrix} = T_q w, \quad T_q = \begin{pmatrix} \frac{r}{2} & \frac{r}{2} \\ \frac{r}{2b} & -\frac{r}{2b} \end{pmatrix}. \tag{5}$$

Using similarity transformations, from expressions (4) and (5) we receive:

$$\dot{z} + \bar{A}z = \bar{B}u, \tag{6}$$

$$\dot{z} + \bar{A}z = \bar{B}u, \tag{6}$$

where $\bar{A} = T_q A T_q^{-1} = \begin{pmatrix} p_v & 0 \\ 0 & p_w \end{pmatrix} = \begin{pmatrix} a_1 + a_2 & 0 \\ 0 & a_1 - a_2 \end{pmatrix}$.

$$\bar{B} = T_q B = \begin{pmatrix} B_1 & B_1 \\ B_2 & -B_2 \end{pmatrix} = \begin{pmatrix} \frac{r(b_1 + b_2)}{2} & \frac{r(b_1 + b_2)}{2} \\ \frac{r(b_1 - b_2)}{2} & -\frac{r(b_1 + b_2)}{2} \end{pmatrix}.$$

The energy that comes from the battery power converts into mechanical energy of motion and heat loss. Heat loss causes the internal resistance of the battery, resistances of the controlling device (driver) of engine, the anchor resistance of engine and viscous friction during movement.

On fig.1 is shown the simplified diagram of the electrical system of a mobile robot. To reduce heat losses in the engine control device used controller PWM, because it has less power consumption and generates less heat than linear voltage regulator. Therefore, we can determine the resistance of the amplifier R_{amp} and PWM u^R, u^L. To simplify the calculations, we assume that the heat loss through the internal resistance of the battery and the resistance of the amplifier control device of engine are small, and therefore they are not included.

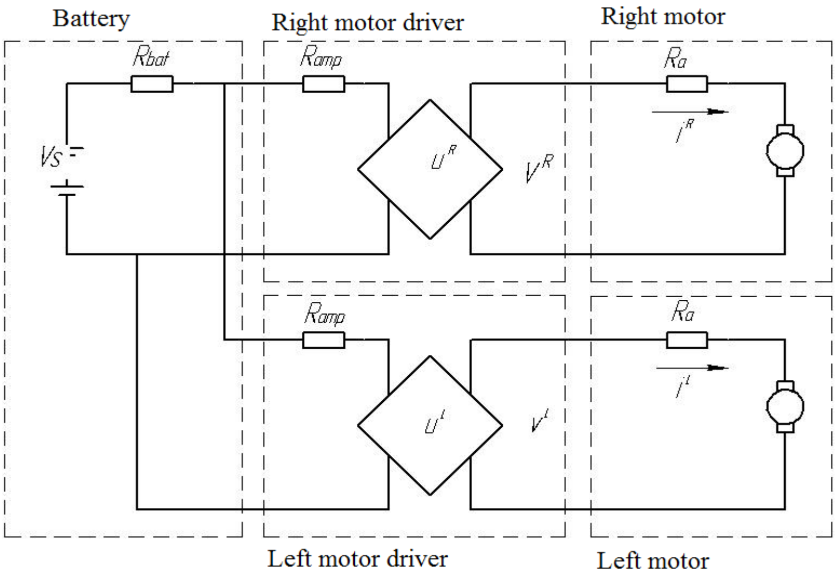

Fig. 1. Simplified electrical scheme of a mobile robot.

Thus the energy which is supplied from the battery to drive circuit of the mobile robot is a function for minimizing and it can be shown as [4]:

$$E_w = \int_{t_0}^{t_f} i^T V dt = V_s \int_{t_0}^{t_f} i^T u dt, \quad (7)$$

where $V = [V^R V^L]^T$ – input voltage, which comes to the from the accumulator battery (V_s – voltage of battery), $u = \frac{V}{V_s} = [u^R u^L]^T$.

As the battery capacity is limited, the voltage will be limited as well:

$$-u^{max} \leq u^R, u^L \leq u^{max}. \quad (8)$$

According to the phrases (2),(5) we can write down the function of optimization E_w through the velocity as:

$$E_w = \int_{t_0}^{t_f} (k_1 u^T u - k_2 z^T T^{-T} u) dt, \quad (9)$$

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де $k_1 = \frac{V_s^2}{R_a}$, $k_2 = \frac{K_b n V_s}{R_a}$, $z = [v\ \ w]^T$.

Thus, taking into consideration expressions (2), (3) overall optimization function can be represented as follows:

$$E_w = R_a \int_{t_0}^{t_f} i^T i dt + F_v \frac{K_b}{K_t} \int_{t0}^{t_f} z^T T_q^{-T} T_q^{-1} z dt + \frac{\text{稔}_b}{K_t} \int_{t0}^{t_f} \dot{z}^T T_q^{-T} J^T T_q^{-1} z dt. \quad (10)$$

In the expression (10) first term ($E_r = R_a \int_{t_0}^{t_f} i^T i dt$) – is the energy, dissipates by the resistance in the engine anchor [5]; second term ($E_F = F_v \frac{K_b}{K_t} \int_{t0}^{t_f} z^T T_q^{-T} T_q^{-1} z dt$) corresponds to the loss of energy to overcome friction; the last term ($E_K = \frac{K_b}{K_t} \int_{t0}^{t_f} \dot{z}^T T_q^{-T} J^T T_q^{-1} z dt$) - is the kinetic energy of the mobile robot that zero average value when speed the constant or final speed is equal to the initial. This means that the contribution of the last term in power consumption is zero.

As the robot moves mostly straight, we consider only this option. Thus rotation velocity of robot - w in this period is zero, but $P(t) = [x(t)\ 0\ 0]^T$– is the position, $z(t) = [v(t)\ 0]^T$ - speed at the moment of t. Then the problem of minimizing energy consumption can be formulated as follows: find the value of linear velocity $v(t)$ and controlling figure $u(t)$, that will minimize the function:

$$E_w = \int_{t_0}^{t_f} \left(k_1 u^T u - k_2 z^T T_q^{-T} u\right) dt \quad (11)$$

under the following conditions:

1) initial and final position: $P(t_0) = [x_0\ 0\ 0]^T$ and $P(t_f) = [x_f\ \ 0\ 0]^T$;

2) initial and final velocity: $z(t_0) = [v_0\ 0]^T$ and $z(t_f) = [v_f\ \ 0]^T$;

3) satisfying value of battery, where t_0 and t_f start and end time of the robot moving.

We assume that the initial and final velocity of robot are zero and its motion starts with initial position. Then the energy minimization task can be written as [6]:

$$min\, E_w = \int_{t_0}^{t_f} (k_1 u^T u - k_2 z^T T_q^{-T} u) dt, \quad (12)$$

$$\dot{z} = -\bar{A} z + \bar{B} u, \quad (13)$$

$$z(0) = z(t_f) = [0\ 0]^T, \quad (14)$$

$$P_f = \int_0^{tf} T_p z dt = \left[x_f \; 0 \; 0\right]^T, \tag{15}$$

$$-\begin{pmatrix} u^{max} \\ u^{max} \end{pmatrix} \leq u = \begin{pmatrix} u^R \\ u^L \end{pmatrix} \leq \begin{pmatrix} u^{max} \\ u^{max} \end{pmatrix}. \tag{16}$$

Taking into account the cost of energy, which minimizes the equation (12) satisfying the constraints (14) - (16) for the system of equations (13), search for optimal speed we will do using the method of variations. Based on studies that are presented in [1], Lagrange multiplier for expression (15) will be $a = \left[a_x a_y a_и\right]^T$. Defined functions for function expression (13) $\lambda = [\lambda_v \lambda_w]^T$, where the Hamiltonian function would be:

$$H = k_1 u^T u - k_2 z^T T_q^{-T} - a^T T_p z + \frac{a^T P_f}{t_f} + \lambda^T(-\bar{A}z + \bar{B}u). \tag{17}$$

Necessary conditions for optimal velocity $z*$ and out coming signal $u*$:

$$\frac{\partial H}{\partial u} = 2k_1 u - k_2 T_q^{-1} z + \bar{B}^T \lambda = 0, \tag{18}$$

$$\frac{\partial H}{\bar{a}z} = -k_2 T_q^{-T} u - T_p^T a + \bar{A}^T \lambda = -\lambda, \tag{19}$$

$$z = -\dot{\bar{A}} z + \bar{B}u. \tag{20}$$

From the expressions (18) - (20) we obtain the following differential equation:

$$\ddot{z} - \left(\bar{B}\bar{B}^T \bar{A}^T \bar{B}^{-T} \bar{B}^{-1} \bar{A} - \frac{k_2}{k_1} \bar{B}\bar{B}^T T_q^{-T} \bar{B}^{-1}\right) z + \frac{1}{2 \cdot k_1} \bar{B}\bar{B}^T T_p^T a = 0 \tag{21}$$

Because of $\bar{B}\bar{B}^T$ and $\bar{A}$ - are diagonal matrixes, equation (21) can be reduced to:

$$\ddot{z} - Q^T Q z + R T_p^T a = 0, \tag{22}$$

where $Q^T Q = \bar{A}^T \bar{A} - \frac{k_2}{k_1} \bar{B}\bar{B}^T T_q^{-T} \bar{B}^{-1} \bar{A}$, $Q = \begin{pmatrix} \frac{1}{\phi_v} & 0 \\ 0 & \frac{1}{\phi_w} \end{pmatrix}$,

and $R = \frac{\bar{B}\bar{B}^T}{2k_1} = \begin{pmatrix} n_v & 0 \\ 0 & n_w \end{pmatrix}$.

Here $\phi_v = \frac{J_1 + J_2}{\sqrt{F_v(F_v + K_t K_b n^2 / R_a)}}$ – electromechanical time constant for moving,

$\phi_w = \frac{J_1 - J_2}{\sqrt{F_v(F_v + K_t K_b n^2/R_a)}}$ electromechanical time constant for the turning of mobile robot.

As the energy loss by turning a mobile robot is not captured (considering moving on a straight line) optimal linear velocity z ^ * can be expressed as:

$$z^*(t) = \begin{pmatrix} v^*(t) \\ w^*(t) \end{pmatrix} = \begin{pmatrix} C_1 e^{t/\phi_v} + C_2 e^{-t/\phi_v} + K_v \\ 0 \end{pmatrix}, \quad (23)$$

where $C_1 = \frac{e^{-t_f/\phi_v} - 1}{e^{t_f/\phi_v} - e^{-t_f/\phi_v}} K_2$, $C_2 = \frac{1 - e^{t_f/\phi_v}}{e^{t_f/\phi_v} - e^{-t_f/\phi_v}} K_v$, and $K_v = \frac{x_f(e^{t_f/\phi_v} - e^{-t_f/\phi_v})}{2\phi_v\left(2 - e^{\frac{t_f}{\phi_v}} - e^{-\frac{t_f}{\phi_v}}\right) + t_f(e^{t_f/\phi_v} - e^{-t_f/\phi_v})}$.

Then equation ((13)gives the equation of optimal control signal of u^*:

$$(t) = \bar{B}^{-1}(\dot{z}^* + \bar{A}z^*) =$$

$$\frac{1}{2 \cdot в_1 \cdot \phi_v} \begin{pmatrix} C_1(1 + \phi_v p_v)e^{\frac{t}{\phi_v}} - C_2(1 - \phi_v p_v)e^{-\frac{t}{\phi_v}} + \phi_v p_v K_v \\ C_1(1 + \phi_v p_v)e^{\frac{t}{\phi_v}} - C_2(1 - \phi_v p_v)e^{-\frac{t}{\phi_v}} + \phi_v p_v K_v \end{pmatrix}. \quad (24)$$

For construction of dependencies of optimal velocity from relative time (from the beginning):

Parameter	Value	Parameter	Value
resistance of anchor, R_a	0,71 Ом	battery voltage, V_s	12 В
Torque, K_t	0,0230 N·м/A	Limitation of voltage, u^{max}	1
Anti-emf, K_b	0,0230 В/(rad/sec)	coefficient of friction, F_v	0,054 N·м/(rad/sec)
The radius of the wheels, r	0,15 м	Gear ratio, n	49,8
Base	0,206 м	The inertia of engines, $J = \begin{pmatrix} J_1 & J_2 \\ J_2 & J_1 \end{pmatrix}$	$\begin{pmatrix} 0.1241 & 0.0098 \\ 0.0098 & 0.1241 \end{pmatrix}$

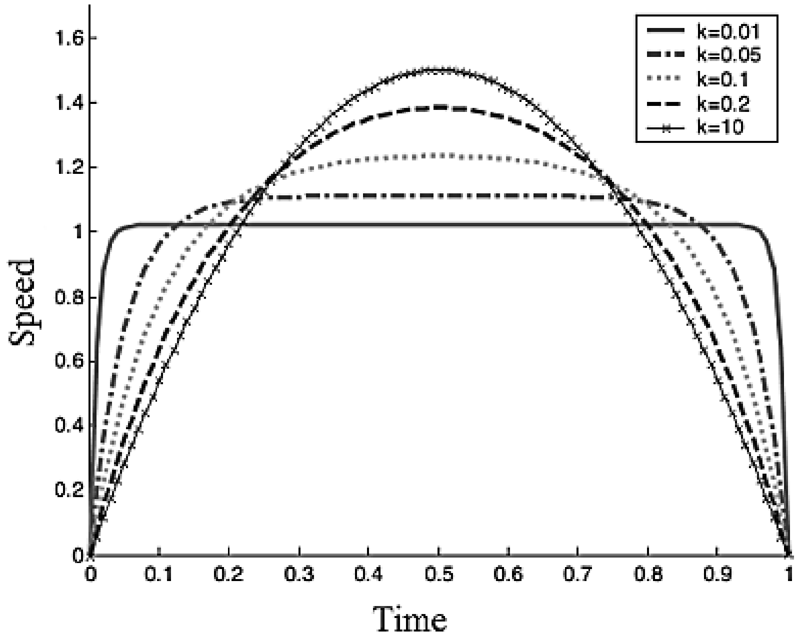

Fig. 2. Speed depends on the relative distance of moving at different values meaning of$k$ (mechanical time constant before the time of displacement $k = \tau_v/t_f$)

The analysis of materials which are shown in Fig. 2 can to make the fconclusions that the minimal power consumption rate graphic has a symmetrical shape:

- if $k \approx 0$ $(k = \phi_v/t_f)$ then graphic of optimal velocity is trapezoidal;
- if k>0,2 then graphic takes the form of a parabola.

Basing on (12) – (15) we can receive:

$$v^*(t) = \frac{x_f}{\phi_v} \cdot \frac{\sin h\left(\frac{t_f}{\phi_v}\right) - \sin h\left(\frac{(t_f - t)}{\phi_v}\right) - \sin h\left(\frac{t_f}{\phi_v}\right)}{2\left(1 - \cos h\left(\frac{t_f}{\phi_v}\right)\right) + \frac{t_f}{\phi_v}\sin h\left(\frac{t_f}{\phi_v}\right)}. \quad (25)$$

Energy consumption are defined by losses because of anchor resistance (the first component of expression (10)) - minimization of energy of an anchor were investigated; losses because of resistance of an anchor and losses on friction (the first and second parts of expression (10) - minimization of expenses of energy.

At the parabolic graphic of velocity of power consumption is somewhat compensated for the account of partial operation of the engine in the generator mode.

Comparing two ways of optimization of power consumptions, we draw a conclusion that minimization of power consumptions of an anchor is

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expedient in case of movement of the robot on distance to 5 meters, (the friction significantly doesn't influence this movement). Full minimization of energy is otherwise more expedient.

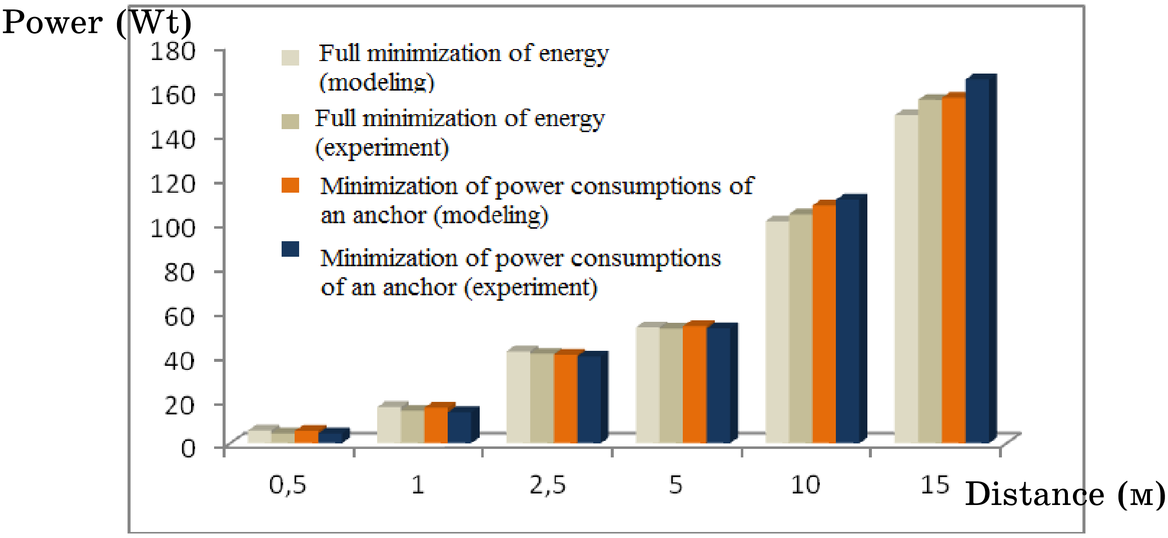

Fig. 3. Comparison of data of modeling to the data received during experiment.

CONCLUSION

1. By results of analytical designing of regulators, expression of optimum linear velocity of movement of the mobile robot that minimizes power expenses is received.

2. The choice of velocity of movement and parameters of optimization depends on distance on which the robot has to move: at distance to 5 meters the parabolic graphic of velocity is used, and at the bigger – trapezoidal.

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A MULTI-OBJECTIVE IMMUNE APPROACH TO RECONSTRUCT GENE REGULATORY NETWORK USING ALGORITHM CLONAL SELECTION

Abstract: *The inference of gene regulatory networks is one of the main challenges in systems biology. In this paper we address the problem of finding gene regulatory networks from experimental DNA microarray data. We suggest to use a multi objective clonal selection algorithm to identify the parameters of a non linear system given by the observed data. Not only the actual parameters of the examined system are unknown, also the connectivity of the components is a priori not known. However, this number is crucial for the inference process. Consequently we propose a method based on algorithms of artificial immune system which uses the connectivity as an optimization objective in addition to the data dissimilarity (relative standard error RSE) between experimental and simulated data.*

Keywords: *gene regulatory networkst; multi objective optimizacion; clonal selection algorithm; SOS DNA repair network.*

1. INTRODUCTION

Gene Regulatory Networks (GRNs) are the functioning circuitry in living organisms at the gene level. It is regarded as an abstract mapping of the more complicated biochemical network which includes other components such as proteins, metabolites, etc. The purpose of GRN is to represent the regulation rules underlying the gene expression. Understanding GRNs can provide new ideas for treating complex diseases and breakthroughs for designing new drugs [1].Gene regulatory network reconstruction is currently a topic under heavy research in the computational biology field. The study of GRN is made much easier with the recent introduction of *microarray* technology. Using this method, expression levels of thousands of genes can be measured simultaneously, as they change over time and are affected by different stimuli. Thereby, it is possible to obtain a global view of the dynamic interaction among genes. But it is a great challenging problem to discover these networks of interacting genes that generate the fluctuations in the gene expression levels [1]. Gene regulatory networks are distributed system of genes in various combinations. The interaction of genes controls the biological structure and functions of proteins. Properties of a gene undergo changes when it comes in the presence of other genes. Identifying a gene network is a complex nonlinear problem. Before the invention of microarray technology, parallel processing of the genes was a complex and difficult problem for the biologists. The introduction of microarrays transformed the problem of gene profiling to a simple and efficient one. For example, microarray representation may be used for clustering genes and reconstruction of gene network making use of gene expression time series. Reverse engineering approach for the identification of gene networks is a well-accepted approach in the literature. In this, gene expression profiles identified by the microarray are used to predict the gene regulatory network [2] . Inference of GRNs based on microarray data is referred to as *reverse engineering* [3], as the microarray expression levels are the outcome of gene regulation. Mathematically, *reverse engineering* [RE] is a traditional inverse problem.

Reverse Engineering (RE) can be considered as a process from which is possible inferring structural and dynamics feature of a given system from external observations and relevant knowledge. Thanks to this feature, today RE techniques play a central role in systems biology [4-5], since it is not only important a knowledge of genes and proteins, but also to understand their structures and dynamics [6].

The solution to the problem is, however, not tri vial, as it is complicated by the enormously large scale of the unknowns in a rather small sample size. In addition, the inherent experimental defects, noisy readings, and many other factors play a role. These complexities call for heavy involvement of a powerful mathematical modeling together with reliable inference, which play an increasingly important role in this research [1].

Many types of models have been already proposed for reconstruction of gene regulatory networks in biological systems, including Boolean networks [7], linear weighting networks [8], differential equations [9], Bayesian Networks [10], S-system [11], Fuzzy Set [12] and Artificial & Recurrent Neural Network [13] etc. Researchers have proposed a number of evolutionary algorithms for the construction of gene regulatory networks. In work [14] has proposed a ***LMS-GP algorithm*** that uses ***Genetic programming*** (GP) to reduce mean-square-error between observed and experimentally identified arrays. In this algorithm, a general form of differential equation is used to model the system. In work [15] has proposed a ***Genetic Program*** proposed which makes use of ***Kalman filter*** for estimating the parameters of the model.The algorithm

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requires the noise statistics for the successful optimization of the parameters of the regulatory network using ***Kalman filtering***. Hence, it is not easy to apply for the reconstruction of GRN. In work [16] proposed a method that consists of a decomposed S-system model and an ***extended version of the fitness function***. S-system is a power full nonlinear model proposed by Savageau [17] based on the mathematical modeling of chemical processes. An evolutionary algorithm called trigonometric differential evolution along with a greedy search is employed to optimize the parameters. The effect of decoupled S-system reduces the dimensionality in computation. For clustering purpose, a ***hybrid algorithm*** that consists of **Genetic algorithm** and ***expectation maximization algorithm*** is employed. Another work is the ***adaptive fuzzy evolutionary*** gene regulatory network reconstruction framework proposed in work [18]. This approach is based on the ***fuzzy clustering using EA*** and **Spearman correlation**. In [19], authors considered biological network as a scale free network and used advancement of GA called ***Distributed genetic algorithm*** to optimize S-system parameters. The issue here is that the knowledge about such properties are often not available. Gene Regulatory Network Modeling using **Cuckoo Search** and **S-system** [20] used a cuckoo search method for the optimization of the S-system. This approach converges at a faster rate when compared to existing Clonal selection based algorithm using S-system [21]. In work [22] proposed a **memetic inference method** for gene regulatory network based on S-system. The memetic algorithm is a hybrid algorithm, which employs a combination of genetic algorithm (GA) and covariance matrix evolution strategy (CMES) [22]. GA is used to optimize the structural topology, and the evolutionary strategy is a local search algorithm for optimizing the S-system parameters. This is considered as a standard algorithm, which is used for comparative studies of new proposal of this paper. S-system is the most well accepted and standard differential equation model introduced by Savageau [17]. Even though S-system is the best model as per the current state of art, this model has disadvantages. Number of parameters in the model is large and it will reduce the convergence speed for the problem. The exponential terms will again affect the computational speed. In order to avoid such disadvantages in this paper introduced a new model called Two Weight Matrix model (TWM).

Currently, most of the existing algorithms developed for the reconstruction of the GRN are single-objective [23].

However, previous research on single objective GRN showed that on single objective can generate similar results of experimental data, but they may not be numerical or structural similarity with real network [24-26].

This may occur because the optimization process is caught in local optima. Stochastic multi-objective approaches preserve the diversity of solutions in a population and present them as a Pareto front. Thus they are able to find multiple optima hopefully including the global optimum [27]. The multi-objective optimization approach is likely to be more suitable for genetic regulatory modeling and its associated parameter estimation based on following three reasons [28]:

a) Multiple data types (continuous, discrete, and/or categorical) are very problematic for the design of a single objective function;

b) Individual data sets usually are from different sources and may be inconsistent;

c) Tradeoffs between solutions may reveal the magnitude of discrepancies.

On the basis of the above reasons, research on multi-objective algorithms in modeling gene regulatory network is relatively new but rapidly growing area of research. There are few attempts to use more objective approach to GRN have been described in [27-28]. Further more, previously work on this topic showed that, due to the multi-modal character of the solution space, several sets of parameter exist, which fit the data satisfactorily. Thus, standard optimization techniques are easily caught in local optima, i.e. finding a solution with a good RSE but with no structural resemblance with the true system. This is known to be a major problem in the inference process [23-28]. Because multi-objective algorithms preserve the diversity of the solution within a population by maintaining the Pareto-front and are therefore able to find multiple optima hopefully including the global optimum. All work on the application of multi-objective algorithms for reconstruction of GRN apply genetic algorithms. Researches have shown the advantage of artificial immune system algorithms to genetic algorithms, since the first combine local and global search. For that reason, this paper is devoted to application of clonal selection algorithm to solve the problem of reconstruction GRN using multi-objective optimization based on s-systems.

2. PROPOSED METHOD

2.1. The Genetic Network Model and S-System

While there are a series of attempts already been conducted by different researchers, received all the solutions are still not satisfactory, that in relation to the time required and the achieved degree of accuracy. Therefore there is need for further research on this topic to reach satisfactory solutions with improved performance. GRNs network describe bimolecular interactions that are inherently non-linear and can be expressed by a common system of differential equations. Biochemical systems like GRNs are generally modeled by systems of ordinary differential equations (ODEs). However, nonlinear differential equation models, such as S-system, can model much more complicated GRN behavior successfully. In general, modeling GRNs may be considered as a nonlinear identification of dynamics problem. If there are *N* genes of interest; define *xi* as the state (such as the gene expression level) of the *i*-th gene, then the dynamics/interactions of the GRN may be modeled as

$$\frac{dx_i(t)}{dt} = f_i[x_1(t), \ldots, x_N(t)] \tag{1}$$

for i = 1,...,*N*, where *N* this number of genes, x_i – gene expression level, but f_i –a function that describes the influence of genes on a gene *i*. . For example, if *j*-th gene activates *i* –th gen, the value $f_i$increases with x_j and conversely, if *j*-th gene inhibits *i*-th gene.

The proposed method used by S- system, which is widely recognized as a model for the reconstruction of gene regulatory networks .

One of the ways the mathematical description of a genetic network is the S-system [17], which is a system of differential equations of the form:

$$\frac{dX_i}{dt} = \alpha_i \prod_{j=1}^{n} X_j^{g_{ij}} - \beta_i \prod_{j=1}^{n} X_j^{h_{ij}} \tag{2}$$

where *n* - number of state variables that characterize the investigated object or the number of reagents X_i. $\alpha_i$and $\beta_i$are the positive rate constants for increasing and decreasing respectively. $g_{i,j}$ and $h_{i,j}$ are the exponential parameters that are also called as kinetic orders. If $g_{i,j} > 0$, gene *j* will excite the expression level of gene *i*. On the other hand, gene *j* will inhibit the expression level of gene i if $g_{i,j} < 0$. $h_{i,j}$ have the inverse effects on controlling gene expressions compared to $g_{i,j}$. S-system model is characterized by power-law functions and it has the rich configuration capability of capturing various dynamics in many complex biochemical systems. As the S-system model has been proven to be successful in modeling GRNs.

2.2 Multi-objective criterion [29]

For examining the connectivity and the RSE in parallel, we used a multi-objective EA, which optimizes the parameters of g, h, α_i and β_i in respect to the following two optimization objectives:

a.) For evaluating the RSE fitness of the individuals we used the following

equation for calculation of the fitness values:

$$f_1 = \sum_{i=1}^{N} \sum_{t=1}^{T} \left\{ \left(\frac{X_{i,cal,t} - X_{i,\exp,t}}{X_{i,\exp,t}} \right)^2 \right\} \tag{3}$$

where N is the total number of genes in the system, T is the number of sampling points taken from the experimental time series $X_{i,cal;t}$ - the level of expression of the gene X_i-*th* gene at time t is calculated numerically by solving a system of differential equations **(1)** for the intended set of parameters and $X_{i;\,exp;\,t}$ is experimentally observed gene expression level of X_i in time $\boldsymbol{t}$.

The problem is to minimize the fitness value f_1.

b) The second optimization objective is to minimize the connectivity of the system, as biologically the gene regulatory network is known to be sparse. The connectivity is defined in two different ways: first, the maximum connectivity of the genes, i.e. the total number of interactions of the system:

$$f_2^a = \sum_{i=1}^{N} \left(\left| sign(\alpha_i) \right| + \left| sign(\beta_i) \right| \right) + \sum_{i=1}^{N} \sum_{j=1}^{N} \left(\left| sign(g_{i,j}) \right| + \left| sign(h_{i,j}) \right| \right) \tag{4}$$

And secondly, the median average connectivity of all genes, i.e. the median

average number of interactions of each gene:

$$f_2^b = median\left(\frac{f_2^a}{N}\right) \tag{5}$$

The proposed method is based on an algorithm of artificial immune network (AIS). The structure of the genome (the antibody Ab) is represented as a set of values of the optimization parameter $\alpha_i, \beta_i, g_{ij}, h_{ij}$.

2.3. Clonal Selection Algorithm

When solving the optimization problem, the goal is to find the optimal values (minimum or maximum) of some criterion, $y = f(f_1,\ f_2^b),\ x_i \in X,\ i = \overline{1, l}$ where X - the feasible set of tasks. In general, we consider problems of multi-objective optimization:

$$y = (f_1,\ f_2^b) \to min\ , \tag{6}$$

where $y_j = f_j(f_1,\ f_2^a,\ f_2^b),\ \ j = \overline{1, n}$ - number of objective for the task. Depending on the conditions of the problem finding possible global or local optima.

In optimization problems, the generalized form of antibodies is a vector of arguments $Ab = (x_1,\ x_2,\ \ldots,\ x_l)$, and as antigens used optimality criteria y_j, expressed as functions $Ag = f(x_1,\ x_2,\ \ldots,\ x_l)$. Affinity values g_j calculated on the basis of criteria values y_j reflected in the set of nonnegative numbers such as:

$$f : X \to \Re, \quad F : \Re \to \Re^+ \tag{7}$$

Thus, there is some affinity function $g = F\big(f(x_1,\ x_2,\ \ldots,\ x_n)\big)$, that determines that determines the degree of conformity of individuals to each other. In such problems, we can not to operate the notion of distance, so that the best value criteria is previously unknown, and, therefore, we do not know the maximum possible extent to which individuals. Thus, the control dynamics of AIS is performed by the relative affinity values or by rank individuals set. This approach is very close to the concept of suitability (fitness) used in evolutionary algorithms that have some earlier theory of artificial immune systems

Formally algorithm of clonal selection can be represented as:

$$CLONALG = (P^l, G^k, l, k, m_{Ab}, \delta, f, I, \tau, AG, AB, S, C, M, n, d), \quad (8)$$

where P^l is space of search (space of forms); G^k is space representation; $l$is the length of vector of attributes (dimension of space of search); $k$is the length of antibody receptor; m_{Ab} is dimension of population of antibodies; δ is the expression function; f is the affinity function; I is the function of initialization of the initial population of antibodies; $\tau$is the condition of completion of algorithm work; AG is the subset of antigenes; AB is population of antibodies; S is the operator of selection; C is the operator of cloning; M is the mutation operator; $n$is the number of the best antibodies selected for cloning; $d$is the number of the worst antibodies subjected to substitution for new ones.

Consider the shape- space (P^l) phenotypes and their space images as antibodies (G^k) or genotype space .

Function:

$$\delta : P^l \to G^k \quad (9)$$

is a function of conversion options with P^l solutions to their internal image G^k in a population of individuals.

This function is another called function expression. It should be noted that in practice, the development AIS often impose similar transformation for reasons of convenience, the application of immune operators and calculate affinity individuals.

For example, a vector of real attributes of dimension l can be transformed into a bit string of length$k$, which enables the use of specific operators mutation and affinity calculations using different types of Hemming distance.

Therefore, the terms "*genotype*", "*phenotype*" and "*expression*" in this description are borrowed from relatives by their functional structure and evolutionary algorithms, although more suitable for use in the context of the evolution of chromosomes than the molecular structure of antibodies. It is assumed also that for every solution $p \in P^l$ there is one and only one of his images $\delta(p) \in G^k$. Thus in general the opposite assertion is not correct.

Using a generalized mapping [29], you can type affinity function f:

$$f : P^l \times P^l \to \Re^+ . \tag{10}$$

This problem is to maximize the function of affinity. Taking the initial population size of antibodies (m_{Ab}), you can enter the initialization function as:

$$I : G^k \times m_{Ab} \to AB(G^k). \tag{11}$$

Often, the initialization is carried out randomly with uniform distribution.

Let the Q- unary operator stochastic transformation on the set G^k, which uses administering set K_Q to generate control parameters that determine the way to convert the current step of the procedure. For example, if mutations bit string, bit mask can be used as a control parameter, which determine the position of individual numbers of the individual bits that undergo mutations. Thus, the functional entry operator Q can be represented as follows:

$$Q : G^k \times K_Q \to G^k. \tag{12}$$

The optimum solution of $Ab_{opt} \in G^k$ concerning the operator of Q and antigen $Ag \in AG, \quad AG \subset G^k$ is called an individual, whose affinity can't be increased at further influence of the operator of transformation Q, ie

$$\forall k \in K_G : f(Q(Ab_{opt}, k), Ag) \le f(Ab_{opt}, Ag). \tag{13}$$

The condition of shutdown (τ) is executed when the population of antibodies fully recognizes the population of antigens, ie

$$\forall Ag \in AG : \exists Ab \in G^k \mid Ab = Ab_{opt} . \tag{14}$$

Operator selection S forms a subset of G_S individuals whose affinity is better in this generation. Thus, S together with the management set K_S represents the function:

$$S : G^k \times K_S \to \{0, 1\}, \tag{15}$$

set, which is formed by the selection:

$$G_S = \{Ab \in G^k \mid S(Ab, k_S) = 1\}, \quad |G_S| = n . \tag{16}$$

Similarly, the selection is made of individuals in a population of cells of memory. Operator cloning C increases of elements of the set G_S in population and with the management set K_C can be written as:

$$C : G_S \times K_C \to G_S . \tag{17}$$

The operator of a mutation of M with operating set K_M :

$$M : G^k \times K_M \to G^k . \tag{18}$$

Metadynamic system expressed as a function of substitution worst antibody population:

$$R : G^k \times d \to AB_d\left(G^k\right). \tag{19}$$

Worse antibodies previously selected by the operator selection.

Model process of transformation states populations clonal antibodies using procedures:

$$AB_t \xrightarrow{Selection(S)} G_S \xrightarrow{Cloning(C)} G_C \xrightarrow{Mutation(M)}$$
$$G_M \xrightarrow{\text{Repeat mutation}(S)} G_S \xrightarrow{\text{Replacement}(d)} AB_{t+1},$$

where$t$– number generation; AB– population of antibodies (detectors); G_S – best subset of selected antibodies; G_C – a subset of the clones; G_M – a subset of clones after mutation.

Let us show the generalized stepwise description of the algorithm.

1. *Initialization.* Creation (usually by random generation) of the initial population of antibodies AB.

2. *Determination of affinity.* For every antibody AB_j, $AB_j \in AB$ determine its affinity relative to every antigen Ag_i, $Ag_i \in AG$. Write the result into the matrix of affinities $D : D = \left[|AG| \times m_{Ab}\right]$, and $d_{ij} = f\left(Ab_j, Ag_i\right)$, $d_{ij} \in D$.

3.*Clonal selection and propagation.* Select from population n of each the best antibodies for every row of the matrix D and place them into separate population of clones $AB_C, |AB_C| = n \cdot |AG|$. It is necessary to generate clones of elements of the population AB_C proportionally to their affinity, i.e., the greater it is, the greater number of clones is generated and vice versa.

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4. *Affinity maturation*. Subject to mutation all the clones of population AB_C with probability inversely proportional to affinities, i.e., probability of mutation is the greater, the lower is its affinity. Determine new affinity of every antibody AB_j, $AB_j \in AB_C$ similar to item 2 and obtain the matrix of affinities D_C. Select n antibodies from the population AB_C, for which the corresponding vector-column of the matrix D_C gives the best generalized result of affinity, and transfer them into population of cells of memory M_R.

5. *Metadynamics*. Substitute the worst d antibodies of the population AB by new random individuals.

6.Substitute n antibodies of the population AB by cells of memory from M_R and pass to item 2 until the stoppage criterion is reached.

The operator of cloning used to create a set of copies of the best individuals in the population . This operator makes it possible to increase the study intensity of solutions area space. Cloning (generation of identical copies) is the selection of an individuals quantity, while the quantity of copies in proportion to their affinity: the higher the affinity, the larger clone (offspring quantity). In optimization tasks the n antibodies with highest affinity are shown. The number of clones is calculated by the formula:

$$N_c = \sum_{i=1}^{N} round(\beta \cdot N) \quad , \tag{20}$$

where N_c is the total number of clones created for each of the antigens-multiplying factor, N - is the total number of antibodies, $round(\cdot)$ - rounding operator of argument to an integer.

Each antibody is seen in the local scale and does not have any advantages when cloning to other antibody. Antigenic affinity (matching the value of objective function) further is used to determine the hyper mutation level for each clone of the antibody.

After cloning operation, the clones are subject to a hypermutation process inversely proportional to their affinity; the higher the affinity the smaller the mutation rate. Hence, the mutation rate of a clone is inversely proportional to the fitness of its parent. The antibodies in each subpopulation which consists of the parent and its clones maturated by hypermutation operation are then evaluated in the affinity function, and the best antibody of each subpopulation becomes memory cell and is allowed to survive. The antibodies with d lowest affinities are replaced by the new antibodies generated randomly to maintain the diversity of antibody population so that the new areas of the search space can be potentially explored. The next generation starts with a new antibody population produced as described above. These processes are repeat d until a termination criterion is attained or a predetermined generation number is reached [30-32].

Principle 1: *The proliferation rate of each immune cell is proportional to its affinity with the selective antigen (higher the relative affinity, themoreprogeny)* [33].

Principle 2: *The mutation suffered by each immune cell during reproduction is inversely proportional to the affinity of the cell receptor with the antigen (higher the relative affinity, the lower the mutation)* [33].

Each candidate solution (an attribute string in a given shape space) has an independent mutation rate in proportion to its affinity with the optima solutions. Thus, candidates in higher peaks of the affinity land will be subject to smaller mutation rates while candidates located far from optima solutions will suffer larger mutation rates. One problem with this approach is that, usually, nothing is known a priori about the optima solutions of a problem In this case, one can evaluate the relative affinity of each candidate solution by scaling (normalizing) their affinities. The inverse of an exponential function can be used to establish a relationship between the hypermutation rate $\alpha(\cdot)$and the normalized affinity D^* [30-32]. In some cases it might be interesting to re-scale a to an interval such as [0..0.1].

$$\alpha\left(D^*\right) = \exp\left(-\rho D\,*\right), \tag{21}$$

where ρ is a parameter that controls the smoothness of the inverse exponential, and D^* is the normalized affinity, that can be determined by $D^* = D / D_{\max}$.

3. EXPERIMENTS AND RESULTS

This methodology has been analyzed in the reconstruction of well-known SOS DNA repair network in *Escherichia coli*. It is the longest, most complex and best understood DNA damage-inducible network to be

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characterized to date. In this work, the experiment was carried out by the gene expression data set collected in Uri Alon Lab. It was taken from www.weizmann.ac.il/mcb/UriAlon/Papers/SOSData/. In this system, there are six major genes that control the process of repair. Those genes are uvrD, LexA, umuD, recA, uvrA and polB. The data set obtained was normalized before using it for the prediction of relations in the gene network. In the SOS DNA repair system of *Ecoli*. LexA is a suppressor of all the other genes. Whenever DNA damage occurs, the concentration of LexA drops. This activates all other genes and starts repairing. After repairing, LexA gets back to original position and all the other genes are suppressed. Thus, the system attains a stable state.

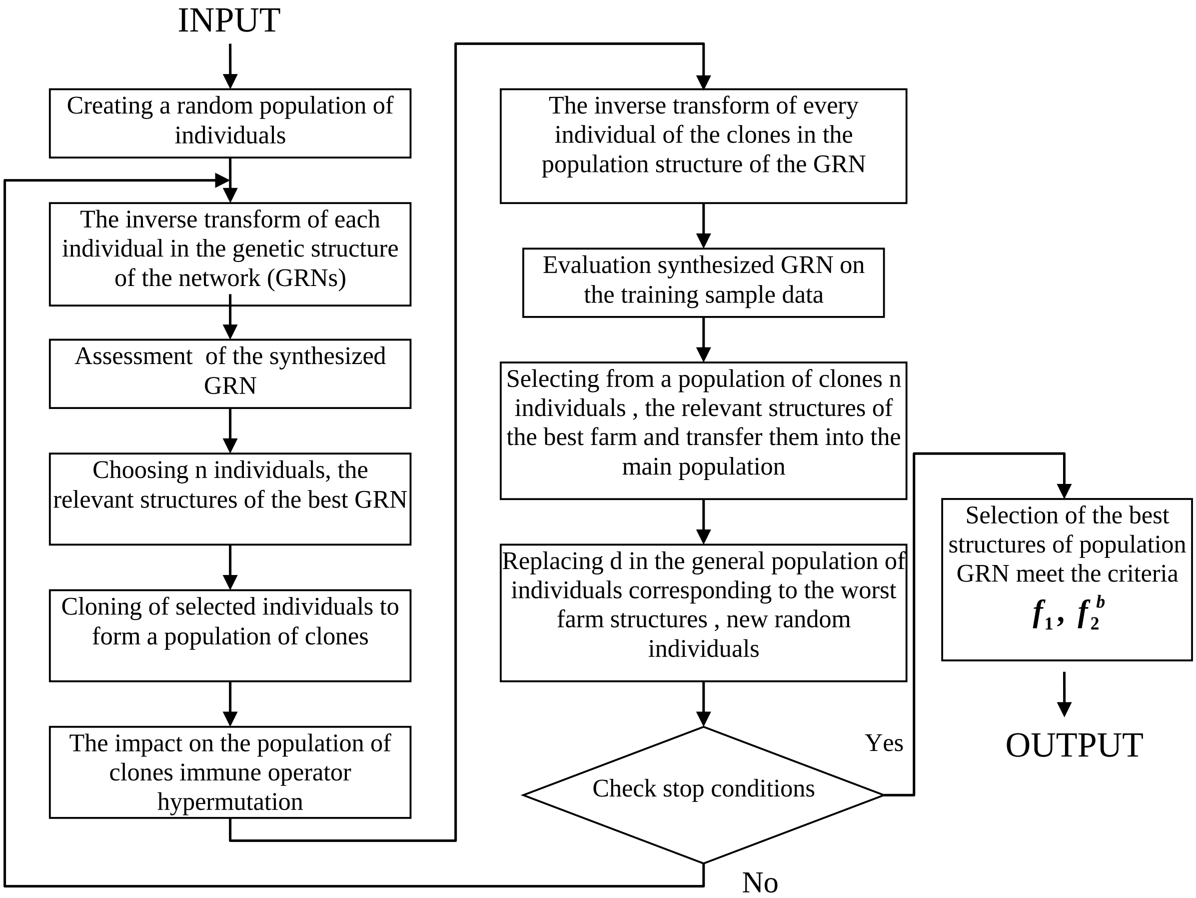

Fig. 1. Workflow of multi-objective clonal algorithm optimization for the identification of a gene regulatory network

RecA identifies the damage and activates the processing of cleavage of LexA. Hence, the concentration of the LexA will be reduced and will lead to the excitation of other genes. After the clearance of damage, cleavage of LexA will be slow downed and stopped, and this leading to increased concentration of LexA. The LexA will repress the other genes and will advance to a balanced state. Construction of gene network allows predicting the roles of each of the genes in the DNA repairing system.There are 50 time periods for the experiment in which 49 are used for the experimentation where the first time period is at zeroth time and contains zero knowledge. Out of the 8 genes we had selected, 6 important genes are specified. All the values in the expression are normalized in the range of [0, 1].

Table 1 shows the results of reconstruction of the gene regulatory network using as an objective function f_1

Table 1.

The results of the application of clonal selection algorithm for single optimization

	ubrD	lexA	umuD	recA	uvrA	polB
ubrD	0	0	1	1	0	0
lexA	1	1, -1	0	1, -1	1, -1	-1
umuD	1, -1	0	1	1	1	
recA	-1	1, -1	-1	0	1	1
uvrA	1	1	0	0	-1	1
polB	0	0	0	0	0	-1

In Table 2 shows the results of the reconstruction of gene networks using multi-objective function $y=(f_1, f_2^b)\to min$

Table 2.

The results of the reconstruction of gene networks using clonal selection algorithm with the application of multi-objective optimization

	ubrD	lexA	umuD	recA	uvrA	polB
ubrD	-1	-1	-1	0	0	1
lexA	-1	-1	0	-1	1	1
umuD	0	-1	-1	-1	1	-1
recA	0	-1	-1	1	1, -1	-1
uvrA	1	-1	1	-1	-1	-1
polB	1, -1	0	-1	-1	1, -1	-1

Using clonal selection algorithm with the application of multi-objective optimization predicted the major biological relations such as lexA to lexA, umuDc, recA, and uvrA. It also identified major positive

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relation from recA to lexA, recA to recA and lexA to lexA. The proposed clonal selection algorithm identified two biological relations (recA to recA, lexA to umuDc) that are not identified by the clonal selection algorithm based S-system approach. The existing clonal selection algorithm based S-system approach predicted six biologically identified relations and the proposed approach identified seven biologically identified relations. An advantage of the proposed approach is that the number of uncertain relations identified is much lower than that of clonal selection algorithm based S-system approach. Uncertain relations are the relations that are not sure whether they exist. For the clonal selection algorithm based S-system approach, the numbers of uncertain relations are 22 and for the proposed clonal selection algorithm are 12. This clearly indicates that the proposed approach can successfully use for the real life data set, and it is efficient in predicting relation than the clonal selection algorithm based S-system.

4. CONCLUSION

In this work, we presents an immune multi-objective approach to inference network of S-system, using the clonal selection algorithm based S-system. Due to the proposed multi-objective optimization model, there is no need to preset any parameter value before the inference MOEA is run. Thus, our method could be generally applicable to various kind of GRN model. Future work will be focused on inference of GRN based on noisy data, and how to generalize the proposed method to infer big-scale GRNs.

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V.V. Marasanov, A.A. Sharko

TRIANGULATION METHODS OF POSITION DEFECTS IN

Annotation. *A description of the characteristics and applications of acoustic emission nondestructive testing of metal. It is shown that important information parameter is the degree of localization of the source of acoustic emission. It provides analytical support of triangulation methods to determine the origin of defects by measuring the difference in arrival times of the pulses of acoustic emission sensors to different configurations.*

Keywords: *triangulation, location, nondestructive testing, acoustic emission, the coordinates of defects.*

Relevance of the topic. One method of detecting cracks in industrial facilities is acoustic emission method of non-destructive testing based on detection of acoustic signals generated in the development of various defects. In this method, the coordinates of defects is determined by the difference of the arrival time of signals from a single source to the spaced apart sensors which are arranged in antennas group. To determine the coordinates of acoustic emission sources under the control of extended objects using two sensors. If you want to calculate the coordinates of the acoustic emission sources on the plane must be at least three sensors. In order to determine the location of defects in the bulk of the provisions of the controlled object requires four or more sensors, the larger the sensor is used, the less methodical error of calculations. Development of methods of triangulation location of defects in determining the coordinates of acoustic emission sources in a variety of configurations of the sensors on the test surface is one of the important directions of the acoustic emission method.

Analysis of publications on the problem of locating defects by acoustic emission shows the presence of several approaches, based on the analysis of various mathematical models, establishing communication parameters of acoustic emission parameters characterizing the state of the controlled object [1-5]. Thus, in [4] in the Cartesian coordinate system is considered antenna group of the sensors of acoustic emission signals in the form of a square where the distance from its summit to the source of acoustic emission. Similar studies carried out for the centered square. In the development of methods of triangulation location of defects by acoustic emission method in this paper the different configuration of the sensors.

By the unresolved parts of the general problem of nondestructive testing of metal structures are scientific and methodological support of the configurations of the sensors under the control of developing defects in the triangulation method of acoustic emission.

Objective. Search for analytical dependences of planar defects by determining the coordinates of the sources of acoustic emission signals triangulation methods.

Statement of the basic material. Traditional methods of non-destructive testing reveal geometric heterogeneity by emitting energy in the investigated structure. The acoustic emission signal source is the material itself, rather than an external source, so, the method is passive. Acoustic emission method is based on the detection of waves at a fast restructuring of the local material. If the loading of local deformation caused by the existence of the defect exceeds the threshold, there is acoustic emission. Emissions level is greater than the above strain. At the same time the total power can be judged about the dangers of the defect.

Acoustic emission sources are the processes of plastic deformation and fracture. They cause the occurrence of stress waves, which propagate in the material structure and reach the piezoelectric transducer.

According to the kinetic theory of strength of the concept [2], the fundamental equation that describes the kinetics of the process of destruction is:

$$\tau = \tau_0 \exp\left(\frac{u_0 - \gamma\sigma}{kT}\right),$$

where τ - the time remaining before destruction;

τ_0 = 10-13 s - period of oscillations of atoms in solids;

u_0 - activation energy gaps interatomic bonds;

γ - structure-sensitive factor;

σ - constant tensile stress;

k - constant of Boltzmann;

T - temperature.

In this equation, the values, τ_0, u_0 and γ strength characteristics are properties of materials, and the magnitude u_0 is not dependent on the

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structure of the material, and a parameter γ dependent on the size of the product and the technology of its manufacture. This greatly complicates the calculations of the time remaining before destruction, and therefore the degree of danger of defects is determined empirically. An important parameter of defects in the structure of information is the degree of localization of the source, due to developing defect. The method is based on the coordinates of defects by measuring the difference in arrival time of the pulses to multiple, spaced-point acoustic sensors registration acts of acoustic emission.

To determine the origin of defects sensors installed in a specific configuration, which forms so-called antenna array.

According to the location of receivers of acoustic emission signals, they are divided into triangulyar where sensors form an antenna array of triangles, rektangulyar where the array is formed from a rectangle, circle, where the array is formed from circles.

The circuit arrangement of the sensors is determined by the task of monitoring and the required accuracy of location of acoustic emission sources.

Algorithms calculate the coordinates of the defects based on the determination of the difference between the arrival times of the acoustic wave to the front several receivers. To determine the coordinates of the source of acoustic emission signals at the surface of the structure, as a minimum, it is necessary to have three sensors.

In determining the origin of the three-point scheme surface must be covered with a network of receivers and measuring the difference in arrival time of the signal at three adjacent receiver, forming a triangle. Then the source of acoustic emission will be located inside the triangle, and its coordinates are determined uniquely. However, with this method, the location of the receivers have problems in the control object boundaries.

These difficulties disappear when using a four-point control scheme.

The system of linear equations for the control with four receivers is:

$$xx_i + yy_i + Rr_i = \frac{x_i^2 + y_i^2 - r_i^2}{2}, \ i = \overline{0,3};$$

where x_i , y_i- the coordinates of the receivers;

R - is distance to the defect from the origin;

r - the distance to the receiver of acoustic emission signal.

Decision of the system of equations is:

$$x = \frac{\left(y_2\left(x_1^2 + y_1^2 - r_1(r_1 + 2R)\right)\right) - y\left(x_2^2 + y_2^2 - r_2 + \left(r_2(r_2 + 2R)\right)\right)}{2R\left(x_1 y_2 - x_2 y_1\right)}$$

$$y = \frac{\left(y_2\left(x_1^2 + y_1^2 - r_1(r_1 + 2R)\right)\right) - x\left(x_1^2 + y_1^2 - r_1 + \left(r_1(r_1 + 2R)\right)\right)}{2R\left(x_1 y_2 - x_2 y_1\right)}$$

Here are the formulas for determining the coordinates of acoustic emission sources for some specific ways of arranging receivers on the plane.

- An equilateral triangle with the center (fig. 1)

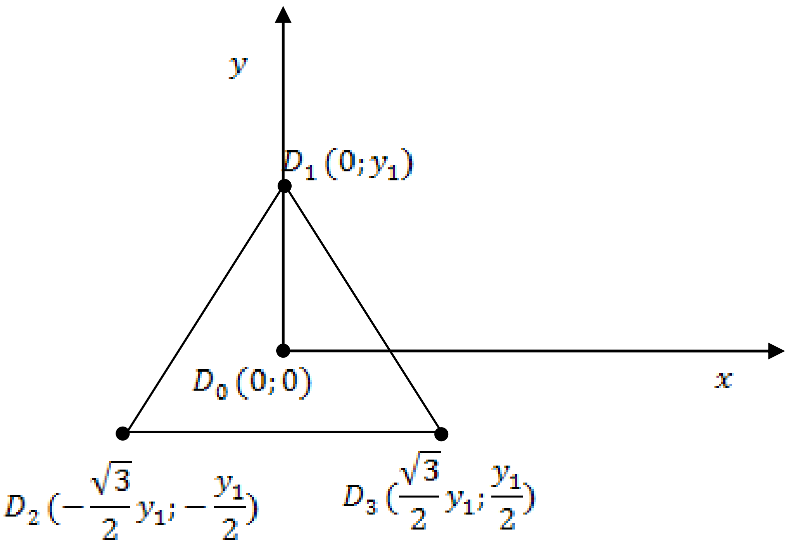

Fig. 1. Location of the receivers in the form of an equilateral triangle with the center

$$2R = \frac{\left(3y_2^2 - r_1^2 - r_2^2 - r_3^2\right)}{r_1 + r_2 + r_3},$$

$$x = \frac{(r_3 - r_2)(2R + r_2 + r_3)}{2\sqrt{3y_1}},$$

$$y = \frac{\left(y_1^2 - r_1(r_1 + 2R)\right)}{2y_1}.$$

- receivers are arranged in a perpendicular (fig. 2)

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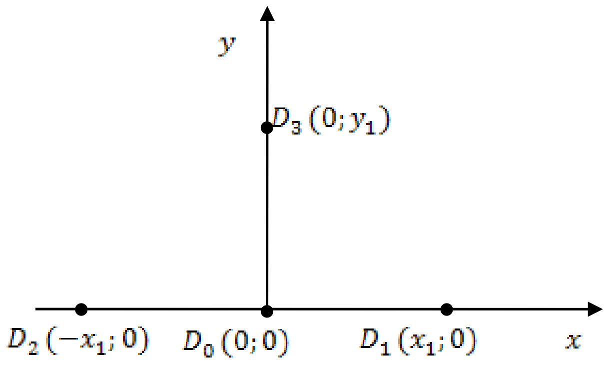

Fig. 2. The arrangement of the receivers in the form of a perpendicular

$$2R = \frac{\left(2x_1^2 - r_1^2 - r_2^2\right)}{\left(r_1 + r_2\right)},$$

$$x = \frac{\left(x_1^2 - r_1\left(r_1 + 2R\right)\right)}{2x_1},$$

$$y = \frac{\left(y_3^2 - r_3\left(r_3 + 2R\right)\right)}{2y_3}.$$

- receivers arranged in the shape of a rectangle (fig. 3)

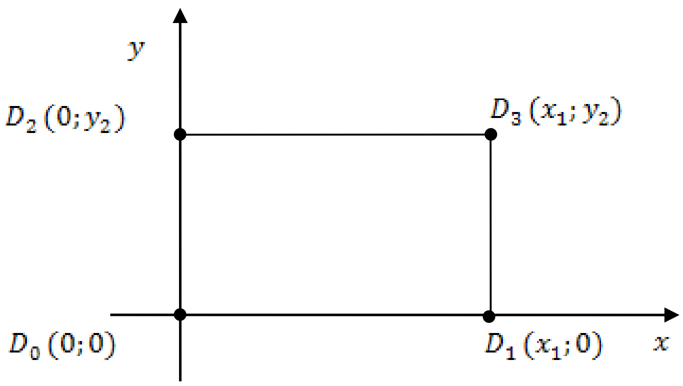

Fig. 3. Location of the receivers in the form of a rectangle

$$2R = \frac{\left(r_3^2 - r_2^2 - r_1^2\right)}{r_1 + r_2 - r_3}$$

$$x = \frac{\left(x_1^2 - r_1\left(r_1 + 2R\right)\right)}{2x_1}$$

$$y = \frac{\left(\left(\ y_2^2 - r_2\ \right)\left(r_2 + 2R\right)\right)}{2y_2}$$

- receivers arranged in the shape of a rhombus (fig. 4)

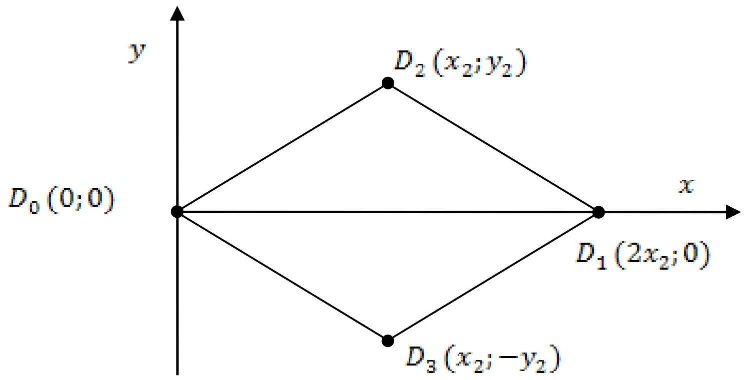

Fig. 4. Location receivers rhombus

$$2R = \frac{\left(2\left(y_2^2 - x_2^2\right) - r_3^2 - r_2^2 - r_1^2\right)}{r_3 + r_2 \cdot r_1}$$

$$x = \frac{\left(4x_2^2 - r_1\left(r_1 + 2R\right)\right)}{4x_2}$$

$$y = \frac{\left(\left(r_3 - r_2\right)\left(r_3 + r_2 + 2R\right)\right)}{4y_2}$$

Tasks for the calculation of the coordinates of the defects based on the determination of the difference in arrival time of the acoustic emission signals to the sensors pezoantenny followed the solution nonlinear equations. In this case, the calculation of the coordinates of defects will be authentic if the following conditions are met:

- The speed of propagation of surface acoustic waves is the same in all directions;

- An acoustic signal from a defect in any part of the controlled object reaches to each sensor without encountering on his way any obstacles;

- Error in determining the difference in arrival time of the acoustic emission signals to the appropriate sensors pezoantenny should be minimal.

In this arrangement, the following schemes:

- Triangular arrangement - the object's surface is covered by triangles control receivers of acoustic emission. This method is similar rectangular placement, but location is necessary, so that the signal from the source of acoustic emission hit all three sensors;

- Rectangular arrangement - the sensors are installed in rectangular lattice, and thus can more effectively cover the surface of the object of

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control. Additional sensors can be placed on the top and bottom of the object of control. The source of acoustic emission which produced location in contact with the receivers of acoustic emission.

The formula for determining the coordinates using the difference between the time of arrival of the four input sources only arithmetic operation that allows you to monitor an area that does not lie within the figure bounded by lines connecting these receivers, so you can use the group and a method for arranging receivers on the surface of the object under control.

Conclusions. Effect of acoustic emission is characterized by a group of independent parameters which includes: the fact of occurrence of the event, the time it arrives, the peak amplitude of the signal, the number of acts of oscillation parameters of the location of defects, the order of arrival. For information about the source of acoustic emission contains the pulse amplitude, duration, and time of the signal at a given point on the surface. Using the acoustic emission method significantly reduces the time of the diagnostic work and saves money spent on their conduct.

The resulting formula for calculating the coordinates of acoustic emission sources in the amount of the controlled object in the perspective of their use may serve as a justification for the analytical models and algorithms for determining the coordinates of developing defects.

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PROBLEM WITH DEVELOPING ALGORITHMS FOR SYSTEM LEVEL SELF-DIAGNOSIS

Abstract: *Article is devoted to sequence, structure and strategy of solving the problem of self diagnosis of homogeneous systems. Considered in detail the problem of the development of algorithms for system self test level. The conditions and requirements to obtain the correct diagnosis.*

Keywords: *self diagnosis, homogeneous systems, diagnosis algorithms, sequential diagnosis, excess diagnosis, intermittent faults, hybrid faulty situation*

1. Introduction

The paper tackles the system level self-diagnosis which was introduced by Preparata [1] and then has been broadly investigated in literature. Before providing self-diagnosis, it is necessary to perform several steps, such as to choose the diagnosis strategy (i.e., unique diagnosis, sequential diagnosis or excess diagnosis); to make decision about allowable faulty situations (i.e., only permanent faults, only intermittent faults or hybrid faulty situation); to make decision on how to interpret test results. Depending on the decision made at each step, different diagnosis algorithms can be developed. In the paper, some problems of developing of diagnosis algorithms for system level self-diagnosis are discussed for the case of uniquely diagnosable systems.

2. Algorithms for uniquely diagnosable systems

There have been developed many algorithms allowing to identify a fault set uniquely (when some assumptions are made about the faulty units). The main task while developing these algorithms is to reduce their complexity. Among the most efficient algorithms there could be named algorithm proposed by Dahbura and Masson [2] which has $O(N^{2.5})$ time complexity and $O(t^3 + |E|)$ algorithm suggested by Sullivan [3]. Both algorithms were developed for t-diagnosable systems under the symmetric invalidation model and when permanent fault are allowable only. There are many special classes of t-diagnosable systems that support more efficient diagnosis techniques than above mentioned ones, and this is reason to believe that an $O(|E|)$ diagnosis solution exists for all t-diagnosable systems. Preparata et al. defined the $D_{\delta,t}$ structure in which unit $u_i$tests u_j if and only if

$$j - i = \delta m \pmod{n},$$

where $m=1,2,...,t$.

Meyer and Masson [4] gave $O(nt)$ solution to the case of $\delta=1$.

The efforts to develop the simplest algorithm are continue till now.

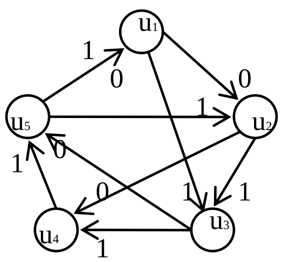
For developing the table algorithm there have been made the same assumptions as those made for the above mentioned algorithms. Underlying strategy before developing this algorithm is to structure the algorithm so that it can be split into several branches each of which is characterised by its own complexity and its own probability of their using while executing system diagnosis. It is expected that the simplest branch will be executed most of the time.

The algorithm deals with table of syndrome which is the matrix presentation of syndrome. Table of syndrome $M_R[r_{ij}]$ is square matrix of dimension *NЧN*, where N is the total number of units in the system.

If the result of the test which is performed by unit ui on unit uj is the element of syndrome, then the value of r_{ij}will be placed on the intersection of i-th row and j-th column of the table.

Since test result can take values either 0 or 1 only, a table of syndrome also contains only these values. If there is no test between two units (i.e., there is no such element in the syndrome) then dash will be placed on the corresponding intersection. To present the table of syndrome for computer modelling, it is possible to substitute the dash with the value of "-1".

As an example of table of syndrome, in the Figure 1, the testing graph with weights of edges and the table of syndrome corresponding to this graph are depicted.



$M_R =$

	1	2	3	4	5
1	-	0	1	-	-
2	-	-	1	0	-
3	-	-	-	1	0
4	0	-	-	-	1
5	1	1	-	-	-

Figure 1. Testing graph with weighted edges and table of syndrome M_R.

The goal of the diagnosis algorithm based on matrix $M_R$is to identify all faulty units (on the condition that the total number of faulty units does not exceed the value t which is defined by the testing graph). Otherwise, the algorithm with a great probability should be able to find out that total number of faulty units has exceeded the value t.

As a preliminary step for developing the algorithm, the value t is determined by examining the testing graph.

Generally, it can be obtained arbitrary testing graph, but mostly tests have being performed until certain graph is formed. Usually, such graphs insure desired value of t which at the same time is equal to t_{max}.

Having the value of t and matrix M_R, the following steps should be performed:

Step 1. For each row and column of matrix M_R the total number of "1" is counted. The total number of "1" in the row $\boldsymbol{x}_i$ is equal to

$$S_{x_i} = \sum_{j=1}^{n} r_{ij}$$

The total number of "1" in the column $\boldsymbol{y}_j$ is equal to

$$S_{y_j} = \sum_{i=1}^{n} r_{ij}$$

Step 2. For each $i=1,2,..,n$ the following sum is calculated

$$S_i = S_{xi} + S_{yi}$$

As a result, there will be obtained the tuple $(S_1, S_2,..,S_n)$.

Step 3. Successively each value S_i , $i=1,2,..,n$ is compared with the value of t. As a result of comparing there are possible three situations:

A) $S_i > t$

B) $S_i = t$

C) $S_i < t$

The next step depends on the arising situation. Thus, after performing of *Step 3* there possible three branches: A, B and C.

Branch A. In this case, it is easy to show that unit u_i is faulty. For this, let's assume that unit u_i is fault-free. Then, all of the units that evaluate the unit u_i as faulty must be faulty since they have tested unit u_i incorrectly. Consequently, the total number of faulty units in the system will be greater than t, which contradicts the main assumption about *t-diagnosability* of the system. Thus, our assumption about the state of unit u_i was wrong, and unit u_i must be identified as faulty.

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Branch B.In this case, given value S_i, it is not possible to conclude directly whether unit u_i is faulty or not. Firstly, it is assumed that unit u_i is fault-free. Given such assumption, all of the units which either evaluate unit u_i as faulty or those that are evaluated as faulty by unit u_i must be identified as faulty.

Thus, unit u_j is marked as faulty if

$$(r_{ij} =1) \vee (r_{ji} = 1).$$

On the contrary, units that are evaluated by unit u_i as fault-free (i.e., $r_{ij}=0$) must be identified and marked as fault-free. The set of such units is denoted as Z_i.

Next, the units from the set $Z_i$are successively selected, and the whole procedure described above for unit u_i is repeated, but this time for the selected unit.

This way there can be selected further units, and the procedure will continue until either there is found a contradiction in marking of a unit, or all of the units which are assumed as fault-free have been inspected.

In the former case, when a contradiction is found, unit u_i should be identified as faulty. In the latter case, the initial assumption about the state of unit $u_i$is correct.

Branch C.If this situation arises, the next operations on matrix $M_R$depend considerably on the number of system units and on the system testing assignment.

For $N<13$ it is sufficient to find in matrix M_R the column which contains only zero elements. This column corresponds to the unit which should be identified as fault-free. Using tests results related to this unit, it is possible to make decision about the states of all the remaining system units. This can be done by using the procedure which is similar to the one described for branch *B*.

For $N\geq 13$ it is possible to prove that the testing graph contains the simple directed cycle of length $t+1$ each edge of which has the weight of “0”. Such cycle can be determined directly from the matrix M_R. All of the units which are represented in the testing graph by the vertices of this cycle can be identified as fault-free.

It should be noted that the probabilities of the event that the situations *A, B* or C will arise depend considerably on the number of system units, on the structure of testing graph, and on the interpretation of test result (see Table 1).

Table 1.

Test results and their probabilities

Test resultandits probability		Testing unit u_i fault-free	Testing unit u_i faulty
Testedunit u_j	fault-free	$r_{ij} = 0$ (P_C)	$r_{ij} = 0$ ($1 - P_S$)
		$r_{ij} = 1$ ($1 - P_C$)	$r_{ij} = 1$ (P_S)
	faulty	$r_{ij} = 0$ ($1 - P_{AT}$)	$r_{ij} = 0$ ($1 - P_F$)
		$r_{ij} = 1$ (P_{AT})	$r_{ij} = 1$ (P_F)

So, for example, for the testing graph depicted in Fig. 1 there are possible only situations *A* and *B*. For this example with $t=2$ and testing graph $D_{1,2}$of type $D_{\delta,t}$, it is easy to prove that S_i cannot be lesser than t.

Proof.Since $t=2$, there are possible only two cases. In the first case, only one unit is faulty, and in the second case, two units are faulty.

Case 1. In the system with $D_{1,2}$graph, each unit is tested by two other system units. For this case, both units which test the faulty unit are fault-free and will produce the test result equal to 1. Thus, the total number of 1 will be equal to two (i.e., not lesser than t).

Case 2. In this case, there are possible two situations. The first situation arises when faulty unit is not tested by another faulty unit. The second situation arises when faulty unit is tested by another faulty unit. The first situation is identical to the Case 1 and leads to the same result. In the second situation, there can be use the property of structure $D_{\delta,t}$ such that there are no units which test each other. It means that if one faulty unit tests another faulty unit, then this faulty testing unit is not tested by faulty unit. Thus, this faulty testing unit is tested by two fault-free units with the test result equal to 1. It means that the total number of 1 will be equal to two (i.e., not lesser than t).

Now, let's take into consideration the fact that faulty testing unit can produce the test result equal to 1 with some probability (i.e., probabilities P_F and P_S are not equal to zero), and estimate the probability of the event that the situation *A* will arise, P_a. For the system with $D_{1,2}$ testing graph the probability $P_a$can be estimated as follows.

It is evident that the more faulty units in the system, the greater is probability P_a. That is why we consider only the "worst" case when only one faulty unit is in the system. This faulty unit will perform two tests on other system units. If we assume that $P_F = P_S=0.5$ then $P_a=0.75$. The greater the values of $P_F$and $P_S$the greater the probability P_a. As one of the solutions of how to increase the probability P_a, there can be suggested to repeat the tests two or more times. So, for example, if the tests will be repeated twice the probability P_a will increase to 0,9375.

4. Algorithm based on the table of potential syndromes

Vedeshenkov in [5] suggested an original algorithm based on the table of potential syndromes. Similarly to the table algorithm, the execution of this algorithm depends considerably on the obtained syndrome and may be very simple for most cases. The table of potential syndromes is formed before the testing procedure begins.

The table contains all possible syndromes that can be obtained when the system has different combinations of faulty units. The total number of faulty units is restricted by value of t. Consequently, only combinations that contain not more than t faulty units are presented in the table.

The number of combinations of faulty units, Q, is equal to

$$Q = \sum_{i=1}^{t} \binom{n}{i}$$

For example, for the system with testing graph shown in Fig.1 there should be considered the following fifteen combinations:

S_1: unit u_1 is faulty
S_2: unit u_2 is faulty
S_3: unit u_3 is faulty
S_4: unit $u_4$is faulty
S_5: unit u_5 is faulty
S_6: units u_1 and u_2 are faulty
S_7: units u_1 and u_3 are faulty
S_8: units u_1 and u_4 are faulty
S_9: units u_1 and $u_5$are faulty
S_{10}: units u_2 and u_3 are faulty
S_{11}: units $u_2$and $u_4$are faulty
S_{12}: units u_2 and u_5 are faulty
S_{13}: units u_3 and u_4 are faulty
S_{14}: units u_3 and u_5 are faulty
S_{15}: units u_4 and $u_5$are faulty

If actual state of the system is so that it has more than *t* faulty units, then result of diagnosis based on the table of potential syndromes may be either incorrect (false negative) or zero. Zero result means that it is not possible to make any solutions about the faulty situation in the system.

A table of potential syndromes has the following columns:

- denotations of the situations (S_i)
- the set of faulty units (e.g., $\{u_1, u_5\}$)
- denotations of the potential syndromes (R_p^i) that correspond to the situations S_i, $i=1,2,...Q$
- separate elements (r_{ij}) of the syndrome (R_p^i). These elements construct l columns of the table, where l is the number of edges (resp. tests) in testing graph.

The table of potential syndromes contains as many rows as there are situations. The values of separate elements of potential syndrome (r_{ij}) are set according to the model of test results suggested by Preparata [1]. It means that a test result can be represented in the table as 0 or 1 when testing unit is fault-free or as *X* when testing unit is faulty. Actual syndrome as distinct to the potential syndrome contains only values of 0 or 1.

For the example under consideration the table of potential syndrome looks like as follows

Table 2

Table of potential syndromes

S_i	*faulty units*	*potential syndrome*	*test results*									
			r_{12}	r_{12}	r_{12}	r_{12}	r_{12}	r_{12}	r_{12}	r_{12}	r_{12}	r_{12}
S_1	u_1	R_p^1	X	X	0	0	0	0	0	1	1	0
S_2	u_1	R_p^2	1	0	X	X	0	0	0	0	0	1
S_3	u_1	R_p^3	0	1	1	0	X	X	0	0	0	0
S_4	u_1	R_p^4	0	0	0	1	1	0	X	X	0	0
S_5	u_1	R_p^5	0	0	0	0	0	1	1	0	X	X
S_6	u_1 , u_2	R_p^6	X	X	X	X	0	0	0	1	1	1
S_7	u_1 , u_3	R_p^7	X	X	1	0	X	X	0	1	1	0
S_8	u_1 , u_4	R_p^8	X	X	0	1	1	0	X	X	1	0
S_9	u_1 , u_5	R_p^9	X	X	0	0	0	1	1	1	X	X
S_{10}	u_2 , u_3	R_p^{10}	1	1	X	X	X	X	0	0	0	1
S_{11}	u_2 , u_4	R_p^{11}	1	0	X	X	1	0	X	X	0	1
S_{12}	u_2 , u_5	R_p^{12}	1	0	X	X	0	1	1	0	X	X
S_{13}	u_3 , u_4	R_p^{13}	0	1	1	1	X	X	X	X	0	0
S_{14}	u_3 , u_5	R_p^{14}	0	1	1	0	X	X	1	0	X	X
S_{15}	u_4 , u_5	R_p^{15}	0	0	0	1	1	1	X	X	X	X

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From the table it is easy to infer that any two potential syndromes differ at least in one element. This difference plays the key role for diagnosis based on the table of potential syndromes.

Having performed all tests and obtained actual syndrome, one can apply diagnosis algorithm. Diagnosis algorithm consists in comparing an actual syndrome with the potential syndromes presented in the table. The goal of diagnosis algorithm is to find in the table the potential syndrome that coincides with actual syndrome. Comparing is performed so that each element of actual syndrome is compared with the corresponding element of the potential syndrome. Element of potential syndrome denoted as X is always complying with element of actual syndrome.

Comparing procedure can be executed according to different strategies. Basic and straightforward strategy consists in successive comparing the elements of actual syndrome with elements of separate potential syndromes depicted in separate rows of the table. Comparing starts from the first row and goes on until there is coincidence.

It is worth noting, that such strategy may be not efficient because the comparing procedure may require a large number of single comparing (up to QЧl single comparing). Application of this basic strategy to the system under consideration gives the result that actual syndrome coincides with the potential syndrome R_p^{14}. It means that units $u_3$and $u_5$are identified as faulty. In this case, the actual syndrome was compared with 14 potential syndromes (i.e., there were 14Ч10 = 140 single comparing).

One can easily notice that total number of single comparing can be reduce if comparing procedure is organised so that only part of the syndrome is chosen in each step of comparing procedure.

So, for example, if it is chosen only first element of the syndrome for comparing, then only 11 potential syndromes remain for further consideration.

The algorithm developed according to this strategy consists in the following:

At the first step, only rows that contain the first element that coincides with the first element of actual syndrome are chosen. For the considered example these are the rows 1,3,4,5,6,7,8,9,13,14,15.

At the second step, the second element of just chosen rows is compared with the second element of actual syndrome. Only rows which contain the second element that coincides with the second element of actual syndrome remain for further consideration. In the given case, these are the rows 1,3,6,7,8,9,13,14.

This procedure continues for the next elements and ends at the seven element of actual syndrome when only one potential syndrome remains, particularly R_p^{14}.

It is worth noting, that there can be suggested other strategies for organising the comparing of actual syndrome with potential syndromes which could allow to reduce the total number of single comparing.

Both considered above algorithms use the table as the starting point for identifying the set of faulty units. These algorithms have advantages and drawbacks with regards to their development and application.

Advantages:

- their development requires only basic information about the system (such as, total number of system units, system testing assignment and the results of testing)
- the tables could be very easy developed. They are illustrative (telling) which may reduce mistakes while their processing.

Drawback:

- these algorithms don't take into account the reliability of system units which reduces the credibility of result of diagnosis.

5. Conclusions

Unique diagnosis considered in the paper is based on the statement that the made assumptions about allowable faulty sets will be satisfied. Thus, the diagnosis algorithms developed for the unique diagnosis will provide correct diagnosis only in the case when the made assumptions are correct. In practice, we can find much evidence of the fact that making such assumptions is reasonable. It is also worth noting that the algorithms considered in the paper are applicable only for homogeneous systems.

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SYNTHESIS OF 3D-DISTRIBUTIONS TO RADIATION INTENSITY FOR TORCH OF DIRECT-FLOW PLASMATRON BASED ON TWO-DIMENSIONAL IMAGING

***Summary**. Non equilibrium plasma sources are crucial for plasmochemical technologies variety, e.g.: a destruction of the toxic high molecular weight compounds in water solutions, the hydrocarbon energy carrier reforming, and a creation of the nanomaterials with organic fluids. Such plasma experimental investigations typically provide observation direction averaged results which are irrelevant for synthesis of physical models of the processes in the optically dense objects. The purpose of present work is a solution of this problem by an algorithms creation which reconstruct an emission characteristics spatial distribution in a bulk of the optically dense objects with arbi trary geometry. The direct flow plasmatron torch has been se lected as a constructive example of this aim.*

***Keywords**: direct flow plasmatron torch, spatial distribution, abelisation, segmentation.*

Introduction

Experimentation studies of the direct-flow plasmatron torch dynamics [1] shown that one cannot be considered as a optically thin source of a radiation (Fig. 1).

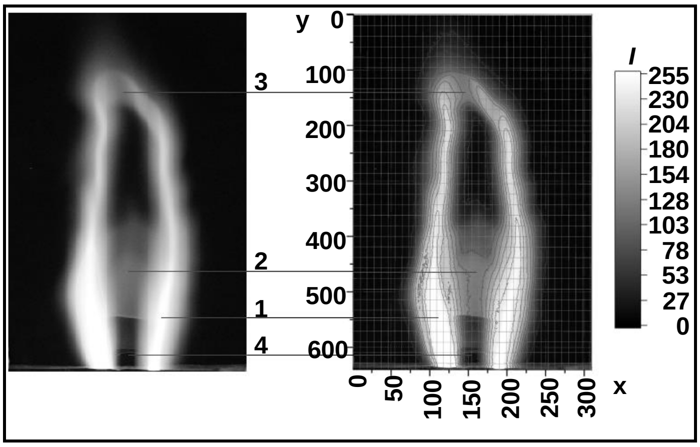


Fig. 1. Direct-flow plasmatron torch. Following areas are highlighted: classical arc (1); secondary discharge region (2); diffusion area (3); "dead zone" (4).

However, the spatial distribution of the torch emission properties carries an information concerning physicochemical properties of its bulk processes.The proposed work is devoted to building of algorithm for syntes 3D .

This problem overcome approach (one could be treated as classical) is a solution of integral equations for integrals set for the observation direction aligned with optical axes of the object inhomogeneity. In case of axial symmetry objects, these equations are given by Abel equation form:

$$g(y_i) = 2\int_{y_i}^{r_0} \frac{\vartheta(r)r}{\sqrt{r^2 - y_i^2}}dr. \quad (1)$$

Here, $g(y_i)$ is a radiation intensity along i-th observation direction which pass the symmetry axis beyond distance y_i; $\vartheta(r)$ is a radiation intensity radial distribution of the axially symmetric object; r is a radial coordinate ($r = 0$ is a symmetry axis).

A formal algorithm of such equations solution is known as abelisation procedure [2]. Input data of this procedure are instrumentally obtained two-dimensional images which de facto form a matrix of the intensity integrals along an observation direction.

One is worst to highlight that abelisation method could be adequately applied only to objects with known geometry, which is not often the case in real applications.

The proposed work is devoted to algorithm design for the 2D imaging based synthesis of the 3D intensity distribution of unsymmetrical objects radiation.

Algorithm design

For such cases when generally non-symmetric object is formed as a result of the actions of the stochastic and determinate perturbations with some initial symmetry, the object could be considered as a system of randomly oriented fragments with non-perturbed symmetry in their bulk. For the direct-flow plasmatron torch, a carrier of an initial symmetry could be an arc discharge channel with symmetry which could be treated as an axial one with high level of accuracy[3, 4] (Fig. 2).

Two-dimensional images based procedure of synthesis of a spatial distribution of torch optical parameters includes two stages. First stage is a fragmentation algorithm execution resulting in a set of uniform geometry image sections. Second stage is a sequential abelisation execution for each fragment with connection of result aligned with fragments boundaries.

The uniform parameters section localization algorithm for cylindrical coordinates is a determination of opposite minimally outlying point image for any point on isosurface.

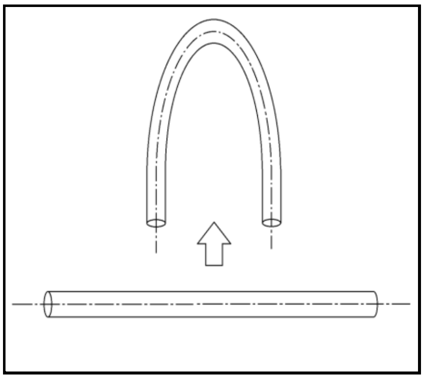


Fig. 2. Direct-flow plasmatron torch formation by a perturbation of the arc-channel cylindrical geometry.

In order to determine isosurface one was used the image segmentation algorithm based on pixel analysis [5]. Coordinates of the obtained points were recalculated into such local cylindrical coordinate system parameters as incident angle φ of the symmetry axis and the intersection coordinate ξ_0 of the symmetry axis and allocated axis in an image field. The procedure was executed for all points on an image isosurface. Adjacent areas with difference of ξ_0 and φ not exceeding given accuracy classes, were related to same fragment (Fig. 3).

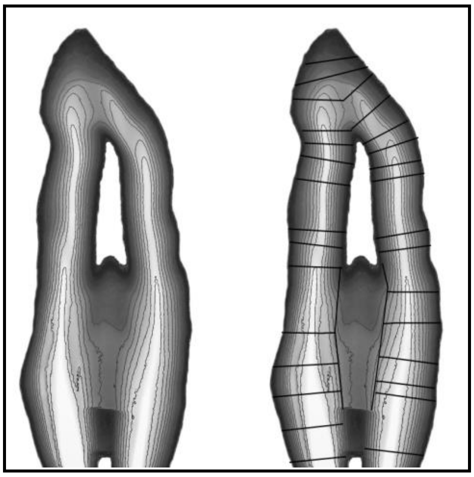


Fig. 3. Fragmentation result of direct-flow plasmatron torch image.

Asanoverallimagedissymmetryratethefollowingvaluehasbeenselected $\eta = \frac{S_0 - \bar{S}}{S_0}$, where S_0 isatotalareaof the torch image, $\bar{S}$ is a mean area of fragments with uniform geometry.

The abelisation was applied to each of these fragments in a way as one could be done for cylindrical geometry objects. An optimal abelisation method for this case is the Pearce method [2] which requires the following linear algebraic equations set solution:

$$g_j = \sum_{k=j}^{N} a_{jk} \vartheta_k \tag{2}$$

against unknowns ϑ_k .

Here, g_j is a j -thpixelimageintensity; ϑ_k isamean specificbulk originated radiation intensity from the element with a projection coincided with the j -th pixel; a_{jk} is a value related to corresponding volume element normalized to the pixel size third degree.

A calculation of the coefficients a_{jk} for axial symmetry geometry has been made according to following expressions:

$$a_{j,k} = \begin{cases} \dfrac{k^2}{2}\left(\arcsin\left(2\dfrac{(k-1)\sqrt{2k-1}}{k^2}\right) - 2\dfrac{(k-1)\sqrt{2k-1}}{k^2}\right), \text{ for } j = k; \\ a_{k,k} - \sum\limits_{p=j}^{k}\sum\limits_{q=p}^{k} a_{p,q}\Big|_{p \neq j \cup q \neq k}, \text{ for } j < k. \end{cases} \tag{3}$$

The parameters connection on fragments boundary is processed by averaging of adjacent elements in case of a difference less than selected accuracy level. Otherwise, for elements which could not be connected, the algorithm was applied additionally with increased accuracy level.

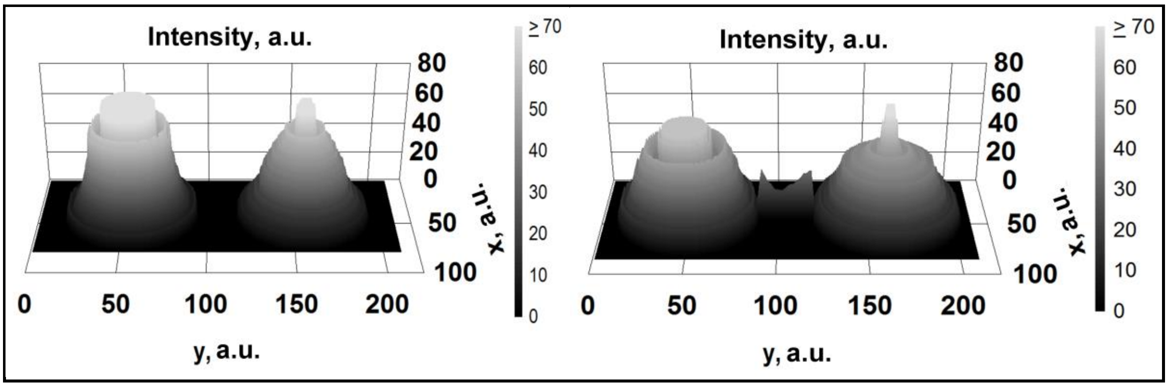
According to test algorithm applications, its convergence is satisfactory when the image dissymmetry rate is $\eta \leq 0.95$.

Plasma torch processing

Using proposed algorithm, an image calculation of regular direct-flow plasmatron torch has been performed. As an algorithm result, one was obtained tree-dimensional array with elements which are spatial samples of the being investigated object emission characteristicsintensity bulk distribution.

The Fig. 4 provides distributions of emission characteristics of the direct-flow plasmatron torch in frontal cross-sections which overlap the dead zone and secondary discharge zone.

As far as a radiation intensity of central part of some transverse arc channel sections exceeded dynamic range of the camera, one was happened partial data loss concerning corresponding section intensity distribution.



a) b)

Fig. 4. Distributions of radiation intensity of the direct-flow plasmatron torch in frontal cross-sections which overlap the dead zone (a) and secondary discharge zone (b).

It is obvious that the spatial distribution synthesis procedure applied to these sections did not provide correct results. Particularly, a plateau on the spatial distributions in the plot part of the interval $60 \leq y \leq 75$ emerges exactly due to an original image lost data. However, a plot part of the interval $80 \leq y \leq 220$ contains results which are plausible according to the camera resolution.

Based on an analysis of the synthesized radiation intensity spatial distribution one can be concluded that the bright glowing section localized close to discharge channel center is most probably not caused by a radiation area geometrical size growth along an observation direction, but rather by a plasma emission characteristic change which can be related to neutral component temperature change.

For an illustrative purpose of the present method emission characteristics three-dimensional distribution synthesis capabilities one could be considered an information which cannot be unambiguously obtained directly from two-dimensional images (Fig. 5). It contains the radiation intensity distribution series for different cross-sections of secondary discharge.

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A givens series intensity distribution analysis leads to following facts determination concerning the direct-flow plasmatron torch structure.

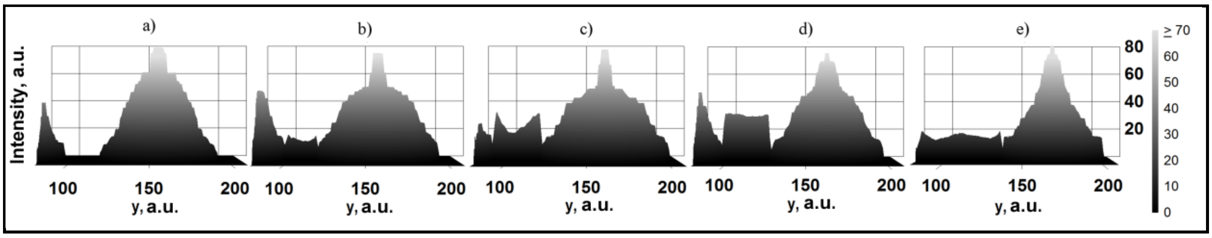

Fig. 5. Distributions of radiation intensity of the direct-flow plasmatron torch in frontal cross-sections which overlap the different sections of secondary discharge: dead zone (a); secondary discharge outlying by 20% of its effective length from the dead zone (b); same for 50% (c) 75% (d) and 95% (e).

First, a mean intensity of the secondary discharge intensity corresponds to the same level as an arc channel peripheral section with a longitudinal air blowing. Second, self-consistent heat-mass exchange conditions between the arc channel and the torch-forming air flow are favorable simultaneously for the secondary discharge formation and an emergence of the separated arc channel section with half radiation intensity value.

Conclusions

As an outcome of the present work, the Pearce methods application algorithm has been developed for radiation intensity three-dimensional distributions of axially non-symmetric optically dense objects.

A calculation results confirm that the proposed algorithm is applicable for a synthesis of the optical parameters spatial distributions for such objects that have complex geometry originated by perturbation of initial axial symmetry in both determinate and stochastic manner. Regions of regular symmetry should by simply-connected (as a topological space). The original symmetry perturbation rate $\eta = \frac{S_0 - \bar{S}}{S_0}$ should not exceed 0.95. Here, S_0 is a two-dimensional object image total area; $\bar{S}$ is a mean area of fragments with the same geometry.

Torches of plasmatron with different design usually correspond to these requirements. Hence, the proposed algorithm could be used for such objects in an adequate manner.

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FAST EVOLVING DIAGNOSTIC NEURO-FUZZY SYSTEM AND ITS LEARNING IN MEDICAL DATA MINING TASKS

Annotation. *Architecture and training method for evolving diagnostic neuro fuzzy system for Medical Data Mining Tasks are proposed.*

Key words.*MedicalData Mining, classification, fuzzification, neuro fuzzy system.*

INTRODUCTION

For various Data Mining tasks, connected with diagnostics, classification, clusterization, pattern recognition etc. nowadays methods of Computational Intelligence, firstly Soft Computing and Machine Learning [1-8] are widely used.

Ones of the most effective are neuro-fuzzy systems because of its learning abilities, including self-learning, universal approximative capacities, linguistic interpretability and “transparency” of results. ANFIS and TSK-systems of different order, like approximators and extrapolators, and NEFCLASS [9] with its different modifications, oriented for classification (pattern recognition) tasks solving have the widest spread.

But there exist a broad class of tasks where these systems are not effective. Primarily, there are the tasks where training set is short, data sets are fed to processing sequentially, in the form of data stream [10] and learning of system has to realize in parallel with analysis of input information.

This situation often appears in Medical Data Mining tasks [11, 12] and complicated by the fact that data set under processing is nonstationary and dimensionality of input features space can be comparable with size of training data set. When it comes to diagnosis task, firstly, data set can have very low size in situation of rare diagnosis, and secondly, quantity of possible diagnosis (especially in situation of screening programs) can change during analysis. Naturally, that traditional diagnostic neuro-fuzzy systems like NEFCLASS can not overcome there problems.

1. FAST DIAGNOSTIC NEURO-FUZZY SYSTEM

Let's consider architecture of diagnostic neuro-fuzzy system (DNFS) that consist of six sequentially connected layers (fig.1) [13]. Here $(n\times 1)$ input vector of signals-attributes $x(k)=(x_1(k),x_2(k),..x_n(k))^T\in R^n$, where $k=1,2,...$ is current time, is fed in input layer of system. First hidden layer of system contains nh membership functions $\mu_{li}(x_i(k))$, $i=1,2,...,n$; $l=1,2,...,h$ and provides fuzzification of input feature space.

Because of this in system scatter partitioning of feature space is realized as a membership functions standard bell shape functions with unlimited supports are used. Most often they are traditional Gaussians or more exotic functions, for example, derivatives of tangent hyperbolic function.

Second hidden layer realizes aggregation of membership levels, calculated in first layer, and consist of h simple multipliers. Third hidden layer is a layer of synaptic weights w_{jl} ($j=1,2,...,m$ – number of possible diagnosis taken on the basis of empiric consideration) which have to be adjusted in training process. It is the most «responsible» layer of DNFS because effectiveness of whole system depends of precision and speed of training.

Common quantity of synaptic weights equals to mh. Fourth hidden layer is formed by $m+1$ adders, which realize elementary operations. In fifth hidden layer, formed by m division units, defuzzification of «gravity center» type is realized. And at last output (sixth) layer contains m nonlinear activation functions. In diagnostics task simple signum function is often used, which takes value +1 in case of true diagnosis and -1 – in other case. That's why output signal of DNFS $y_j(k)$ can take only two values ± 1.

When feature vector $x(k)\in R^n$ becomes on input of system, in output of first hidden layer hn values of $\mu_{li}(x_i(k))$ are appear, in output of second hidden layer – h signals $\prod_{i=1}^{n}\mu_{li}(x_i(k))$, in output of third hidden layer – mh values $w_{jl}\prod_{i=1}^{n}\mu_{li}(x_i(k))$, output of fourth layer – $m+1$ signals:

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$\sum_{l=1}^{h} w_{jl} \prod_{i=1}^{n} \mu_{li}(x_i(k))$ and $\sum_{l=1}^{h}\prod_{i=1}^{n} \mu_{li}(x_i(k))$, fifth layer –

$$u_j(k) = \frac{\sum_{l=1}^{h} w_{jl} \prod_{i=1}^{n} \mu_{li}(x_i(k))}{\sum_{l=1}^{h}\prod_{i=1}^{n} \mu_{li}(x_i(k))} = \sum_{l=1}^{h} w_{jl} \frac{\prod_{i=1}^{n} \mu_{li}(x_i(k))}{\sum_{l=1}^{h}\prod_{i=1}^{n} \mu_{li}(x_i(k))} = \sum_{l=1}^{h} w_{jl}\varphi_l(x(k)) = w_j^T \varphi(x(k))$$ and

sixth – m diagnostics signals $y_j(k) = sign\, u_j(k)$.

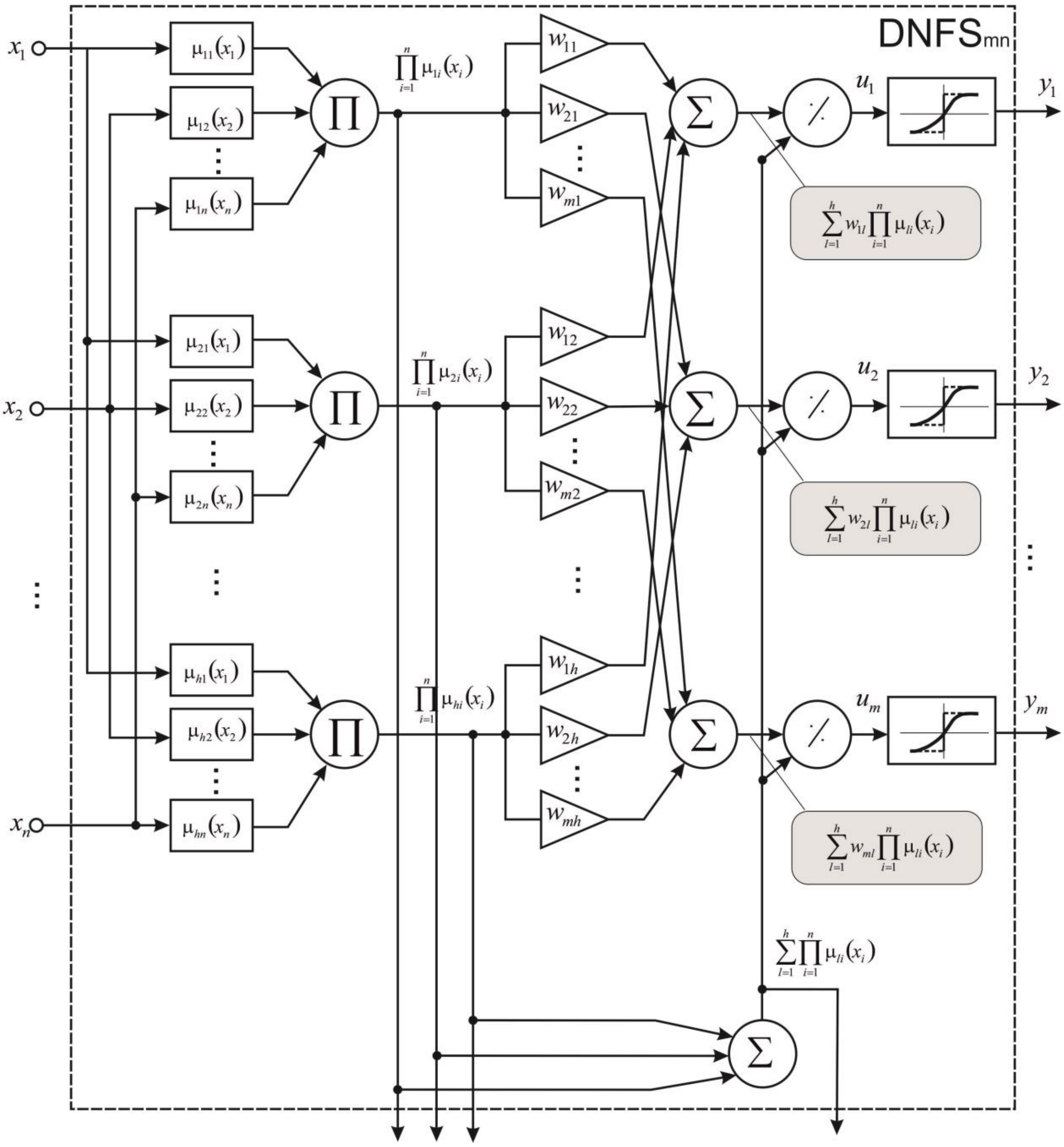

Fig.1 – Diagnostic neuro-fuzzy system DNFSmn with n inputs and m outputs

So, system under consideration is a modification of neuro-fuzzy system of Wang-Mendel [14] and intended for solving of diagnostic-classification tasks.

For training of this system in [13] traditional criterion of pattern recognition neural network was used [15]:

$$E_j(k) = e_j(k)u_j(k) = \left(d_j(k) - sign\ w_j^T \varphi(x(k)) w_j^T \varphi(x(k))\right) = d_j(k)u_j(k) - \left|u_j(k)\right| \quad (1)$$

and algorithm for synaptic weights matrix tuning:

$$W(k+1) = W(k) + \frac{\left(d(k) - sign\ W(k)\varphi(x(k))\right)}{\eta + \left\|\varphi(x(k))\right\|^2}\varphi^T(x(k)), \quad (2)$$

where $W(k) = \begin{pmatrix} w_1^T(k) \\ w_2^T(k) \\ \cdot \\ \cdot \\ w_m^T(k) \end{pmatrix}$ – $(m \times h)$-synaptic weights matrix;

$$sign\, u(k) = \left(sign\, u_1(k), sign\, u_2(k), \ldots, sign\, u_n(k)\right)^T;$$

$d(k) = \left(d_1(k), d_2(k), \ldots, d_m(k)\right)^T$ – reference signals vector, taking only two values ± 1;

$\eta \geq 0$ – momentum term.

Easy to see, that when $\eta = 0$ algorithm (2) can be rewrited in simple form

$$W(k+1) = W(k) + \left(d(k) - sign\ W(k)\varphi(x(k))\right)\varphi^+(x(k)). \quad (3)$$

Elementary analysis of (1)-(3) shows, that training error $e_j(k)$ can take only three values: -1, 0, +1, that's mean the training process has oscillatory «bang-bang» nature. It can lead to its delaying and in situation when training is realized in tandem with processing in online mode these oscillations may never stop.

To exclude these oscillations we can introduce in sixth layer (instead of signum functions) activation function of hyperbolic tangent type that are often used in neural networks:

$$y_j(k) = \tanh \gamma u_j(k) = \frac{1 - e^{-2\gamma u_j(k)}}{1 + e^{-2\gamma u_j(k)}},$$

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where gain parameter γ increasing leads to approaching of function $\tanh \gamma u_j$ to $sign\ u_j$ without derivative discontinuity.

Using standard quadratic criterion of training

$$E_j(k) = \frac{1}{2} e_j^2(k) = \frac{1}{2}\left(d_j(k) - \tanh \gamma w_j^T \varphi(x(k))\right)^2 = \frac{1}{2}\left(d_j(k) - \tanh \gamma u_j(k)\right)^2$$

we can write standard δ-rule of Rosenblatt's perceptron training

$$w_j(k+1) = w_j(k) + \eta(k) e_j(k)\gamma\left(1 - y_j^2(k)\right)\varphi(x(k)) = w_j(k) + \eta(k)\delta_j(k)\varphi(x(k)), \quad (4)$$

where $\eta(k) > 0$ – learning rate parameter, $\delta_j(k)$ – δ-error of training for *j*-th output at *k*-th time iteration.

Using ideas of quasi-Newtonian learning [16] we can introduce optimized variation of (4) like [17]:

$$w_j(k+1) = w_j(k) + \frac{\delta_j(k)\varphi(x(k))}{\eta + \left\|\varphi(x(k))\right\|^2}$$

or in matrix form like (2):

$$W(k+1) = W(k) + \frac{\delta(k)\varphi^T(x(k))}{\eta + \left\|\varphi(x(k))\right\|^2},$$

when $\eta = 0$

$$W(k+1) = W(k) + \delta(k)\varphi^+(x(k)), \quad (5)$$

where $\delta(k) = \left(\delta_1(k), \delta_2(k), \ldots, \delta_m(k)\right)^T$

$$\delta_j(k) = e_j(k)\gamma\left(1 - y_j^2(k)\right) = \left(d_j(k) - \tanh \gamma u_j(k)\right)\gamma\left(1 - \left(\tanh \gamma u_j(k)\right)^2\right).$$

By selecting of tuning gain parameter γ we can obtain necessary character of learning process convergence. Also, conspicuously, training algorithm (5) is very simple in numeric implementation.

2. EVOLVING DIAGNOSTIC NEURO-FUZZY SYSTEM

Diagnostic system under consideration is designed to be used in condition, when quantity of diagnostic features *n* and diagnosis quantity *m* is fixed, that is natural for neural networks and neuro-fuzzy-systems, whose architecture is set a priori during synthesis.

In real medical tasks during training new diagnosis can appear, those was not previously involved. To enlarge quantity of possible diagnosis we can use ideas of evolving systems of computational intelligence [18, 19], that can tune their parameters and architecture. Architecture of evolving system $DNFS_{m+1,n}$ with n inputs and $m+1$ outputs is shown in Figure 2.

It is based on $DNFS_{mn}$ system, shown on Fig.1,neuro-fuzzy-element NFE was added, containing h synaptic weights $w_{m+1,l}$, one adder (summation block), one divider and activation function $\tanh \gamma w_{m+1}^{T}\varphi(x(k))$.

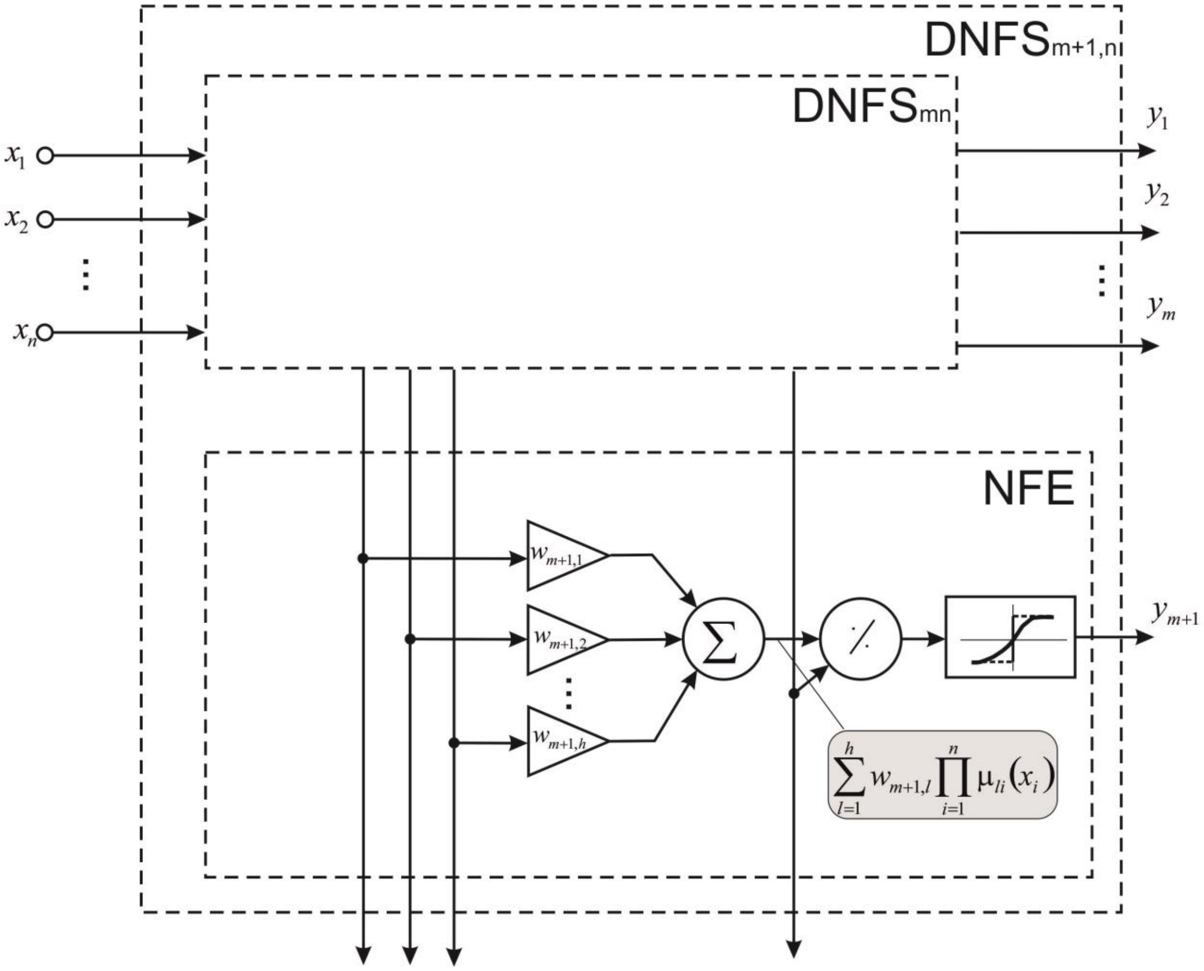

Fig.2 – Evolving diagnostic neuro-fuzzy system with n inputs and $m+1$ outputs ($DNFS_{m+1,n}$)

Rearranging training algorithm (5) for $DNFS_{mn}$ in the form

$$W^{m}(k+1)=W^{m}(k)+\delta^{m}(k)\varphi^{+}(x(k)),$$

we can introduce algorithm for $DNFS_{m+1,n}$:

$$W^{m+1}(k+1)=\begin{pmatrix} W^{m}(k+1) \\ ------ \\ w_{m+1}^{T}(k+1) \end{pmatrix}=\begin{pmatrix} W^{m}(k) \\ ---- \\ w_{m+1}^{T}(k) \end{pmatrix}+\begin{pmatrix} \delta^{m}(k) \\ ---- \\ \delta_{m+1}(k) \end{pmatrix}\varphi^{+}(x(k)).$$

Easy to see, that including of new NFE blocks in extended diagnostic system does not change original $DNFS_{mn}$ training.

3. CONCLUSION

In this paper architecture and training method for evolving diagnostic neuro-fuzzy-system are proposed. This system is designed for broad class of Data Stream Mining tasks, especially Medical Data Mining ones in online mode in situations of unknown quantity of possible diagnosis, that can change during training-diagnostics processes. Proposed system is simple in numeric realization and characterized by a high learning rate, that make possible to use it in conditions of small training sets and on big data sets, coming to processing in onlinemode.

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G.V. Rudakova

METHODS TO IMPROVE THE RELIABILITY OF ORGANIZATIONAL-TECHNICAL SYSTEMS

Annotation. *In the article the subjective factors that affect the reliability of the automated control systems of complex systems is analysed. The analysis of the properties, models and management methods for systems of varying degrees of complexity are spend. Lack of appropriate methods and means for forming reasoned decisions about managing of large systems in a critical mode operation is revealed. Advisability of using distributions approximating models for large systems in the form of shells substantiated.*

Keywords: *a large distributed system, a critical mode of operation, continuous model, decision support system, reliability of operation*

Introduction

A characteristic of modern industrial complexes is large branching of processing subsystems, the large number and diverse nature of equipment, complexity of control algorithms. All this the occurance ofthe problems in the operational management of large technical systems, due to the lack of methods and tools for reasoning control decision-making, especially under time pressure.

Analysis of recent research and publicatsons

Management systems in the organizational and technical systems have a hierarchical structure, where all levels use the automated dispatch control systems (ADCS) for operational management, connected to each other. Among the most important operating and technical characteristics, which determine the effectiveness of the objects, the reliability, vitality and non-failure operation occupy a special place [1]. Reliability of operation - it is the ability to keep the stability of the planned operation of the process, which is the absence the forced termination of the process (disruption) and a wrong of its execution in relation to the planned (faulty actions) [2].

Reliability of complex systems is dependent on multiple factors, without which it is impossible to ensure the safety and reliability of individual types of equipment and entire systems [3]. All the factors which affect the reliability of specific equipment such as Automated Control System (ACS) of complex systems are shown in Fig. 1.

Most significant impact on the the reliability of complex highly responsible systems have the reliability of operational staff [70], ie the action of the subjective factors on the operating system.

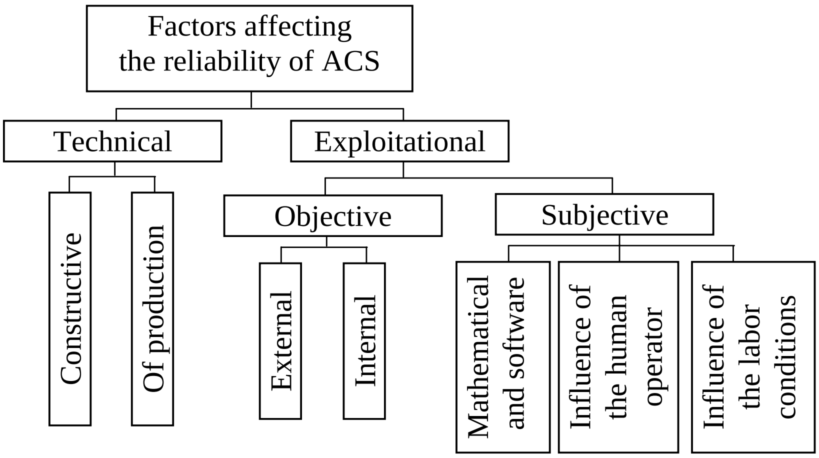

Figure 1 – Factors affecting the reliability of the ACS

Numerous studies have found that from 25 till 40% of ACS failures is caused by defects of the service such as: violation of instructions, mistakes in the perception of signals, delay and errors in the operator's actions, etc. In many industries, the percentage of staff failures is the sufficiently large. For example, about half of emergencies at nuclear power plants, including the most serious, directly or indirectly related to the human operator errors [2]. Operator error statistics is shown in Fig. 2.

Mistakes are maded at three structural levels of activity:

- At the task level (incorrect identification or wrong decision);
- At the level of operations (wrong choice or erroneous execution);
- At the level of actions (wrong choice or erroneous execution).

The structure of the automated dispatch control system, which is used for the operational management of modern production [4], shown in Fig. 3. Automation work station (AWS) allows dispatchers to directly monitor the status indicators and form executive management of equipment by a telecommunications technology.

Usual problems wich periodically solved at the operational management are [5]:

1. Assessing the current state of the control object (system).

2. Determining the deviation of object motion from the desired trajectory.

3. The solving problem of finding the optimal control (forming control actions for the coming period).

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4. Implementing the control (adjustment of the system state - returning it to the given trajectory).

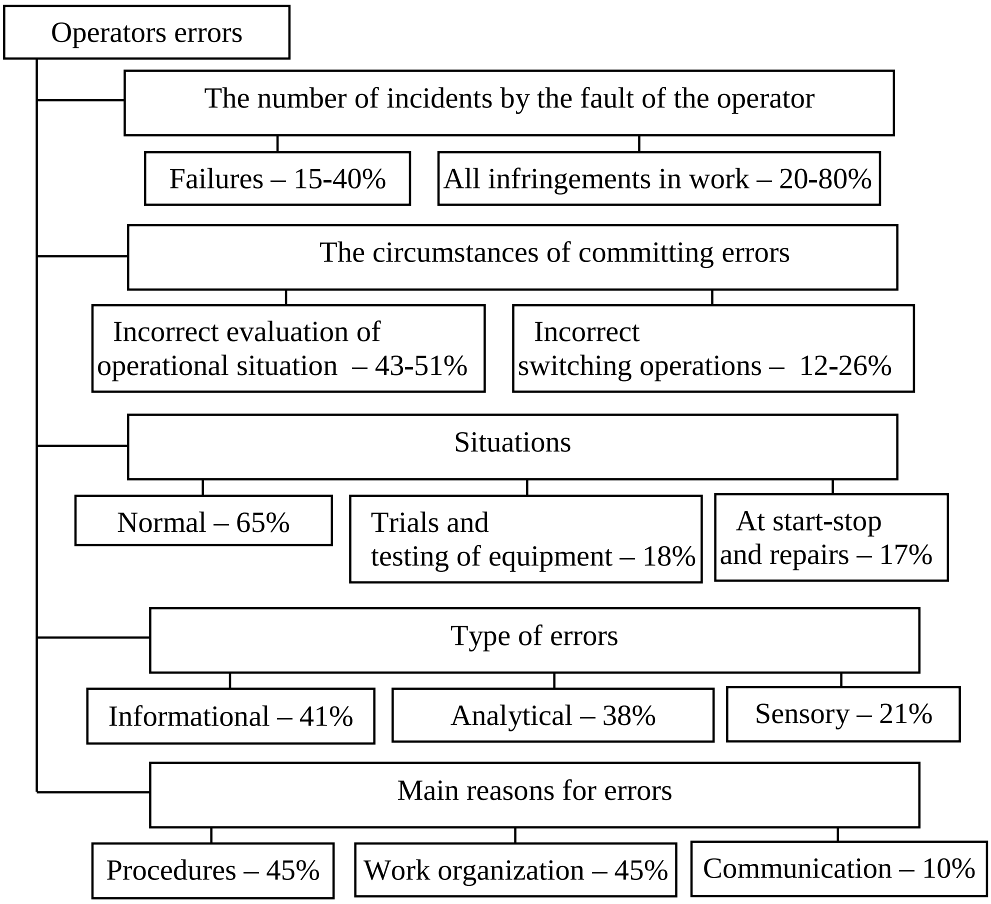

Figure2–Operatorserrorsstatistics

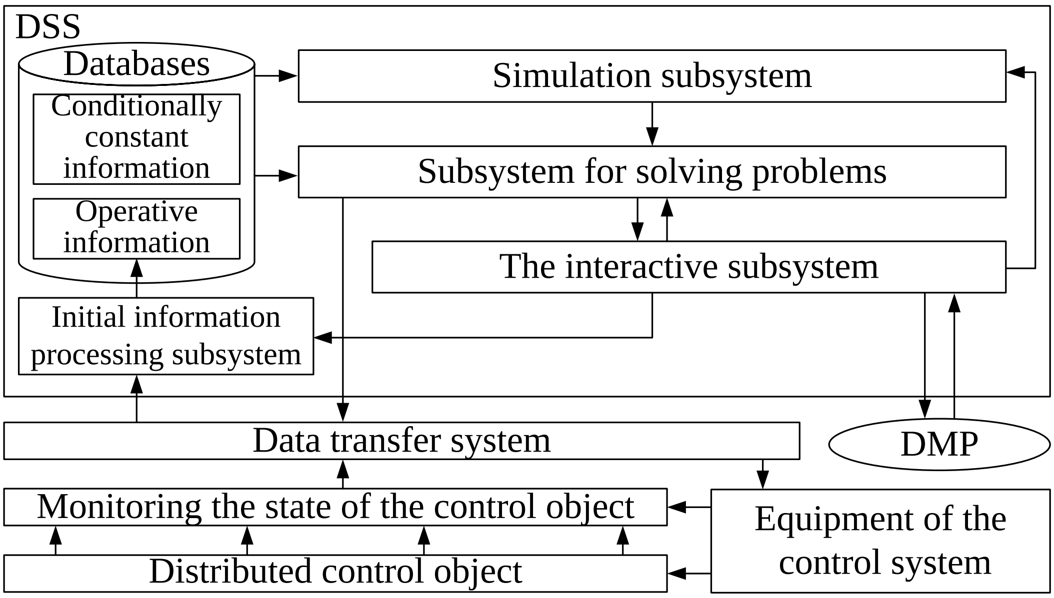

Figure 3 – Structure of ADCS for the operational management of modern production

Calculation of optimal control can performed in the dispatcher's AWS, by a decision support system (DSS), which structure is show in Fig. 3. The problem of ensuring reliability ADCS is becoming a key problem of modern engineering. A large proportion of errors due to the imperfection of methods and tools for operational decision-making, task complexity, and lack of time [1].

At shortage of time to making ground decision in a critical mode of a large system operation and the risk of transition to the disaster regime, the precise control of this system is not essential; we need just a good, qualitative assessment of possible control [6].

Statement of the problem research

In this regard, the actual problem is to find the mathematical apparatus, development of methods for constructing models that will determine the conditions for the transition of the system in the critical mode, then in the emergency and disaster mode, as well as the development of management techniques that will stabilize the state system in real time.

Purpose and objectives of research

The goal of research is to improve the efficiency of operational management of modern organizational and technical systems through the development of scientific and technical bases, principles and methods, which solves the problem of forming an optimized control in critical operation modes.

The main material of research

Organizational and technical system calledsuch set of technical systems, which operate in interconnection with each other and with the staff. Theycould be considered (accordingGlushkov) as aclassoflargesystems [7].

Stages of system evolution and comparative characteristics of their properties, models and management methods for systems of varying degrees of complexity are show in Fig. 4 [8].

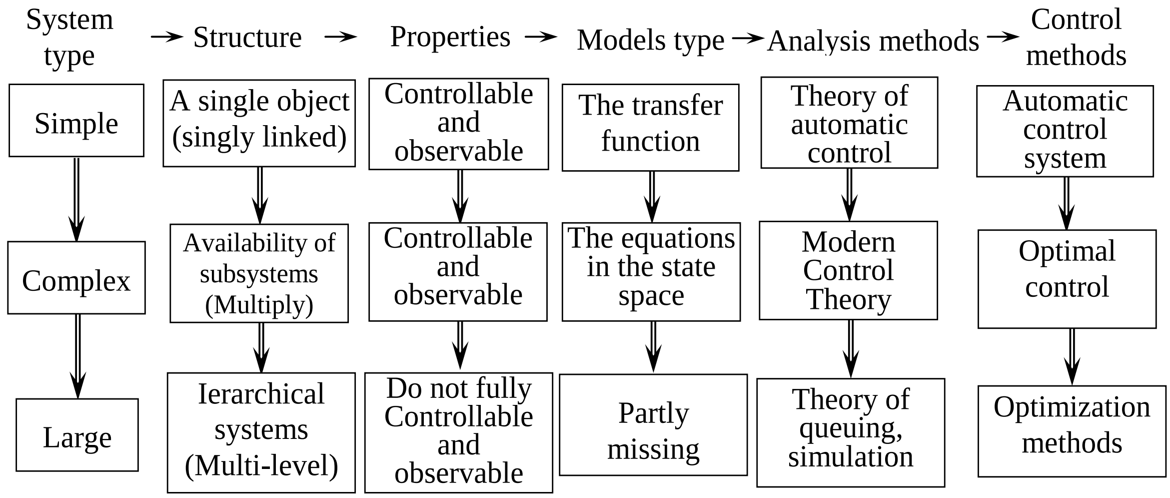

Figure 4 – Stagesof systems evolution

Table 1 shows the characteristics of efficiency using of existing models and management methods, which are use in different operation modes of large systems.

Table 1

The influens of models and methods characteristics on the control efficiency

Components	Normal mode	Critical mode	Disastermode
Model	Exact	Approximate	Incomplete
Control	Functional(optimal)	Inefficient	Missing
ControlResource	Satisfactory	Limited	Limited

Solving of problems,arising atthe operational management of large systems can carried out in two ways:

1). Design of partial models [8], ie the use for a large system of simplified solutions obtained using linearization procedures, minimizing and structuring. This is the introduction of restrictions in finding of optimal solution, and naturally makes the achired optimum weak. It is allowed to decrease the effectiveness of the solution due to unnecessary restrictions. At the same time, there is a high probability of determining the local optima for the system parts, which do not lead to the global optimum system as a whole.

2). Construction of generalized approximate models (shells), according to the comparison principle, majorizing behavior of the original system, based on which can be formed a management evaluation close to the optimal. Presentation of a large system can be reduced to a continuous description, which corresponds to the limiting case $n \to \infty$ [9].

Taskinsuchstatementbelongstothenarrowclass, alwayshasasolutionthatcanbequickly (timely) found.

To describe the systems used by the different levels of modeling from micro level, which allows describing the objects with distributed parameters, to a meta-level, intended for the description of distributed objects with lumped parameters (Fig. 5). To build models of complex technical systems the mathematical tool of ordinary differential or integral-differential equations, typical for the formal description of objects with undistracted parameters, is used.

For large developing systems non-linear transformation of input data (vectors of the state, input and output) in the space of a higher dimension can perform.With increasing size of the system (the order of n and approach it to the infinity), it is expedient to use a continuous description of the systems which approximates discrete values in some neighborhood [9].Coordinate transformation from the discrete representation of the continuous allows to change vector and matrix models in state-space by theire continuous analogs - analytical functions.

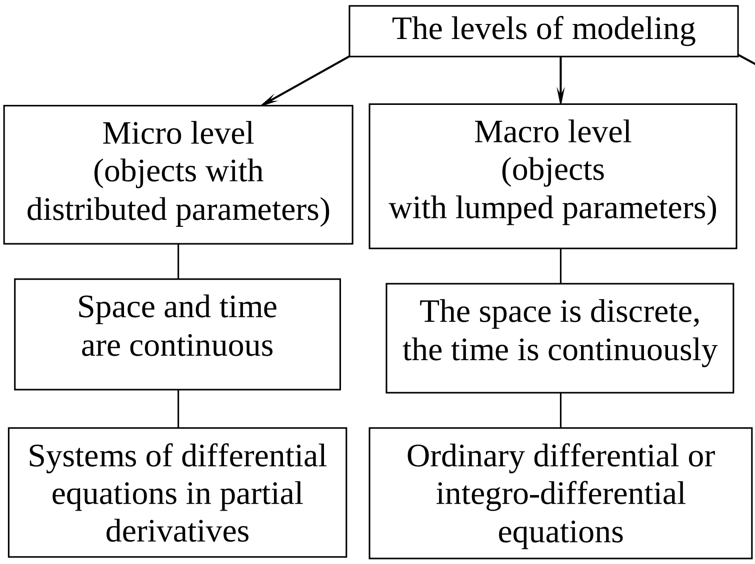

Figure 5 – Types of models and methods for modeling distributed objects

The dimensions comparison of discrete and continuous systems description in state-space is show in Fig. 6.

Description of n-dimensional first order distributed system is converted into a continuous form in which the matrix corresponds to a function of two variables independently of scale n. For distributed systems with second-order, functions approximating the matrix of the system depend on 4 variables and vectors - on 2. Forthethirdorder, respectively - on 6 and 3 variables.

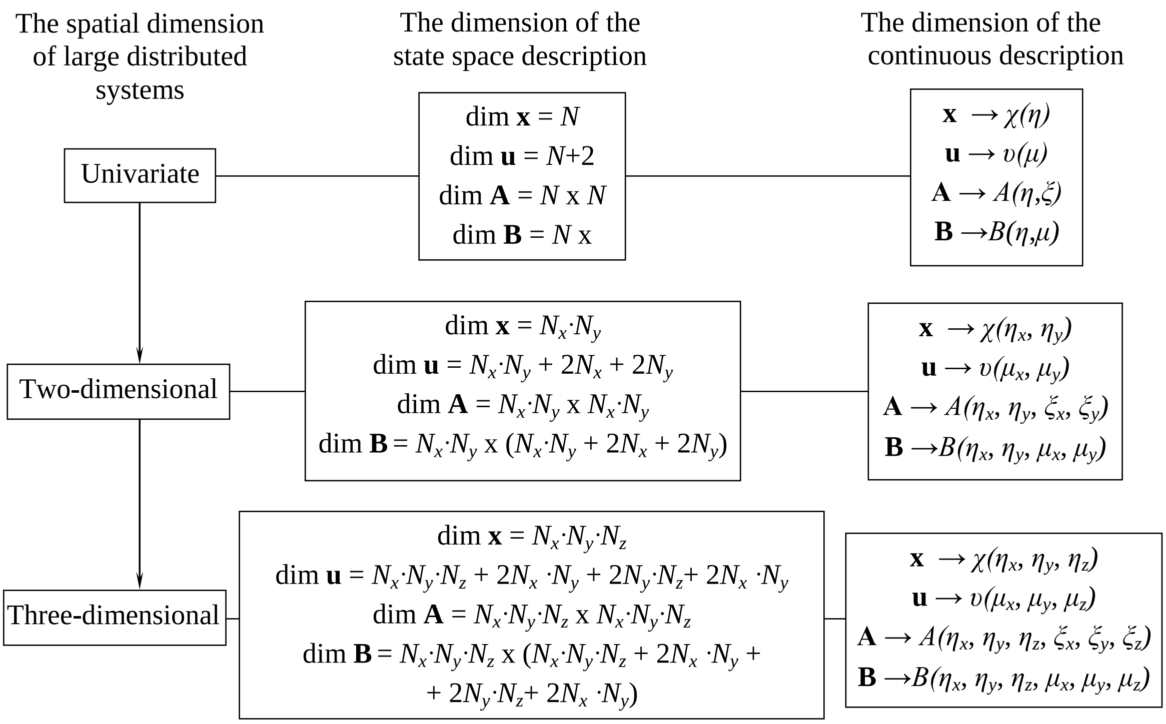

Figure 6 – The dimension of the distributed systems model

This approach avoids the problems in analyzing the large systems, caused by increasing of its dimensions. At the same time optimal control problem for distributed systems can be transformed into a class of problems with partial derivatives.

To improve the efficiency of decision-making of the optimal management of the system in the critical mode of operation is necessary to improve the scheme of interactions DSS units (Fig. 7) [10].

It is necessary to add in the DSS the following elements:

1. Provide the Simulation Subsystem to the pre-fault model, formed based on the continuous model of a distributed system in the form of approximating shells.

2. Add the Prediction of Emergency Subsystem, which analyzes the state of the system based on the surface model and allows us to estimate the stabilization time.

3. Decision-making unit must supplemented by an appropriate method of formation of large system control of the equipment for the forthcoming period, taking into account the current state and prediction of disturbing conditions.

4. Provide back-up data transfer system to the informational subsystem. In the transition the critical situation in disaster mode, as usual, there is the physical destruction of not only the individual elements of distributed objects, as well as and informational connecting objects.

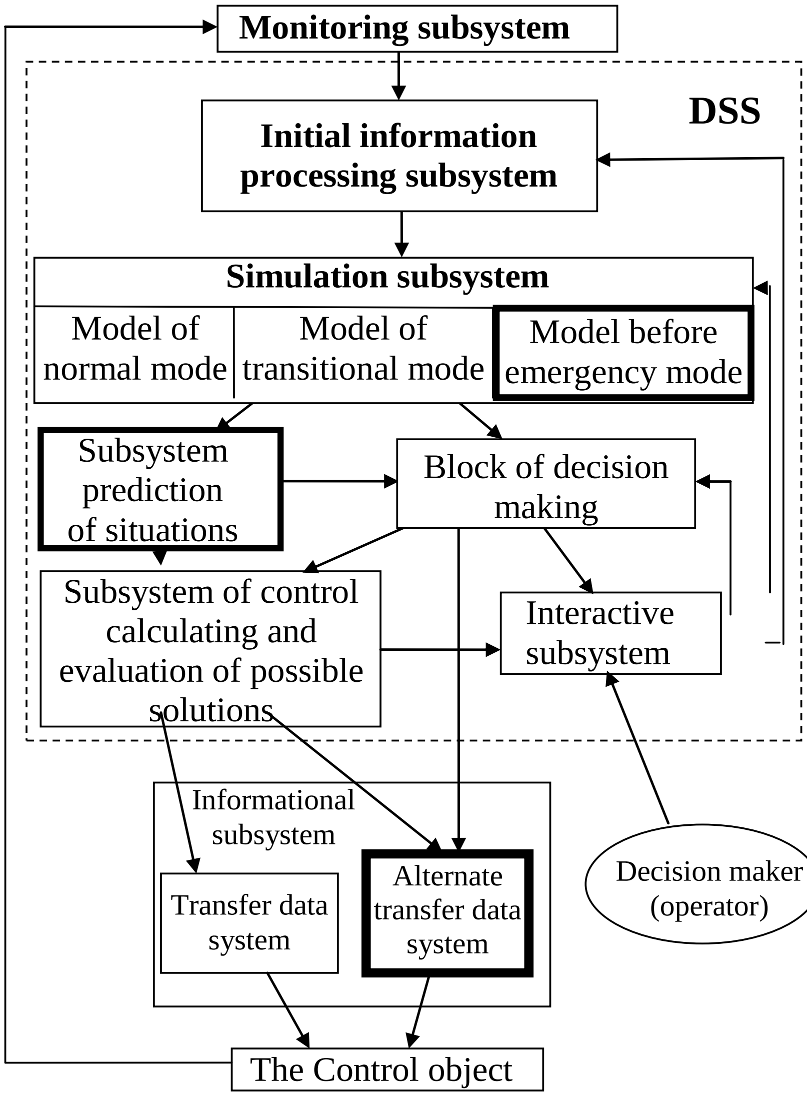

Figure 7 – The scheme of interaction between sub systems DSS

Conclusions and prospects for further research

Theresearches are baseontheconceptoftheuseofinformationmanagementsystemstocontrolamodernindustrialcomplex.

The method of constructing continuous models in the form of surfaces, based on the principle of majorization, allows creating models of geographically distributed objects to predict the state of the object, identify the location of critical nodes in real-time systems and to assess the remaining time to stabilize the operation.

Improving the decision support system at the automated dispatch control systems by adding a module assessing the state of the distributed object subsystem forecast the dynamics of distributed object, methods of synthesis of the optimum (sustainable) management based on the use of continuous models, makes it possible to improve the reliability of operation of organizational and technical systems by forming more informed and timely decisions in operational management, especially in critical modes.

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V.I. Shynkarenko, T.M. Vasetska, E.Y. Boiko

REDUCING THE NUMBER OFEXPERT JUDGMENTS IN ANALYTIC HIERARCHY PROCESS BY SORTING AND SURVEY MANAGEMENT

Annotation. *Modification of the classical method of analytic the hierarchy process with elements of sorting for the ranking a large number of alternatives in multicriterial choice problems was developed. The ways to achieve the best consistency of the matrix of pairwise comparisons of alternatives were proposed.*

Keywords: *analytic hierarchy process, consistency, multicriterial choice, sorting.*

Introduction

The analytic hierarchy process (AHP) [1, 2, 3], which was proposed by T. Saaty, is one of the popular methods of multi-criteria choice.

The fact that this method is widely used is confirmed by the existence of a large number of modifications [4-7] and software that implements this method [2, 8-14].

However, this method has several disadvantages which significantly complicate its use.Most AHP modifications were developed to eliminate the problems associated with its use [7, 15, 16].Among the problems of the AHP should be noted following: the ability to compare a small number of alternatives (about 10), the complicated procedure of approval the matrices of paired comparisons, the need to redefine the matrices of paired comparisons at adding (removing) alternatives and others.This paper presents some possible solutions to the problems of AHP.

The Problems of Classic AHP

Let us consider the problems associated with AHP using and existing methods of their solving.AHP works very well on a small number of alternatives and criteria. But the analysis of the consistency of expert judgments causes many difficulties.There are transitive (order) [5] and cardinal (numerical) consistency of matrices [1].Author of AHP adheres to the numerical consistency. The matrix is consistent, when all its elements are in the next relation [1]:

$$a_{ij} = a_{ik} \cdot a_{kj}, \quad (1)$$

where a_{ij} is judgment of preferences in pairwise comparisons of i-thand$j$-thalternatives. T. Saaty introduced the concept of consistency index (IC) to assess the degree of deviation from the ideal consistency matrix:

$$IC = \frac{\lambda_{max} - n}{n - 1}, \qquad (2)$$

where $\lambda_{\max}$ - the maximum eigenvalues of the matrix of pairwise comparisons, n - the matrix size.

The ratio of the consistency index (CI) to the average random consistency index (RI) of the matrix of the same order is called the consistency ratio (CR):

$$CR = \frac{CI}{RI}. \qquad (3)$$

CR is a normalized measure of evaluation the consistency of the any dimension matrix. CR value less than or equal to 0.1 is considered as acceptable.

Under the ordinal consistency is understand the transitive preferences for any three alternatives (A, B, C), i.e., if $A \succ B$ and $B \succ C$, then $A \succ C$, where $\succ$-some preference relation.

Ideal consistency matrix is a matrix satisfying a cardinal and transitive consistency.

The experience of the practical use of AHP shows that to make consistency matrix of order 3..4 isquite difficult. For example, $a_{12} = 0{,}25$ and $a_{23} = 3$, and $a_{13} = 1$. Consistency ratio is more then 0.1 therefore the matrix of pairwise comparison is inconsistent. Expert was recommended to review the judgment and re-weigh the alternatives, which can take a long time and will not bring the desired result.

There are several approaches to make the consistency of matrices. In [5] it is proposed to achieve the transitive consistency if there is no cardinal consistency.But this approach greatly narrows the range of acceptable values, and some matrices are discarding.Forexample, considerthematrix $A_1 = \begin{bmatrix} 1 & 3 & 1 \\ 1/3 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$. CR is 0.068 that is less than 0.1. This matrix has an acceptable cardinal consistency, but there is no transitive consistency. In this case the statement is violated, that the first alternative is superior to the second in 3 times, and the second and third

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are equivalent, so the first must be superior to the third. But the first and third alternatives are equivalent too.

Another problem stems from the fact that when the cardinal and transitive consistency are going beyond the scale proposed by Saaty [1]. Forexample, $A_1 = \begin{bmatrix} 1 & 9 & 81 \\ 1/9 & 1 & 9 \\ 1 & 1 & 1 \end{bmatrix}$. Inthiscasethe first alternative is much superior the second, the second is much superior the third, consequently, the first must be superior to the third.

The degree of excellence was calculated by formula (1), is 81, andnot included tothe Saaty`s scale. The matrix is an inconsistent by replacing the 81 by 9.To solve this problem is proposed to normalize the calculated values in accordance with the scale of Saaty, which allows creating a quite consistent matrix [12].

It is required to ensure the consistency of matrices of large dimensions, when we have many alternatives. It is a difficult task. The problem of a limited number of alternatives is solved by using an absolute measurement scale [4], i.e, the so-called ideal model to which each alternative should be compared. In fact, with this formulation of the problem the expert ranks all the alternativesimmediately.But the problem of matrix consistency still remains.

The second approach is based on the fact that expert fills only a basic set of alternatives [1, 2], and other relations are calculated according to the formula (1).Thus, the expert primary forms the consistent matrix, but some matrices, which are consistent by Saaty (i.e. $OC < 0.1$), are eliminated, and theexpert can not sufficiently plausible assess the situation.

AHP Modification

The matrices of order 3 were investigated. Using a scale of Saaty it is possible to form 4912 matrices, of which only 1495 will be consistent (i.e., will have the consistency ratio less than 0.1).The software, which provides the specific interface for setting matrices of paired comparisons, was developed.The expert submitted three ways to specify matrices - graphic [6], semantic and numeric (Saaty scale)simultaneously.The ratio of the alternatives is represented as a triangle the vertices of which are the alternatives (Fig. 1).

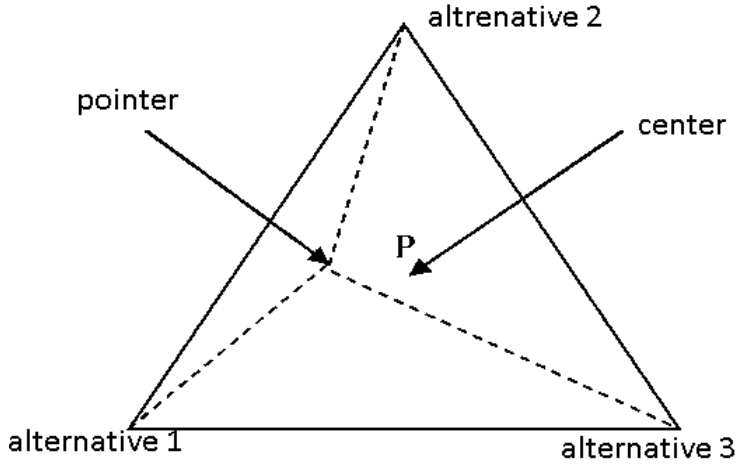

Figure 1 -Graphic representation of a matrix of pairwise comparisons by Saaty.

The distance from the point to the indicating vertices of the triangle shows the preferred alternative, concerning the others.In the center of the triangle is the point of the matrix filled with ones (i.e, the case when all the alternatives have equal importance). The problem of minimizing the function was solved for all consistent matrices:

$$F = \sum_{i=1}^{N}\sum_{j=1}^{N}(a_{ij} - \frac{s_{ij} - r_i}{s_{ij} - r_j})^2 , \quad (4)$$

$$r_i = (x_i - x)^2 + (y_i - y)^2 , \quad (5)$$

$$s_{ij} = (x_i - x_j)^2 + (y_i - y_j)^2 , \quad (6)$$

where N - number of alternatives, a_{ij}- an element of the matrix of paired comparisons, s_{ij}- the distance between the vertices corresponding to the alternatives i and j, r_i - the distance between the vertex of the appropriate alternative i and the pointing point.It is also assumed that $s_{ij} = 1$, as this parameter is used to normalize the values.

The distribution of pointing points corresponding to the consistent matrices of paired comparisons (CR<0.1) was obtained.As seen in Figure 2, there is a certain regularity of points distribution. Expert determines the appropriate degree of preference alternatives using the developed control element.

The developed system is proposed to group alternatives by 3..4 in the group and to fill the corresponding matrix. The experiment was conducted: the four consistent matrices of dimension 3 (A_1, A_2, A_3, A_4)

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formed the matrix of dimension 4 (A_5). All possible combinations of values of the matrix elements of dimension 3 were used.

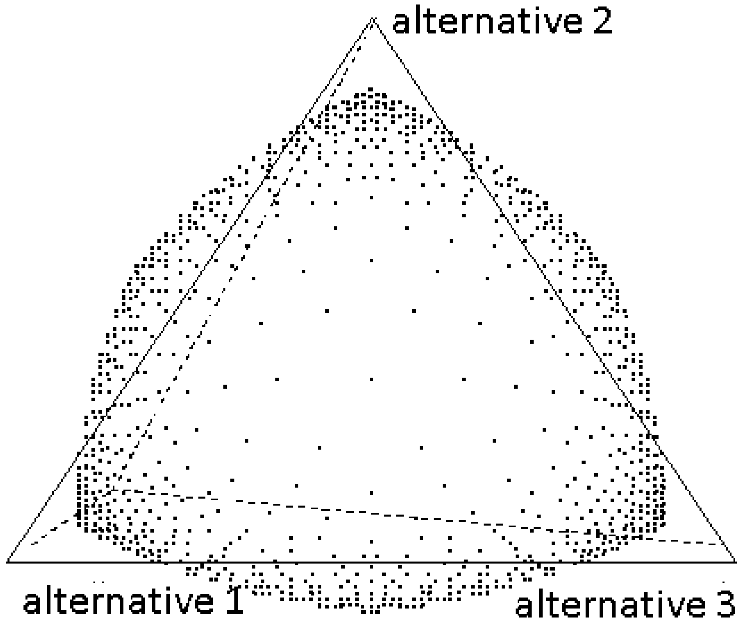

Figure 2 -Distribution of pointing points for the consistent matrices

During the inspection for consistency derived matrices of the order 4 it was proved that if the matrix is formed from the 4 consistent matrices of order 3, it also will be consistent.It solves the problem of redefining matrices of paired comparisons while adding (removing) alternatives.

$$A_1 = \begin{bmatrix} 1 & a_{12} & a_{13} \\ 1/a_{12} & 1 & a_{23} \\ 1/a_{13} & 1/a_{23} & 1 \end{bmatrix}; \; A_2 = \begin{bmatrix} 1 & a_{12} & a_{14} \\ 1/a_{12} & 1 & a_{24} \\ 1/a_{14} & 1/a_{24} & 1 \end{bmatrix}; \; A_3 = \begin{bmatrix} 1 & a_{23} & a_{24} \\ 1/a_{23} & 1 & a_{34} \\ 1/a_{24} & 1/a_{34} & 1 \end{bmatrix};$$

$$A_4 = \begin{bmatrix} 1 & a_{13} & a_{14} \\ 1/a_{13} & 1 & a_{34} \\ 1/a_{14} & 1/a_{34} & 1 \end{bmatrix}; \; A_5 = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} \\ 1/a_{12} & 1 & a_{23} & a_{24} \\ 1/a_{13} & 1/a_{23} & 1 & a_{34} \\ 1/a_{14} & 1/a_{24} & 1/a_{34} & 1 \end{bmatrix}.$$

The expert must fill four matrix of dimension 3.At each step, the system will request only those coefficients which have not been inputyet.Thus, in the first matrix the expert inputs three values, in the second two and only one in the third, the fourth matrix is filled automatically. When filling each of the following matricesthe field of assessments of possible values is narrowed, as those values that were cut off do not match the consistent matrices (Fig. 3). In the figure the points on the second and third triangles, those are marked in areas, corresponding to consistent matrices.

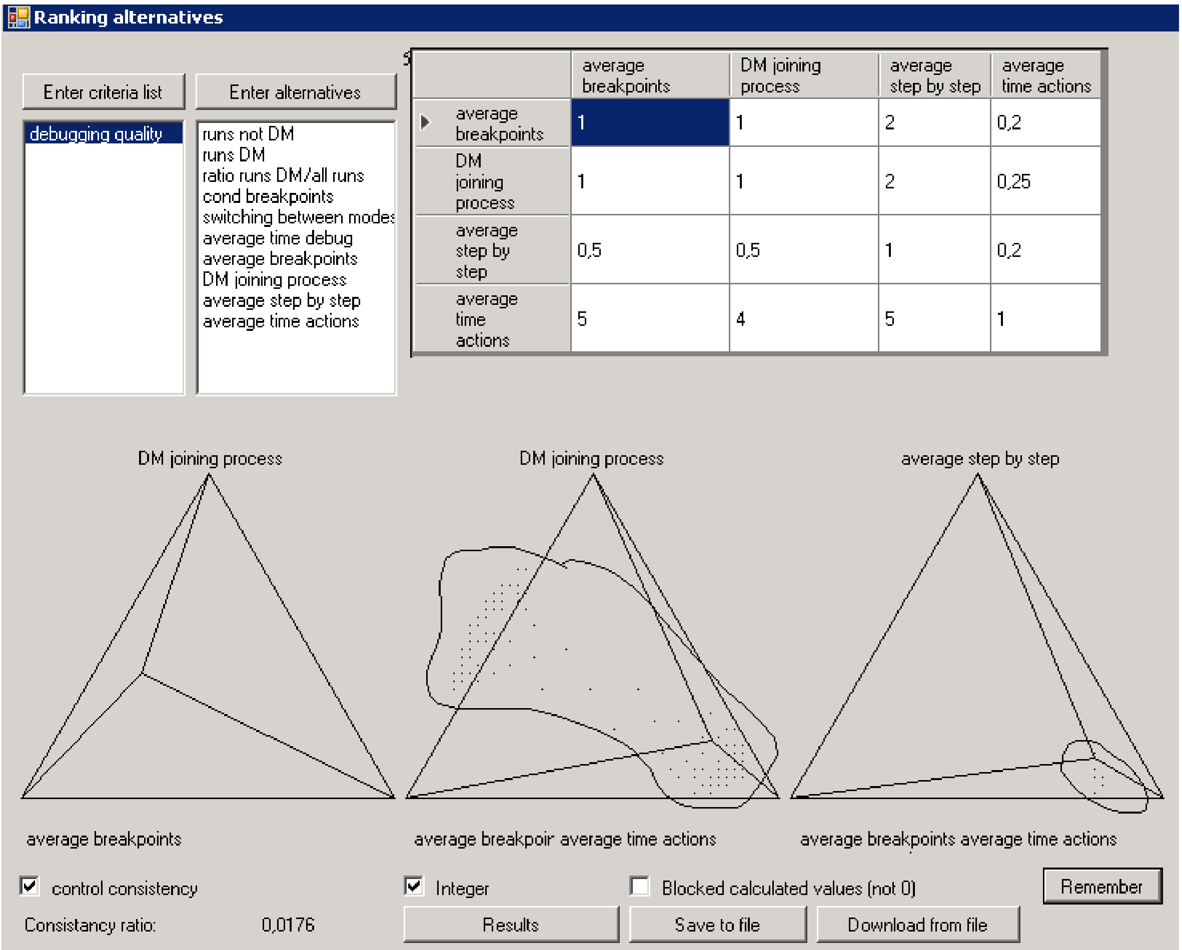

Figure 3-Filling the matrices of pairwise comparisons with control of consistency

It is proposed to modify the method of analytic hierarchy process to simplify the filling of matrices of pairwise comparisons for a large number of alternatives. The essence of the modification is to dividealternativesinto groups, apply AHP to each of the groups and rank alternatives in the groups.Thereafter, to perform the rearrangement and apply AHP for each of the groups.To perform these activities as long as the positions of the alternatives in groups no longer change.Finally, to extend the definition of the general matrix of pairwise comparisons based on the automatically calculated values assessments and rank the alternatives according to the weights.Since regrouping leads to the sorting of alternatives, this method is called AHP with sorting (AHPS).

The initial grouping reduces to determining the number of groups of 4 alternatives and the number of groups of 3 alternatives.Consider the table of partitions for different number of alternatives (Table 1).

Table 1.

The Grouping

Number of alternatives	Grouping
3	3
4	4
5	3 3
6	3 3
7	3 4
8	4 4
9	3 3 3
10	3 3 4
11	4 4 3
12	4 4 4
13	3 3 3 4
14	3 3 4 4

Number of alternatives	Grouping
15	3 4 4 4
16	4 4 4 4
17	3 3 3 4 4
18	3 3 4 4 4
19	3 4 4 4 4
20	4 4 4 4 4
21	3 3 3 4 4 4
22	3 3 4 4 4 4
23	3 4 4 4 4 4
24	4 4 4 4 4 4
25	3 3 3 4 4 4 4

It is necessary that the group had four or three alternatives, with preference given to four.Based on the analysis partition table for the different number of alternatives the following dependencies were derived for determining the number of groups from 4 (7) and 3 (8) alternatives:

$$k_4 = \begin{cases} N/4, & if \quad \mathrm{mod}(N,4) = 0, \\ 0, & if \quad N = 3 \;\; or \;\; N = 5, \\ N/4 - (3 - \mathrm{mod}(N,4)), & in\ other\ cases. \end{cases} \tag{7}$$

$$k_3 = \begin{cases} 0, & if \quad \mathrm{mod}(N,4) = 0, \\ 1, & if \quad N = 3, \\ 2, & if \quad N = 5, \\ (N - k_4 * 4)/3, & in\ other\ cases, \end{cases} \tag{8}$$

where N -the number of alternatives.

The alternatives regrouping must be performed in groups after ranking of alternatives.For this purpose in each group the value l is calculated as integer part from the dividing number of alternatives in the group for 2 (without rounding) according to:

$$l = [M_k / 2]. \tag{9}$$

The new group is formed of the latest elements of the current and the first elements of the following groups as follows:

$$G'_k = \{G_{k,M_k-p}\} \cup \{G_{k+1,1}, G_{k+1,2}\},$$

$$G_k = G_k / \{G_{k,M_k-p}\},\ G_{k+1} = G_{k+1} / \{G_{k+1,1}, G_{k+1,2}\}\ \forall p \in [1,l], \forall k \in [1,Q] \tag{10}$$

where M_k -numberofelementsin k -thgroup; G'_k -set of alternatives in k -th new group, G_k - set of alternatives in k -th group, $G_{i,j}$ -j-th alternative in$i$-thgroup, $Q = k_3 + k_4$ -number of groups. When addingalternativesin new group such alternatives are removed from the previous group. If after applying the AHP and the ranking the positions of alternatives were changed in each group, it is necessary to return the alternatives that stand in these positionsand re-ranking.

When returning the alternatives in appropriate positions according to the formula (9) for each group, the integer part from dividing the alternatives number in the group for 2 is determined. The new group is formed from elements of the current and the following groups as follows:

$$G_k = \{G_{k,1,} G_{k,2,}\} \cup \{G'_{k,p}\}, \ \forall p \in [1,l], \ \forall k \in [1,Q], \tag{11}$$

$$G_{k+1} = \{G'_{k,M_k-p}\} \cup \{G_{k+1,M_k-p}\}, \forall p \in [1,l], \ \forall k \in [1,Q], \tag{12}$$

where M_k — numberofelementsin k -thgroup; G'_k -set of alternatives in k -th group on the previous step, $G_{i,j}$ $-p$ -th alternative in$k$-thgroup, $Q = k_3 + k_4$ -number of groups.

Let us consider the the work of AHPS on example of indicators ranking of program debugging (Table 2) for assessment of student work. Debugging indicators will be alternatives; criterion of assessing in this problem isone -the quality of debugging.

Table 2.

Software debugging indicators

№	Name of indicators
1	Number of runs the program without debugging
2	Number of runs the program in debug mode (DM).
3	Number of different use conditional breakpoints.
4	Number of switching between runs to the DM and without debugging
5	The ratio of the number of runs in the PO to the total number of program runs
6	Average time of debugging
7	Average number of breakpoints for each run debugging
8	Number of runs in debug mode with joining process.
9	The average number of step by step operations.
10	The average time between the user's actions in the DM

When the expert has inputted all the necessary information: alternatives and criteria, the system divides them into groups according to formula (10).Expert is proposed to fill a matrix of pairwise comparisons for each group using matrices of graphical control or a table. The result

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of filling the general matrix of pairwise comparisons of alternatives is given in Table 3.

Table 3.

Filling a matrix of pairwise comparisons for the first three groups

№ alter-ve	1	2	3	4	5	6	7	8	9	10
1	1	1	3							
2	1	1	4							
3	0.33	0.25	1							
4				1	0.25	0.33				
5				4	1	1				
6				3	1	1				
7							1	0.5	0.33	1
8							2	1	2	3
9							3	0,5	1	4
10							1	0.33	0.25	1

Thenaccordingtothealgorithmthe evaluation of alternativesingroupsbyAHPandsortingalternativesingroups (step1 inTable 4)are carried out.Each step in the table 4 has two columns: the alternatives order in groups before the application of AHP in each group and the overall ranking ("before"), and after ranking ("after"). Blank lines in the table are the boundaries of the groups.The alternatives position in groups was changed; therefore, new groups areformed (step 2 tab. 4).

Table 4.

The order of alternatives in groups for step-by-step AHPS

1step		2step		3 step		4step		5 step		6 step		Ranking		
before	after	before	after	before	after	before	after	before	after	before	after	№ al	Rank 1	Rank 2
1	2	3	3	2	2	2	2	1	1	2	2	2	0.283	0.285
2	1	5	5	1	1	1	1	3	3	6	6	1	0.281	0.271
3	3	6	6	3	3	9	9	6	6	10	10	3	0.167	0.17
				5	5			5	5			6	0.062	0.066
4	5	4	4			5	6			1	1	5	0.061	0.058
5	6	8	8	6	6	6	5	2	2	3	3	4	0.058	0.056
6	4	9	9	4	4	4	4	4	4	4	4	8	0.029	0.029
				8	8	8	8	8	8	8	8	9	0.023	0.025
7	8			9	9			7	7			7	0.019	0.019
8	9					3	3			5	5	10	0.014	0.016
9	7					7	7			7	7			
10	10					10	10			9	9			

Groups are created automatically; the expert fills the offered matrices (Table 5).In Table 5 and later (Table 6) the alternatives assessments of the first group at this step are highlighted with light gray, and alternatives of the second group-the dark gray.The values that are inputted by expert on the second step are bold.Alternatives in new groups are assessed by AHP and sorted in accordance with estimates.The alternatives positions in groups have not changed (step 2 Table 4).

Table 5.

Filling a matrix of pairwise comparisons at the 2 step of sorting

№ alt-ve	1	2	3	4	5	6	7	8	9	10
1	1	1	3							
2	1	1	4							
3	0,33	0,25	1		**6**	**8**				
4				**1**	0,25	0,33		**3**	**6**	
5			**0,167**	4	1	1				
6			**0,125**	3	1	1				
7							1	0,5	0,33	1
8				**0,33**			2	1	2	3
9				**0,167**			3	0,5	1	4
10							1	0,33	0,25	1

But as the general matrix of pairwise comparisons is not full and not enough data to calculate the remaining values, then the regrouping alternatives is executed (step 3 Table 4).Alternatives return to the previous group and from each of the following group the alternative is added to the previous one. Thus two groups of four alternativesin each are obtained.The result of filling the matrix of pairwise comparisons in step 3 is shown in Table 6.

Table 6.

Filling a matrix of pairwise comparisons in step 3 of sorting

	1	2	3	4	5	6	7	8	9	10
1	1	1	3		**9**					
2	1	1	4		**7**					
3	0,33	0,25	1		6	8				
4				1	0,25	0,33		3	6	
5	**0,11**	**0,14**	0,167	4	1	1				
6			0,125	3	1	1		**4**	**7**	
7							1	0,5	0,33	1
8				0,33		**0,25**	2	1	2	3
9				0,167		**0,147**	3	0,5	1	4
10							1	0,33	0,25	1

The alternatives positions have not changed, but the data for the calculation of other valuesare still insufficiently, so the system generates the thre new groups(step 4 Table 4). Expert inputs the necessary assessment values of alternatives for each group (in bold in Table. 7).

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Table 7.

Filling a matrix of pairwise comparisons in step 4 of sorting

	1	2	3	4	5	6	7	8	9	10
1	1	1	3		9				9	
2	1	1	4		7				9	
3	0,33	0,25	1		6	8	**9**			**9**
4				1	0,25	0,33		3	6	
5	0,11	0,14	0,167	4	1	1		**3**		
6			0,125	3	1	1		4	7	
7			0,11				1	0,5	0,33	1
8				0,33	**0,33**	0,25	2	1	2	3
9	**0,11**	**0,11**		0,167		0,14	3	0,5	1	4
10			**0,11**				1	0,33	0,25	1

The assessments of alternatives for each group are marked with the corresponding color (1st - dark gray, 2nd - gray, 3rd - light gray).

Aftersortingofalternativesingroupsthealternativespositioninthesecon dgroupwaschanged, thusthe newgroupsareformed (step5 in Table 4).The result of filling the matrix of pairwise comparisons is presented in Table 8.Aftersortingofalternativesingroupsthealternativespositioninthesecondg roupwaschanged, thusthe newgroupsareformed (step5 in Table 4).The result of filling the matrix of pairwise comparisons is presented in Table 8.

Table 8.

Filling a matrix of pairwise comparisons in step 5 of sorting

	1	2	3	4	5	6	7	8	9	10
1	1	1	**3**		9	**6**			9	
2	1	1	4	**5**	7		**8**	**9**	9	
3	0,33	0,25	1		6	8	9			9
4		**0,2**		1	0,25	0,33	**5**	3	6	
5	0,11	0,14	0,167	4	1	1		3		
6	**0,167**		0,125	3	1	1		4	7	
7		**0,125**	0,11	**0,2**			1	0,5	0,33	1
8		**0,11**		0,33	0,33	0,25	2	1	2	3
9	0,11	0,11		0,167		0,14	3	0,5	1	4
10			0,11				1	0,33	0,25	1

Thepositionofalternatives in groups has not changed, at the ranking of alternatives in each group by AHP. The expert has input enough data for further calculations.

The system filledthe missing values of the estimatesautomatically; the resulting matrix of pairwise comparisons is presented in Table 9 (marked in gray values that were calculated with system, as the average number of all possible values obtained on the basis of the formula (1)).The consistency ratio of the matrix is 0.164, but the calculated evaluation of alternatives does not match the scale of Saaty, and the result can not be checked for validity.

Table 9.

Pre-filled matrix of pairwise comparisons

1	1	3	18	9	6	51	60	9	186
1	1	4	5	7	20	8	9	9	202
0,333	0,25	1	6	6	8	9	22	27	9
0,055	0,2	0,167	1	0,25	0,33	5	3	6	12
0,11	0,143	0,167	4	1	1	3	3	4	9
0,167	0,05	0,125	3	1	1	3	4	7	15
0,019	0,125	0,11	0,2	0,33	0,33	1	0,5	0,33	1
0,0167	0,11	0,045	0,33	0,33	0,25	2	1	2	3
0,11	0,11	0,037	0,167	0,25	0,143	3	0,5	1	4
0,005	0,005	0,11	0,083	0,11	0,067	1	0,33	0,25	1

Two approaches can be applied to make estimates appropriate to the Saaty scale to solve this problem. At the first pass the transitivity of estimates of maximum excellence is eliminated. All values of pairwise comparisons that exceed 9 are replaced with 9 (as the maximum possible value at very strong superiority). The result is shown in Table 10 (the assessments values calculated by the system are marked with grey). For this matrix, the consistency ratio is equal to 0.129, which is slightly more than an acceptable level.

Table 10.

The matrix of pairwise comparisons with the equation estimates the maximum superiority

1	1	3	9	9	6	9	9	9	9
1	1	4	5	7	9	8	9	9	9
0,33	0,25	1	6	6	8	9	9	9	9
0,11	0,2	0,167	1	0,25	0,33	5	3	6	9
0,11	0,143	0,167	4	1	1	3	3	4	9
0,167	0,11	0,125	3	1	1	3	4	7	9
0,11	0,125	0,11	0,2	0,33	0,33	1	0,5	0,33	1
0,11	0,11	0,11	0,33	0,33	0,25	2	1	2	3
0,11	0,11	0,11	0,167	0,25	0,143	3	0,5	1	4
0,11	0,11	0,11	0,11	0,11	0,11	1	0,33	0,25	1

Then the expert has an opportunity to review the automatically calculated estimates. All assessments completed automatically by rows are selected: $a_{1,4}, a_{1,7}, a_{1,8}, a_{1,10}$, $a_{2,6}, a_{2,10}$, $a_{3,4}, a_{3,8}, a_{3,9}$, $a_{4,1}, a_{4,3}, a_{4,10}$, $a_{5,7}, a_{5,9}, a_{5,10}$, $a_{6,2}, a_{6,7}, a_{6,10}$, $a_{7,1}, a_{7,5}, a_{7,10}$, $a_{8,1}, a_{8,3}$, $a_{9,3}, a_{9,5}$, $a_{10,1}, a_{10,2}, a_{10,4}, a_{10,5}, a_{10,6}$.For the formation of new groups the alternative with the lowest number of unfilled estimates is selected and group of 3-4 alternatives ,with which it is linked, is formed: for the alternative 2 this are 6 and 10.Because the 10th alternative is already in the group, the estimations related with it are not counted and the next alternative is selected for the formation of groups: this 4-th alternative and the associated with it 1-st and 3-rd, which in turn are associated with 8-th alternative. Thus, the group of 4 alternatives is formed: 1, 3, 4, 8. And the last group will include those alternatives that are not included in the previous: 5, 7, 9.

Expert, using the control element to fill the matrices of pairwise comparison, refines the estimates that were calculated automatically (see Table 11, changes in bold).

Table 11.

The matrix of of pairwise comparisons with the equated estimates of the maximum excellence, complemented by the expert

1	1	3	**5**	9	6	9	9	9	9
1	1	4	5	7	**7**	8	9	9	9
0,33	0,25	1	**2**	6	8	9	5	9	9
0,2	0,2	**0,5**	1	0,25	0,33	5	3	6	9
0,111	0,143	0,167	4	1	1	**1**	3	**3**	9
0,167	**0,143**	0,125	3	1	1	3	4	7	**2**
0,111	0,125	0,11	0,2	1	0,333	1	0,5	0,33	1
0,111	0,11	0,2	0,33	0,33	0,25	2	1	2	3
0,111	0,11	0,111	0,167	**0,333**	0,143	3	0,5	1	4
0,111	0,111	0,11	0,111	0,111	**0,5**	1	0,33	0,25	1

The alternatives ranking in groups based on the new estimates are performed.The consistency ratio of the general matrix of the comparison alternatives is a valid 0.1. The alternatives ranking is presented in Table 4, column "Ranking", corresponding ranks of alternatives "Rank1".

Consider the second variant of definition the general matrix of pairwise comparisons.If to analyze the pre-calculated matrix of pairwise comparisons (Table 9), it can be seen that all values greater than 9 have a very wide range. Consequently, for all values calculated automatically it is necessary to perform the normalization on a scale of Saaty.The normalization will be done only for large values (greater than 9), in the second half of the scale of Saaty (beginning with 5). Previously, all values, that are larger then 81, are replaced with 81. The normalization coefficient and value corresponding to the current value on the scale of Saaty are calculated as follows:

$$norm = (maxR - minR)/(maxS - minS), \tag{13}$$

$$zS = minS + [(z - maxS) / norm], \tag{14}$$

where *norm* – normalization coefficient;maxR, minR – maximum and minimum values on the current scale;maxS, minS – maximum and minimum values on the scale of Saaty;*z* – current value of assessment;*zS*– normalized value of assessment.

Here are the appropriate ranges of values calculated on a scale of Saaty: values from 9 to 23 are replaced with 5, between 24 and 38 – 6, from 39 to 53 – 7, from 54 to 68 – 8, from 69 to 83 – 9.As a result of this replacement the matrix was obtained (Table 12) which hasconsistency ratioequal 0.11 that is slightly greater than allowable.

Table 12.

The matrix of pairwise comparisons with the norm

1	1	3	5	9	6	6	7	9	9
1	1	4	5	7	5	8	9	9	9
0,33	0,25	1	6	6	8	9	5	6	9
0,2	0,2	0,167	1	0,25	0,33	5	3	6	5
0,11	0,14	0,167	4	1	1	1	3	4	5
0,167	0,2	0,125	3	1	1	1	4	7	5
0,167	0,125	0,11	0,2	1	1	1	0,5	0,33	1
0,14	0,11	0,2	0,33	0,33	0,25	2	1	2	3
0,11	0,11	0,167	0,167	0,25	0,14	3	0,5	1	4
0,11	0,11	0,11	0,2	0,2	0,2	1	0,33	0,25	1

To improve the consistency is proposed to form groups of the alternatives with estimations that should be reconsidered.It is proposed to use the approach described above. The groups are formed: alternatives 2, 6 and 10 - the first group, alternatives 1, 3, 4, 8 - the second group and alternatives 5, 7, 9 - the third group (Table 4, step 6, column "before").Expert refines assessment of alternatives for each group using the control element (Table 13, changes in bold). The alternatives in groups are ranked, and the ranking of all the alternatives on the basis of re-calculated the ranks is executed (Table 4, "Ranking - Rank2"). And the consistency ratio of the general matrix (Table 13) is equal to 0.1.

Conclusions

The developed system for ranking of alternatives allows essentially reduce the expert's assessment work of a large number of alternatives, as well as reduce the occurrence of inconsistent judgments.

This article presents the application of AHP for ranking indicators of debugging.In this approach the matrix of pairwise comparisons (dimension of 10) with a total of 45 expert judgments was formed.The proposed modified AHP allowsreducing the number of expert judgments

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to 29.Control of consistency of paired comparisons matrix helps to get the consistent matrix in the result.

Table 13.

The matrix of pairwise comparisons with the norm, is supplemented by expert

1	1	3	**4**	9	6	**6**	**9**	9	**9**
1	1	4	5	7	**5**	8	9	9	**9**
0,33	0,25	1	**3**	6	8	9	**5**	**6**	9
0,2	0,2	**0,33**	1	0,25	0,33	5	3	6	**5**
0,11	0,14	0,167	4	1	1	**2**	3	**2**	**5**
0,167	**0,2**	0,125	3	1	1	**3**	4	7	**2**
0,167	0,125	0,11	0,2	**0,5**	**0,33**	1	0,5	0,33	1
0,11	0,11	**0,2**	0,33	0,33	0,25	2	1	2	3
0,11	0,11	**0,167**	0,167	**0,5**	0,14	3	0,5	1	4
0,11	**0,11**	0,11	**0,2**	**0,2**	**0,5**	1	0,33	0,25	1

The developed method allows getting a rough picture of ranking of alternatives in a few steps of sorting.Subject to consistent judgments (assessments) the matrix of pairwise comparisons is filled mainly automatically. Expert only corrects some calculatedassessments.

This method also allows allocating groups of alternatives that are meaningless to compare with each other, as the result of the comparison is obvious - strong superiority, and it does not affect the result of ranking.The expert receives the maximum consistent matrix for this assessment (even if the ratio of consistency is more than 0.1). The completion of the system for multi-criteria ranking is perspective.

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UDC 621-83 681.51

V.B. Zvorykin, A.P. Egorov, A.I. Mikhalyov

STRUCTURAL IDENTIFICATION OF THE AUTOMATIC CONTROL SYSTEM OF THERMAL AGGREGATE

Annotation. *In the work are considered the objects and principles of the industrial control systems of thermal regime on the basis of objects using thermal automation tools. Regulators are described, the objects used to control actuators in the form of a heater and a shutter. The system for thermal management of electric heating furnace was offered. Implemented structural identification system of automatic control of temperature in the heating furnace.*

Key words: *control systems; thermal regime; regulators; control of temperature; heating furnace*

The use of electrical energy for heating blanks and articles facilitates adjustment of thermal conditions, can accurately maintain a specified temperature range and provides a high degree of uniformity of heating products [1]. In turn, if necessary, in the electric furnaces may be carried out by heating local control of individual sections of the product. It is possible [1], because the electric furnaces, as compared, for example, flaming furnaces much easier to seal, thus reducing heat loss from the exhaust gases, and this in turn provides a higher thermal efficiency of the unit. All this makes it relevant research automatic control systems (ACS) thermal mode of heating products for various purposes and the development of thermal automation in general.

Objects of control thermal automation

Consider some types of control objects and principles of industrial control systems, thermal control mode based on the object using a thermal automation tools.

Thermal objects in terms of creating automatic control systems can be divided into two types:

1) as executive mechanism heater (cooler) (fig. 1),

2) as executive mechanism in the form of a flap actuator (valve) and single-turn electric motor (fig. 2).

The first type electrical resistance heating furnace; a furnace in which heating takes place due to eddy currents; and etc.

The second type of objects include methodical furnaces, heated with gas; soaking pits.

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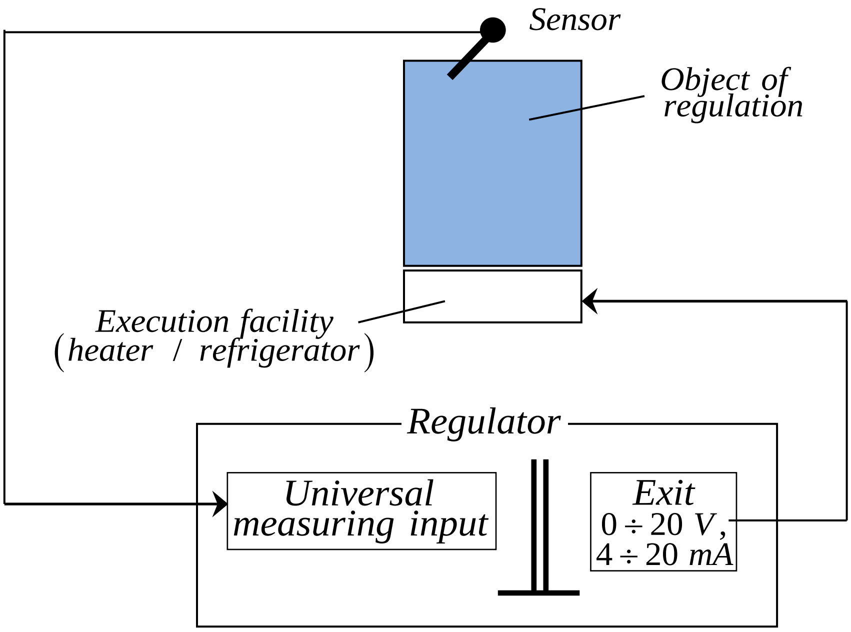

Figure 1 - ACS with executive mechanism heater (cooler)

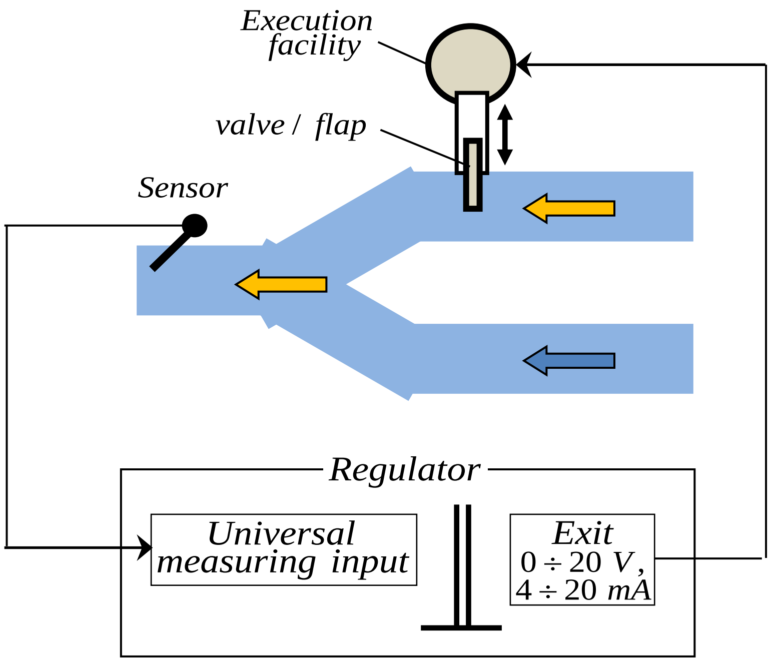

Figure 2 - ACS with executive mechanism in the form of a flap actuator (valve) and single-turn electric motor

In the local automation systems of heating objects are most common in proportion - integral - differential (PID) and the proportion - differential of the second order (PDD) regulators.

These controllers are available in a compact microprocessor devices and have the output either an analog signal or a relay-type signal, or pulse-width modulated signal.

The controller generates a control action so that the value of the controlled parameter $A_{изм}$ is aspired to a predetermined value $A_{зад}$. Thereby it compensating for the external impact on the controlled system.

In the process of adjusting the control is generated at the output of the PID controller signal U_p, the effect of which is aimed at reducing the deviation ε measure value $A_{изм}$ from set point $A_{зад}$.

$$U_p = K_p \left[1 + T_d p + \frac{1}{T_i p} \right] \varepsilon , \qquad (1)$$

where ε - the difference between the target $A_{зад}$ and current $A_{изм}$ value controlled parameter; K_p - proportionality coefficient; T_d - constant differentiation of time; T_i - constant integration of time; $K_p \varepsilon$ - proportional component of the controller output signal; $\frac{K_p}{T_i p} \varepsilon$ - integral component of the signal at the output of the regulator; $K_p T_d p \varepsilon$ - differential component of the signal at the output of the regulator.

The control method (1) is used for executive mechanismheater (cooler).

In the case of the control object with single-turn actuator integral control method in the regulator is not applicable. In the direct channel control circuit of the structural there are two elements: the controller and the actuator. As a result, the control system becomes structurally unstable [2, 6]. Therefore, in such systems use proportional-derivative (PD) or proportional-differential second order (PDD) control method:

$$U_p = K_p \left[1 + T_{d1} p + T_{d2} p^2 \right] \varepsilon . \qquad (2)$$

To simulate and research ACS of the temperature was designed facility. It is an automatic temperature control system in the working space of the electric furnace made on the basis of the PID-controller TZN4W [3].

Fitting description - control system temperature control electric heating furnace

Functional diagram of ACS furnace temperature is shown in fig. 3, and functional structure diagram - fig. 4.

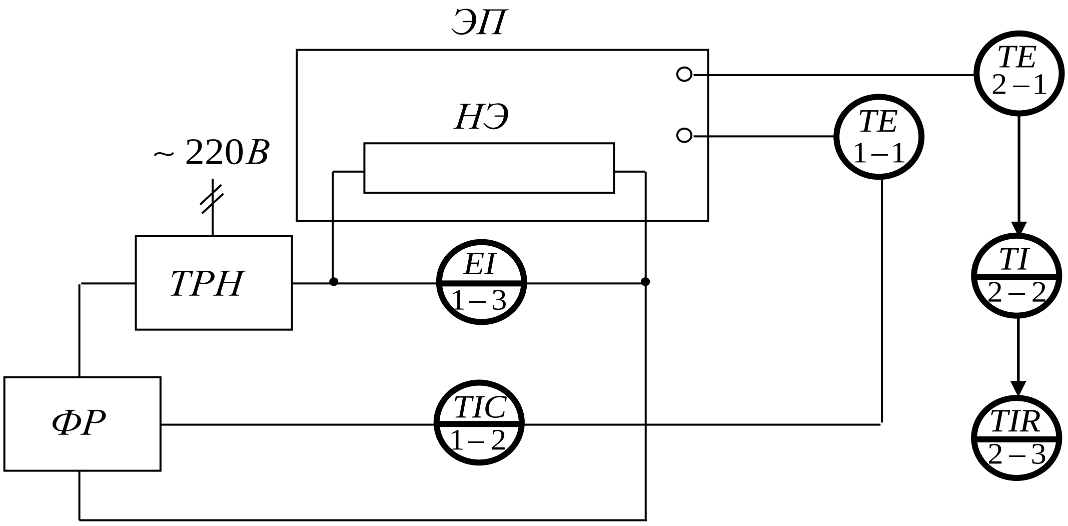

Figure 3 - Functional diagram of ACS furnace temperature

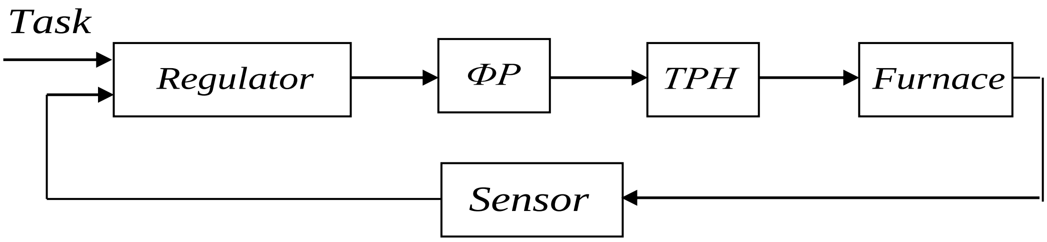

Figure 4 - Functional structure diagram of ACS furnace temperature

Laboratory facilityincludes:

- TSP1-11 temperature sensors, range temperatures of -50 … + 250 ^{O}C (1-1), (2-1);
- regulating device TZN4W (1-2) [3];
- phase regulator *ФР* type RM1E [4];
- thyristor voltage regulator *ТРН* ;
- laboratory furnace, model "Elektrodelo", 300 W, 220 V;
- the technological multichannel registrar RMT69 (2-3) [5].

The electric furnace *ЭП* (fig. 3) has a heating element *НЭ* , powered by a single-phase AC current through the thyristor voltage regulator *ТРН* . The temperature of the furnace workspace controlled by a temperature sensor TSP1-11 (1-1).

Automatic control of the furnace temperature is as follows.

Setting the desired temperature is generated in the controller TZN4W (1-2). The actual temperature in the oven *ЭП* is measured by a temperature sensor (1-1), whose signal is input TZN4W PID-regulator (1-2). Manipulated variable from output TZN4W (1-2) enters the phase control regulator *ФР* .

The phase controller $ФР$ affects on the thyristor voltage regulator $ТРН$. Thyristor regulator $ТРН$ changes the voltage at the terminals of the electric furnace $ЭП$ and, consequently, the current flowing through the heater $НЭ$. Changing the voltage at the terminals of the electric furnace $ЭП$ occurs before until equality is achieved between the actual value and the desired furnace temperature.

The voltage supplied to the furnace is controlled by a voltmeter (1-3).

Multi-channel recorder RMT69 (2-3) designed for the registration and control of temperature. Furnace temperature signal fed from the temperature sensor TSP1-11 (2-1) through a secondary converter (2-2) to one of the inputs RMT69 recorder (2-3).

At furnace temperatures affect the disturbance caused by a change in the supply voltage, as well as changes in the amount of air supplied to the furnace.

The task is, using developed facility, based on the results of experimental studies of the thermal unit to carry out the identification of the transfer function of control object with the subsequent calculation of the controller parameters for the class of heated products.

Structural identification of an automatic temperature control system

In this article, we solve the problem of structural identification system for automatic temperature control in an electric furnace. We proposed structure closed temperature control system in a heating furnace, and its transfer function is defined as a mathematical model in the frequency domain.

Block diagram of the ACS in the form of a chain of serially connected linear and non-linear units is shown in fig. 5.

The mathematical description of the system is based on the physics of processes occurring in it, when the controller $W_p(p)$ generates a control signal U_p, the effect of which is aimed at reducing the deviations ε of the measured temperature T from the set value $T_з$.

$$U_p = K_p\left[1 + T_d p + \frac{1}{T_i p}\right]\varepsilon . \qquad (3)$$

In turn, in the simulation of thermal facilities should be borne in mind that the object of regulation includes, in general, non-linear element

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- the furnace and the temperature sensor, which may have different passport data for a certain class of thermal units.

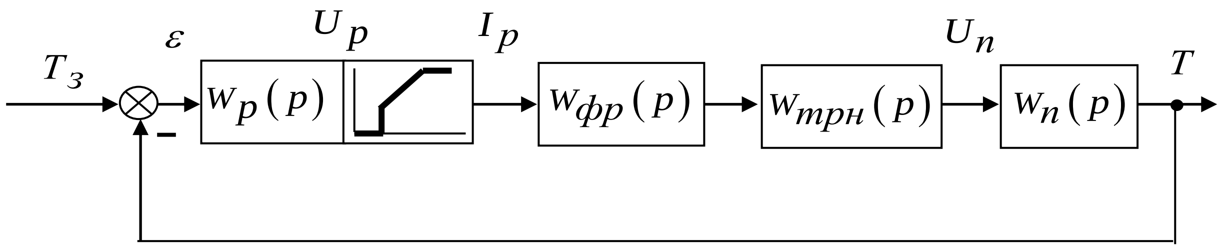

Figure 5 - Block diagram of the researching ATS temperature in the furnace: $W_p(p)$ – - transfer function PID-controller TZN4W; $W_{фр}(p)$ – the transfer function of the phase regulator RM1E; $W_{трн}(p)$ – the transfer function of the thyristor voltage regulator; $W_n(p)$ – the transfer function of the furnace and the temperature sensor; $T_з$ - set point temperature in the furnace; T - the current value of the temperature in the furnace; ε - disagreement on the regulator inlet.

In this context, for the proposed facility of the transfer function of the controlled system is defined as the multiplication of the transfer functions used in the furnace "Электродело" and the temperature sensor TSP1-11.

В свою очередь, при моделировании тепловых агрегатов следует учитывать, что объект регулирования включает в себя в общем случае нелинейный элемент - печь и датчик температуры, которые могут иметь различные паспортные данные для определённого класса тепловых агрегатов.

In this context, for the proposed facility of the transfer function of the controlled system $W_n(p)$ is defined as the multiplication of the transfer functions used in the furnace "Электродело" and in the temperature sensor ТСП1-11.

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РЕФЕРАТИ

УДК 519.216

Атаманюк І.П. **Метод оптимальної екстраполяції реалізацій векторних випадкових послідовностей на основі нелінійного канонічного розкладання**/ І.П. Атаманюк, І.М. Гвоздева, В.П. Прокопишін// Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 3–14.

Робота присвячена вирішенню важливої науково технічної проблеми формування методу оптимальної (в середньоквадратичному сенсі) екстраполяції реалізацій векторних випадкових послідовностей для довільної кількості відомих значень, що використовуються для прогнозу, і порядку нелінійних стохастичних зв'язків. Прогнозна модель синтезована на основі нелінійного канонічного розкладання векторної випадкової послідовності. Отримана формула для визначення середнього квадрата похибки екстраполяції, яка дозволяє оцінити точність рішення задачі прогнозування за допомогою запропонованого методу. Враховуючи рекурентний характер процесів оцінки майбутніх значень послідовності, що досліджується, метод досить простий в обчислювальному відношенні. Запропонований метод екстраполяції, також як і покладене в його основу векторне канонічне розкладання, не накладає ніяких суттєвих обмежень на клас випадкових послідовностей, для яких вирішується задача прогнозування (лінійність, марковість, стаціонарність, скалярність, монотонність і т.д.).

Бібл. 13, іл. 5.

УДК 681.5+519.7

Гече Ф.Е. **Реалізація бульових функцій одним узагальненим нейронним елементом** // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 33–37.

У статті розглядаються нейронні елементи з узагальненою пороговою функцією активації і наводяться критерій реалізованості бульових функцій на таких нейронних елементах.

Бібл. 10.

УДК 004.931

Гнатушенко В.В. **Виявлення та видалення тіней на супутникових зображеннях надвисокого дозволу** / В.В. Гнатушенко, О.О. Кавац, Ю.В. Кавац // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 38–43.

В роботі запропоновано ефективний підхід для виявлення і видалення тіней на мультиспектральних супутникових зображеннях міської забудови на основі HSI–моделі для вирішення проблем розпізнавання, викликаних тінями. У пропонованому підході тіні виявляються і компенсуються з використанням інфрачервоного каналу. Тестування алгоритму довело свою високу ефективність при обробці ДЗЗ зображень.

Бібл. 9, іл. 2

УДК 519.6

Кобилінський І.А. **Особливості оцінювання ризиків на основі нечітких моделей**/ І.А. Кобилінський, О.П. Гожий // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 44–57.

Розглянуто методологію оцінки ризику на основі нечітких моделей, а також різних методів агрегування нечіткої інформації. У моделях управління ризиками, триангулярні норми можуть розширити ймовірнісні моделі до нечітких моделей, і тим самим зробити можливим їх використання в умовах неповноти статистичної інформації. Була обгрунтована ефективність методики проектування нечітких контролерів та систем підтримки прийняття рішень на основі нечітких моделей оцінки ризику. Розглянуто деякі практичні приклади, які демонструють, що нечіткі заходи та інтеграли добре підходять для вирішення різних складних проблем.

Бібл. 15, іл. 1.

УДК 007.52

Лисенко В.П.**Оптимізація енергоспоживання мобільних роботів** / В.П. Лисенко,І.М. Болбот, І.І. Чернов// Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 58–66.

Аналіз факторів, що впливають на витрату ресурсу акумуляторної батареї мобільного робота для фітомоніторингу рослин в теплиці та використання методу варіаційного числення для оптимізації споживання енергії.

Бібл. 6, іл. 3.

УДК 519.716.39: 519.6: 57.017

Литвиненко В.І. **Багатокритеріальний імунний підхід для реконструкції генних регуляторних мереж з використанням алгоритму клонального добору**/ В.І. Литвиненко, А.О. Фефелов, М.А. Таіф, І.А. Лур'є // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 67–84.

Моделювання генних регуляторних мереж є однією з основних проблем в системної біології. У даній роботі ми розглядаємо задачу знаходження структур генних регуляторних мереж на основі експериментальних даних ДНК мікрочіпів. В роботі запропановано використовувати багатокритеріальний алгоритм клонального відбору для визначення параметрів нелінійної системи, що задається спостережуваними даними. В моделі використовується випадок коли невідомі не тільки фактичні параметри даної системи, а також і апріорна зв'язність компонентів генної мережі. Проте, це число має вирішальне значення для процесу логічного висновку. Тому ми пропонуємо метод, заснований на алгоритмах штучного імунної системи, яка використовує з'єднання в якості мети оптимізації на додаток до розходження даних (відносна стандартна похибка – ВСП) між експериментальними і змодельованих даними.

Бібл. 33, іл. 1, табл. 2.

УДК 667. 64: 678. 02

Марасанов В.В.**Триангуляційні методи локації дефектів в акустіко–емісійному контролі**/ В.В. Марасанов, А.О. Шарко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 85–91.

Дається опис характеристик і сфер застосування акустичної емісії в неруйнівному контролі металопродукції. Показано, що важливим інформаційним параметром є міра локалізації джерела сигналу акустичної емісії. Дається аналітичне обґрунтування тріангуляційному методу за визначенням координат дефектів шляхом виміру різниці часів приходу імпульсів акустичної емісії до різних конфігурацій датчиків.

Бібл. 5, іл. 4.

УДК621.007.52

Машков В.А. **Проблема розробки алгоритмів для системного рівня самодіагностики** / В.А. Машков, В.І. Литвиненко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 92–101.

Статтю присвячено проблемі послідовності, структурі і стратегії вирішення завдання самодіагностики систем. Детально розглянуто проблеми розробки алгоритмів для системного рівня самодіагностики. Показані умови і вимоги отримання правильного діагнозу для однорідних систем.

Бібл . 5, іл. 1, табл. 2.

УДК 53; 533.9.082.5

Ольшевський С.В. **Синтез 3D–розподілів інтенсивності випромінювання факелу прямоточного плазмотрона на основі двовимірних зображень**/ С.В. Ольшевський, А.М. Шкарбута // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 102–108.

В статті розглянуто новий підхід використання методу Пірса для синтезу тривимірних розподілів оптичних характеристик аксіально несиметричних об’єктів. На прикладі фотографій факелу прямоточного плазмотрона було показано, що запропонований в роботі алгоритм дає задовільні результати обробки зображення та дозволяє зняти неоднозначність інтерпретації градієнтів інтенсивності двовимірного зображення, спричинених ноднорідністю тривимірних об’єктів.

Бібл. 5, іл. 5.

УДК 615.471:616–071:004.032.26

Перова І.Г. **Швидка еволюціонуюча нейро–фаззі система та алгоритм її навчання для задач медичної обробки даних**/ І.Г. Перова, Є.В. Бодянський // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 109–116.

Запропоновано архітектура та алгоритм навчання швидкої еволюціонуючої нейро–фаззі системи для задач обробки медичних даних. Запропанована система характеризується високим рівнем швидкодії та простотою чисельної реалізації.

Бібл. 19, іл. 2.

УДК 681.5: 517.977

Рудакова Г.В. **Методи підвищення надійності організаційно–технічних систем** // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 117–126.

У статті аналізуються суб'єктивні чинники, які впливають на надійність функціонування автоматизованих систем управління складними системами. Розглянуто етапи еволюції систем. Проведено аналіз властивостей, моделей і методів управління для систем різного ступеня складності. Виявлено відсутність належних методів і засобів для формування обґрунтованих рішень про управління великими системами в критичному режимі функціонування. Обґрунтовано доцільність використання узагальнених апроксимуючих моделей великих систем у вигляді оболонок. Запропоновано підвищення ефективності оперативного управління в сучасних організаційно–технічних системах здійснювати шляхом додавання модуля оцінки стану розподіленого об'єкта, підсистеми прогнозу динаміки розподіленого об'єкта, методів синтезу оптимального (раціонального) управління, заснованих на використанні безперервних моделей.

Бібл. 10, іл. 7, табл. 1.

УДК 004.02, 004.8, 004.9; 519.6

Шинкаренко В.І. **Зменення кількості експертних оцінок методу аналіза ієрархій засобами сортування та керування опитуванням**/ В.І. Шинкаренко, Т.М. Васецька, Є.Ю. Бойко // Системні технології. Регіональний міжвузівська збірка наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 127–143.

Розглянуто деякі проблеми, пов’язані з використанням методу аналізу ієрархій та можливі шляхи їх розв’язку. Запропоновано ще одну модифікацію класичного методу аналізу ієрархій з елементами сортування для ранжування великої кількості альтернатив в задачах багатокритеріального вибору. Описано програмну реалізацію запропонованої модифікації. Розроблена система дозволяє суттєво зменшити роботу експерта при оцінюванні великої кількості альтернатив, а також зменшити кількість випадків неузгоджених оцінок. Розглянуто шляхи досягнення найкращої узгодженості матриць парних порівнянь альтернатив.

Бібл. 16, іл. 3, табл 13.

УДК 621–83 681.51

Зворикін В.Б. **Структурна ідентифікація системи автоматичного управління тепловим агрегатом**/ В.Б. Зворикін, О.П. Єгоров, О.І. Михальов // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 144–150.

Розглянуті об'єкти управління та принципи побудови промислових систем регулювання теплового режиму на базі об'єктів з використанням засобів теплової автоматики. Описано регулятори, які використовуються для управління об'єктами з виконавчими механізмами у вигляді нагрівача і у вигляді заслінки.

Запропоновано установку для управління температурним режимом електричної нагрівальної печі. Виконана структурна ідентифікація системи автоматичного регулювання температури в нагрівальної печі.

Бібл. 5, іл. 6.

 ISSN 1562-9945

УДК 519.216

Атаманюк И.П. **Метод оптимальной экстраполяции реализаций векторных случайных последовательностей на основе нелинейного канонического разложения**/ И.П. Атаманюк, И.М. Гвоздева, В.П. Прокопышин // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 3–14.

Работа посвящена решению важной научно технической проблемы формирования метода оптимальной (в среднеквадратическом смысле) экстраполяции реализаций векторных случайных последовательностей для произвольного количества известных значений, используемых для прогноза, и различного порядка нелинейных стохастических связей. Прогнозная модель синтезирована на основе полиномиального степенного канонического разложения векторной случайной последовательности. Получена формула для определения среднего квадрата погрешности экстраполяции, которая позволяет оценить точность решения задачи прогнозирования с помощью предложенного метода. Учитывая рекуррентный характер процессов оценки будущих значений исследуемой последовательности метод достаточно прост в вычислительном отношении.

Предложенный метод экстраполяции, также как и положенное в его основу векторное каноническое разложение, не накладывает никаких существенных ограничений на класс прогнозируемых случайных последовательностей (линейность, марковость, стационарность, скалярность, монотонность и т.д.).

Библ. 13, ил. 5.

УДК 681.5+519.7

Гече Ф.Є. **Реализация булевых функций на одном обобщенном нейронном элементе** // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 33–37.

В статье рассматриваются нейронные элементы с обобщенной пороговой функции активации и приводятся критерий реализуемости булевых функций на таких нейронных елементах.

Библ. 10.

УДК 004.931

Гнатушенко В.В.**Обнаружение и удаление теней на спутниковых изображения сверхвысокого разрешения** / В.В. Гнатушенко, А.А. Кавац, Ю.В. Кавац // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 38–43.

В работе предложен эффективный подход для обнаружения и удаления теней намультиспектральных спутниковых изображениях городской застройки на основе HSI модели для решения проблем распознавания, вызванных тенями. В предлагаемом подходе тени обнаруживаются и компенсируются с использованием инфракрасного канала. Тестирование алгоритма доказало свою высокую эффективность при обработке ДЗЗ изображений.

Библ. 9, ил. 2.

УДК 519.6

Кобылинский И.А., Гожий А.П. **Особенности оценки рисков на основе нечетких моделей** / И.А. Кобылинский, А.П. Гожий // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 44–57.

Рассмотрена методология оценки риска на основе нечетких моделей, а также различных методов агрегирования нечеткой информации. В моделях управления рисками, триангулярные нормы могут расширить вероятностные модели до нечетких моделей и тем самым сделать возможным их использование в условиях неполноты статистической информации. Была показана эффективность методики проектирования нечетких контроллеров, систем поддержки принятия решений, на основе нечетких моделей оценки риска. Расмотрены некоторые практические примеры, которые демонстрируют, что нечеткие меры и интегралы хорошо подходят для решения различных сложных проблем.

Библ. 15, ил. 1.

УДК 007.52

Лисенко В.П. **Оптимизация энергопотребления мобильных роботов** / В.П. Лисенко,И.М. Болбот, И.И. Чернов// Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 58–66.

Анализ факторов, влияющих на расход ресурса аккумуляторной батареи мобильного робота для фитомониторинга растений в теплице и использования метода вариационного исчисления для оптимизации потребления энергии.

Библ. 6, ил. 3.

УДК 519.716.39: 519.6: 57.017

Литвиненко В.И.**Многокритериальный иммунный подход для реконструкции генных регуляторных сетей с использованием алгоритма клонального отбора** / В.И. Литвиненко, А.О. Фефелов, М.А. Таиф, И.А. Лурье // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 67–84.

Моделирование генных регуляторных сетей является одной из основных проблем в системной биологии. В данной работе мы рассматриваем задачу нахождения структур генных регуляторных сетей на основе экспериментальных данных ДНК микрочипов. В работе предложено использовать многокритериальный алгоритм клонального отбора для определения параметров нелинейной системы, которая задается на основе экспериментальных данных. В рассматриваемой модели используется случай, когда неизвестные не только фактические параметры данной системы, а также и априорная связность компонентов генной сети. Однако, данное число имеет решающее значение для процесса логического вывода. Поэтому нами предлагается метод, на основ алгоритмов искусственной иммунной системы, которая использует связанность генов в качестве цели оптимизации в дополнение к различию данных (относительная стандартная ошибка) между экспериментальными и смоделированных данными.

Библ. 33, ил. 1, табл. 2.

УДК 667. 64: 678. 02

Марасанов В.В.**Триангуляционные методы локации дефектов в аккустико эмиссионном контроле**/ В.В. Марасанов, А.А. Шарко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 85–91.

Приведено описание характеристик и сфер применения аккустической эмиссии в неразрушительном контроле металлопродукции. Показано, что важным информационным параметром является мера локализации источника сигнала аккустической эмиссии. Дается аналитическое обоснование триангуляциооному методу по определению координат дефектов путем измерения разницы времен прихода импульсов аккустической эмиссии к разным конфигурациям датчиков.

Библ. 5, ил. 4.

УДК 621.007.52

Машков В.А. **Проблема разработки алгоритмов для системного уровня самодиагностики** / В.А. Машков, В.И. Литвиненко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 92–101.

Статья посвящена проблеме последовательности, структуре и стратегии решения задачи само диагностики однородных систем. Детально рассмотрены проблемы разработки алгоритмов для системного уровня самодиагностики. Показаны условия и требования получения правильного диагноза.

Библ. 5, ил. 1, табл. 2.

УДК 53; 533.9.082.5

Ольшевский С.В.**Синтез 3D–распределений интенсивности излучения факела прямоточного плазмотрона на основе двумерных изображений**/ С.В. Ольшевский, А.Н. Шкарбута // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 102–108.

В статье рассмотрен новый подход использования метода Пирса для синтеза трехмерных распределений оптических характеристик аксиально несимметричных объектов. На примере фотографий факела прямоточного плазмотрона было показано, что предложенный в работе алгоритм дает удовлетворительные результаты обработки изображения и позволяет снять неоднозначность интерпретации градиентов интенсивности двумерного изображения, вызванных ноднородностью трехмерных объектов.

Библ. 5, ил. 5.

УДК 615.471:616 071:004.032.26

Перова И.Г. **Быстрая эволюционирующая диагностическая нейро фаззи система и ее обучение для задач медицинской обработки данных**/ И.Г. Перова, Е.В. Бодянский // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 109–116.

Предложены архитектура и алгоритм обучения быстрой эволюционирующей нейро фаззи системы для задач обработки медицинских данных. Предложенная система характеризуется высоким быстродействием и простотой численной реализации.

Библ. 19, ил. 2.

УДК 681.5: 517.977

Рудакова А.В. **Методы повышения надежности организационно–технических систем** // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 117–126.

В статье анализируются субъективные факторы, которые влияют на надежность функционирования автоматизированных систем управления сложными системами. Рассмотрены этапы эволюции систем. Проведен анализ свойств, моделей и методов управления для систем разной степени сложности. Выявлено отсутствие надлежащих методов и средств для формирования обоснованных решений об управлении большими системами в критическом режиме функционирования. Обоснована целесообразность использования обобщенных аппроксимирующих моделей больших систем в виде оболочек. Предложено повышение эффективности оперативного управления в современных организационно–техничных системах осуществлять путем добавления модуля оценки состояния распределенного объекта, подсистемы прогноза динамики распределенного объекта, методов синтеза оптимального (рационального) управления, основанных на использовании непрерывных моделей.

Библ. 10, ил. 7, табл. 1.

УДК 004.02, 004.8, 004.9; 519.6

Шинкаренко В.И.**Снижение количества экспертных оценок метода анализа иерархий средствами сортировки и управления опросом**/ В.И. Шинкаренко, Т.Н. Васецкая, Е.Ю. Бойко // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 127–143.

Рассматриваются некоторые проблемы, связанные с использованием метода анализа иерархий и возможные пути их решения. Предложена еще одна модификация классического метода анализа иерархий с элементами сортировки для ранжирования большого количества альтернатив в задачах многокритериального выбора. Описана программная реализация предложенной модификации. Разработанная система позволяет существенно сократить работу эксперта по оценке большого количества альтернатив, а также сократить случаи несогласованных суждений. Рассмотрены пути достижения наилучшей согласованности матриц парных сравнений альтернатив.

Библ. 16, илл. 3, табл 13.

УДК 621–83 681.51

Зворыкин В.Б. **Структурная идентификация системы автоматического управления тепловым агрегатом**/ В.Б. Зворыкин, А.П. Егоров, А.И. Михалев // Системні технології. Регіональний міжвузівський збірник наукових праць. – Випуск 6 (101). – Дніпропетровськ, 2015. – С. 144–148.

Рассмотрены объекты управления и принципы построения промышленных систем регулирования теплового режима на базе объектов с использованием средств тепловой автоматики. Описаны регуляторы, используемые для управления объектами с исполнительными механизмами в виде нагревателя и в виде заслонки.

Предложена установка для управления температурным режимом электрической нагревательной печи. Выполнена структурная идентификация системы автоматического регулирования температуры в нагревательной печи.

Библ. 5, илл. 6.

UDK 519.216

Atamanyuk I.P. **Method of optimal extrapolation of vector random sequences realizations on the basis of nonlinear canonical decomposition**/ I.P. Atamanyuk, I.M. Hvozdeva, V.P. Prokopyshin // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 3–14.

The given work is devoted to the solving of important scientific and technical problem of the method development of the optimal (in mean–square sense) extrapolation of the realizations of vector random sequences for any quantity of the known values, used for forecasting, and for any order of nonlinear stochastic relations. Forecasting model is synthesized on the basis of polynomial canonical decomposition of vector random sequence. There is obtained the formula for determination of the mean–square error of extrapolation that allows to estimate the solution accuracy of the forecasting problem with using the proposed method. Taking into account the recurrent character of the estimation processes of the future values of investigated sequence the method is quite simple in calculating respect. The developed method of extrapolation as well as the vector canonical expansion assumed as its basis don't put any essential limitations on the class of prognosticated random sequences (linearity, Markovian property, stationarity, scalarity, monotony etc.).

Bibl. 13, ill. 5.

УДК 506+510

Baklan I.V. **Linguistic models of fractal data series** // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 15–21.

The properties of construction linguistic models of dynamic processes time series. In the article the theoretical bases of linguistic models of dynamic processes. Attention is paid to the peculiarities of forming patterns with fractal properties.

Bibl. 5, ill. 4.

УДК 506+510

Baklan I.V. **Modeling sustainable development processes**/ I.V. Baklan,Y.M. Selin, T.V. Shulkevich// System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 22–32.

The paper contains the description of the feasible approach to modeling and forecasting of ecological processes that are the component of the sustainable development paradigm. The suggested mathematical apparatus is based on the statistical methods and comprises hidden Markov models with the linguistic modeling.

Bibl. 16, ill. 4.

UDC 681.5+519.7

Geche F.E. **Implementation of Boolean functions by one generalized neural element** // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 33–37.

Present article considers the neural elements (NE) with generalized threshold activation function and represents criterion of Boolean functions implementation on such neural elements.

Bibl. 10.

UDC 004.931

Hnatushenko V.V. **Shadow detection and removal from very high resoluton satellite image**/ V.V. Hnatushenko, O.O. Kavats, Y.V. Kavats // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 38–43.

This paper presents an efficient and simple approach for shadow detection and removal based on HSI color model in complex urban color remote sensing images for solving problems caused by shadows. In the proposed method shadows are detected and compensated using the infrared channel. Testing of the algorithm proved its high efficiency in the processing of remote sensing images.

Bibl. 9, ill. 2.

UDC 519.6

Kobylinskyi I.A. **Peculiarities of risks assessment based on fuzzy models**/ I.A. Kobylinskyi, A.P. Gozhyi // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 44–57.

The risk assessment methodology based on fuzzy models as well as different aggregation techniques were described. In the models of risk management, triangular norms can extend the probabilistic models to fuzzy models and thereby make possible their use in conditions of poor statistics. The effectiveness of the methodology for the design of fuzzy controllers, decision support systems based on fuzzy models of risk assessment was shown. There are some practical examples that demonstrates fuzzy measures and integrals are good techniques to solve different complex problems.

Bibl. 15, ill. 1.

UDC 007.52

Lysenko V.**The Optimization of Power Consumption of Mobile Robots** / V. Lysenko, I. Bolbot, I. Chernov // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 58–66.

In this article the analysis of factors affecting on battery life consumption of mobile robot for phytomonitoring of plants in the greenhouse and usage of variation calculus method for optimization of energy consumption have been conducted.

Bibl. 6, ill. 3.

UDC 519.716.39: 519.6: 57.017

Lytvynenko V.I.**A multi–objective immune approach to reconstruct gene regulatory network using algorithm clonal selection** / V.I. Lytvynenko, A.A. Fefelov, M.A. Taif, I.A. Lur`ie // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 67–84.

The inference of gene regulatory networks is one of the main challenges in systems biology. In this paper we address the problem of finding gene regulatory networks from experimental DNA microarray data. We suggest to use a multi–objective clonal selection algorithm to identify the parameters of a non–linear system given by the observed data. Not only the actual parameters of the examined system are unknown, also the connectivity of the components is a priori not known. However, this number is crucial for the inference process. Consequently we propose a method based on algorithms of artificial immune system which uses the connectivity as an optimization objective in addition to the data dissimilarity (relative standard error – RSE) between experimental and simulated data.

Bibl. 33, tabl. 2.

УДК 667. 64: 678. 02

Marasanov V.V. **Triangulation methods of position defects in acoustic–emissione control** V.V. Marasanov, A.A. Sharko // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 85–91.

Description and application of acoustic emission domains is given in non–destructive control. It is rotined that an important informative parameter is a degree of localization of source of signal of acoustic emission. An analytical ground is given a triangulation method on determination of co–ordinates of defects by measuring of difference of times of arrival of impulses of acoustic emission to different configurations of sensor.

Bibl. 5, ill. 4.

UDC 621.007.52

Mashkov V.A. **Problem with developing algorithms for system level self–diagnosis** / V.A. Mashkov, V.I. Lytvynenko// System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 92–101.

Article is devoted to sequence, structure and strategy of solving the problem of self–diagnosis of homogeneous systems. Considered in detail the problem of the development of algorithms for system self–test level. The conditions and requirements to obtain the correct diagnosis.

Bibl. 5, Fig. 1, Tabl. 2.

UDC 53; 533.9.082.5

Olszewski S.V**. Synthesis of 3D–distributions to radiation intensity for torch of direct–flow plasmatron based on two–dimensional imaging**/ S.V. Olszewski, A.M. Shkarbuta// System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 102–108.

New approach of Pearce methods application is considered for synthesis of three–dimensional distributions of optical characteristics in axially non–symmetrical objects. The direct–flow plasmatron torch photos have been selected as a constructive example of this aim. One was derived that proposed algorithm provides satisfactory results of these images processing and allow to remove an interpretation ambiguity of the two–dimensional image intensity gradients due to inhomogeneity of three–dimensional objects.

Bibl. 5, ill. 5.

UDC 615.471:616–071:004.032.26

Perova Iryna G. **Fast evolving diagnostic neuro–fuzzy system and its learning in medical data mining tasks**/ Iryna G. Perova, Yevgeniy V. Bodyanskiy // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 109–116.

Architecture and training method for fast evolving diagnostic neuro–fuzzy–system for Medical Data Mining Tasks are proposed. System under consideration characterizes by high speed of operation and simplicity of the numerical realization.

Bibl. 19, ill. 2.

UDC 681.5: 517.977

Rudakova G.V. **Methods to improve the reliability of organizational–technical systems** // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 117–126.

In the article the subjective factors that affect the reliability of the automated control systems of complex systems is analysed. The stages of systems evolution are considered. The analysis of the properties, models and management methods for systems of varying degrees of complexity are spend. Lack of appropriate methods and means for forming reasoned decisions about managing of large systems in a critical mode operation is revealed. Advisability of using distributions approximating models for large systems in the form of shells substantiated. Proposed to increase the effectiveness of operational management in modern organizational and technical systems carried out by adding a module assessing the state of the distributed object subsystem prediction the dynamics of distributed object, methods of synthesis of the optimum (rational) management based on the use of continuous models.

Bibl. 10, ill. 7, tabl. 1.

UDC 004.02, 004.8, 004.9; 519.6

Shynkarenko V.I. **Reducing the Number of Expert Judgments in Analytic Hierarchy Process by Sorting and Survey Management**/ V.I. Shynkarenko, T.M. Vasetska, E.Y. Boiko // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 127–143.

Some problems associated with AHP using and existing methods of their solving are considered. Modification of the classical method of analytic the hierarchy process with elements of sorting for the ranking a large number of alternatives in multicriterial choice problems was developed. The software implementation of the proposed modification was described. The developed system allows essentially reduce the expert's assessment work of a large number of alternatives, as well as reduce the occurrence of inconsistent judgments. The ways to achieve the best consistency of the matrix of pairwise comparisons of alternatives were proposed.

Ref. 16, ill. 3, tables 13.

UDC 621–83 681.51

Zvorykin V.B. **Structural identification of the automatic control system of thermal aggregate**/ V.B. Zvorykin, A.P. Egorov, A.I. Mikhalyov // System tecnologies. №6 (101). – Dnepropetrovsk, 2015. – P. 144–148.

In the work are considered the objects and principles of the industrial control systems of thermal regime on the basis of objects using thermal automation tools. Regulators are described, the objects used to control actuators in the form of a heater and a shutter.

The system for thermal management of electric heating furnace was offered. Implemented structural identification system of automatic control of temperature in the heating furnace.

Ref. 5, ill. 6.

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