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MANAGING A GROUP OF OBJECTS AS A TASK OF SYSTEM ANALYSIS

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In this paper, we consider the general statement of the problem of identification and management of a group of objects. A group refers to several objects combined for the manufacture of a product. The main feature is that when managing such systems, it is necessary to change the setting actions for each object.

This is due to the fact that today the technological regulations in many cases are wider than they should be for good operating. This is a consequence of the fact that the current production culture (this, in particular, has been shown by the experience of processing data from the technological process for the production of transistors at Svetlana) is rather low, which leads to some organizational problems. It is clear that it is necessary to have certain models of objects that naturally differ from each other and can be considered under conditions of both parametric and nonparametric uncertainty. Moreover, there may be cases when an object is considered simultaneously under conditions of both parametric and nonparametric uncertainty over various channels. Now, regarding the delay, due to the fact that the measurement of some variables is carried out in a significantly longer time interval than the object constant, it is necessary to distinguish the time of measuring technological variables and, in fact, the delay typical to the process itself, taking into account the difference between the channels.

This leads to the fact that dynamic processes are essentially forced to be considered as inertialess with delay. Another significant feature is that the components of the output variables are stochastically dependent in advance in an unknown manner. The use of correlation or dispersion relations in this case does not lead to success. A special analysis of T-processes and the ability to simulate such processes are required. In particular, this is one of the tasks of this article. It contains: T-processes, T-models and the corresponding heterogeneous control algorithms. The process of hydrodeparaffinization of diesel fuel is considered according to available data, which can be said a priori that they are incomplete, that is they do not reflect the complex behavior of the process. From here it follows that these data require replenishment, which today is not carried out for various reasons. Thus, the process of hydrodewaxing can be taken to the T-process.

Modeling a multidimensional system based on real data has shown that in this problem the presetting effect for different objects should be different. The exception is only the setting actions for the entire complex or group of objects. Modeling was carried out on the basis of T-models considered in the article. It has already been noted that these models should not be taken as complete, giving an idea of reality. They will be subject to algorithmic refinement during further research. The decision is made by the researcher. At this stage that an assessment is given that, under the circumstances, the resulting models and control algorithms can be adopted for use in a production environment. An attempt to use the existing theory of identification and control for the process of hydrodewaxing will inevitably lead to a significant degradation and increase in the cost of a computer system for operating the quality of this process.

Keywords: group of objects, identification, control, setting actions, nonparametric algorithms, T-process, multidimensional objects, adaptation.

ОБ УПРАВЛЕНИИ ГРУППОЙ ОБЪЕКТОВ КАК О ЗАДАЧЕ СИСТЕМНОГО АНАЛИЗА

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В настоящей работе рассматривается общая постановка задачи идентификации и управления группой объектов. Под группой понимается несколько объектов, объединенных для изготовления того или иного продукта. Главной особенностью является то, что при управлении подобными системами необходимо изменять задающие воздействия для каждого объекта.

Сегодня технологический регламент во многих случаях оказывается более широким, чем следовало бы для качественного управления. А это есть следствие того, что нынешняя культура производства (это, в частности, показал опыт обработки данных технологического процесса производства транзисторов на «Светлане») довольно невысока. Это приводит к некоторым организационным проблемам. Следовательно, необходимо иметь те или иные модели объектов, которые естественно отличаются друг от друга и могут быть рассмотрены в условиях как параметрической, так и непараметрической неопределенности. Более того, могут быть случаи, когда объект рассматривается одновременно в условиях как параметрической, так и непараметрической неопределенности по различным каналам. Измерение некоторых переменных осуществляется в значительно больший интервал времени, чем постоянная объекта, поэтому необходимо отличать время измерения технологических переменных и, собственно, запаздывание, присущее самому технологическому процессу с учетом отличия каналов. Это приводит к тому, что динамические процессы по существу вынуждены рассматриваться как безынерционные с запаздыванием. Другой существенной особенностью является то, что компоненты выходных переменных стохастически зависимы заранее неизвестным образом. Использование в этом случае корреляционных или дисперсионных отношений не приводит к успеху. Необходим специальный анализ Т-процессов и умение моделировать подобные процессы. В частности, это является одной из задач настоящей статьи. В ней приведены: Т-процессы, Т-модели и соответствующие разнотипные алгоритмы управления. Рассмотрен процесс гидродепарафинизации дизельного топлива по имеющимся данным, о которых априори можно сказать, что они неполные, т. е. не отражают комплексное поведение технологического процесса. Отсюда становится ясно, что эти данные требуют пополнения, которое сегодня по разным причинам не осуществляется. Таким образом, процесс гидродепарафинизации может быть отнесен к Т-процессу. Моделирование многомерной системы по реальным данным показало, что в этой задаче задающее воздействие для различных объектов должно быть различным. Исключение составляет только задающие воздействия для всего комплекса или группы объектов.

Моделирование осуществлялось на основании рассмотренных в статье Т-моделей. Уже отмечалось, что эти модели не следует воспринимать как завершенные, дающие представление о действительности. При дальнейших исследованиях они будут подлежать алгоритмическому уточнению. Решение об этом, естественно, принимает исследователь. Именно на этом этапе дается оценка, что в создавшихся условиях полученные модели и алгоритмы управления могут быть приняты для использования в производственных условиях. Попытка использования существующей теории идентификации и управления для процесса гидродепарафинизации неизбежно приведет к значительному ухудшению и увеличению стоимости компьютерной системы управления качеством данного процесса.

Ключевые слова: группа объектов, идентификация, управление, задающие воздействия, непараметрические алгоритмы, Т-процесс, многомерные объекты, адаптация.

Introduction. Modeling of multidimensional inertialess objects continues to be an urgent task of identification. The article emphasizes the case when the vector of the constituents of the output variables stochastically dependents in an unknown manner. In this case, the approach to modeling such objects does not fit within the framework of the existing identification theory. There are plenty of examples of such objects. In particular, they can include processes that occur in the construction industry (cement production), in metallurgy (steel smelting process), in the energy sector (coal burning process), in oil refining (the process of cleaning diesel fuel from sulfur compounds), and also practically all organizational processes, including an educational one [1; 2]. We can consider a multidimensional process at an oil refinery, where there is an installation for hydrotreating diesel fuel from sulfur compounds, combined with the process of hydrodewaxing and increasing the cold flow of diesel fuel [3]. The measurement of the main output stochastically dependent variables of a given process, for example, such as "density at a temperature of 15 ^{o}C" or "boiling point temperature", takes place once a day. In this case, the process under study is considered as inertialess with time delay [4].

It should be noted that any of these processes corresponds to the statement of different formulations of the problems, and this difference is due to the presence of various a priori information about the process under study.

The most interesting case is when the nature of the stochastic coupling between the output components is unknown up to parameters. Fig. 1 shows the simplest diagram of series-connected objects. Nevertheless, it demonstrates that in the analysis of such a group of objects specificity arises in modeling, and in the operating similar processes in reality.

In fig. 1, the following notations are agreed: O_q, $q=\overline{1,r}$ – the number of objects (technological devices) included in the group (the group consists of local objects); $-u=(u_1,u_2,...,u_m)$ – input control actions; $\mu=(\mu_1,\mu_2,...,\mu_p)$ – input, unmanaged, but controlled variables (for example, it can be all kinds of additives when working with bulk materials that enter the input of an object); $x=(x_1,x_2,...,x_n)$ – characteristics that determine the composition of the initial product x_1 of semi-finished products $x_2,...,x_n$; z – parameters characterizing the finished product (product). All variables are vectors. The process flow is subject to the technological regulations (GOSTs), which defines the ranges of values of all technological parameters.

The main feature that arises in a group of processes is largely due to its emergence [5] and unreasonably large ranges of technological regulations. Moreover, the compression of technological regulations in real production in most cases cannot be carried out due to emerging organizational problems. Unfortunately, it leads to the production of low-quality products, and often to a large proportion of defective goods. Difficulties are further exacerbated by the fact that defective products cannot always be sent to recycling. A way out can be found using correction of technological regulations in each case. This naturally leads to the problem of automation of a similar process in each local case, at each redistribution of the technological process. In this regard, it is necessary to solve the identification problem and the control task for each technological object, and only then combine them into a group. Thus, there is a need to conduct the process all the time in different ways. This is akin to the well-known idea expressed by the Polish philosopher Ferdinand-Bronislaw Trentovsky in 1843 in the book "The Attitude of Philosophy to Cybernetics as the Art of Managing the People": "The application of the art of control without any serious study of the corresponding theory is like healing without any deep understanding medical science".

He emphasized that truly effective management should take into account all the most important external and internal factors affecting the object of management: "With the same political ideology, cybernet should govern differently in Austria, Russia or Prussia. In the same way, in the same country he must rule tomorrow differently than today".

In such complex multidimensional processes, the output variables of an object are somehow dependent, but this dependence is a priori unknown. Similar processes were called T-processes, and their models – T-models [6]. Identification and management of such processes should be carried out in a non-traditional way [7], because it will not lead to success due to a lack of a priori information about the investigated object. The peculiarity is that the vector of the output constituent, we denote it as $x(t)=(x_1(t),x_2(t),...,x_n(t))$, $j=\overline{1,n}$, is so, that the constituents of this vector are dependent in advance in an unknown manner. Therefore, the mathematical description of the object can be represented as a system of implicit functions:

$$F_j\left(u(t),\mu(t),x(t)\right)=0,\ \ j=\overline{1,n}, \tag{1}$$

where $u(t)=(u_1(t),u_2(t),...,u_m(t))$, $k=\overline{1,m}$ – input controlled constituent vector; $\mu(t)=(\mu_1(t),\mu_2(t),...,\mu_p(t))$, $\nu=\overline{1,p}$ – vector of input unmanaged but controlled constituents; constituent (t) – means the consideration of input-output variables at a particular point in time. t. The task of identifying the objects under consideration is reduced to the fact that it is necessary to solve the system of implicit nonlinear equations (1) with respect to the constituents of the vector of output variables $x(t)$ with known input $u(t),\mu(t)$. Of course, the task is complicated if there is a group of objects where each local object will have to be considered separately.

The management of such objects is considered in conditions of uncertainty when there is no description of the object accurate to the parameter vector. Moreover, for a group of objects, the preset influences for each individual object will have to be changed.

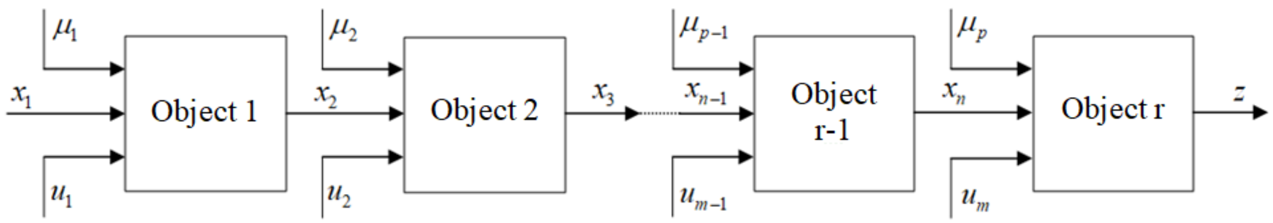

Fig. 1. The group of objects implementing a technological process

Рис. 1. Группа объектов, реализующих технологический процесс

Algorithms identifying local objects. To model a group of objects, the necessary step is to build models of the local objects themselves. In this case, it will be necessary to consider well-known methods, in particular, identification algorithms in a narrow and broad sense. Next, we consider the basic algorithms for modeling local objects. We distinguish two identification classes - parametric and nonparametric.

We consider parametric identification or identification in the narrow sense [8]. In the narrow sense of identification, two main steps are usually considered. The first is the determination of the parametric structure of the object accurate to the coefficients, the second is the determination of the values of the coefficients according to the results of measurements of input-output variables or parameter estimates.

Most often, parameter estimation algorithms are considered in various sources. The most vulnerable stage is the choice of the model structure of the object accurate to the coefficients. It is quite clear that if the structure of the model is chosen inaccurately, this will lead to inaccuracy of the model. It is appropriate to recall the phrase of the ancient Greek philosopher Democritus: "Even a slight departure from truth in the future leads to endless mistakes".

Thus, at the first stage, a class of equations is selected:

$$F_j\left(u,\mu,x,\alpha\right)=0,\ \ j=\overline{1,n}\,, \tag{1}$$

where u are the input controlled process variables, μ are the input unmanaged, but controlled process variables, x are the output variables, α is the parameter vector.

The parameter estimation algorithms are based on the stochastic approximation method, in particular, they have the following form:

$$\alpha_s^k=\alpha_{s-1}^k+\gamma_s\left(x_s-\sum_{i=1}^{N}\alpha_{s-1}^i\varphi_i\left(u_s\right)\right)\varphi^k\left(u_t\right). \tag{2}$$

There are many similar algorithms, but we will not dwell on this in detail.

In the case of nonparametric identification or identification in the broad sense, algorithms for simple statement of problems can be based on nonparametric estimates of the Nadarai-Watson regression function [9]. For the multidimensional case, the form of this estimate is as follows:

$$x_s\left(u\right)=\frac{\sum_{i=1}^{s}x_i\prod_{k=1}^{m}\Phi\left(\frac{u_k-u_{ki}}{c_s}\right)}{\sum_{i=1}^{s}\prod_{k=1}^{m}\Phi\left(\frac{u_k-u_{ki}}{c_s}\right)}, \tag{3}$$

where bell-shaped functions $\Phi\left(\cdot\right)$ and blur parameters c_s satisfy some convergence conditions and satisfy the following properties [9]:

$$0<\Phi\left(c_s^{-1}\left(u_k-u_{ki}\right)\right)<\infty\,;$$

$$c_s^{-1}\int_{\Omega(u)}\Phi\left(c_s^{-1}\left(u_k-u_{ki}\right)\right)du=1\,;$$

$$\lim_{s\to\infty}c_s^{-1}\Phi\left(c_s^{-1}\left(u_k-u_{ki}\right)\right)=\delta\left(u_k-u_{ki}\right);\ c_s>0\,;$$

$$\lim_{s\to\infty}c_s=0\,;\ \lim_{s\to\infty}sc_s^{\ m}=\infty\,.$$

In practice, the most common cases are when the vectors of the output variables of the object are stochastically dependent. In this case, the description of the process can be represented as:

$$F_j\left(u,\mu,x\right)=0,\ \ j=\overline{1,n}\,. \tag{4}$$

And the model of the object in this case, based on the approximation of a local type, can be as follows:

$$\hat{F}_j\left(u,\mu,x,u_s,\mu_s,x_s\right)=0,\ \ j=\overline{1,n},\ \ i=\overline{1,s}\,, \tag{5}$$

where u_s,μ_s,x_s are time vectors (data set received at the s-th moment of time). Moreover, the functions $\hat{F}_j\left(\cdot\right)$ are unknown because dependencies of the output variables of the process are unknown. As noted above, processes having a stochastic dependence of the output variables were called T-processes.

We consider each individual object in the group as a separate multidimensional object with dependencies of input and output variables, as well as unknown dependencies of output variables among themselves. We show such an object in the following fig. 2.

In fig. 2, the vector of input variables arrives at the input of the object $u=\left(u_1,...,u_m\right)$, the vector of output variables is observed at the output $x=\left(x_1,...,x_n\right)$, $\xi\left(t\right)$ – random jamming acting on the object. When considering such an object, one can notice the dependences of the output variables, which may not always be known.

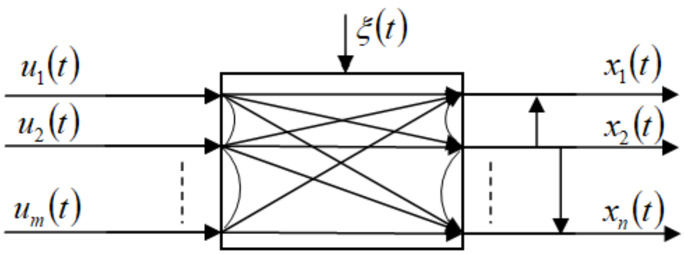

Fig. 2. Multidimensional object

Рис. 2. Многомерный объект

Through various channels of a multidimensional T-object, the dependence of the j constituent of the vector of output variables $\bar{x}$ can be represented as a certain dependence on certain constituents of the vector of input variables $\bar{u}$: $x^{<j>} = f_j\left(u^{<j>}\right),\ j = \overline{1,n}$.

Such functions are determined by the researcher from the available a priori information, and they are called a composite vector. A composite vector is a vector composed of some constituents of the input and output variables, it can also be any set, for example $x^{<2>} = (u_3, u_6, x_4)$, $x^{<4>} = (u_2, u_5, u_6, x_3)$. Different channels of a multidimensional system can have a different number of constituents $u(t)$, included in composite vectors $x(t)$.

A model of such a process is considered as a system:

$$\hat{F}_j\left(u^{<j>}, x^{<j>}\right) = 0,\ j = \overline{1,n}. \tag{6}$$

where functions $\hat{F}_j(\cdot)$ remain unknown.

As a result of measurements of the input and output variables of the object, a training sample can be obtained $\{u_i, x_i\},\ i = \overline{1,s}$. In this case, for given values of the input variables $u(t)$ it is necessary to solve system (6) with respect to the constituents of the output variables $x(t)$. As a result, it is possible to obtain estimates of the constituents of the output variables from the known input, and this is the main purpose of the desired model.

T-models. It was noted above that if the output variables have unknown stochastic dependencies, then they were called T-objects, and their models are T-models. The description of such a process is specified as follows:

$$F_j\left(u^{<j>}(t), x^{<j>}(t)\right) = 0,\ j = \overline{1,n}, \tag{7}$$

where $u^{<j>}(t), x^{<j>}(t)$ is composite vectors, the type of function $F_j(\cdot)$ is unknown. The system of models of the studied object can be represented as follows:

$$\hat{F}_j\left(u^{<j>}(t), x^{<j>}(t), \vec{x}_s, \vec{u}_s\right) = 0,\ j = \overline{1,n}, \tag{8}$$

where $\vec{x}_s, \vec{u}_s$ are time vectors, but in this case $\hat{F}_j(\cdot)$ they remain unknown. Therefore, the problem comes down to the fact that for a given value of the vector of input variables $u(t)$ it is necessary to solve system (8) with respect to the vector of output variables $x(t)$. The general scheme for solving such a system is reduced to a nonparametric two-step algorithmic chain, which allows one to find the predicted values of the vector of output variables $x(t)$ from known input $u(t)$.

First, the deficiencies are calculated by the formula:

$$\varepsilon_{ij} = f_j\left(u^{<j>}, x^{<j>}(i), \vec{x}_s, \vec{u}_s\right),\ j = \overline{1,n}, \tag{9}$$

where functions $f\left(u^{<j>}, x^{<j>}(i), \vec{x}_s, \vec{u}_s\right)$ are taken in the form of a nonparametric estimate of the Nadarah-Watson regression function [9]:

$$\varepsilon_j(i) = f_{\varepsilon j}\left(u^{<j>}, x_j(i)\right) = x_j(i) - \frac{\sum_{i=1}^{s} x_j[i] \prod_{k=1}^{<n>} \Phi\left(\frac{u'_k - u_k[i]}{c_{su_k}}\right)}{\sum_{i=1}^{s} \prod_{k=1}^{<n>} \Phi\left(\frac{u'_k - u_k[i]}{c_{su_k}}\right)}, \tag{10}$$

where $j = \overline{1,n}$, $<m>$ is dimension of a composite vector u_k. Bell-shaped functions $\Phi(\cdot)$ and the blur parameter c_{su_k} y some convergence conditions and have the following properties [9]: satisfy $\Phi(\cdot) < \infty$; $\lim_{s\to\infty} sc_s = \infty$; $\lim_{s\to\infty} c_s = 0$; $\int_{\Omega(u)} \Phi\left(c_{su_k}^{-1}\left(u'_k - u_k[i]\right)\right) du = 1$; $\lim_{s\to\infty} c_{su_k}^{-1} \Phi\left(c_{su_k}^{-1}\left(u'_k - u_k[i]\right)\right) = \delta\left(u'_k - u_k[i]\right)$.

Next, the conditional expectation is estimated:

$$x_j = M\left\{x \mid u^{<j>}, \varepsilon = 0\right\},\ j = \overline{1,n}. \tag{11}$$

where the nonparametric estimation of the regression function is taken as the basis. And ultimately, the forecast for each constituent of the vector of the output variable will be as follows:

$$\hat{x}_j = \frac{\sum_{i=1}^{s} x_j[i] \cdot \prod_{k_1=1}^{<n>} \Phi\left(\frac{u_{k_1} - u_{k_1}[i]}{c_{su}}\right) \times \prod_{k_2=1}^{<m>} \Phi\left(\frac{\varepsilon_{k_2}[i]}{c_{s\varepsilon}}\right)}{\sum_{i=1}^{s} \prod_{k_1=1}^{<n>} \Phi\left(\frac{u_{k_1} - u_{k_1}[i]}{c_{su}}\right) \times \prod_{k_2=1}^{<m>} \Phi\left(\frac{\varepsilon_{k_2}[i]}{c_{s\varepsilon}}\right)},\ j = \overline{1,n} \tag{12}$$

where bell-shaped functions $\Phi(\cdot)$ can be taken in the form of a triangular kernel for inputs (13) and residuals (14):

$$\Phi\left(\frac{u_{k_1} - u_{k_1}[i]}{c_{su}}\right) = \begin{cases} 1 - \frac{\left|u_{k_1} - u_{k_1}[i]\right|}{c_{su}}, & \frac{\left|u_{k_1} - u_{k_1}[i]\right|}{c_{su}} < 1, \\ 0, & \frac{\left|u_{k_1} - u_{k_1}[i]\right|}{c_{su}} \ge 1. \end{cases} \tag{13}$$

$$\Phi\left(\frac{\varepsilon_{k_2}[i]}{c_{s\varepsilon}}\right) = \begin{cases} 1 - \frac{\left|0 - \varepsilon_{k_2}[i]\right|}{c_{s\varepsilon}}, & \frac{\left|0 - \varepsilon_{k_2}[i]\right|}{c_{s\varepsilon}} < 1, \\ 0, & \frac{\left|0 - \varepsilon_{k_2}[i]\right|}{c_{s\varepsilon}} \ge 1. \end{cases} \tag{14}$$

Nonparametric algorithm (10) and (12) is a two-step algorithmic chain that allows one to find the predicted values of the constituents of the output vector for the known constituents of the input variables, in the case of stochastic dependence of the output variables [10].

General statement of the problem of identification and management of a group of objects. Modeling and managing a group of objects is significantly different from modeling and managing local objects. And the main difference is that when managing a group, it is necessary to change the defining influences for controlling local objects. Each time, changing the technological regulations, it is requires by reality. Actually, this is shown by the example below at an oil refinery. Otherwise, the technological map requires expansion, but the result of the implementation of this expanded technological regulation is absolutely clear, which will inevitably lead to poor quality products and even to defective product. Thus, the goals that are set in front of a group of objects are significantly different from the goals that are set in front of local objects. It should to be noted that models and control algorithms are not an arithmetic sum of models and algorithms of a group of objects However, the above models and control algorithms can be taken as a basis. Only the contents of the input and output variables of local objects and groups will change. Thus, for good management of the group, a difference in the relevant technological regulations is necessary [11].

At the end of the 70s, one of the authors was able to participate in studies of the technological process for the production of transistors (Svetlana Production Association, Leningrad), due to the fact that the volume of defective products and low-quality products reached 85 %. The studies showed that the range of technological parameters is incredibly wide in all sections of the technological process, although they corresponded to the technological regulations. The research results made it possible to give relevant recommendations, which were included in industry guidance materials [12].

A wide range of values is characteristic of many mining or processing industries. Of course, one can develop, on the basis of studies conducted for each particular enterprise, a more stringent technology regulations and continue to follow it. But it cannot always be used, because strict technological regulations can be implemented only in enterprises with a high level of production culture. This is, first of all, the high quality of technological equipment, local automation, qualifications of workers and their attitude to the subject.

There may be another way, it is necessary to follow the existing technological regulations, but to optimize the process mode in the given technological object taking into account a carried out technological operation at the previous object. This way is more realistic for enterprises, because it does not require expenditures for reconstruction and can significantly improve the quality of products and reduce losses in the production of certain products. For this, it is necessary to develop and introduce computer systems to improve technological conditions. Such computer systems are quite effective.

Let us consider the control scheme of a local object with time delay (fig. 3).

In fig. 3, the following notation is accepted: $u(t)=(u_1(t),...,u_m(t))$ – managed input variables; $\mu(t)=(\mu_1(t),...,\mu_p(t))$ – unmanaged but controlled variables; $x(t+\tau)=(x_1(t+\tau),...,x_n(t+\tau))\in R^n$ – process output variables; $x^*(t+\tau)=(x_1^*(t+\tau),...,x_n^*(t+\tau))\in R^n$ – setting actions; ξ_t, h_t^μ, h_t^x – random stationary interference influencing the object and the measurement channels of the input and output variables; τ – known lag on various channels of a multidimensional system.

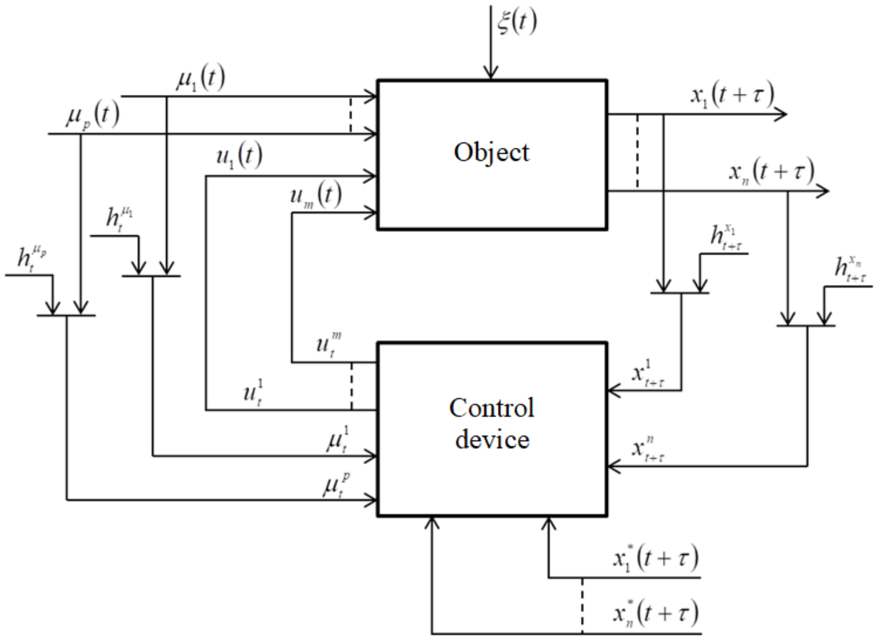

Fig. 3. Multidimensional Object Management Scheme

Рис. 3. Схема управления многомерным объектом

The management of a group of objects should be carried out taking into account the fact that moving from one object to another, it is necessary to change the setting actions.

Multidimensional systems management. The control of multidimensional T-objects is considered under conditions of nonparametric uncertainty, i. e. under conditions when the process model, up to the parameter vector, is completely absent [13]. In this case, well-known techniques are not applicable and other approaches should be used to solve the problem [14–18].

In the problem of controlling a multidimensional process with a stochastic dependence of the output variables, a multistep algorithmic chain is used. It is the following: the input variable $u_1^*(t)$ is taken arbitrarily from the area $\Omega(u_1)$. The following input variable $u_2^*(t)$ is in accordance with the following algorithm:

$$u_2^* = \frac{\sum_{i=1}^{s} u_2^i \Phi\left(\frac{u_1^* - u_1^i}{c_{u_1}}\right) \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \times \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}{\sum_{i=1}^{s} \Phi\left(\frac{u_1^* - u_1^i}{c_{u_1}}\right) \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \times \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}, \quad (15)$$

where $< n_q >$, $< p_w >$ – dimension of the corresponding compound vectors $\bar{x}$ и $\bar{\mu}$, $< n_q > \le n$, $< p_w > \le p$, q, w – the number of constituents included in the composite vector. Compound vectors are determined by the researcher from the available a priori information. If the researcher does not have such information about the object, he uses all the constituents of the input and output variables in a composite vector. Next, the input variable $u_3^*(t)$ is as follows:

$$u_3^* = \frac{\sum_{i=1}^{s} u_3^i \Phi\left(\frac{u_1^* - u_1^i}{c_{u_1}}\right) \Phi\left(\frac{u_2^* - u_2^i}{c_{u_2}}\right) \times \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}{\sum_{i=1}^{s} \Phi\left(\frac{u_1^* - u_1^i}{c_{u_1}}\right) \Phi\left(\frac{u_2^* - u_2^i}{c_{u_2}}\right) \times \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}, \quad (16)$$

And then the control algorithm continues to find each input constituent of the object, and with each subsequent step, the values of the input variables found at the previous step are added to the algorithm. We write a control algorithm for a multidimensional system that will look like this:

$$u_k^{*s} = \frac{\sum_{i=1}^{s} u_k^i \prod_{k=1}^{k-1} \Phi\left(\frac{u_k^* - u_k^i}{c_{u_k}}\right) \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \times \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}{\sum_{i=1}^{s} \prod_{k=1}^{k-1} \Phi\left(\frac{u_k^* - u_k^i}{c_{u_k}}\right) \prod_{j=1}^{<n_q>} \Phi\left(\frac{x_j^* - x_j^i}{c_{x_j}}\right) \times \prod_{\nu=1}^{<p_w>} \Phi\left(\frac{\mu_\nu^* - \mu_\nu^i}{c_{\mu_\nu}}\right)}, \quad k = \overline{1, m} \quad (17)$$

In the control algorithm (17), the blur parameters for the input and output variables remain the adjustable parameters c_{u_k}, c_{x_j} and c_{μ_ν}, the following formulas can be used for them: $c_{u_k} = \alpha \left| u_k^* - u_k^i \right| + \eta$, $c_{x_j} = \beta \left| x_j^* - x_j^i \right| + \eta$ and $c_{\mu_\nu} = \gamma \left| \mu_\nu^* - \mu_\nu^i \right| + \eta$, where α, β and γ some parameters are more than 1, and parameter $0 < \eta < 1$. It should be noted that the choice of blur parameters c_{u_k}, c_{x_j} и c_{μ_ν} is carried out at each control step. Moreover, if c_{u_k} is determined then the determination of c_{x_j} and c_{μ_ν} is carried out taking into account this fact. The order of determining the blur parameters c_{u_k}, c_{x_j} and c_{μ_ν} is not significant.

Group of objects at a refinery. Installation for hydrotreating diesel fuel from sulfur compounds, combined with the process of hydrodewaxing and improving the cold flow of diesel fuel, operates at a refinery. Imagine the technological scheme of the process (fig. 4).

Fig. 4 shows the reactor block R-301, which combines the processes of hydrotreating and hydrodewaxing; and also shows the cleaning blocks of the circulating hydrogen-containing gas S-301a; stabilization of diesel fuel with the extraction of the side shoulder strap K-301; stabilization of distillation of gasoline; purification of hydrocarbon gases. The input is "Raw materials for installation", and the output is "SDF".

The depicted blocks are a group of objects with which combined hydrotreating and hydrodewaxing processes occur.

During the operation of such an installation, information on the progress of the process is collected and accumulated. Therefore, it is necessary to process the accumulated information in order to monitor the entire process and subsequent decision-making on its management [19].

Due to the lack of a priori information about the process in the required volume for the implementation of its modeling and control, it is proposed to use nonparametric systems methods that will help in determining the current state of the process flows at the input and output of the process, identifying inaccurate data, predicting the quality indicators of finished products at the output, correct process control.

Let us depict the general identification scheme for hydrotreating and hydrodewaxing processes in the following form (fig. 5).

The following input and output variables were used for the hydrotreating and hydrodewaxing process: $u_1(t)$ – density at 15 °C, кг/м³; fractional composition, °C: $u_2(t)$ – boiling point, $u_3(t)$ – full boiling point 50 %, $u_4(t)$ – full boiling point 96 % и $u_5(t)$ – final boiling point; $u_6(t)$ – upstream pressure in Р-301, кгс/см²; $u_7(t)$ – inlet temperature в Р-301, °C; $x_1(t)$ – density at 15 °C, кг/м³, fractional composition, °C: $x_2(t)$ – initial boiling point, $x_3(t)$ – full boiling point 50 %, $x_4(t)$– full boiling point 96 %, $x_5(t)$ – final boiling point; $x_6(t)$ – cloud point.

Due to the fact that the nature of the dependence of the input and output variables is unknown, as well as the dependences of the output variables on each other, the two-step non-parametric algorithm of the T-model (10) and (12) considered above is used to determine the predicted values of the vector components exit by known input constituents.

The accuracy of the modeling was estimated by the following formula:

$$\delta_j = \frac{\sum_{i=1}^{s}\left|x_i^j - x_s^j(u_i)\right|}{\sum_{i=1}^{s}\left|x_i^j - \hat{x}^j\right|}, \quad j=\overline{1,n}, \tag{18}$$

where x_i^j – observations at the object, $x_s^j(u_i)$ – object exit forecast, $\hat{x}^j$ – average value for each constituent of the vector $\overline{x}$.

For modeling, we carry out the procedure of a rolling exam.

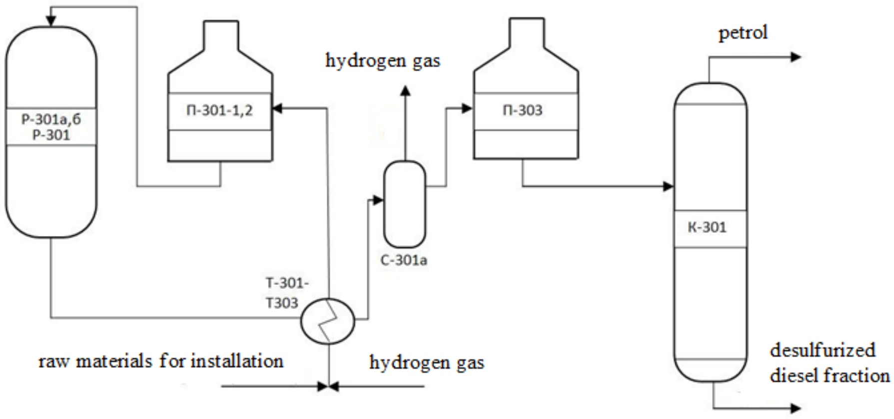

Fig. 4. Fragment of a scheme for hydrotreating diesel fuel and hydrodewaxing

Рис. 4. Фрагмент схемы гидроочистки дизельного топлива
и гидродепарафинизации

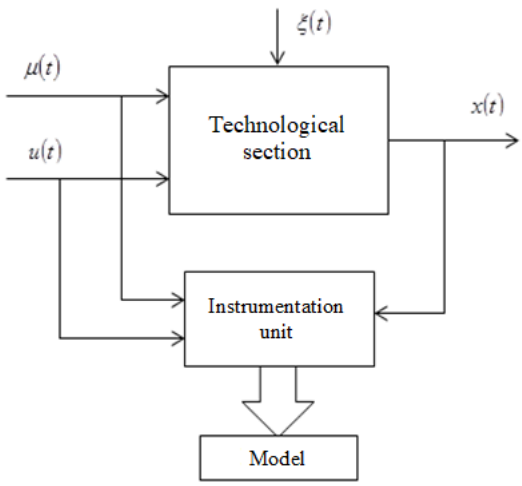

Fig. 5. Fragment of modeling hydrotreating
and hydrodewaxing processes

Рис. 5. Фрагмент моделирования процессов гидроочистки
и гидродепарафинизации

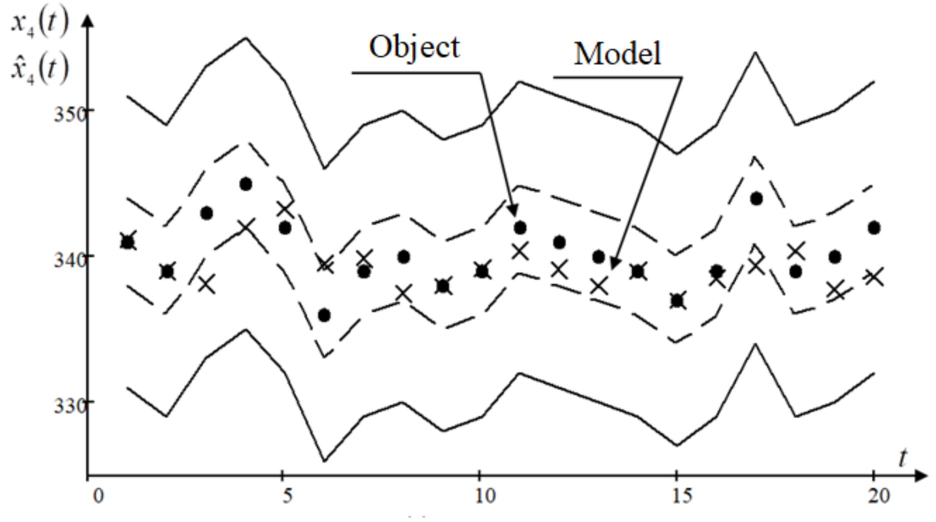

Fig. 6. Prediction of the output constituent $x_4(t)$ for the corresponding input variables $u(t)$

Рис. 6. Прогноз выходной компоненты $x_4(t)$ при соответствующих входных переменных $u(t)$

The adjustable parameters will be the blur parameters c_{su} and $c_{s\varepsilon}$, which in this case we take equal to 0.5 and 0.4, respectively (the values were determined as a result of numerous experiments in order to reduce the quadratic error between the output of the object and model). Sample size $s = 115$. We give the results for the output variable $x_4(t)$ – the boiling point is 96 % (fig. 6).

In fig. 6, the "dot" denotes the outputs of the object, and the "crosses" represent the outputs of the model. For clarity, the presentation of the results on the graph shows 20 sample points. According to GOST R 51069–97 "Oil and oil products. Method for determination of density, relative density and density in degrees by API hydrometer" the accuracy indicators of the method obtained by a statistical study of interlaboratory test results may deviate, for $x_4(t)$ the minimum value is 3 ^{o}C, as shown in dashed lines in fig. 6, and the maximum value is 10 ^{o}C, as shown in fig. 6 in solid lines. For each constituent of the object output, its own deviation limits are approved. Which of the boundaries to choose, minimum or maximum, are determined by a technologist. According to the schedule, we can say that the forecast was quite satisfactory, the modeling error was $\delta_4 = 0.04$. But it is worth paying attention to the fact that the maximum boundaries of deviations are too wide in all sections of the technological process, and the process itself must take place at the minimum boundaries of deviations. The resulting forecast values sometimes go beyond the minimum boundaries, but lie within the maximum limits, many factors can influence this, such as the small size of the training sample, the inaccuracy of a priori information, random interference affecting the process, etc. But well-tuned models make it possible to increase its accuracy and, in the future, will help in high-quality process control [20].

Conclusion. The article considers nonparametric algorithms for modeling and controlling a group of objects under conditions of both parametric and nonparametric uncertainty. The creation of groups is determined not only by the structure of the enterprise, but also by the nature of the technological process. One feature is emphasized, which manifests itself in the fact that the driving actions for each object are the subject of special consideration at each control step. The paper presents models and algorithms for managing a group of objects, as well as some local and specially emphasized property of emergence. Models of multidimensional inertia-free complexes are presented and, in particular, an example is considered based on the results of measurements of real data of the technological combined process of hydrotreating and hydrodewaxing of diesel fuel occurring at a refinery.

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