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ON NONPARAMETRIC ALGORITHMS OF OBJECT GROUPS CONTROL

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The paper is devoted to the identification and control of a group of both identical and varied objects. First the control system of a local object is considered. Further on, all random factors acting in the measurement channels of an object are omitted and only the relationships between objects are preserved. Nonparametric algorithms of identification and control are given in a rather general form. The main attention is paid to different relationships between local objects. First the simplest case is considered, that is, a serial technological chain for whose control it is offered to use an external circuit of control when control influences in an external circuit play the role of a setting influence of local systems. The group of objects of a parallel-serial type is the following in complexity and here some feature inherent in many variables figuring in the corresponding section of a group of objects shows itself. This essential feature is that the output variables are measured with different discreteness, and the discreteness of control can significantly vary, including hours, shifts, days and weeks, depending on the nature of the production process and the scheme of measurement and control of corresponding variables. For example, the fineness of grinding in the production of cement is measured several times per shift, and the activity of cement showing its brand is determined only after 28 days. This circumstance should be taken into account when developing computer systems for identification, control and decision-making. The most difficult are such groups that fit into the scheme of interrelated objects, where feedback takes place in the technological process. The external control circuit can have a hierarchical structure, where the number of hierarchies is related to technical-economic, production-economic factors and in active systems to social factors as well. Control of such complexes is a complicated task, where the application of the theory of adaptive and learning systems is justified. This paper considers a class of algorithms of a non-parametric type, i.e. algorithms oriented to the case when information for describing objects is insufficient for parameterization, i.e. selection up to a set of vector parameters. Similar algorithms are presented in a rather general way. As a result, some cases of using control systems for groups of objects for thermal power plants are considered, and condensed information is provided for the metallurgical processing of the Norilsk Combine.

Keywords: a priori information, a group of mutually connected objects, active systems, a complex of non-parametric models.

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О НЕПАРАМЕТРИЧЕСКИХ АЛГОРИТМАХ УПРАВЛЕНИЯ ГРУППАМИ ОБЪЕКТОВ

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Рассмотрена идентификация и управление группой объектов как идентичными, так и разнотипными. Сначала рассматривается система управления локальным объектом. В дальнейшем все случайные факторы, действующие в каналах измерения на объект, опущены, и сохраняются только связи между объектами. Также приводятся непараметрические алгоритмы идентификации и управления в достаточно общей форме. Основное внимание уделяется вопросам различных связей между локальными объектами. Первоначально рассматривается случай наиболее простой – это последовательная технологическая цепочка, для управления которой предлагается использовать внешний контур управления, когда роль управляющих воздействий во внешнем контуре играет роль задающего воздействия локальных систем. Следующей по сложности является группа объектов параллельно-последовательного типа, и здесь проявляется некоторая особенность, присущая многим переменным, фигурирующим в соответствующем сечении группы объектов. Эта существенная особенность в том, что выходные переменные измеряются с различной дискретностью, причем дискретность контроля может существенно отличаться, это могут быть часы, смена, сутки и недели, в зависимости от характера того или иного производства и схемы измерения и контроля соответствующих переменных. Например, тонкость измельчения помола при производстве цемента измеряется несколько раз в смену, а активность *цемента, показывающая его марку, определяется только через 28 суток. Это обстоятельство должно учитываться при разработке компьютерных систем идентификации, управления и принятия решений. Наиболее сложными являются такие группы, которые укладываются в схему взаимосвязанных объектов, где в технологическом процессе имеют место обратные связи. Внешний контур управления может иметь иерархическую структуру, где число иерархий связанно с технико-экономическими, производственно-экономическими, а в активных системах – еще и с социальными факторами. Управление такими комплексами является сложной задачей, где оправданно применение теории адаптивных и обучающихся систем. Рассматривается класс алгоритмов непараметрического типа, т. е. алгоритмов, ориентированных на случай, когда информация для описания объектов недостаточна для параметризации, т. е. выбора с точностью до набора вектора параметров. Подобные алгоритмы приведены в достаточно общем виде. В итоге рассматриваются некоторые случаи использования систем управления групп объектов для теплоэлектростанций и приводятся сжатые сведения для обогатительного металлургического передела Норильского комбината.*

Ключевые слова: априорная информация, группа взаимосвязанных объектов, активные системы, комплекс непараметрических моделей.

Introduction. The paper is devoted to control of a group of static and dynamic objects in conditions of both parametric and nonparametric indeterminacy. The identification problem is one of the major ones in the control theory and is also closely related to the amount of information a researcher has at the stage of setting appropriate identification tasks. The control of a group of objects should be based on the following principles:

– collection of a priori information and analysis of current information about the process under investigation;

– mathematical formulation of the problem, assuming certain assumptions;

– synthesis of appropriate control algorithms.

The classical control problem. At first the control task is considered in the standard setting [1]. The task is viewed as a certain local object (fig. 1).

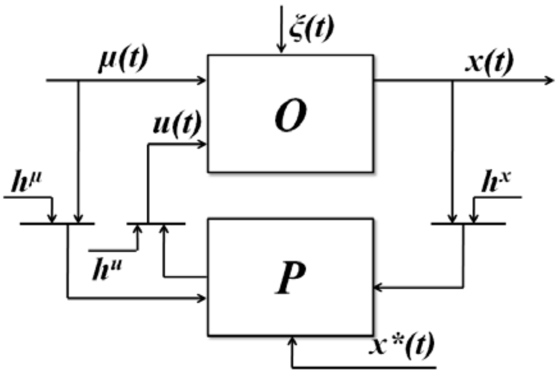

Fig. 1. The general control scheme

Рис. 1. Общая схема управления

The fig. 1 shows the following designations: O is an object, P is a regulator, $u(t) = (u_1(t), ..., u_n(t))$ $\Omega(u)\subset R^n$, $x(t) = (x_1(t), ..., x_n(t))$, $\Omega(x)\subset R^k$, $\mu(t) = (\mu_1(t), ..., \mu_n(t))$, $\Omega(\mu)\subset R^m$, the input variable $\mu(t)$ is monitored, but not controlled, $x^*(t)$ is a setting impact. Random perturbations h^u, h^μ, h^x are errors in the measurement of variables, and $\xi(t)$ is the random perturbation affecting an object. The scheme has a local character [2]; further all random variables will be omitted for simplicity. In identification of such objects the models can have the following appearance: $\hat{x}(u, \mu) = F(u, \mu, \alpha)$ is in case of a parametric setting, or $x_s(u, \mu) = S(u, \mu, \overrightarrow{u_s}, \overrightarrow{x_s}, \overrightarrow{\mu_s})$ in case of a nonparametric setting. Here $\overrightarrow{u_s}$, $\overrightarrow{x_s}$, $\overrightarrow{\mu_s}$ are temporal vectors equal to $\overrightarrow{x_s} = (x_1, x_2, \ldots, x_s)$, $\overrightarrow{u_s} = (u_1, u_2, \ldots, u_s)$, $\overrightarrow{\mu_s} = (\mu_1, \mu_2, \ldots, \mu_s)$ respectively [3; 4]. Nonparametric models are commonly expressed by the following formula:

$$x_{sl}(u,\mu) = \frac{\sum_{i=1}^{s} x_{li} \prod_{j=1}^{n} \Phi\left(\frac{u_j - u_{ji}}{c_s}\right) \prod_{j=1}^{m} \Phi\left(\frac{\mu_j - \mu_{ji}}{c_s}\right)}{\sum_{i=1}^{s} \prod_{j=1}^{n} \Phi\left(\frac{u_j - u_{ji}}{c_s}\right) \prod_{j=1}^{m} \Phi\left(\frac{\mu_j - \mu_{ji}}{c_s}\right)}, \quad l = \overline{1,k} \tag{1}$$

and control algorithms will be expressed like this:

$$u_{sl}(x,\mu) = \frac{\sum_{i=1}^{s} u_{li} \prod_{j=1}^{k} \Phi\left(\frac{x_j^* - x_{ji}}{c_s}\right) \prod_{j=1}^{m} \Phi\left(\frac{\mu_j - \mu_{ji}}{c_s}\right)}{\sum_{i=1}^{s} \prod_{j=1}^{k} \Phi\left(\frac{x_j^* - x_{ji}}{c_s}\right) \prod_{j=1}^{m} \Phi\left(\frac{\mu_j - \mu_{ji}}{c_s}\right)}, \quad l = \overline{1,n}. \tag{2}$$

Groups of objects. Further on groups of objects will be considered, in particular the simplest of them is a group of serial objects shown in fig. 2. For simplicity, random perturbations acting in channels of measurements and affecting an object are not presented any more, though they are surely present.

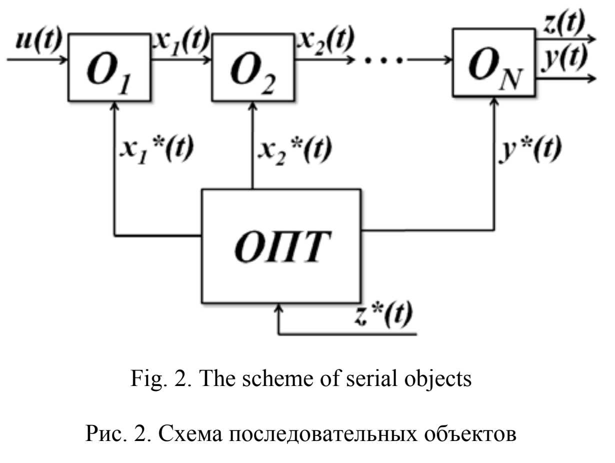

Fig. 2. The scheme of serial objects

Рис. 2. Схема последовательных объектов

Here O_1, O_2, ..., O_N objects are shown in a general view and each of them may contain the macro object shown in fig. 1, where *ОПТ* is the optimizer. $X_1*(t)$, $x_2*(t)$, ..., $x_N*(t)$, $y*(t)$ are controlling variables for the optimizer. The purpose of the optimizer is to find the controlling impacts $x_1*(t)$, $x_2*(t)$, ..., $x_N*(t)$, $y*(t)$, for achieving $z*(t) \approx z(t)$. Z(t) is the most important output variable which characterizes the result of the work of the whole group of objects. It is important to note that the discreetness of measurements $z(t)$, $y(t)$ and $x(t)$ can significantly differ. Therefore the accelerated forecast $z(t)$ is often used in such systems; it is this value that creates the cost of the final product. The measurement discreetness $z(t)$ is the greatest of all variables and can be equal to days, weeks, and sometimes reaches a month. The optimization task takes the following form:

$$R = M_{\xi}\left\{\sum_{i=1}^{k}\alpha_i f_i(\mu,u,\xi)\right\}, \qquad (3)$$

where R is a utility function; $f_i(x,u)$, $i = \overline{1,k}$, is a set of quality criteria which are created on the basis of the model of the researched process $x_i = \varphi(\mu,u)$, $i = \overline{1,k}$; in their turn, φ_i, $i = \overline{1,k}$ are continuous functions; α_i is a weight factor which is defined by the decision-maker.

The following restrictions were adopted in the utility function:

$$\begin{aligned} &M_{\xi}\left\{\varphi(\mu,u,\xi)\right\} \geq 0,\ j=\overline{1,\lambda},\\ &M_{\xi}\left\{\varphi(\mu,u,\xi)\right\} = 0,\ j=\overline{1,\sigma}, \end{aligned} \qquad (4)$$

where ξ is random perturbations with unknown probability density $P(\xi)$.

Then the algorithm of computation u_p^j, $j = \overline{1,m}$, can have the following appearance:

$$u_p^j = \frac{\sum_{i=1}^{s} u_i^j \alpha_{tps}}{\sum_{i=1}^{s}\alpha_{tps}}, \qquad (5)$$

$$\alpha_{tps} = \prod_{v=1}^{k}\Phi\left(\frac{f_v(\mu_t,u_t)}{c_s^f}\right)\prod_{v=1}^{m}\Phi\left(\frac{f_v(\mu_t,\mu_v^t)}{c_s^{\mu}}\right)\times$$

$$\times\prod_{j=1}^{v}\Phi\left(\frac{\Psi_j(\mu_t,u_t)}{c_s^{\Psi}}\right)\prod_{j=1}^{\lambda}\frac{\operatorname{sng}\varphi_j(\mu_t,u_t)}{c_s^{\varphi}}. \qquad (6)$$

In case of appearance of a decision-making problem, algorithms (5), (6) can be slightly changed. It is caused by the fact that in this case it is necessary to consider learning selection limitation and as a result of it the absence of blur coefficients aspiration to zero with the increase of s. In this case it is more expedient to present the algorithm of decision-making (6) in the following form:

$$\alpha_{tps} = \prod_{v=1}^{k} W\left(\gamma_{vp}\cdot f_v(\mu_t,u_t)\right)\prod_{v=1}^{m} W\left(\gamma_{vp}\cdot(\mu_v-\mu_v^t)\right)\times$$

$$\times\prod_{j=1}^{v} W\left(\gamma_{vp}\cdot\Psi_j(\mu_t,u_t)\right)\prod_{j=1}^{\lambda}\operatorname{sng}\varphi_j(\mu_t,u_t), \qquad (7)$$

where $W(\cdot)$ function is an analog of $\Phi(\cdot)$, and γ_{vp} coefficients are a peculiar analog of the blur coefficients playing the role of weight factors in this case [5].

The parallel-serial scheme (fig. 3) of technological devices interaction which is often met at the enterprises of a discrete-continuous type is more complicated [6–8].

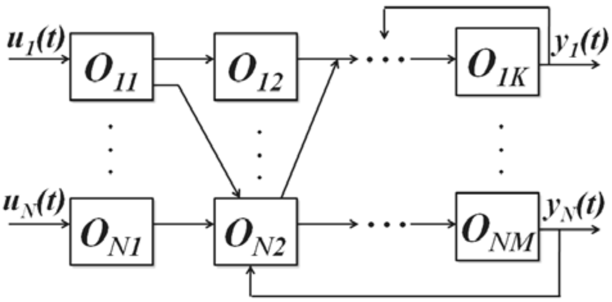

Fig. 3. The parallel-serial objects scheme

Рис. 3. Схема параллельно-последовательных объектов

The following designations are accepted in the fig. 3: N is a number of process lines; all designations of technological variables are excluded for simplicity, generally the emphasis is placed on communication of technological chains.

Finally, an interdependent technological process illustrated in fig. 4 is the most complicated one.

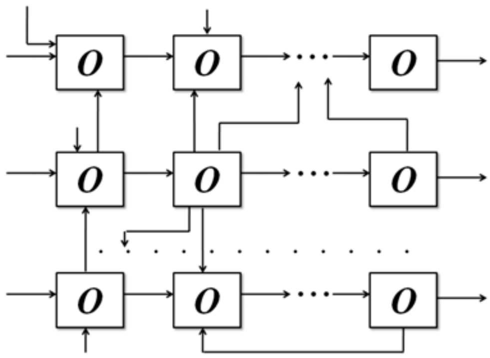

Fig. 4. The scheme of interdependent objects

Рис. 4. Схема взаимосвязанных объектов

The most important here are technological communications between industrial facilities, which are not described separately in the paper. Any technological variables are not described as well [9].

Similar processes are also met in the active systems. Researchers have paid much attention to them lately. Active systems include processes with involvement of a man or a group of people in any field of activity. Typical features of such processes are incompleteness of a prior data, uncertainty, mutual connectivity, difficulty of formation of the agreed targets and methods of their achievement. Incompleteness of a priori data results in the necessity to formulate these or those tasks of local character in a variety of essentially different settings, and their combining in a single system presents serious theoretical difficulties. The general scheme of the active process is presented in fig. 5.

Here $\lambda(t)$ is a variable which may be known to the researcher, but it is hardly measureable, i. e. its control takes place rather seldom and the procedure of measurement is long and expensive. The variable $\Theta(t)$ is responsible for the impact on an object of external environment. For organizational systems such impact can include any instructions, resolutions, orders, acts which undergo these or those changes eventually. $\omega^i(t)$, $i = \overline{1,k}$, are the process variables monitored along the object length which show additional information about the process. Θ_t, μ_t, u_t, ω^i_t, x_t, y_t, z_t are measurements of the appropriate variables which are carried out through different intervals of time.

At present two fundamental differences between organizational systems and technical ones are revealed. The first difference is the existence of back couplings, control circuits, etc., built in the researched process from outside. The second difference is characterized by monitoring aids or measurement of the appropriate variables, as one of elements of gauges of some input-output variables characterizing a process status is a person or a group of experts. The estimates of some variables are impossible without involvement of a person; therefore there will be a subjective factor in measurements. The control system of organizational processes is a hierarchical, multiple-loop system including a person as a necessary and major element; in this case the formation of a matrix of observations is of some difficulty as it includes variables of different types belonging to different scales. One more cornerstone in active systems control is ignorance about the process that leads to the mismatch between the assumptions of the researched object and the object itself. It happens because of a lack of a priori information, influence of arbitrary factors whose characteristics are not known to the researcher, imperfection of monitoring aids of variables, and not enough representativeness of sampling for measurements [10–13].

An object group which is widespread at thermal power plants will be considered as an example (fig. 6).

It should be noted that objects O_1, O_2, ..., O_N are boiler units, T_1, T_2, ..., T_L are turbines which can be in different statuses up to switch-off in production. It naturally significantly complicates the control task of such an interdependent complex. Similar systems are at a development stage at present time [14; 15].

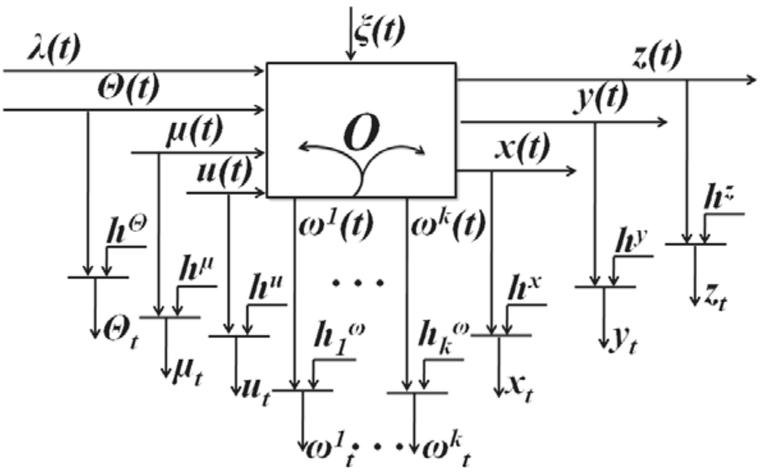

Fig. 5. The general scheme of a multivariate active process

Рис. 5. Общая схема многомерного активного процесса

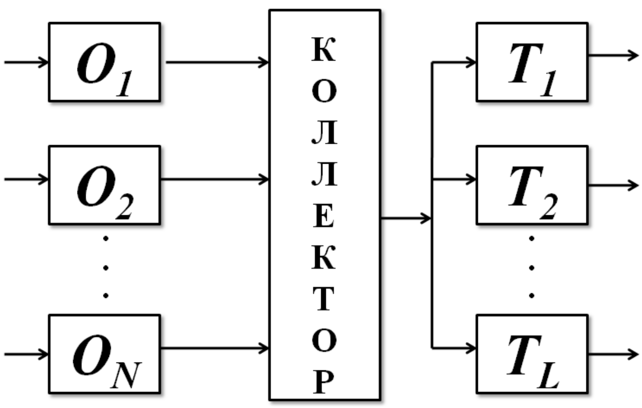

Рис. 6. The general scheme of a power unit of a thermal power plant.

Рис. 6. Общая схема энергоблока теплоэлектростанции

It seems reasonable to provide some data on mathematical simulation by concentrating metallurgical conversion NMMC which passed numerous tests and was implemented in production. The fragment of a similar technological chain is presented in fig. 4. In this case the initial variables were technological parameters of the ores extracted in the territory of the Norilsk industrial region (Oktyabrskii, Komsomolskii, Medvezhii ruchey and others) as well as the amount of furnace charge, sandstone, concentrate, waste, matte and others and contents of different elements in them. The similar system which was called "Metal" system was implemented at Norilsk MMC with considerable economic effect. K-, H-, T-models which are included in "Metal" represented a system of more than 330 ratios of parametric and non-parametric types [10].

Conclusion. The paper deals with the problem of identification and control of a group of serial, parallel and parallel-serial type of technological objects sequences. The special features of the relationships between objects and process variables in each case are defined. Algorithms of identification and control of a group of objects, as well as the decision-making algorithm are given in a general form. Examples of technological processes representing groups of local objects are described.

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