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OPTIMIZATION OF MONITORING SUBSYSTEMS OF THE DISTRIBUTED OBJECTS BY METHODS OF THE SPECTRAL ANALYSIS

Annotation. The method of functioning parameters optimization subsystem of territorially distributed monitoring system which basis on application of spectral analysis methods (one-dimensional and bidimentional) is offered. The given method allows to avoid information redundancy and to simplify technical realization of state identification contour of the distributed object which efficiency causes an information-control system efficiency.

Key words: territorially distributed system, a subsystem of monitoring, the spectral analysis, correlation function, optimization of the sensor arrangement scheme.

Statement of a problem

Modern industrial complexes represent complex territorially distributed objects, controled by integrated automated control systems (IACS) [1]. Functioning information-control systems essentially depends on coordination and an efficiency of all of its subsystems, in particular - subsystems of monitoring. Increase of efficiency of functioning of subsystems of monitoring is appreciably connected to enhancement of methods and means of collecting and analysis of the data.

Optimization of subsystems of monitoring of the distributed objects consists in determination of the sensor arrangement scheme, their necessary and sufficiency, periodicity of their interrogation with the purpose of reduction of information redundancy of measurements and, as consequence, reduction of volume of the information intended for storage and processing, reduction in requirements to computing means and telecommunication channels.

The analysis of publications on a theme of research

Operative control during all term of functioning of object, will consist of the following periodically repeating stages: an estimation of the current condition of object of control; determination of a deviation of movement of object from the set trajectory; the solution of a problem of a finding of optimum control (formation of control actions) for the forthcoming period; realization of control (updating of a condition of system - returning to the set trajectory) [2].

In connection with presence uncertainties concerning a condition of the object, caused by the stochastic change of external and internal conditions of functioning of system, the primary goal of a subsystem of monitoring is timely identification of a condition of object based on which control is formed in IACS .

Calculation of optimum control as a rule is carried out in an automated workplace of the dispatcher, with the help of decision support systems (DSS) [2] the structure of which is shown on fig. 1.

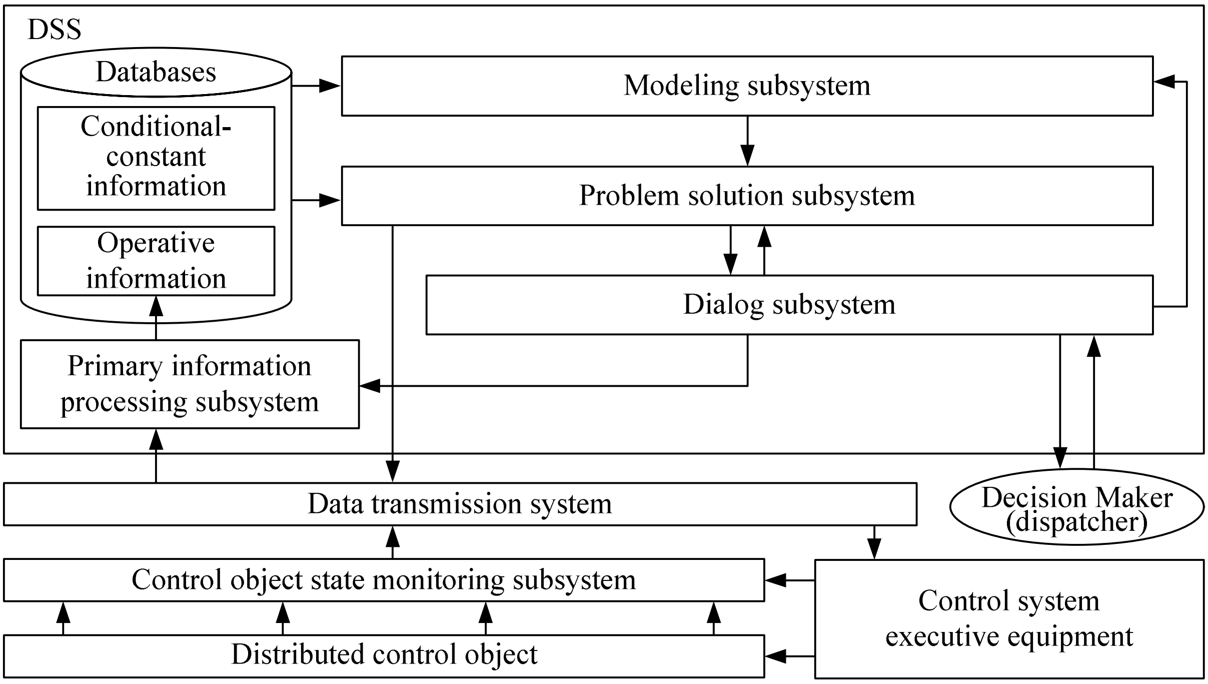

Figure 1 – Structure of DSS for control of the distributed object

In the integrated automated control system of the distributed object availability of corresponding models and programs for the forecast of dynamics of a condition and planning of distribution of resources, system of monitoring for an estimation of quality of control, participation of the controlling personnel during the coordination of the decisions taken is necessary.

The subsystem of monitoring should carry out regular measurement of all current parameters of functioning of object, parameters of an environment, updating of databases by the new information and to fix changes of parameters of system for the possibility of the further forecast. Thus, the purpose of functioning of a subsystem of monitoring is providing DSS with the operative information about object condition, and the information about operating mode of the executive equipment also.

The subsystem of processing of the primary information analyses the external input information, processing of the information received from the operator, display of the data as convenient for the subsequent processing and transfer of the information to a database.

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The subsystem of modelling forms model of dynamics of a condition of the distributed object on the basis of conditional - constant and poerative information from database. For simplification of the analysis of the distributed object it is possible to use continuous model as a surface with use of approximating shells which enables to predict a condition in any point territorially - distributed systems [3].

In a subsystem of the problems decision operating modes of the equipment for the forthcoming period taking into account of the forecast of dynamics of object condition are formed [4].

The system of data transmission connecting DSS with the equipment of system and a subsystem of monitoring, can be realized on the basis of wireless telecommunication technologies.

For increase of efficiency of functioning of territorially - distributed system the necessary condition is effective work of a subsystem of monitoring. First of all it is necessary to avoid information redundancy of measurements and to simplify technical realization of a contour of identification of a condition of the distributed object.

Statement of a problem

To achieve this goal it is necessary to develop a method of optimization of parameters of functioning of a subsystem of monitoring of territorially distributed object which will allow to determine the sensor arrangement scheme and periodicity of their interrogation, on the basis of application of methods of the one-dimensional and bidimentional spectral analysis.

The main part

On the basis of known dynamic model of territorially distributed object functioning $Z(x,y,t)$, constructed as an approximating surface [3], in each point $(x,y)\in\Omega$ it is possible to define correlation function which characterizes speed of processes in system, under the formula

$$r_Z(x,y,\tau)=\frac{1}{T}\int_0^T\frac{\overset{\circ}{Z}(x,y,t)\cdot\overset{\circ}{Z}(x,y,t+\tau)}{D_Z(x,y)}dt\ , \qquad (1)$$

where $\overset{\circ}{Z}(x,y,t)=Z(x,y,t)\ \ -m_Z(x,y)$ – centered value of controlled parameter in a point with coordinates (x,y);

$m_Z(x,y)=\frac{1}{T}\int_0^T Z(x,y,t)dt$ – expected value;

$D_Z(x,y) = \frac{1}{T}\int\limits_0^T [Z(x,y,t) - m_Z(x,r)]^2 dt$ – dispersion of parameter values; $Z(x,y,t)$ – concrete realization of a random process, which can be obtained on the basis of statistical information on the functioning of the object for an extended period of time T.

For simplification of practical calculations of correlation (1) it is possible to take advantage of discretized formulas for a finding of autocorrelation function as [5]

$$r_Z(x,y,\tau) = \frac{1}{N-m}\sum_{i=0}^{N-m-1}\frac{\overset{\circ}{Z}(x,y,t_i)\cdot\overset{\circ}{Z}(x,y,t_i+m\Delta t_{ä})}{D_Z(x,y)}, \qquad (2)$$

where $\Delta t_{ä} = T/N$ – a period of time between adjacent measered parameter values; N – quantity of calculation points (big enough); $\tau = m\Delta t_{ä}$ – a correlation interval $m = 0, 1, \ldots, N$.

To find of an expected value and a dispersion it is possible to use the following expressions

$$m_Z(x,y) = \frac{1}{N}\sum_{i=0}^{N-1} Z(x,y,t_i),\ D_Z(x,y) = \frac{1}{N-1}\sum_{i=0}^{N-1}\left[\overset{\circ}{Z}(x,y,t_i)\right]^2. \qquad (3)$$

The spectral analysis allows to estimate the maximum frequency of the spectrum of a random process on the basis of which it is possible to find the discretization step according to Kotelnikov's theorem as [5]

$$\Delta t \le \frac{\pi}{\omega_c}, \qquad (4)$$

where ω_c – the maximum frequency of the spectrum of the limited signal in a point with the specified coordinates (x,y) for finding which Parseval's identity traditionally used

$$\frac{1}{\pi}\int\limits_0^{\omega_ñ}[S(\omega)]^2 d\omega = \frac{\eta}{\pi}\int\limits_0^{\infty}[S(\omega)]^2 d\omega, \qquad (5)$$

where η – the coefficient describing fidelity of reproduction $\eta = 0{,}95$; $S(\omega)$ – spectral density of amplitudes of random process which can be found with the help of Fourier transformation of correlation function

$$S_Z(\omega) = \frac{2}{\pi}\int\limits_0^{\infty} r_Z(\tau)\cos\omega\tau d\tau. \qquad (6)$$

The periods of sensor interrogation on all territory of the distributed object Ω can be defined as function depending on coordinates

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$$\Delta t(x, y) \le \frac{\pi}{\omega_c(x, y)}, \tag{7}$$

or, that it is more rational from convenience of practical realization of a subsystem of monitoring, as

$$\Delta t = \min_{(x,y)\in\Omega} \Delta t(x, y). \tag{8}$$

Modelling was carried out for a subsystem of monitoring of of agricultural land soil moisture. Dynamics of change of moisture content in certain points of territory depending of various modes of functioning of irrigation systems, soil types and crops considering on precipitationon during all vegetative period, received on the basis of model stated in [6], is shown on fig. 2.

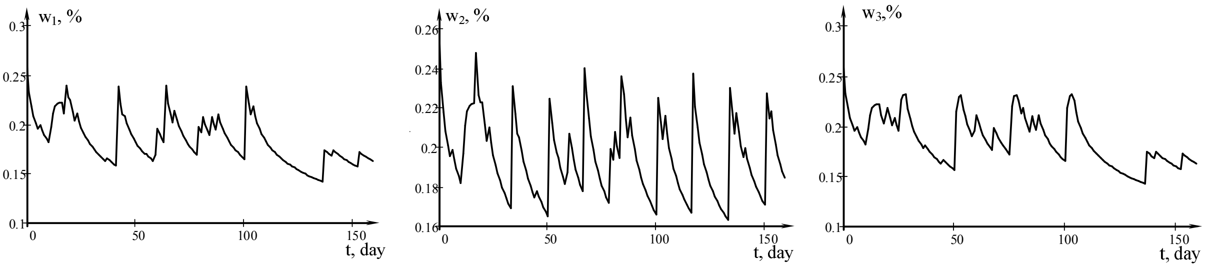


Figure 2 – Results of modelling of soil moisture content

Autocorrelation dependences for the given processes, calculated according to (2) and (3) are shown on fig. 3.

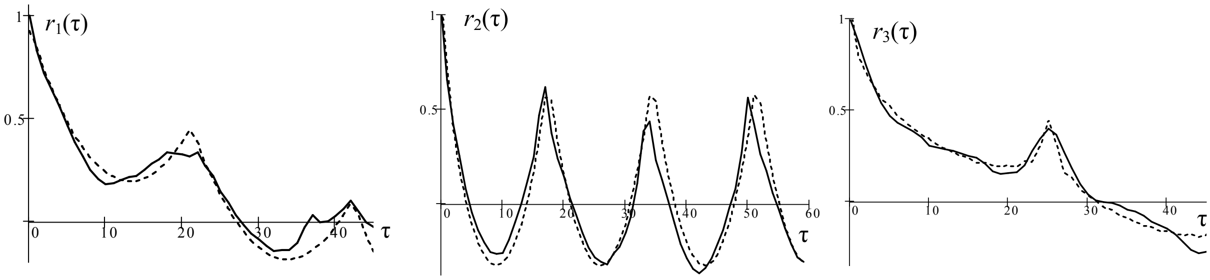


Figure 3 – Correlation dependences:

(—— – calculated value; --- –approximated values)

To find of spectral density of processes of change of soil moisture content $S(\omega)$ correlation dependences should be submitted in the analytical form which can be received from graph of function with the help of a least-squares method [7]. As a result of approximation the following dependences are received:

$$r_1(\tau) = -0{,}18 \cdot \sum_{n=1}^{10} (-1)^{n+1} \frac{\cos(n \cdot (0{,}3\tau - 9{,}5))}{n^2} + 0{,}65 - \left(\frac{\tau}{52}\right)^{0.8},$$
$$r_2(\tau) = -0{,}4 \cdot \sum_{n=1}^{10} (-1)^{n+1} \frac{\cos(n \cdot (0{,}37\tau - 9{,}6))}{n^2} + 0{,}5e^{-\tau}, \qquad (9)$$
$$r_3(\tau) = -0{,}11 \cdot \sum_{n=1}^{10} (-1)^{n+1} \frac{\cos(n \cdot (0{,}245\tau - 9{,}3))}{n} + 0{,}8 - \left(\frac{\tau}{48}\right)^{0.6}.$$

As a result of substitution of analytical correlation dependences (9) in the equations (5) and (6) cutoff frequencies $\omega_{c1} = 0{,}324\ day^{-1}, \omega_{c2} = 0{,}738\ day^{-1}$, $\omega_{c3} = 0{,}475\ day^{-1}$ are obtained, and estimations of descritization steps according to (7) $\Delta t_1 \le 9{,}7\ day$, $\Delta t_2 \le 4{,}25\ day$, $\Delta t_3 \le 6{,}6\ day$. As the period of time of sensor interrogation it is possible to choose the minimal value $\Delta t \le 4{,}25\ day$ for all points (x, y) of territorially distributed irrigational system.

The two-dimensional spectral analysis of superficial model of territorially distributed object allows to determine the sensor arrangement scheme of a subsystem of monitoring on a plane $(x, y) \in \Omega$.

The degree of dependence of values of the distributed parameter $Z(x, y, t)$ in a direction of various coordinates for any fixed moment of time $t \in (0, T)$ can be estimated with the help of two-dimensional autocorrelation function of the form

$$r(\tau_x, \tau_y) = \frac{1}{(N_1 - m_1)(N_2 - m_2)} \sum_{i=0}^{N_1 - m_1 - 1} \sum_{j=0}^{N_2 - m_2 - 1} \frac{\overset{0}{Z}(x_i, y_j) \cdot \overset{0}{Z}(x_i + \tau_x, y_j + \tau_y)}{D_Z}, \qquad (10)$$

where N_1 and N_2 – quantity of readout on coordinates x and y;

$\tau_x = m_1 \Delta x$, $\tau_y = m_2 \Delta y$ – intervals between the process points;

$\overset{0}{Z}(x_i, y_j) = Z(x_i, y_j) - m_Z$ – centered values of process $Z(x, y)$;

$m_Z = \frac{1}{N_1 \cdot N_2} \sum_{i=0}^{N_1-1} \sum_{j=0}^{N_2-1} Z(x_i, y_j)$ and $D_Z = \frac{1}{N_1 \cdot N_2 - 1} \sum_{i=0}^{N_1-1} \sum_{j=0}^{N_2-1} \left[\overset{0}{Z}(x_i, y_j)\right]^2$ – expected value and a dispersion of random process $Z(x, y)$.

At the analysis of a two-dimensional spectrum it is possible to estimate the maximum frequency of the spectrum of a random distributed process on the basis of which it is possible to determine the discretization step according on coordinates x and y according to Kotelnikov's theorem as

$$\Delta\overline{x}_i \le \frac{\pi}{\omega_{cx_i}}, \ \Delta\overline{y}_j \le \frac{\pi}{\omega_{cy_j}}, \ i = \overline{0, N_2 - 1}, \ j = \overline{0, N_1 - 1}, \quad (11)$$

where ω_{cx_i} and ω_{cy_j} – the maximum frequency of the spectrum for each cut of correlation function on coordinates x and y accordingly.

Recalculation to real coordinates taking into account the scaling factor k dependent on a type and radius of action of the executive equipment can be carried out as $\Delta x = k \cdot \Delta\overline{x}$, $\Delta y = k \cdot \Delta\overline{y}$.

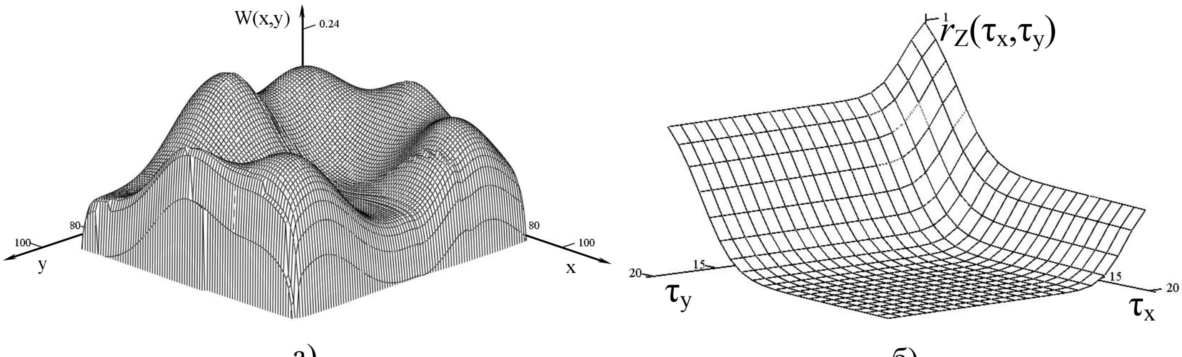
Calculations of the maximum frequencies of a spectrum ω_{cx_i} and ω_{cy_j} can be carried out as for an one-dimensional case on Parseval's identity (5) where spectral density of amplitudes of random process is determined with help of Fourier transformation on correlation function (6).

The sensor arrangement step on all territory of the distributed object is accepted as

$$\Delta x = \min\left(\Delta x_i\right) \text{ and } \Delta y = \min\left(\Delta y_j\right). \quad (12)$$

Modelling of the offered method of determination of the optimum sensor arrangement sheme was carried out in boundaries of territory of a separate facilities. The type of superficial model of soil moisture content in relative coordinates at the moment of time $t = 20$ of day from the beginning of the vegetative period is showen on fig. 4a. The graph of the calculated correlation function $r_z(\tau_x, \tau_y)$ is shown on fig. 4b.

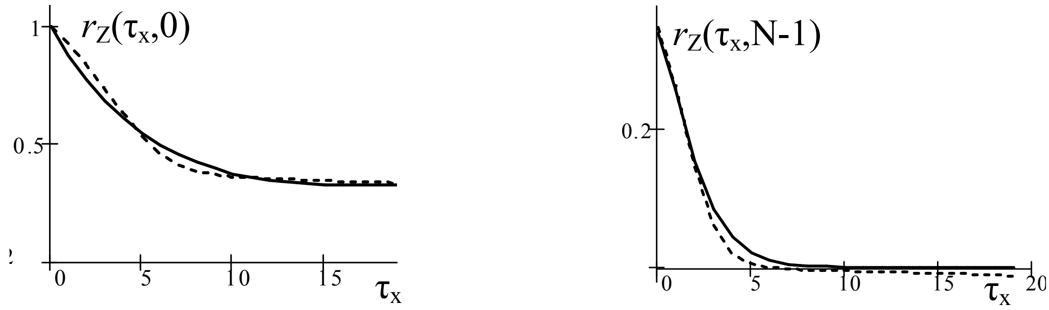
Approximation of cuts of correlation function on two axes was carried out by a least squares method. Some dependences received are showen on fig. 5, fig. 6.



а) б)

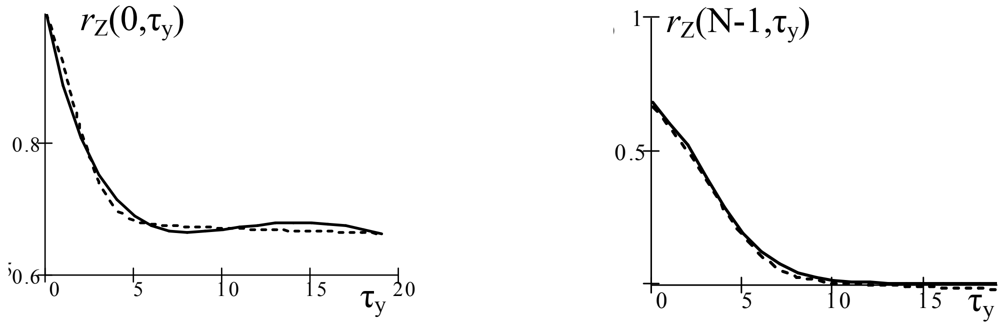
Figure 4 – Models of characteristic parameters:

a) – soil moisture content; б) – correlation function



а) – for $i = 0$ ($\Delta x \le 22{,}12k$) б) – for $i = N_2 - 1$ ($\Delta x \le 4k$)

Figure 5 – Approximation of cuts of correlation function on an axis x



а) – for $j = 0$ ($\Delta y \le 67k$) б)– for $j = N_1 - 1$ ($\Delta y \le 7{,}24k$)

Figure 6 – Approximation of cuts of correlation function on an axis y

Analytical expressions for boundary cuts of correlation functions on two axes are received as

$$
\begin{aligned}
r_Z(x,0) &= e^{-0{,}068x} \cdot \left(1 - 0{,}066x + 0{,}004x^2\right), \\
r_Z(x, N-1) &= e^{-0{,}875x} \cdot \left(0{,}338 + 0{,}273x + 0{,}0006x^2\right).
\end{aligned} \tag{13}
$$

$$
\begin{aligned}
r_Z(0, y) &= e^{-0{,}1y} \cdot \left(1 - 0{,}027y + 0{,}011y^2\right), \\
r_Z(N-1, y) &= e^{-0{,}76y} \cdot \left(0{,}681 + 0{,}37y + 0{,}23y^2\right).
\end{aligned} \tag{14}
$$

On the basis of the received analytical dependences (13), (14) the maximal and minimal step on an axis x and on an axis y have been determined accordingly. In result of determination of a moisture content sensor arrangement step from ratio (12) was obtained $\Delta x \le 4k$ and $\Delta y \le 7{,}24k$.

Conclusions

Application of dynamic superficial model allows to optimize the sensor arrangement sheme on territorially - distributed object. The developed technique of determination of optimum sensor arrangement sheme and periodicity of their interrogation on the basis of methods of the one-dimensional and bidimentional spectral analysis allows to avoid information redundancy and to simplify technical realization of a contour of identification of a condition of the distributed object.

THE LITERATURE

1. Рудакова А.В. Информационно-управляющая система для систем водораспределения / А.В. Рудакова, С.П. Шейник, О.В. Поливода // Вестник Херсонского национального технического университета. – 2009. – №1(34). – С. 333–337.

2. Поливода О.В. Оптимизация управления влагообеспечением в ирригационных системах/ О.В. Поливода, А.В. Рудакова, С.П. Шейник // Международная научно-практическая конференция «Технические науки: современные проблемы и перспективы развития», 10 декабря 2012 г.: [материалы] / Приволжский научно-исследовательский центр. – Йошкар-Ола: Коллоквиум, 2013. – С. 120 – 123.

3. Поливода О.В. Использование непрерывных оболочек для моделирования влагосодержания почвы/ О.В. Поливода, С.П. Шейник, А.В. Рудакова // Вестник Херсонского национального технического университета. – 2009. – №2(35). – С. 357–362.

4. Поливода О.В. Методы оперативного управления влагообеспечением в ирригационных системах с прогнозирующей моделью / О.В. Поливода, А.В. Рудакова // SAIT 2013: XV міжнародна науково-технічна конференція, Київ, 27-31 травня 2013 р.: тези доповідей. – К.: ННК “ІПСА” НТУУ “КПІ”, 2013. – С.165.

5. Дмитриев В.И. Прикладная теория информации. – М.: Высшая школа, 1989. – 320 с.

6. Поливода О.В. Динамическая модель распределения влаги в пахотном слое/О.В. Поливода, Н.И. Рыженко, А.В. Рудакова // Вестник Херсонского национального технического университета.– 2010. – №3(39).– С. 374 – 380.

7. Дрейпер Н. Прикладной регрессионный анализ. Множественная регрессия / Н. Дрейпер, Г. Смит– 3-е изд.– М.:«Диалектика», 2007.– 912 с.