# Computer's Analysis Method and Reliability Assessment of Fault-Tolerance Operation of Information Systems

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**Abstract.** In this paper there was obtained an calculation method of the assessment of the probability of fail-safe operation of information systems in the future instants of time. The method is based on the algorithm for modeling a posteriori nonlinear random sequence of change of values of the controlled parameters which is imposed a limitation of belonging to a certain range of possible values. The probability of fail-safe operation is defined as the ratio of the number of realizations that fell in the allowable range to the total number of them, formed as a result of the numerical experiment. The realization of an a posteriori random sequence is an additive mixture of optimal from the point of view of mean-square nonlinear estimate of the future value of the parameter analyzed and of the value of a random variable, which may not be predicted due to the stochastic nature of the parameters. The model of a posteriori random sequence is based on the Pugachev's canonical expansion. The calculation method offered does not impose any significant constraints on the class of random sequences analyzed (linearity, stationarity, Markov behavior, monotoneness, etc.).

**Keywords.** calculation method, random sequence, canonical decomposition, estimation, probability.

**Key Terms.** computation, mathematical model.

## 1 Introduction

One of the most important problems that arises constantly in the process of information and communication systems service is the problem of the estimation of system reliability with the following making decision about the possibility of its further exploitation on the basis of the information about possible failures in the future [1-5]. The problem becomes especially important in the case when information system is used for the management of the objects that relate to the class of critical or dangerous and under the threat of accident objects (aircraft, sea mobile objects, nuclear power stations, chemical industry plants etc.) [6-8]. The forecasting of failures is the primary stage of the providing of the dependability of the systems of such class. However, nowadays the problem of failures forecasting (in overwhelming majority cases) is solved by means of informal methods and the decision about the possibility of dependable exploitation of the corresponding information system is made on the basis [9-11]:

- qualitative and quantitative estimation of its current state;
- the experience of the exploitation of the given and analogous information systems.

As far as information and communication systems (ICT) become more complicated and also as far as there is the growth of requirements to the probability of their reliable work, informal methods of making decision are becoming less and less effective. Hence, the usage of stricter approaches to the estimation of the dependability and reliability of ICTs functioning based on the quantitative estimations of future state of experimental information systems is very important.

## 2 Statement of the problem

Accuracy of the obtained solutions for correspondent class of problems and the time during which given solutions can be obtained are the most universal parameters characterizing the quality of information system functioning. Stated parameters (accuracy and time) have stochastic character because of the presence of inner defects of the system and uncontrolled external destabilizing factors. That's why the problem of the forecasting control of information system reliability can be formulated in the following way.

Without the restriction of the generality of the next calculations let us assume that the state of the information system in exhaustive way is determined with scalar parameter $X$ (accuracy or time of problem solution). The change of the values of the parameter $X$ in discrete range of points $t_i, i=\overline{1,I}$ is described by random sequence $\{X\} = X(i),\ i=\overline{1,I}$. The values of the parameter $X$ must satisfy the condition

$$a < x(i) < b,\ i=\overline{1,I} \tag{1}$$

In the case of the crossing by parameter X the limits of acceptable area [a; b] the failure of information system in the process of its functioning is registered. The state of the system is controlled periodically in discrete moments of time $t_\mu,\ \mu=\overline{1,k}$ by measurement of the values $x(\mu),\ \mu=\overline{1,k}$ of the parameter $X$ where $x(\mu),\ \mu=\overline{1,k}$ is the realization of the random sequence $\{X\}$ in the cut set $t_\mu,\ \mu=\overline{1,k}$. It is evident that for the segment of the time $[t_1;t_k]$ the inequation $a < x(\mu) < b, \mu=\overline{1,k}$ must be correct. Otherwise as it follows from (1) under

$$x(i) < a,\ i=\overline{1,I}$$

or

$$x(i) > b,\ i = \overline{1,I}$$

on the interval of examination $[t_1;t_k]$ the failure would take place that would lead to the suspension of the process of information system functioning.

The statement of the problem can be formulated in the following way: on the basis of stated (measured) information about current values of the parameter X on the time interval $[t_1;t_k]$ the conclusion about the usability of the information system to exploitation in future moments of time $t_i, i = \overline{k+1, I}$ must be made.

Similarly the problem of providing of dependable functioning and forecasting of the state of the technical systems or objects to the structure of which information systems or management-information systems enter in the form of components can be formulated. Herewith the dependability of functioning and usability of such complicated systems and objects certainly depend on reliability and fail-safety of all their components..

## 3 Solution

Given that the value of the controlled parameter $X$ changes randomly within the forecast region, the probability of fail-safe operation becomes an exhaustive feature of the safety of functioning of the information system examined.

$$P^{(k)}(I) = P\{a < X^{(k)}(i) < b, i = \overline{k+1, I} \,/\, x(\mu), \mu = \overline{1,k}\}. \tag{2}$$

The problem is thus reduced to the determination of the probability of non-falling of the realization of the a posteriori random sequence $X^{(k)}(i / x(\mu), \mu = \overline{1,k}), i = \overline{k+1, I}$ outside the limits of the permissible region $[a;b]$.

In [12], [13] there was proposed an approach to the estimation of likelihood (2) through multiple statistical modeling of possible extensions $x_l(i), i = \overline{k+1, I}, l = \overline{1, L}$ of the random sequence analyzed $\{X\}$ in the forecast region, verification for each realization of condition (1) and calculation as a result of the required estimation experiment $P^{*(k)}(I) = n/L$ ($n$ is the number of successes). In this method, its canonical expansion [14] within the range of points analyzed is used as a model of the random sequence $t_i, i = \overline{1, I}$ :

$$X(i) = M\left[X(i)\right] + \sum_{\nu=1}^{i} V_\nu \phi_\nu(i), i = \overline{1, I}, \tag{3}$$

where $V_\nu, \nu = \overline{1, I}$ - random coefficients: $M[V_\nu] = 0, M[V_\nu V_\mu] = 0$ for $\nu \neq \mu, M[V_\nu^2] = D_\nu$ ;

$\phi_\nu(i), i, \nu = \overline{1, I}$ - nonrandom coordinate function: $\phi_\nu(\nu) = 1, \phi_\nu(i) = 0$ under $\nu > i$.

Elements of the canonical representation (3) are defined by the following recursions:

$$V(i) = X(i) - M[X(i)] - \sum_{\nu=1}^{i-1} V_\nu \varphi_\nu(i), i = \overline{1, I}, \quad (4)$$

$$D_i = M[X^2(i)] - \{M[X(i)]\}^2 - \sum_{\nu=1}^{i-1} D_\nu \varphi_\nu^2(i), i = \overline{1, I}; \quad (5)$$

$$\begin{aligned} \varphi_\nu(i) = \frac{1}{D_\nu} \{ & M[X(\nu)X(i)] - M[X(\nu)]M[X(i)] - \\ & - \sum_{j=1}^{\nu-1} D_j \varphi_j(\nu)\varphi_j(i)\}, \nu = \overline{1, I}, i = \overline{\nu, I}. \end{aligned} \quad (6)$$

Tipping in the expression (3) of known values $X(\mu) = x(\mu), \mu = \overline{1, k}$ converts the a priori random sequence into the a posteriori one:

$$X^{(k)}(i) = m_x^{(k)}(i) + \sum_{\nu=k+1}^{i} V_\nu \phi_\nu(i), i = \overline{k+1, I}, \quad (7)$$

where $m_x^{(k)}(i)$ - linear optimal, by the criterion of mean square minimum of prediction error, estimate of the future value of the random sequence $\{X\}$ at the point $t_i$ according to the known initial values of $k$.

Expressions for finding $m_x^{(k)}(i)$ have two equivalent forms of notation

$$m_x^{(\mu)}(i) = \begin{cases} M[X(i)], \text{ if } \mu=0, \ i=\overline{1,\mathrm{I}}; \\ m_x^{(\mu-1)}(i) + [x(\mu) - m_x^{(\mu-1)}(\mu)]\phi_\mu(i), \ \ \mu=\overline{1,k}, \ i=\overline{\mu+1,I}; \end{cases} \quad (8)$$

or

$$m_x^{(k)}(i) = M[X(i)] + \sum_{j=1}^{k} (x(\mu) - M[X(\mu)]) f_\mu^{(k)}(i), \ i = \overline{k+1, I}; \quad (9)$$

$$f_\mu^{(k)}(i) = \begin{cases} f_\mu^{(k-1)}(i) - f_\mu^{(k-1)}(k)\phi_k(i), \ \ \mu \le k\text{-}1; \\ \phi_k(i), \ \mu=k; \end{cases} \quad (10)$$

Formation of possible extensions of random sequence $\{X\}$ by the expression (7) is to compute estimates $m_x^{(k)}(i), i = \overline{k+1, I}$, generating one of the known methods of statistical modeling of values of independent random coefficients $V_\nu, \nu = \overline{k+1, I}$ with the required distribution law and transforming of the values obtained by the coordinate functions $\varphi_\nu(i), i, \nu = \overline{k+1, I}$.

The calculation method of forecasting of fail-safe operation of information systems on the basis of the model (7) covers a fairly wide class of random sequences (non-markovian, non-stationary, non-monotonic, etc.), but this representation of an a posteriori random sequence is optimal only within the framework of linear stochastic properties, thus reducing significantly the accuracy of prediction of random sequences, which have non-linear links.

The clearing of this trouble is possible through the use on the basis of estimation method of the probability of fail-safe operation of an information system of nonlinear canonical expansion of the random sequence [15], changing values of the parameter controlled:

$$X(i) = M[X(i)] + \sum_{\nu=1}^{i} \sum_{\lambda=1}^{N-1} V_\nu^{(\lambda)} \phi_{1\nu}^{(\lambda)}(i), i = \overline{1, I}. \quad (11)$$

Elements of the expansion (11) are determined by the following recursions:

$$V_\nu^{(\lambda)} = X^\lambda(\nu) - M[X^\lambda(i)] - \sum_{\mu=1}^{\nu-1} \sum_{j=1}^{N-1} V_\mu^{(j)} \varphi_{\lambda\mu}^{(j)}(\nu) - \sum_{j=1}^{\lambda-1} V_\nu^{(j)} \varphi_{\lambda\nu}^{(j)}(\nu), \ \nu = \overline{1, I}; \quad (12)$$

$$\begin{aligned} D_\lambda(\nu) = M[\{X(\nu) - M[X(\nu)]\}^{2\lambda}] - \sum_{\mu=1}^{\nu-1} \sum_{j=1}^{N-1} D_j(\mu) \{\phi_{\lambda\mu}^{(j)}(\nu)\}^2 - \\ - \sum_{j=1}^{\lambda-1} D_j(\nu) \{\phi_{\lambda\nu}^{(j)}(\nu)\}^2, \nu = \overline{1, I}; \end{aligned} \quad (13)$$

$$\begin{aligned} \phi_{h\nu}^{(\lambda)}(i) = \frac{1}{D_\lambda(\nu)} \{M[X^\lambda(\nu) X^h(i)] - M[X^\lambda(\nu)] M[X^h(i)] - \\ - \sum_{\mu=1}^{\nu-1} \sum_{j=1}^{N-1} D_j(\mu) \phi_{\lambda\mu}^{(j)}(\nu) \phi_{h\mu}^{(j)}(i) - \sum_{j=1}^{\lambda-1} D_j(\nu) \phi_{\lambda\nu}^{(j)}(\nu) \phi_{h\nu}^{(j)}(i)\}, \lambda = \overline{1, h}, \nu = \overline{1, i}. \end{aligned} \quad (14)$$

In the canonical expansion (11) the random sequence $\{X\}$ is represented in the range of points analyzed $t_i, i = \overline{1, I}$ via $N-1$ the arrays $\{V^{(\lambda)}\}, \lambda = \overline{1, N-1}$ of uncorrelated centered random coefficients. $V_i^{(\lambda)}, \lambda = \overline{1, N-1}, i = \overline{1, I}$. These coefficients contain information on the values $X^\lambda(i), \lambda = \overline{1, N-1}, i = \overline{1, I}$, and the coordinate functions $\phi_{h\nu}^{(\lambda)}(i), \lambda, h = \overline{1, N-1}, \nu, i = \overline{1, I}$ describe probabilistic links of the order $\lambda + h$ between the sections $t_\nu$ and $t_i, \nu, i = \overline{1, I}$.

Block-diagram of the procedure for calculating the parameters of the canonical decomposition is shown in Fig. 1.

The concretization of values $X^{\lambda}(\mu)=x^{\lambda}(\mu), \lambda=\overline{1,N-1}, \mu=\overline{1,k}$ allows to move from the a priori random sequence (11) to the a posteriori one:

$$X^{(k)}(i)=m_x^{(k,N-1)}(1,i)+\sum_{\nu=k+1}^{i}\sum_{\lambda=1}^{N-1}V_{\nu}^{(\lambda)}\phi_{1\nu}^{(\lambda)}(i), i=\overline{1,I}. \tag{15}$$

The expression $m_x^{(k,l)}(1,i)=M[X(i)/x^{\nu}(j), j=\overline{1,k}, \nu=\overline{1,N-1}]$ is the conditional expectation of a random sequence providing that values $x^{\nu}(j), \nu=1,\overline{N-1}, j=\overline{1,k}$ are known and the process analyzed is fully specified by the discretized moment functions $M[X^{\lambda}(\nu)], M[X^{\lambda}(\nu)X^{h}(i)], =\lambda, h=\overline{1,N-1}, \nu, i=\overline{1,I}$.

The computing algorithm $m_x^{(k,l)}(1,i)=M[X^{1}(i)/x^{\nu}(j), j=\overline{1,k}, \nu=\overline{1,N-1}]$ has two equivalent forms of notation [16]:

$$m_x^{(\mu,l)}(h,i)=\begin{cases} M[X^{h}(i)], \quad \mu=0; \\ m_x^{(\mu,l-1)}(h,i)+(x^{l}(\mu)-m_x^{(\mu,l-1)}(l,\mu))\phi_{h\mu}^{(l)}(i), l\neq 1, \\ m_x^{(\mu-1,N-1)}(h,i)+(x(\mu)-m_x^{(\mu-1,N-1)}(1,\mu))\phi_{h\mu}^{(1)}(i), l=1 \end{cases} \tag{16}$$

or

$$m_x^{(k,N-1)}(1,i)=M[X(i)]+\sum_{j=1}^{k}\sum_{\nu=1}^{N-1}x^{\nu}(j)F_{((j-1)(N-1)+\nu)}^{(k(N-1))}((i-1)(N-1)+1), \tag{17}$$

where

$$F_{\lambda}^{(\alpha)}(\xi)=\begin{cases} F_{\lambda}^{(\alpha-1)}(\xi)-F_{\lambda}^{(\alpha-1)}(\alpha)\gamma_k(i), \quad \lambda\leq\alpha\text{-}1; \\ \gamma_{\alpha}(\xi), \ \lambda=\alpha; \end{cases} \tag{18}$$

$$\gamma_{\alpha}(\xi)=\begin{cases} \varphi_{1,[\alpha/(N-1)]+1}^{(\mathrm{mod}_{N-1}(\alpha))}([\alpha/(N-1)]+1), \text{ for } \xi\leq k(N-1); \\ \varphi_{1,[\alpha/(N-1)]+1}^{(\mathrm{mod}_{N-1}(\alpha))}(i), \text{ if } \xi=(i\text{-}1)(N\text{-}1)+1. \end{cases} \tag{19}$$

The simulation procedure of the a posteriori random sequence (15) assumes that densities of random coefficients $V_i^{(\lambda)}, \lambda=\overline{1,N-1}, i=\overline{1,I}$ are known. The simplest and the most effective solution to the problem of determining these one-dimensional densities is to use nonparametric parse type estimates [17]. Together with this the estimate of the required density of distribution $f(V_i^{(\lambda)})$ of the random variable $V_i^{(\lambda)}$ according to $L$ of its realization $\mathrm{v}_{i,l}^{(\lambda)}, l=\overline{1,L}$ is represented as

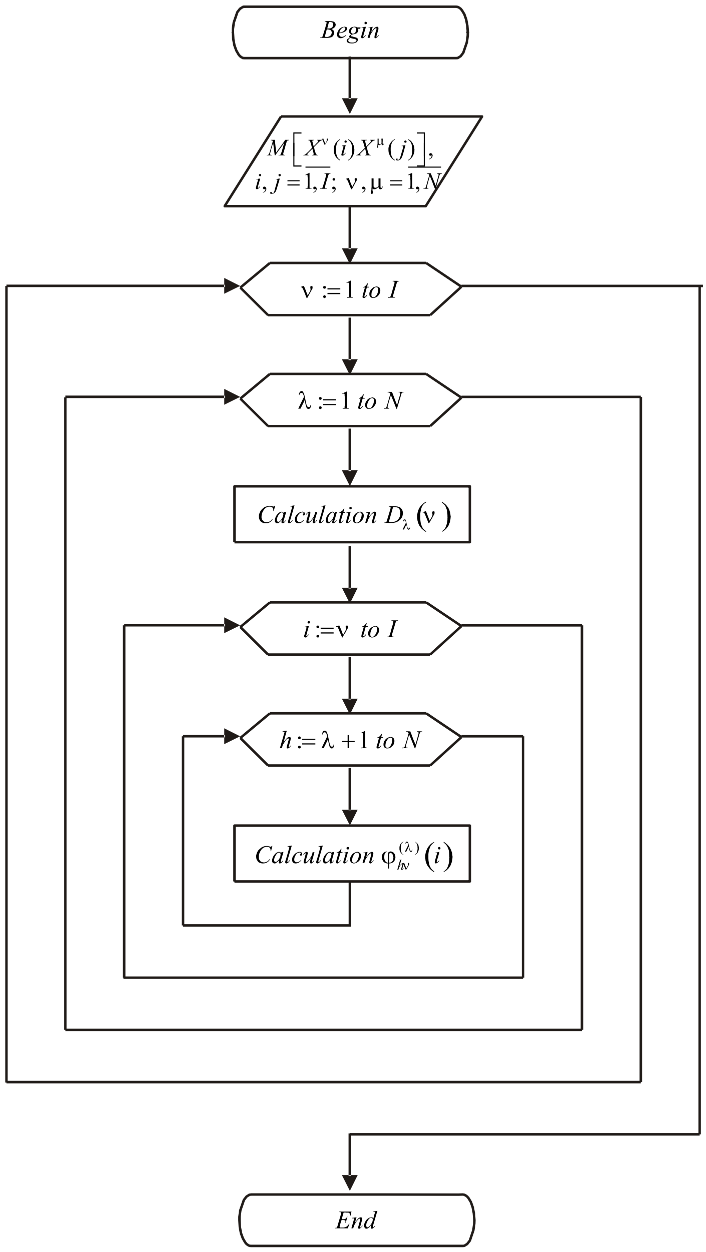


**Fig. 1.** Block-diagram of the procedure for calculating the parameters of the canonical decomposition (11).

$$f_L(V_i^{(\lambda)}) = \frac{1}{dL}\sum_{l=1}^{L} g(u_l), \tag{20}$$

where $u_l = d^{-1}(v_i^{(N)} - v_{i,l}^{(N)})$, $g(u_l)$ - certain weight function (kernel);

$d$ - constant (blur coefficient).

The estimate (20) at all points of the determination region is obtained unbiased, consistent and uniformly converges on the desired distribution density $f(V_i^{(\lambda)})$ with probability one, if the weight function fulfils the condition

$$g(u) \geq 0; \quad \sup_u |g(u)| < \infty; \quad \lim_{u\to\pm\infty} |ug(u)| = 0; \quad \int_{-\infty}^{+\infty} g(u)du = 1. \tag{21}$$

The constant $d$ is selected depending on the number of observations subject to the conditions

$$d > 0; \quad \lim_{L\to+\infty} d(L) = 0; \quad \lim_{L\to+\infty} d(L)L = \infty. \tag{22}$$

When selected as the kernel function $g(u)$ the uniform density distribution blur coefficient is determined on the basis of the correlation

$$d = 0,5\sup_l \left| v_{i,l}^{(N)} - v_{i,l-1}^{(N)} \right|, v_{i,l}^{(N)} > v_{i,l-1}^{(N)}, l = \overline{2,L}. \tag{23}$$

Thus, the offered calculation method of polynomial predictive control of fail-safe operation of information systems consists of the following stages:

- construction on the basis of the known a priori information $M[X^{\lambda}(\nu)], M[X^{\lambda}(\nu)X^{h}(i)], = \lambda, h = \overline{1, N-1}, \nu, i = \overline{1, I}.$ of the canonical expansion (11) of the random sequence of change of the controlled parameter $X$;
- determination from the formula (16) or (17) the values $m_x^{(k,l)}(1,i) = M[X(i)/x^{\nu}(j), j = \overline{1,k}, \nu = \overline{1, N-1}]$ of the conditional expectation of the random sequence analyzed within the forecast region $[t_{k+1}...t_I]$ using the known values $x^{\nu}(j), \nu = 1, \overline{N-1}, j = \overline{1,k}$ on the observation interval $[t_1...t_k]$;
- multiple simulation of values of random coefficients $V_i^{(\lambda)}, i = \overline{k+1, I}, \lambda = \overline{1, N-1}$ under the distribution law (20) and formation using the expression (15) of the set of possible extensions of the realization of the random sequence within the forecast range $[t_{k+1}...t_I]$;
- verification of conditions of non-crossing by the paths obtained of the boundaries of the admissible region $[a;b]$ of the controlled parameter change $X$ and determination of the estimate of the probability of fail-safe operation of the in-

formation system as the ratio of the number of successes to the total number of the experiments conducted.

Increasing the reliability of the estimate of the probability of fail-safe operation on the basis of the model (15) compared to (7) is achieved by using nonlinear stochastic properties of the random sequence analyzed: there rises the accuracy of determination of conditional expectation and reliability of possible paths of a random sequence in the forecast region through the use in the process of simulation of an additional array of random coefficients $V_i^{(\lambda)}, i = \overline{k+1, I}, \lambda = \overline{2, N-1}$. The gain in accuracy can be estimated using the expression:

$$e_{[a,b]}^{(k)} = \frac{\left| m_x^{(k,N-1)}(1,i) - m_x^{(k)}(i) \right| + \{ \sum_{j=1}^{k} \sum_{\nu=1}^{N-1} D_\nu(j)(\beta_{1j}^{(\nu)}(i))^2 - \sum_{j=1}^{k} D_j \phi_\nu^2(i) \}^{1/2}}{b-a}. \quad (24)$$

Let a random sequence $\{X\}$ in the discrete row of points $t_i,\ i = \overline{1, I}$ is set by instant functions: $M\left[ X^{\xi_l}(i - p_{l-1}) X^{\xi_{l-1}}(i - p_{l-2}) ... X^{\xi_2}(i - p_1) X^{\xi_1}(i) \right]$, $\sum_{j=1}^{l} \xi_j \le N,\ p_j = \overline{1, i-1},\ i = \overline{1, I}$. Decomposition of random sequence $\{X\}$ looks like [18],[19]:

$$X(i) = M\left[X(i)\right] + \sum_{\nu=1}^{i-1} \sum_{\xi_1^{(1)}=1}^{N-1} V_{\xi_1^{(1)}}(\nu) \varphi_{\xi_1^{(1)}}^{(1)}(\nu, i) + V_1(i) +$$

$$+ \sum_{\nu=1}^{i-1} \sum_{l=2}^{M(\nu)} \sum_{p_1^{(l)}=1}^{p_1^{'(l)}} \ldots \sum_{p_{l-1}^{(l)} = p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}} \sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}} \ldots \sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}} V_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}(\nu) \times \quad (25)$$

$$\times \varphi_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}^{(1)}(\nu, i),\ i = \overline{1, I},$$

where

$$M(\nu) = \begin{cases} \nu, & \text{if} \quad \nu < N, \\ N, & \text{if} \quad \nu \ge N; \end{cases}$$

$$p_j^{'(l)} = \begin{cases} 0, & \text{if} \quad j \ne \overline{1, l-1} \text{ or } l = 1, \\ \nu - l + j, & \text{if} \quad j \ne \overline{1, l-1}, l > 1; \end{cases}$$

$$\xi_\mu^{'(l)} = N - l + \mu - \sum_{j=1}^{\mu-1} \xi_j^{(l)},\ \mu = \overline{1, l}.$$

The casual coefficients of canonical presentation (9) are defined by the expressions:

$$V_{\alpha_1}(\nu)=X^{\alpha_1}(\nu)-M\left[X^{\alpha_1}(\nu)\right]-\sum_{\lambda=1}^{\nu-1}\sum_{\xi_1^{(1)}=1}^{N}V_{\xi_1^{(1)}}(\lambda)\varphi_{\xi_1^{(1)}}^{(1)}(\lambda,\nu)-\sum_{\xi_1^{(1)}=1}^{\alpha_1-1}V_{\xi_1^{(1)}}(\nu)$$

$$\times\varphi_{\xi_1^{(1)}}^{(\alpha_1)}(\nu,\nu)-\sum_{\lambda=2}^{\nu-1}\sum_{l=2}^{M(\lambda)}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}}V_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}(\lambda)\times \quad (26)$$

$$\times\varphi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\alpha_1)}(\lambda,\nu),\ \nu=\overline{1,I}.$$

The coefficients $V_{\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n}(\nu)$ which contain information about the values $X^{\alpha_n}(\nu-\beta_{n-1})\ldots X^{\alpha_1}(\nu)$ are calculated as

$$V_{\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n}(\nu)=X^{\alpha_n}(\nu-\beta_{n-1})\ldots X^{\alpha_1}(\nu)-M\left[X^{\alpha_n}(\nu-\beta_{n-1})\ldots X^{\alpha_1}(\nu)\right]-$$

$$-\sum_{\lambda=1}^{\nu}\sum_{\xi_1^{(1)}=1}^{N-1}V_{\xi_1^{(1)}}(\lambda)\varphi_{\xi_1^{(1)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\lambda,\nu)-$$

$$-\sum_{\lambda=1}^{\nu-1}\sum_{l=2}^{M(\lambda)}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}}V_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}(\lambda)\times$$

$$\times\varphi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\lambda,\nu)-$$

$$(27)$$

$$-\sum_{l=2}^{n-1}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}}V_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}(\nu)\times$$

$$\times\varphi_{p_1^{(l)}\ldots p_{l-1;}^{(l)}\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\nu,\nu)-$$

$$\sum_{p_1^{(n)}=1}^{p_1^{*(n)}}\cdots\sum_{p_{l-1}^{(n)}=p_{l-2}^{(n)}+1}^{p_{n-1}^{*(n)}}\sum_{\xi_1^{(n)}=1}^{\xi_1^{*(n)}}\cdots\sum_{\xi_n^{(n)}=1}^{\xi_n^{*(n)}}V_{p_1^{(n)}\ldots p_{n-1;}^{(n)}\xi_1^{(n)}\ldots\xi_n^{(n)}}(\nu)\varphi_{p_1^{(n)}\ldots p_{n-1;}^{(n)}\xi_1^{(n)}\ldots\xi_n^{(n)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\nu,\nu).$$

In (27) parameters $p_1^{*(n)},\ldots,p_{n-1}^{*(n)};\xi_1^{*(n)},\ldots,\xi_n^{*(n)}$ are calculated by the following expressions:

$$p_j^{*(n)} = \begin{cases} \beta^*{}_\mu, & \text{if} \quad \mu = 1,\ p_{\mu-1}^{(n)} = \beta^*{}_\mu,\ \mu = \overline{2,n}, \\ \nu - l + \mu, & \text{if } p_{\mu-1}^{(n)} = \beta^*{}_{\mu-1},\ \mu = \overline{2,n}. \end{cases} \tag{28}$$

$$\xi_j^{*(n)} = \begin{cases} \alpha^*{}_i, & \text{if} \quad i = 1,\ \xi_j^{(n)} = \alpha^*{}_{i-1}, i = \overline{2,n}; \\ N - n + i - \sum\limits_{j=1}^{i=1} \xi_j^{(n)}, & \text{if} \quad \xi_j^{(n)} \neq \alpha^*{}_{i-1}, i = \overline{2,n}. \end{cases} \tag{29}$$

The values $\beta^*{}_\mu,\ \mu = \overline{1,n-1}; \alpha^*{}_i,\ i = \overline{1,n},$ are the indexes of casual coefficient $V_{\beta^*{}_1 \ldots \beta^*{}_{n-1}; \alpha^*{}_1 \ldots \alpha^*{}_n}(\nu)$ which proceeds $V_{\beta_1 \ldots \beta_{n-1}; \alpha_1 \ldots \alpha_n}(\nu)$ in canonical decomposition (25) for the moment of time $t_\nu$ :

1. $\beta^*{}_\mu = \beta_\mu, \mu = \overline{1,n-1};\ \alpha^*{}_i = \alpha_i, i = \overline{1,k-1};\ \alpha^*{}_k = \alpha_k - 1;$

$\alpha^*{}_j = N - n + j - \sum\limits_{m=1}^{j-1} \alpha^*{}_m,\ j = \overline{k+1,n};$ if $\alpha_k > 1, \alpha_j = 1,\ j = \overline{k+1,n};$

2. $\beta^*{}_\mu = \beta_\mu, \mu = \overline{1,k-1};\ \beta^*{}_k = \beta_k - 1;\ \beta^*{}_j = \nu - n + j,\ j = \overline{k+1,n-1};\ \alpha^*{}_i = N - n + i -$ $- \sum\limits_{m=1}^{j-1} \alpha^*{}_m, i = \overline{1,n},$ if $\alpha_i = 1, i = \overline{1,n}; \beta_k > \beta_{k-1} + 1;\ \beta_j = \beta_{j-1} + 1;\ j = \overline{k+1,n-1};$

3. $\beta^*{}_\mu = 0;\ \alpha^*{}_i = 0;\ V_{\beta^*{}_1 \ldots \beta^*{}_{n-1}; \alpha^*{}_1 \ldots \alpha^*{}_n}(\nu) = 0,$ if $\beta_\mu = \mu, \mu = \overline{1,n-1};\ \alpha_i = 1, i = \overline{1,n}.$

The expressions for the determination of the dispersion $D_{\alpha_1}(\nu)$**,** of casual coefficients $V_{\alpha_1}(\nu)$ are:

$$\begin{aligned} D_{\alpha_1}(\nu) = M\left[X^{2\alpha_1}(\nu)\right] - M^2\left[X^{\alpha_1}(\nu)\right] - \sum_{\lambda=1}^{\nu-1} \sum_{\xi_1^{(1)}=1}^{N-1} D_{\xi_1^{(1)}}(\lambda) \left\{\varphi_{\xi_1^{(1)}}^{(\alpha_1)}(\lambda,\nu)\right\}^2 - \\ - \sum_{\xi_1^{(1)}=1}^{\alpha_1-1} D_{\xi_1^{(1)}}(\nu) \left\{\varphi_{\xi_1^{(1)}}^{(\alpha_1)}(\nu,\nu)\right\}^2 - \\ - \sum_{\lambda=1}^{\nu-1} \sum_{l=2}^{M(\lambda)} \sum_{p_1^{(l)}=1}^{p'^{(l)}_1} \ldots \sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p'^{(l)}_{l-1}} \sum_{\xi_1^{(l)}=1}^{\xi'^{(l)}_1} \ldots \sum_{\xi_l^{(l)}=1}^{\xi'^{(l)}_l} D_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}(\lambda) \times \\ \times \left\{\varphi_{p_1^{(l)} \ldots p_{l-1;}^{(l)} \xi_1^{(l)} \ldots \xi_l^{(l)}}^{(\alpha_1)}(\lambda,\nu)\right\}^2,\ \nu = \overline{1,I}. \end{aligned} \tag{30}$$

Dispersions $D_{\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n}(\nu)$ of casual coefficients $V_{\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n}(\nu)$ are defined as

$$\begin{gathered}
D_{\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n}(\nu)=M\left[X^{2\alpha_n}(\nu-\beta_{n-1})\ldots X^{2\alpha_1}(\nu)\right]- \\
-M^2\left[X^{\alpha_n}(\nu-\beta_{n-1})\ldots X^{\alpha_1}(\nu)\right]-\sum_{\lambda=1}^{\nu-1}\sum_{\xi_1^{(1)}=1}^{N-1}D_{\xi_1^{(1)}}(\lambda)\times \\
\times\left\{\varphi_{\xi_1^{(1)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\lambda,\nu)\right\}^2- \\
-\sum_{\lambda=1}^{\nu-1}\sum_{l=2}^{M(\lambda)}\sum_{p_1^{(l)}=1}^{p_1^{\prime(l)}}\ldots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{\prime(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{\prime(l)}}\ldots\sum_{\xi_l^{(l)}=1}^{\xi_l^{\prime(l)}}D_{p_1^{(l)}\ldots p_{l-1}^{(l)};\xi_1^{(l)}\ldots\xi_l^{(l)}}(\lambda)\times \\
\times\left\{\varphi_{p_1^{(l)}\ldots p_{l-1}^{(l)};\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\lambda,\nu)\right\}^2- \\
-\sum_{l=2}^{n-1}\sum_{p_1^{(l)}=1}^{p_1^{\prime(l)}}\ldots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{\prime(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{\prime(l)}}\ldots\sum_{\xi_l^{(l)}=1}^{\xi_l^{\prime(l)}}D_{p_1^{(l)}\ldots p_{l-1}^{(l)};\xi_1^{(l)}\ldots\xi_l^{(l)}}(\nu)\times \\
\times\left\{\varphi_{p_1^{(l)}\ldots p_{l-1}^{(l)};\xi_1^{(l)}\ldots\xi_l^{(l)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\nu,\nu)\right\}^2- \\
-\sum_{p_1^{(n)}=1}^{p_1^{*(n)}}\ldots\sum_{p_{l-1}^{(n)}=p_{l-2}^{(n)}+1}^{p_{n-1}^{*(n)}}\sum_{\xi_1^{(n)}=1}^{\xi_1^{*(n)}}\ldots\sum_{\xi_n^{(n)}=1}^{\xi_n^{*(n)}}D_{p_1^{(n)}\ldots p_{n-1}^{(n)};\xi_1^{(n)}\ldots\xi_n^{(n)}}(\nu)\times \\
\times\left\{\varphi_{p_1^{(n)}\ldots p_{n-1}^{(n)};\xi_1^{(n)}\ldots\xi_n^{(n)}}^{(\beta_1,\ldots\beta_{n-1};\alpha_1,\ldots\alpha_n)}(\nu,\nu)\right\}^2,\nu=\overline{1,I}.
\end{gathered} \tag{31}$$

The coordinate functions of canonical decomposition (25) are defined by the formulas:

- to describe the relationship between the value $X^{\alpha_1}(\nu)$ and $X^{a_m}(i-b_{m-1})\ldots X^{a_1}(i)$

$$\varphi_{\alpha_1}^{(b_1 \dots b_{m-1}; a_1 \dots a_m)}(\nu, i) = \frac{1}{D_{\alpha_1}(\nu)} \Big\{ M\Big[ X^{\alpha_1}(\nu) X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i) \Big] -$$

$$- M\Big[ X^{\alpha_1}(\nu) \Big] M\Big[ X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i) \Big] -$$

$$- \sum_{\lambda=1}^{\nu-1} \sum_{\xi_1^{(1)}=1}^{N-1} D_{\xi_1^{(1)}}(\lambda) \varphi_{\xi_1^{(1)}}^{(\alpha_1)}(\lambda, \nu) \varphi_{\xi_1^{(1)}}^{(b_1 \dots b_{m-1}; a_1 \dots a_m)}(\lambda, i) -$$

$$- \sum_{\xi_1^{(1)}=1}^{\alpha_1 - 1} D_{\xi_1^{(1)}}(\nu) \varphi_{\xi_1^{(1)}}^{(\alpha_1)}(\nu, \nu) \varphi_{\xi_1^{(1)}}^{(b_1 \dots b_{m-1}; a_1 \dots a_m)}(\nu, i) - \quad (32)$$

$$- \sum_{\lambda=1}^{\nu-1} \sum_{l=2}^{M(\lambda)} \sum_{p_1^{(l)}=1}^{p_1^{\prime(l)}} \dots \sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{\prime(l)}} \sum_{\xi_1^{(l)}}^{\xi_1^{\prime(l)}} \dots \sum_{\xi_l^{(l)}}^{\xi_l^{\prime(l)}} D_{p_1^{(l)} \dots p_{l-1;}^{(l)} \xi_1^{(l)} \dots \xi_l^{(l)}}(\lambda) \times$$

$$\times \varphi_{p_1^{(l)} \dots p_{l-1;}^{(l)} \xi_1^{(l)} \dots \xi_l^{(l)}}^{(\alpha_1)}(\lambda, \nu) \varphi_{p_1^{(l)} \dots p_{l-1;}^{(l)} \xi_1^{(l)} \dots \xi_l^{(l)}}^{(b_1 \dots b_{m-1}; a_1 \dots a_m)}(\lambda, \nu) \Big\}, \ \nu = \overline{1, I}.$$

– to describe the relationship between the value $X^{\alpha_n}(\nu - \beta_{n-1}) \dots X^{\alpha_1}(\nu)$ and $X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i)$

$$\varphi_{\beta_1, \dots \beta_{n-1}; \alpha_1, \dots \alpha_n}^{(b_1, \dots b_{m-1}; a_1, \dots a_m)}(\nu, i) = \frac{1}{D_{\beta_1, \dots \beta_{n-1}; \alpha_1, \dots \alpha_n}(\nu)} \Big\{ M\Big[ X^{\alpha_n}(\nu - \beta_{n-1}) \dots X^{\alpha_1}(\nu) \times$$

$$\times X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i) \Big] - M\Big[ X^{\alpha_n}(\nu - \beta_{n-1}) \dots X^{\alpha_1}(\nu) \Big] \times$$

$$\times M\Big[ X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i) \Big] - M\Big[ X^{\alpha_n}(\nu - \beta_{n-1}) \dots X^{\alpha_1}(\nu) \Big] \times \quad (33)$$

$$\times M\Big[ X^{a_m}(i - b_{m-1}) \dots X^{a_1}(i) \Big] -$$

$$- \sum_{\lambda=1}^{\nu-1} \sum_{\xi_1^{(1)}=1}^{N-1} D_{\xi_1^{(1)}}^{(j)}(\lambda) \varphi_{\xi_1^{(1)}}^{(\beta_1, \dots \beta_{n-1}; \alpha_1, \dots \alpha_n)}(\lambda, \nu) \varphi_{\xi_1^{(1)}}^{(b_1 \dots b_{m-1}; a_1 \dots a_m)}(\lambda, i) -$$

$$-\sum_{\lambda=1}^{\nu-1}\sum_{l=2}^{M(\lambda)}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}} D_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}(\lambda)\times$$

$$\times\varphi_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}^{(\beta_1,\dots\beta_{n-1};\alpha_1,\dots\alpha_n)}(\lambda,\nu)\varphi_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}^{(b_1,\dots b_{m-1};a_1,\dots a_m)}(\lambda,i)-$$

$$-\sum_{l=2}^{n-1}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}} D_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}(\nu)\times$$

$$\times\varphi_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}^{(\beta_1,\dots\beta_{n-1};\alpha_1,\dots\alpha_n)}(\nu,\nu)\varphi_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}^{(b_1,\dots b_{m-1};a_1,\dots a_m)}(\nu,i)-$$

$$-\sum_{p_1^{(n)}=1}^{p_1^{*(n)}}\cdots\sum_{p_{l-1}^{(n)}=p_{l-2}^{(n)}+1}^{p_{n-1}^{*(n)}}\sum_{\xi_1^{(n)}=1}^{\xi_1^{*(n)}}\cdots\sum_{\xi_n^{(n)}=1}^{\xi_n^{*(n)}} D_{p_1^{(n)}\dots p_{n-1;}^{(n)}\xi_1^{(n)}\dots\xi_n^{(n)}}(\nu)\times$$

$$\left.\times\varphi_{p_1^{(n)}\dots p_{n-1;}^{(n)}\xi_1^{(n)}\dots\xi_n^{(n)}}^{(\beta_1,\dots\beta_{n-1};\alpha_1,\dots\alpha_n)}(\nu,\nu)\varphi_{p_1^{(n)}\dots p_{n-1;}^{(n)}\xi_1^{(n)}\dots\xi_n^{(n)}}^{(b_1,\dots b_{m-1};a_1,\dots a_m)}(\nu,i)\right\},\ \nu=\overline{1,I}.$$

Tipping in the expression (3) of known values $X(\mu)=x(\mu),\mu=\overline{1,k}$ converts the a priori random sequence into the a posteriori one:

$$X(i)=M\left[X(i)\right]+m_x^{(I-N+1,I-N+2,\dots,I-1;1,1\dots1,\nu)}(1,i)+$$

$$+\sum_{\nu=k+1}^{i-1}\sum_{\xi_1^{(1)}=1}^{N-1}V_{\xi_1^{(1)}}(\nu)\times\varphi_{\xi_1^{(1)}}^{(1)}(\nu,i)+V_1(i)+$$

$$+\sum_{\nu=k+1}^{i-1}\sum_{l=2}^{M(\nu)}\sum_{p_1^{(l)}=1}^{p_1^{'(l)}}\cdots\sum_{p_{l-1}^{(l)}=p_{l-2}^{(l)}+1}^{p_{l-1}^{'(l)}}\sum_{\xi_1^{(l)}=1}^{\xi_1^{'(l)}}\cdots\sum_{\xi_l^{(l)}=1}^{\xi_l^{'(l)}} V_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}(\nu)\times \quad (34)$$

$$\times\varphi_{p_1^{(l)}\dots p_{l-1;}^{(l)}\xi_1^{(l)}\dots\xi_l^{(l)}}^{(1)}(\nu,i),\ i=\overline{k+1,I}.$$

Values of conditional expectation are defined as ( $x(i)=m_x^{(\beta_1\dots\beta_{n-1};\alpha_1\dots\alpha_n,\nu)}(b_1\dots b_{m-1};a_1\dots a_m,i)$

$$
x(i)=\begin{cases}
M\left[X^{a_m}(i-b_{m-1})\ldots X^{a_1}(i)\right],\ \nu=0; \\
\\
m_x^{(\beta^*{}_1\ldots\beta^*{}_{n-1};\alpha^*{}_1\ldots\ldots\alpha^*{}_n,\nu)}\left(b_1\ldots b_{m-1};a_1\ldots a_m,i\right)+\left[x^{\alpha_n}\left(\nu-\beta_{n-1}\right)\ldots x^{\alpha_1}\left(\nu\right)\right. \\
\left.-m_x^{(\beta^*{}_1\ldots\beta^*{}_{n-1};\alpha^*{}_1\ldots\ldots\alpha^*{}_n,\nu)}\left(\beta_1\ldots\beta_{n-1};\alpha_1\ldots\alpha_n,\nu\right)\right]\times \\
\times\varphi_{\beta_1\ldots\beta_{n-1};\alpha_1\ldots\ldots\alpha_n}^{(b_1\ldots b_{m-1};a_1\ldots a_m)}\left(\nu,i\right),\text{if}\quad \alpha^*{}_1\neq 0,\ldots,\alpha^*{}_n\neq 0; \\
\\
m_x^{(p_1^{'(n-1)}\ldots p_{n-2}^{'(n-1)};\xi_1^{'(n-1)}\ldots\xi_{n-1}^{'(n-1)},\nu)}\left(b_1\ldots b_{m-1};a_1\ldots a_m,i\right)+\left[x^{\alpha_n}\left(\nu-\beta_{n-1}\right)\ldots\right. \\
\left.\ldots x^{\alpha_1}\left(\nu\right)-m_x^{(p_1^{'(n-1)}\ldots p_{n-2}^{'(n-1)};\xi_1^{'(n-1)}\ldots\xi_{n-1}^{'(n-1)},\nu)}\left(\beta_1\ldots\beta_{n-1};\alpha_1\ldots\alpha_n,\nu\right)\right]\times \\
\times\varphi_{\beta_1\ldots\beta_{n-1};\alpha_1\ldots\ldots\alpha_n}^{(b_1\ldots b_{m-1};a_1\ldots a_m)}\left(\nu,i\right),\ \text{if}\ \alpha^*{}_1=0,\ldots,\alpha^*{}_n=0.
\end{cases}
\tag{35}
$$

Technology of predictive control of fail-safe operation on the model (35) is the same as using the expression (15).

## 4 Conclusion

Thus, there we obtained an calculation method for the estimation of the probability of fail-safe operation of information systems in the future instants of time. The technology is based on the model of the canonical expansion of the a posteriori random sequence of changes of the parameter controlled. Estimation of the probability of fail-safe operation of a information system based on the results of the numerical experiments is determined as a relative frequency of an event characterized by belonging of the realization to the allowable region on the forecast interval. The calculation method offered does not impose any significant constraints on the class of random sequences analyzed (linearity, stationarity, Markov behaviour, monotoneness, etc.). The only constraint is the finiteness of variance that is usually performed for real random processes. In contrast to the known solutions [12], [13] the suggested estimation procedure for fail-safe operation of information systems allows for nonlinear stochastic properties of the random sequence analyzed, which improves the accuracy of the predictive control procedure.

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