DEVELOPMENT OF SCIENTIFIC FOUNDATIONS OF THE THEORY OF ADAPTIVE IDENTIFICATION USED IN AUTOMATION FOR COMPLEX, MULTI-INPUT-OUTPUT OBJECTS

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Abstract. In article, solutions of a task from transition of automation of separate processes to automation are proposedindustrial complexes possibilities of application of the theory of adaptive identification of multicoherent objects are also shown on example of treatment facilities.

Keywords: management of multicoherent objects, adaptive identification, linear non-uniform differential equations, matrix coefficients, compound vectors, structural scheme.

Аннотация. В статье предложены решения задачи от перехода автоматизации отдельных процессов к автоматизации производственных комплексов и показаны возможности применения теории адаптивной идентификации многосвязных объектов на примере очистных сооружений.

Ключевые слова: управление многосвязными объектами, адаптивная идентификация, линейные неоднородные дифференциальные уравнения, матричные коэффициенты, составные векторы, структурная схема.

Annotatsiya. Ushbu maqolada alohida jarayonlarni avtomatlashtirishdan sanoat miqyosidagi kompleks tizimlarni avtomatlashtirish bosqichiga o‘tish masalasi ko‘rib chiqiladi. Shuningdek, oqava suvlarni tozalash inshootlari misolida ko‘p o‘zaro bog‘langan ob’ektlarda moslashuvchan (adaptiv) identifikatsiya nazariyasini qo‘llash imkoniyatlari yoritib berilgan.

Kalit so‘zlar: ko‘paytmali bog‘langan ob‘ektlarni boshqarish, moslashtirilgan identifikatsiya, chiziqli bir jinsli bo‘lmagan differentsial tenglamalar, matritsa koeffitsientlari, birikma vektorlar, blok-sxema.

Introduction

The numerous tasks of managing production processes and complex installations, which should include the chemical and biological treatment of wastewater, are multi-connected objects, requiring the transition from automation of individual processes to automation of production complexes.

This leads to the need to take into account the interconnection of input and output coordinates of individual processes, and consequently, the structural connections between them. The lack of sufficiently complete a priori information about the object, the distribution laws of random parameters, and random influences necessitates the application of adaptive identification theory.

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In the future, we will understand the adaptive identification of multi-linked objects as determining the parameters and structure of objects under initial uncertainty conditions, based on the results of observing changes in input and output values, during normal operation. From this point of view, the electric power systems of water drainage and treatment facilities, in which the simultaneous regulation of frequency and voltage, flows of active and reactive power, and the productivity of turbocompressors of pumping stations is carried out, are of particular interest, and according to their technological regime, they are classified as multi-connected objects with separate control channels and operating modes [1, 2, 4].

Methodology

It is known that the parameters of a controlled object, such as drainage and treatment facilities, vary widely [4, 5, 7]. If we assume that only one factor (e.g., wastewater concentration) influences the change in the object's parameters, neglecting the operating modes of turbocompressors and pump units, then using the obtained control object parameters without significant errors is impossible. If we solve the problem of identifying treatment facilities as a multi-linked object, taking into account all the indicated values during operation, then the resulting parameters of the object will be determined significantly more accurately [3, 4, 6, 9].

The adaptive identification problem arises due to the fact that, in general, the internal and external influence acting on the object is random. For water treatment facilities as objects, this randomness is due to the random nature of disturbing moments and other factors caused by uneven distribution of pump motor power, unstable pressure in turbocompressors from cycle to cycle, active sludge concentration, active chlorine dose, etc. [4, 8, 10, 11]. For treatment plants, such effects are: filling of settling tanks and aeration tanks, failure of one of the symmetrically located engines and pumps, etc.

It is not difficult to determine the distribution laws of each of the indicated factors separately [4, 12, 13], but it is almost impossible to determine the resulting distribution law of the entire set of factors, and accordingly, the dependent identifiable parameters of the object. In this regard, the problem of identifying multi-linked objects reduces to the problem of adaptive identification.

Result and discussion

Currently, there is no complete theory of adaptive identification of multi-linked objects. This article outlines some issues in the theory of adaptive identification of multi-linked objects containing direct and inverse cross-links.

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Let's describe the processes in the multi-linked objects of the system of linear non-homogeneous differential equations of order l with r unknown variables x1, x2,... , xr of the argument t with constant coefficients

$$\sum_{j=1}^{r} a_{ij}(D)x_j = \sum_{j=1}^{r} b_{ij}(D)v_j \quad (1)$$

$\bar{x} = \{x_1, x_2, \ldots, x_r\}$; $\bar{v} = \{v_1, v_2, \ldots, v_r\} a_{ij}(D), b_{ij}(D)$where the coordinate set - vectors - columns of the object's state and control, respectively; i - separation channel number; D=d/dt - differentiation operator; - polynomials from D, which have the form

$$a_{ij}(D) = a_{ij}^{(l)} D^l + a_{ij}^{(l-1)} D^{l-1} + \ldots + a_{ij}^{(1)} D + a_{ij}^{(0)}; \quad (2)$$

$$b_{ij}(D) = b_{ij}^{(l_1)} D^{j_1} + b_{ij}^{(l_1-1)} D^{l_1-1} + \ldots + b_{ij}^{(1)} D + b_{ij}^{(0)};$$

Here, *i, j*=1,2,...,*r*; l, l_1-the order of the polynomial of the coefficients a and b respectively; *r*- number of separate channels of the managed object. The number of direct cross-connections is assumed to be equal to the number of inverse cross-connections; the order of the differential equations of inverse cross-connections is equal to the order of the differential equations of direct cross-connections. These assumptions do not narrow the commonality of the problem, since it reduces to particular cases in the presence of any other variants and combinations of cross-connections, as well as the order of differential equations. Let's introduce a multitude of operator coefficient matrices [4, 13]:

$$\mathrm{A(D)} = \left\| a_{ij}(D) \right\|;$$

$$\mathrm{B(D)} = \left\| b_{ij}(D) \right\|; \quad (3)$$

or in extended form

$$A(D) = \left\| \begin{matrix} a_{11}(D) a_{12}(D) \ldots a_{1r}(D) \\ a_{21}(D) a_{22}(D) \ldots a_{2r}(D) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ a_{r1}(D) a_{r2}(D) \ldots a_{rr}(D) \end{matrix} \right\|; \quad (4)$$

$$B(D) = \left\| \begin{matrix} b_{11}(D) b_{12}(D) \ldots b_{1r}(D) \\ b_{21}(D) b_{22}(D) \ldots b_{2r}(D) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ b_{r1}(D) b_{r2}(D) \ldots b_{rr}(D) \end{matrix} \right\|;$$

Horizontal

$$A_k = \left\| a_{ij}^{(k)} \right\| (i, j = 1, 2, \ldots, r;$$

k=0, 1, 2,... , l; (5)

$$B_q = \left\| b_{ij}^{(q)} \right\| q = 0, 1, 2, \ldots l_1),$$

можно Represent many matrices A (D) in B (D) as polynomials with matrix coefficients.

$$\mathrm{A\ (D) = A_l D^l + A_{l-1} D^{l-1} + \ldots + A_1 D + A_0;}$$

$$\mathrm{B\ (D) = Bl1 Dl1 + Bl\text{-}1 Dl1\text{-}1 + \ldots + B1D + B0;} \quad (6)$$

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Then in matrix form, the system of differential equations (1) takes the form

$$\sum_{k=0}^{l} A_k D^k x = \sum_{q=1}^{l_1} B_q D^q \bar{u} \qquad (7).$$

In extended form for any separate channel, you can write

$$\sum_{k=0}^{l} \sum_{j=1}^{r} a_{ij}^{(k)} D^k x_j = \sum_{q=0}^{l_1} \sum_{j=1}^{r} b_{ij}^{(q)} D^q u_j \qquad (8)$$

Let's rewrite equation (8) in difference form (in recurrent form):

$$x_i[n] = \sum_{k=0}^{l} \sum_{j=1}^{r} c_{ij}^{(k)} x_i[n-k] + \sum_{q=1}^{l_1} \sum_{j=1}^{r} d_{ij}^{(q)} u[n-q] \qquad (9)$$

The matrix coefficients of the equations are related to each other by the relations [4, 14].

$$c_{ij}^{(l-k)} = -\sum_{v=0}^{k} a_{ij}^{(l-v)} (-1)^{k-v} c_{l-v}^{k-v};$$

$$a_{ij}^{(l_1-q)} = -\sum_{v=0}^{q} a_{ij}^{(l_1-v)} (-1)^{q-v} c_{l_1-v}^{q-v};$$

where

$$c_{l-v}^{k-v} = \frac{(1-v)!}{(k-v)!\,(l-k)!};$$

$$c_{l_1-v}^{k-v} = \frac{(1_1-v)!}{(q-v)!\,(l_1-k)!};$$

For a controlled object with only direct cross-connections, equation (9) has the form

$$x_i[n] = \sum_{m=1}^{l} c_{ii}^{(m)} x_i[n-m] + \sum_{j=1}^{r} \sum_{m=1}^{S} d_{ij}^{(m)} v_j[n-m], \qquad (9.a)$$

and if there are only the opposite ones -

$$x_i[n] = \sum_{j=1}^{r} \sum_{m=1}^{S} c_{ij}^{(m)} x_i[n-m] + \sum_{m=1}^{l} d_{ij}^{(m)} v_i[n-m], \qquad (9.b)$$

$c_{ii}^{m}\, d_{ij}^{m}$In some cases, some of the coefficients and can be equal, which corresponds to the absence of any connections.

$\bar{Z}\vec{t}$To solve the identification problem, let's introduce a composite situation vector. By analogy with the work [4, 15, 16, 17], we denote the vector of situations, and the composite vector.

Consider a multiple composite vector of coefficients:

$$\widehat{c_\mu} = f_\mu\left(c_{ij}^{\mu}\right) = f_c(c_{11}^{\mu}, c_{12}^{\mu}, .., c_{1r}^{\mu}; c_{22}^{\mu}, c_{22}^{\mu}, \ldots, c_{2r}^{\mu}; \ldots; c_{1r}^{\mu}, c_{r2}^{\mu}, \ldots, c_{rr}^{\mu};\ d_{11}^{\mu}, d_{12}^{\mu}, \ldots, d_{r1}^{\mu}; \ldots; d_{r1}^{\mu}, d_{r2}^{\mu}, \ldots, d_{rr}^{\mu} \qquad (10)$$

$\widehat{c_\mu}$It should be noted that the dimension of a large number of composite vectors depends on the dimensionality of the system and the order of the difference equation (9).

$\vec{Z}\bar{Z}$:Let's express the composite vector of the situation through the vector

$$\vec{Z}[n] = \varphi_z\left(\vec{Z}_i[n]\right) = \varphi_z\ \ (x_{i1}, x_{i2}, \ldots, x_{ir}, v_{i1}, v_{i2}, \ldots, v_{ir}), \qquad (11)$$

$$\bar{Z}_\iota[n] = \{x_i[n-1], x_i[n-2], \ldots, x_i[n-l], v_i[n-1], v_i[n-2], \ldots, v_i[n-l_1]\}.$$

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where

The quality of identification is evaluated using functionalities from control errors, which represent integral average quadratic estimates. Therefore, each of them is expressed through mathematical expectation, taking into account the stochastic nature of all influences [4, 16, 17]. In general, we write the optimality criterion in the form

$$\hat{c}, \hat{d}\{F[\vec{x}[n] - \widehat{c^m}\vec{\varphi}(x)[n]) - \widehat{d^m}\vec{\varphi}(v)[n])]\}J() = M \quad (12)$$

The adaptive identification algorithm in this case will have the form.

$$\hat{c}[n] = \hat{c}[n-1] + \Gamma_x[n]F_x'\left(\vec{x}[n] - \vec{c}^m[n-1]\vec{\varphi}_x(x[n]) - \hat{d}^m[n-1]\vec{\varphi}_u(v[n])\right)\vec{\varphi}(x[n]);$$

$$\hat{d}[n] = \hat{d}[n-1] + \Gamma_u[n]F_u'\left(\vec{x}[n] - \bar{c}^m[n-1]\vec{\varphi}_x[n]) - \hat{d}^m[n-1]\vec{\varphi}_u(v[n])\right)\vec{\varphi}(v[n]), \quad (13)$$

$\Gamma_x[n]$ и $\Gamma_u[n]\gamma_{ij}^k$where - diagonal matrices of coefficients *(k=x, u),*

$$\Gamma_k[n] = \left\| \begin{matrix} \gamma_{11}^k & 0 & 0 & 0 & 0 \\ 0 & \gamma_{22}^k & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \gamma_{rr}^k \end{matrix} \right\|.$$

The structural diagram of the discrete system corresponding to the identification algorithm (13) in vector form is presented in Figure 1. In expanded form, the algorithm (13) can be expressed through composite vectors.

$$\vec{c}^{\mu}[n] = \vec{c}^{\mu}[n-1] + \Gamma_x[n]x\left(\bar{x}[n] - \sum_{v=1}^{l}\vec{c}^{v}[n-1]\overline{\varphi_{xv}}\ x\ (x)[n]\right) - \sum_{q=1}^{l_1}\overrightarrow{d^q}[n-1]\overline{\varphi_{q_u}}\,x(v[n]))\overline{\varphi_{\mu x}}(x[n]);$$

$$\vec{d}^{\rho}[n] = \vec{c}^{\rho}[n-1] + \Gamma_u[n]x\left(\bar{x}[n] - \sum_{v=1}^{l}\vec{c}^{v}[n-1]\overline{\varphi_{vx}}\,(x)[n]\right) - \sum_{q=1}^{l_1}\overrightarrow{d^q}[n-1]\overline{\varphi_{q_u}}\,v[n]))\overline{\varphi_{\rho u}}(v[n]), \quad (14)$$

$$\mu, \vec{c}^{\mu}c_{11}^{\mu}, c_{12}^{\mu}, \dots, c_{1r}^{\mu};\ c_{21}^{\mu}, c_{22}^{\mu}c_{2r}^{\mu}; \dots;\ c_{r1}^{\mu};\ c_{r2}^{\mu}, \dots, c_{rr}^{\mu};\ \vec{d}^{\rho} = (d_{11}^{p}, d_{12}^{p}, \dots, d_{1r}^{p};\ d_{21}^{p}, d_{22}^{p}, \dots, d_{2r}^{p}; \dots; d_{r1}^{p}, d_{r2}^{p}, \dots, d_{rr}^{p}$$

Where v=0, 1, 2,...,l; q. p=1, 2,...,l_1; = (,...).

$$\bar{\varphi}_{\mu x}(x[n]) = \bar{x}[n-\mu];$$
$$\varphi_{\mu x}(x[n]) = \bar{x}[n-\mu];$$
$$\bar{\varphi}_{qu}(v[n]) = \bar{v}[n-q];$$
$$\bar{\varphi}_{pu}(v[n]) = \bar{v}[n-p]. \quad (15)$$

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$\bar{\varphi}(x[n])$и $\bar{\varphi}(v[n])\bar{\varphi}_{vx}(x[n]) = \bar{x}[n-v]$;In expression (14), the functions represent

Taking into account the values of the functions (15) for the quadratic functional, the algorithm (14) is transformed into the form

$$\vec{c}^{\mu}[n] = \vec{c}^{\mu}[n-1] + \Gamma_x[n]\big(\bar{x}[n] - \sum_{v=0}^{l} c^{v}[n-1]\mathrm{x}\bar{x}\,[n-v] - \sum_{q=1}^{l_1} \vec{d}\,[n-1]\bar{v}[n-q]\big)\bar{x}[n-\mu]; \quad (16)$$

$$\vec{d}^{\mu}[n] = \vec{d}^{p}[n-1] + \Gamma_u[n]\left(\bar{x}[n] - \sum_{v=0}^{l} \overrightarrow{c}\,[n-1]\mathrm{x}\,x\,[n-v] - \sum_{q=1}^{l_1} \overrightarrow{d^{p}}\,[n-1]\bar{v}[n-q]\right)\bar{v}[n-p];$$

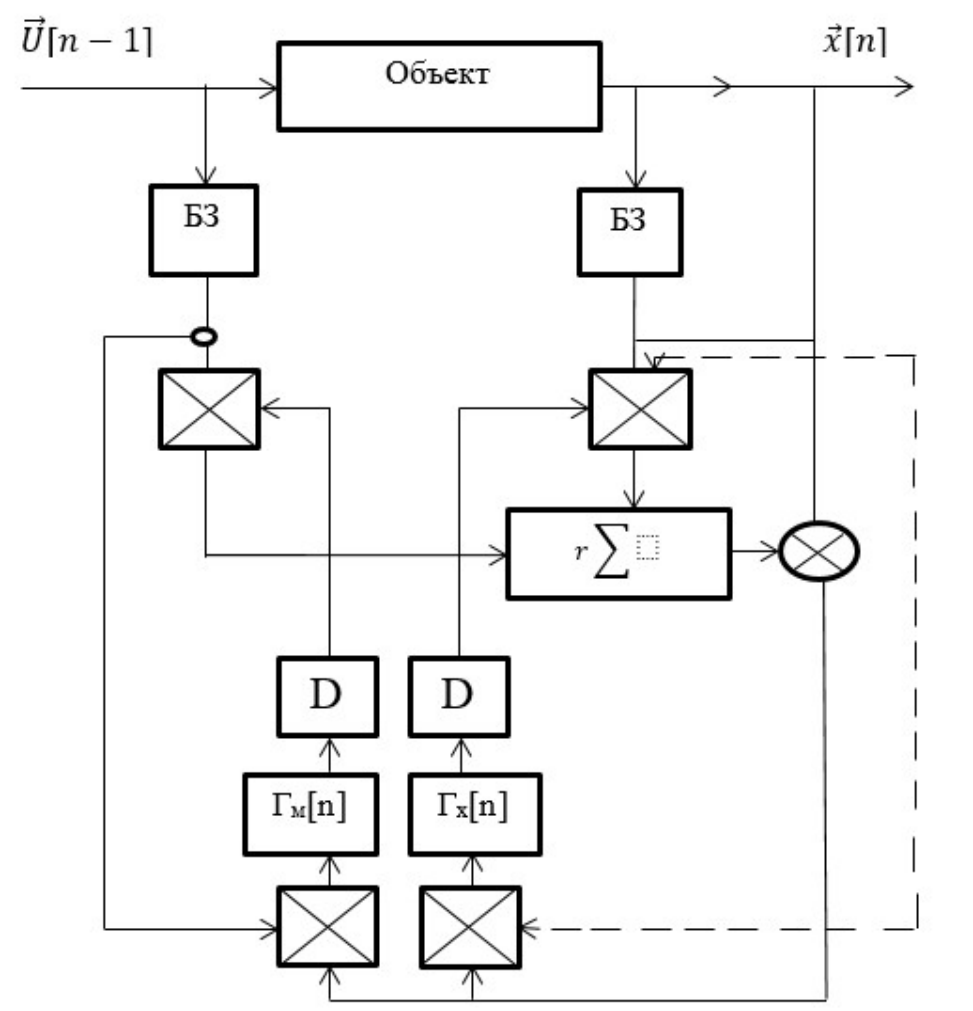


Figure 1. A discrete system that implements the algorithm for adaptive identification of multi-linked objects in vector form.

Conclusion

The presented algorithms allow solving problems related to the transition from the automation of individual processes to the automation of production

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complexes and determine the possibilities of applying the theory of adaptive identification of multi-linked objects, as well as considering complex issues of compiling identification algorithms using the iterative probabilistic method.

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