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Synthesis of adaptive-fuzzy control system of dynamic objects in conditions of uncertainty of information

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ABSTRACT: The problems of synthesis of the adaptive control algorithm for dynamic objects based on a fuzzy dynamic model are considered, while the algorithm is presented in the form of a state space that gives the control system the properties of robustness. A generalized criterion is proposed that combines the quality indicators of the control system and implements the defuzzification of fuzzy values of the quality index of the control system. The proposed algorithm for the synthesis of an adaptive-fuzzy control system helps reduce the time of the transient process and expands the scope of control systems in the presence of a wide range of perturbations.

KEYWORDS: synthesis, fuzzy, dynamic object, adaptability, robustness, uncertainty of perturbations..

I. INTRODUCTION

The modern technological objects represent themselves the difficult feeble formalized systems functioning in conditions of big uncertainty, incompleteness of knowledge and unsharpness of descriptions as the system, the perturbations so operating on it. For control of such objects there is not enough application of classical methods of the theory of control and, there is need of development of new methods and approaches with attraction of achievements of the modern information technologies. One of such approaches which is based on the theory of fuzzy sets and fuzzy logic is basis of creation of the intellectualized control system the technological objects functioning in the conditions of uncertainty of information.

In this case for increase in effective control of technological objects using the modern methods of control it is necessary to solve the following problems:

• assessment of indices of quality of uncertainty;

• lowering (or compensating) prior uncertainty of knowledge of process due to use of operational information from gages and creation of a circuit of adaptation;

• formation of such law of control which would guarantee stability and given accuracy figures and qualities of the control system (CS) in the conditions of noncompensated (posteriori) uncertainty.

One of possible solutions of the specified tasks represents itself use of methods of the adaptive, robustly and fuzzy control [1, 2].

Important point at the same time is creation of a mathematical model for representation of knowledge of dynamic objects in the conditions of fuzzy information which shall allow to define uncertainty indices, to give the description of accidental processes, is invariant to their distribution law.

II. LITERATURE SURVEY

Indefiniteness and dynamic nature of the factors operating in system, essentially hampers prediction of behaviour of dynamic systems, hence, leads to complicating of the solution of a problem of control by dynamic installations [3,4].

Enough considerable quantity of models and algorithms are developed and are applied for making is adaptable-fuzzy management systems grounded on application of neural webs, fuzzy systems, consulting models of control, genetic algorithms [5-6].

For example, in work [6] the problem of the nonlinear adaptive isolated control based on neural networks and multilevel models is solved.

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The most widespread among the intelligent technologies of the formation of robust and adaptive algorithms for regulation and control in the field of complex technical and technological systems is the technology of fuzzy control [7]. The advantages of such systems include: the ability to use complex processes, when there is no simple mathematical model; expert knowledge about the object of management simplicity of structure; property of robustness or adaptability. In [8], two-level fuzzy-logic automatic control systems are constructed. At the lower level of such automatic control systems, traditional PID controllers are used, and on the upper one - fuzzy systems.
The use of intelligent technologies based on fuzzy logic (HJI) provides a solution to a wide range of robust and adaptive control problems under uncertainty [9] that the use of HJI technology allows the creation of high-performance high-speed regulators for a wide class of technical systems in the conditions of random perturbations and uncertainty of external load.
N work [10], a method for constructing a hybrid adaptive control system is proposed, characterized by the possibility of solving problems of managing complex objects in conditions of incompleteness of data by using neural-fuzzy networks and algorithms for training the intellectual component of the control system.

On the other hand, the application of methods of system analysis, mathematical modelling, information processing, management of complex dynamic objects, taking into account the features of dynamic objects and fuzzy cause-effect relations in the information environment, contributes to the increase in production efficiency, which is devoted to this article.

III. PROBLEM DEFINITION

Generally mathematical model of dynamic object can be presented in the form:
• fuzzy equation of state

$$d\bar{x}/dt = \bar{A} \otimes \bar{x} \oplus \bar{B} \otimes u,\ \mu_{\bar{S}}(s), \tag{1}$$

• fuzzy equation of observation

$$\bar{y} = \bar{C} \otimes \bar{x}, \tag{2}$$

• fuzzy initial conditions

$$\overline{x_1}(0) = \bar{D}1,\ \overline{x_2}(0) = \bar{D}2, ..., \overline{x_n}(0) = \bar{D}n, \tag{3}$$

where $\otimes, \oplus$ - fuzzy operations according to addition and multiplication; u –controlling signal (scalar) accepting fuzzy values; $\bar{x} = \{\bar{x}_1, \bar{x}_2, ..., \bar{x}_i, ..., \bar{x}_n\}$ - vector of fuzzy status, $i=1,2,...,n$; $\bar{y} = \{\bar{y}_1, \bar{y}_2, ..., \bar{y}_\varsigma, ..., \bar{y}_l\}$ - vector of fuzzy output variables, $\varsigma=1,2,..., l$; $\mu_{\bar{S}}(s)$ - index of fuzzy (changing) number of state variables and the representing weight of s-th of an equation of state;

$$\bar{A} = \begin{bmatrix} \bar{A}_1^1 & \dots & \bar{A}_n^1 \\ \dots & \dots & \dots \\ \bar{A}_1^n & \dots & \bar{A}_n^n \end{bmatrix},\ \bar{B} = \begin{bmatrix} \bar{B}^1 \\ \dots \\ \bar{B}^n \end{bmatrix},\ \bar{C} = \begin{bmatrix} \bar{C}_1^1 & \dots & \bar{C}_n^1 \\ \dots & \dots & \dots \\ \bar{C}_1^l & \dots & \bar{C}_n^l \end{bmatrix}$$ - matrixes of fuzzy coefficients of model.

Some i-th state vector variable as time function of t can be provided to the fuzzy relation (FR) [11,12]: $\bar{x}_l(t) = \{t, x_i / \mu_{\bar{x}i}(t, x_i)\}$, $i=1,\ 2,...,\ n$, and in the fixed timepoint specified can be expressed by the fuzzy set (FS): $\bar{x}_i = \{x_i / \mu_{\bar{x}i}(x_i)\}$. The similar description has ς-th output variable:

$$\bar{y}_\varsigma(t) = \{t, y_\varsigma / \mu_{\bar{y}\varsigma}(t, y_\varsigma)\},\ \varsigma = 1, 2, ..., l,$$
$$\bar{y}_\varsigma = \{y_\varsigma / \mu_{\bar{y}\varsigma}(y_\varsigma)\},$$

where $\mu_{\bar{x}i}$, $\mu_{\bar{y}\varsigma}$ - function of accessory (FA); x_i, y_ς - values from the universal sets. Elements of matrixes $\bar{A}, \bar{B}, \bar{C}$ are set by FS:

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$$\overline{A}_1^1 = \left\{A_1^1 / \mu_{\overline{A}1}^{\ 1}\left(A_1^1\right)\right\}, \ldots, \overline{A}_n^n = \left\{A_n^n / \mu_{\overline{A}n}^{\ n}\left(A_n^n\right)\right\},$$
$$\overline{B}^1 = \left\{B^1 / \mu_{\overline{B}}^{\ 1}\left(B^1\right)\right\}, \ldots, \overline{B}^n = \left\{B^n / \mu_{\overline{B}}^{\ n}\left(B^n\right)\right\},$$
$$\overline{C}_1^1 = \left\{C_1^1 / \mu_{\overline{C}1}^{\ 1}\left(C_1^1\right)\right\}, \ldots, \overline{C}_n^l = \left\{C_n^l / \mu_{\overline{C}n}^{\ l}\left(C_n^l\right)\right\},$$

Initial conditions are described of FS $\overline{D}_i = \left\{x_i / \mu_{\overline{D}i}(x_i)\right\}$, and number of variables of state vector – FS $\overline{S} = \left\{s / \mu_{\overline{S}}(s)\right\}$, where $s=1,2,\ldots,n$ – sequence number of a variable of state vector.

Functions of accessory are set by analytical dependence [2], for example, for $\overline{x}_i$ -variable:

$$\mu_{\overline{X}_i}(x_i) = \varphi\left(x, a_{\overline{X}i}, b_{1\overline{X}i}, b_{2\overline{X}i}, \nu_{1\overline{X}i}, \nu_{2\overline{X}i}\right) = \left(\left(b_{1\overline{X}i}\left(a_{\overline{X}i} - x\right)\right)^{\nu_{1\overline{X}i}} \frac{sign\left(b_{1\overline{X}i}\left(a_{\overline{X}i} - x\right)\right) + 1}{2} + \left(b_{2\overline{X}i}\left(a_{\overline{X}i} - x\right)\right)^{\nu_{2\overline{X}i}} \frac{sign\left(b_{2\overline{X}i}\left(a_{\overline{X}i} - x\right)\right) + 1}{2} + 1\right)^{-1} \quad (4)$$

In the formula (4) the $a_{\overline{X}_i}$ -coefficient represents mode of FA, coefficients $b_{1\overline{X}i}$ and $b_{2\overline{X}i}$ set width of FA, $\nu_{1\overline{X}i}$ and $\nu_{2\overline{X}i}$ - inclination of FA to an x_i-axis, i.e. contrast. $b_{1\overline{X}i}$, $b_{2\overline{X}i}$, $\nu_{1\overline{X}i}$, $\nu_{2\overline{X}i}$ coefficients allow to form any form of FA and can act as uncertainty indices.

Indices of quality of control system (time of transition processes, readjustment, tracking error, etc.) in the form of usefulness functions are set:

$$\overline{Q}_k^3 = \left\{Q_k^3 / \mu_{\overline{Q}k}^3\left(Q_k^3\right)\right\}, k = 1,2,\ldots,K,$$
$$\mu_{\overline{Q}k}^3\left(Q_k^3\right) = \varphi\left(Q_k^3, a^3{}_{\overline{X}i}, b^3{}_{1\overline{X}i}, b^3{}_{2\overline{X}i}, \nu^3{}_{1\overline{X}i}, \nu^3{}_{2\overline{X}i}\right) \quad (5)$$

where K – number of indices of quality of control system.

The reference model on the basis of the given indices of quality of control is defined:

$$\dot{x}_M = A_M x_M + B_M u_M, \quad (6)$$

where $u_м$ – setting influence of system; $x_м(t)$ – vector reference statuses.

Restrictions for variables of state vector and restriction for control are set:

$$g_1\left(\overline{x}, u, \gamma, t\right) < x_{1\max},\ g_2\left(\overline{x}, u, \gamma, t\right) < x_{2\min}, \ldots,$$
$$g_{2n-1}\left(\overline{x}, u, \gamma, t\right) < x_{n\max},\ g_{2n}\left(\overline{x}, u, \gamma, t\right) < x_{n\min}, \ldots, \quad (7)$$
$$g_{m-1}\left(\overline{x}, u, \gamma, t\right) < u_{\max},\ g_m\left(\overline{x}, u, \gamma, t\right) < u_{\min}.$$

Let as the purpose of control the minimization of an average deviation of variables of state vector of real behavior of a control object from standard be selected.

It is necessary to synthesize control systems and to take in setup of the regulator so that all signals in control systems were restricted, i.e. $|x(t)| < x_{\partial on}$, $|u(t)| < u_{\partial on}$, and transient phenomena in system satisfied to the given indices of quality (5).

IV. DECISION METHOD

For a measure definition of quality of control system are used as time response characteristics of control object $a_{\overline{x}_i}(t)$, $a_{\overline{y}_i}(t)$, and fuzzy parameters $b_{1\overline{x}i}(t)$, $b_{2\overline{x}i}(t)$, $b_{1\overline{y}k}(t)$, $b_{2\overline{y}k}(t)$, the functions of accessory determined by width.

For the purpose of lowering of fuzzy of data on an object and improving of indices of quality of control, maximize values $b_{1\overline{x}i}(t)$, $b_{2\overline{x}i}(t)$, $b_{1\overline{y}k}(t)$, $b_{2\overline{y}k}(t)$.

For giving of property of robustness of the control algorithm use of the discrete algorithm of high-speed gradient in parametric form is offered that will allow to provide minimum of complexity and to consider restrictions for the controlling signal and speed of its change [13, 15].

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At the same time the signal of control is created on the basis of fuzzy set of values of state variables possible in case of variation of behavior of object.
At the same time the model of an object represents the averaging adding filter synthesis of the law of control on the basis of fuzzy model in addition increases robustness of an algorithm of high-speed gradient, saving limitation of phase paths in same area in the conditions of noncompensated uncertainty of values about an object.
For the purpose of improving of quality and accuracy of formation of transition processes in control systems the decision-making algorithm at the choice of the compromise control signal of control of way of its embedding to control algorithms is realized.
The modified law of control has an appearance:

$$u = k_u(t)\cdot u_{м}(t) + \sum_{i=1}^{n} k_x^{\Sigma}(t)\cdot x_i^{\Sigma}(t), \quad (8)$$

$$k_{x1}^{\Sigma}[t+1] = k_{x1}^{\Sigma}[k](1-h\gamma_3) + h(\gamma_5-\gamma_4)\delta\cdot[t]x_1^{\Sigma}[t] - h\gamma_5\delta\cdot[t+1]x_1^{\Sigma}[t+1], \quad (9)$$

$$k_{xn}^{\Sigma}[t+1] = k_{xn}^{\Sigma}[k](1-h\gamma_3) + h(\gamma_5-\gamma_4)\delta\cdot[t]x_n^{\Sigma}[t] - h\gamma_5\delta\cdot[t+1]x_n^{\Sigma}[t+1], \quad (10)$$

$$k_u[t+1] = k_u[k](1-h\gamma_1) + h(\gamma_6-\gamma_2)\delta\cdot[t]u_{м}[t] - h\gamma_6\delta\cdot[t+1]u_{м}[t+1], \quad (11)$$

where $t = mh$, $h>0$ – step of sampling, $m=0,1,2,\ldots, m$; $\gamma = \{\gamma_1,\gamma_2,\gamma_3,\gamma_4,\gamma_5,\gamma_6\}$ - parameters of adaptive regulator; $e_i^{\Sigma} = \int_{X_i}(x_i - x_{iм})\mu_{\tilde{e}_i}(e_i)dx_i$ - mismatch between variables of state vector and reference state variables; $\mu_{\tilde{ei}}(e^i) = (e_i, a_{\tilde{ei}}, b_{1\tilde{ei}}, b_{2\tilde{ei}}, \nu_{1\tilde{ei}}, \nu_{2\tilde{ei}})$ - FA of error, φ –analytical type of accessory function in the form (4), $a_{\tilde{ei}} = a_{\tilde{xi}} - x_{iм}$, $\nu_{1\tilde{ei}} = \nu_{1\tilde{xi}}$, $\nu_{2\tilde{ei}} = \nu_{2\tilde{xi}}$, $b_{1\tilde{ei}} = b_{1\tilde{xi}}$, $b_{2\tilde{ei}} = b_{2\tilde{xi}}$, $x_i^{\Sigma} = \int_{X_i} x_i dx_i$ - integrated variable of state vector; $\delta\cdot[t] = \sum_{i=1}^{n} k_i \cdot e_i^{\Sigma}$, h_i –coefficients received from coefficients of matrix and from solution of Lyapunov's equation and from matrix of reference model of $B_м$.
The task of determination of parameters of adaptive regulator $\gamma = \{\gamma_1,\gamma_2,\gamma_3,\gamma_4,\gamma_5,\gamma_6\}$, when indices of quality of control system (5) and behavior of control object (1), (2), (3) are set in the fuzzy form, can be consolidated also to the classical task of search of extremum of target function in presence of restrictions (7).
The generalized criterion which, for the first - integrates indices of quality of control system, secondly – realizes defazzifikation of fuzzy indices of quality of control system [14,16]:

$$I(\gamma) = K - \sum_{k=1}^{K} \frac{\mu_{\tilde{Q}k}^{\int} \wedge \mu_{\tilde{Q}k}^{з\int}}{\mu_{\tilde{Q}k}^{\int}} \to \min, \quad (12)$$

where $\mu_{\tilde{Q}k}^{\int} = \int_{-\infty}^{\infty} \mu_{\tilde{Q}k}(Q_k)\cdot dQ_k$ - energy of FS $\overline{Q}_k = \{Q_k / \mu_{\tilde{Q}k}(Q_k)\}$, expressing predicted on the basis of fuzzy model the value of k-th indices of quality of control system; $\mu_{\tilde{Q}k}^{з\int} = \int_{-\infty}^{\infty} \mu_{\tilde{Q}k}^{з}(Q_k^{з})\cdot dQ_k^{з}$ - energy of FS, expressing usefulness function.
The research of efficiency of the offered approach by operation of fuzzy adaptive system are conducted in case of control of temperature and level in the carbonization column [1].

V. INFERENCE

The following results are received:
1. Operational formation of controlling signals promotes abbreviation of time of transition processes for 20%.
2. Average deviation of a vector of state variables of real process from reference is reduced by 15% in comparison with indices of the known adaptive control systems.

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Implementation of the offered synthesis algorithm of control system expands a scope of control systems under production conditions in the presence of wide range of perturbations.

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