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Dynamic Behavioral Prediction of Objects Based on Multi-Step Filtration of Signals

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ABSTRACT: Formulated the objective of enhancing the effectiveness of the automated systems of operatively-dispatching management of complex chemical-technological processes operating in real-time, based on short-term forecasting algorithms parameters control objects and procedures, multi-step dynamic filtering. It is shown that in the case of a priori specified linear mathematical models of chemical-technological processes and systems are effective in terms of the accuracy of the forecasts is the optimal adaptive filter type of kalmanov.

KEYWORDS: short-term forecasting, dynamic filtering, parameter estimation models of complex dynamic objects.

I. INTRODUCTION

For processes using formalized mathematical models, the prediction of future states may be performed on the basis of known prediction methods. However, the prediction problem is much more complicated, if the process is a multi-step, differing significantly unsteady and stochastic.

Analysis of a large class of automatic control systems that operate in chemical, food and related industries shows that a significant reduction in the efficiency of technological installations systems, as well as the quality of the final product is due to the low reliability of operational short-term forecasting.

In this context, the task of applying forecasting methods based on dynamic filtering procedures to build chemical and adaptive process control systems is urgent.

Referring to the development of prediction algorithms based on sequential dynamic filtering procedures and formulate a general statement of the characteristics of the problem of forecasting stochastic process in terms of the statistical theory of optimal estimation [1-3].

II. STATEMENT OF THE PROBLEM OF FORECASTING THE PARAMETERS OF DYNAMIC OBJECTS AND MULTI-STEP FILTRATION

Suppose we have a production process, the current state is in the time i can be described by n - dimensional random vector $x_i(i=\overline{1,l})$. Observation of the process at time j can be written as m - dimensional vector $z_j(j=\overline{1,k})$ statistically associated with the state vector. Let determined sequence of observations $z_j(j=\overline{1,k})$. Required to determine the estimate of the state vector $\hat{x}_n$ for a given n - th instant of time, if x_0 is not available to direct observation.

Since the state vector x_i and vector surveillance z_j statistically linked, evaluation path x observations can be given z. You need to select possible rating that which has the greatest accuracy, that is, sets the estimated trajectory $\hat{x}$, closest to the trajectory x. Let the estimate obtained from observations, through $\hat{x}_n$:

$$\hat{x}_n = F_n(z_j),(j=\overline{1,k}) \tag{1}$$

Consider the dynamic relationship:

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$$x_{n+1} = F \cdot x_n + G \cdot U_n, \tag{2}$$

where F and G - characterize the dynamic properties of the process and limit the input signal; U_n - independent Gaussian random sequence with zero mean and covariance matrix Q.

Observations by the relation:

$$z_n = H \cdot x_n + V_n, \tag{3}$$

where H - is characterized by the limitations imposed on the monitoring of $x_n; V_n$ - sequence analogous to U_n with covariance matrix R.

Initial conditions are $x(0)$, and

$M[x(0)] = x,\ cov[x(0), x(0)] = P_0$.

The values of F, G and H may change with time.

The problem of obtaining evaluation $\hat{x}_i (0 \le i \le n)$ set as follows. Gave measurement $z_1, z_2, ..., z_n$. Assessment is required to determine $x_{i/n} (0 \le i \le n)$ Measuring data, which minimize the criterion:

$$J = \frac{1}{2}\left[(\hat{x}_{0/n} - x)^T P_0^{-1} (\hat{x}_{0/n} - x)\right] + \\ + \sum_{i=0}^{n-1} \frac{1}{2} \left\{\left[(z_{i+1} - H\hat{x}_{i+1/n})^T R^{-1} + (z_{i+1} - H\hat{x}_{i+1/n})\right] + \left[(\hat{U}_{i/n})^T Q^{-1} (U_{i/n})\right]\right\}, \tag{4}$$

with constraints

$$\hat{x}_{(i+1)/n} F\hat{x}_{i/n} + G\hat{U}_{i/n} \tag{5}$$

It is necessary to know the optimal estimate $\hat{x}_{n/n}$, minimizing criterion J, i.e., should first solve the filtering problem [2]. The optimum solution can be obtained by using the following relations:

$$\begin{aligned} x_{n/n} &= F\hat{x}_{n-1/n-1} + P_{n/n} H^T R^{-1} (z_n - HF\hat{x}_{n-1/n-1}), \\ P_{n/n} &= P_{n/n-1} - P_{n/n-1} H^T (HP_{n/n-1} H^T + R)^{-1} HP_{n/n-1}, \\ P_{n/n-1} &= FP_{n-1/n-1} F^T + GQB^T. \end{aligned} \tag{6}$$

Let forecast process is given in the form of multi-dimensional discrete systems, which transition from the i - th state in the $(i+1)$ describes multidimensional difference equation:

$$x_{i+1} = A_{j,i+1} x_i + \varepsilon_i, \tag{7}$$

where A_i - known transition matrix dimension $(n \times n)$; x_i - column vector in phase coordinates the i -th time dimension of time $(n \times 1)$: δ_i - column vector of additive noise dimension $(n \times 1)$.

At time i is measured z_i, which is associated vector equation with the vector of the phase state:

$$z_i = D_i x_i + \delta_i, \tag{8}$$

where z_i - column vector of dimension measurements $(m \times 1)$; D_i - matrix coefficients known dimension $(m \times n)$; δ_i - column vector of additive noise dimension $(n \times 1)$.

We assume that the random processes and are independent with zero mean values: $M(\varepsilon) = M(\delta) = 0$ and symmetric, non-negative definite covariance matrices: $M[\varepsilon\varepsilon^T] = Q, M[\delta\delta^T] = R.$

Equation (8) allows the extrapolated estimates of the state vector $(i+1)$ - th point, if known previous estimates:

$$\hat{x}_{i+1} = A_{i,i+1} \hat{x}_i. \tag{9}$$

Extrapolated estimation errors are characterized by the following covariance matrix:

$$K_{i+1} = A_{i,i+1} K_i A^T{}_{i,i+1} + Q_i. \tag{10}$$

ISSN: 2350-0328
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Selecting the optimal estimate of the linear form is determined by the following factors. Firstly, most of the technical problems in the linear operator easiest implemented using linear devices. Secondly, for a normal random process, the criterion A- optimality of the optimal linear operator is generally a linear operator, that is, you can not improve the value of the criterion by shifting from a linear operator to any other non-linear operators.
In accordance with the foregoing, a new assessment will be written in the form:

$$\hat{x}_i^+ = \hat{x}_i + F(z_i - D\hat{x}_i), \tag{11}$$

where F_i - matrix coefficients of enhancing a dimension $(n \times m)$.
Imagine an expression (11):

$$\hat{x}_i^+ - x_i = \hat{x}_i - x_i + F\left[-D(\hat{x}_i - x_i) + \delta_i\right], \tag{12}$$

where $\hat{x}_i$ - the true value of the vector of the phase state of the test process.
Then a new phase state estimation error is equal to:

$$\varepsilon_L^+ = \varepsilon_i + F\left[\delta_i - D_i\varepsilon_i\right]. \tag{13}$$

Define the error covariance's matrix of the new assessment of the State of the managed process. By definition, we have:

$$K_L^+ = M(\varepsilon_i^+ \varepsilon_i^{+T}). \tag{14}$$

Performing an operation definition of mathematical expectation and using lemma on the treatment of matrices, one can show that the system, describing the optimal filter has the form:

$$\begin{aligned} \hat{x}_i^+ &= \hat{x}_i + F_i(z_i D_i \hat{x}_i), \\ F_i &= K_i D^T (R_i + D_i K_i D^T)^{-1}, \\ K_i^+ &= K_i - K_i D_i^T (R_i + D_i K_i D_i^T)^{-1} D_i K_i. \end{aligned} \tag{15}$$

This filter is a filter type of kalmanov and ensures that parameter estimates of the projected process on minimum generalized variance (covariance matrix track minimum K_i^+).
The system that characterizes the optimal prediction filter is as follows:

$$\begin{aligned} \hat{x}_{i+n} &= A_{i,i+n}\hat{x}_i^+, \\ K_{i+n} &= A_{i,i+n} K_i^+ A_{i,i+n} + \sum_{n=1}^{m} A_{i+n,i+n} Q_{i+n-1} A_{i+n,i+}^T \end{aligned} \tag{16}$$

Prediction filter (16) does not impose any restrictions on the kind of laws of distribution clutter ε and δ. Just enough so that the first two were raised initial moment [4].
Thus, in the case of a linear relationship between dimensions and phase a state vector, normal laws of distribution of errors of measurements and assessments of the state of the process, procedures, found on the criterion of minimum footprint of the covariance matrix of errors of assessment and on the criterion of maximum information, equivalent.
The process of forecasting (extrapolating) the state of an object can be accessed, if you use the results of previous measurements, i.e. simulate the dynamics of equation at the time of each subsequent measurement, applying the approximation process as measured by specified class functions, selectable, based on the physical properties of the analyzed process [5]. The most simple form of approximation of the equations of dynamics of nonlinear process is its Taylor series representation for the known interval of quantization Δt:

$$x_{i+1} = x_i + \dot{x}_i \Delta t_i + \frac{1}{2!}\ddot{x}\Delta t^2 + ..., \tag{17}$$

where $x_i = x(t_i)$ - the value of the measured parameter at the time $T = t$.

Since the values of derivatives $\dot{x}_i, \ddot{x}_i$ not exactly known for their determination to seize earlier measurements in moments $(i-1),(i-2)$ and i.e. Having carried out at an interval of quantization operation linear approximation and holding three members of decomposition, after some transformation can come to expression type:

$$x_{i+1} = A_i x_i + A_{i-1} x_{i-1} + A_{i-2} x_{i-2} + \gamma, \tag{18}$$

where γ - column vector approximation error, consisting of the error term, due to the finite number of terms in the expansion and term, due to the inaccuracy of the calculation of derivatives; A_{i-j} - constant matrix coefficients.

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Vol. 3, Issue 5 , May 2016

Expression (18) is a second-order predictors and allows you to predict the State of the process on $(i+1)$ -th time.
Without loss of generality, suppose now that the numerical approximation error characteristics satisfy the conditions:

$$n(\gamma)=0;\; M(\gamma,\gamma^T)=Q. \tag{19}$$

A generalized form of the quasi-optimal filter, when the problem of forecasting in conditions of uncertainty a priori process model involves finding the parameter estimates the object with arbitrarily specified interval lead S l when using predicator order, is as follows:

$$\hat{x}_{(i+s)}=\left\{\prod_{j=1}^{s}A_{(i+s),(i+s-j+1)}\right\}\hat{x}_i^{+}=B_{i,(i+s)}\hat{x}^{+}{}_i,$$

$$K_{i+s}=B_{i,i+1}K_i^{+}B_{i,i+s}^{T}+\sum_{j=1}^{s}B_{i+j,i+s}Q_{i+j-1}B_{i+j,i+s}^{T}, \tag{20}$$

$$\hat{x}_i^{+}=\hat{x}_i+F_i(Z_i-D_i\hat{x}_i),\;\; F_i=K_iD_i^T(R_i+D_iK_iD_i^T)^{-1},$$

$$K_i^T=K_i-K_iD_i^T(R_i+D_iK_iD_i^T)^{-1}D_iK_i$$

where $A_{i,i+1}$ – known transfer matrix dimension ($n\times n$); $\hat{\bar{x}}_i$ – vector-phase column coordinates in the i -th time dimension $(n\times 1)$; $\bar{z}_i$ – vector-column dimension measurements $(n\times 1)$; D_i – matrix coefficients known dimension $(m\times n)$; K_i – covariance matrix of the predictable process in i -th time; $\hat{\bar{x}}_{i+s}^{+}$ – forecast values for the point-in-time process $(i+s, s\ge 1)$; s – the specified point in time.

To obtain the predicted state of the process y_{i+a}, You must enter into a new vector variables x high dimension and using expressions (20), find the value of $\hat{x}_{i+s}$. From the received vector $\hat{x}_{i+s}$ You can select the desired vector process state y_{i+a}.

The increase in the number of component in vector with n before p_n mean increase in computing as in filter equations, and the equations for the transmission matrix of correlation matrices. For example, ten dimensional vector of state $\bar{x}$ and vector 2D measurements $\bar{y}$ $(n=10; m=2)$.When considering the status vector (for example, filter order $p=4$) transfer matrix will have dimension $p_n\times m=40\times 2$, the number of elements in each matrix correlation increases almost 15 times. It follows that the choice of the order of predicator must take into account the accuracy of the solution requirements, restrictions on the time and computer resources.
Thus, the problem of synthesis prediction in case filter quasi-optimal a priori uncertainties in knowledge of mathematical object model, which allows you to predict his condition for each subsequent interval of quantization.

III. CONCLUSION

The analysis shows essential advantage of adaptive filters on the reached forecast accuracy. In the process of predicting the parameters provided automatically update the mathematical model of the process by which indirectly can judge the degree of controllability and the normality of its occurrence in time. For more exact description of the studied process the nonlinear model can be constructed. At the same time dimensions of the corresponding vectors and matrixes will increase. Basic changes won't happen, but requirements to memory size and speed of the computer will increase.
The developed algorithms of forecasting on the basis of procedures dynamic have found for a filtration practical application at expeditious forecasting of behavior of technological processes of extraction, evaporation and drying granulation in production of ammophos on Almalyk ON "Ammophos". The analysis of results of pilot studies demonstrates that the most exact forecast in all considered cases provides algorithm of expeditious forecasting with use of the adaptive filter. This result is represented quite natural as this algorithm, in comparison with algorithms of a quasi-optimal filtration with a predictor of the second order and with use of the ordinary filter of Kallman, possesses ability of adaptation to the changing interference-signal situation and has the largest level of information owing to what reproduces an observed situation more adequately and provides higher precision of forecasting.

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Thus, results of approbation of the developed algorithms confirm efficiency of the accepted approaches and the used mathematical apparatus in problems of forecasting of output variable various technological objects of management and are urged to promote improvement of quality of functioning of the automated systems of supervisory control.

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