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ADAPTATION ALGORITHM FOR SELF-TUNING OF PARAMETERS OF MODELS OF MULTI-STAGE FLOTATION PROCESSES

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Abstract: *Modern methods for solving problems of planning the execution of batches of tasks in multi-stage systems are characterized by the presence of restrictions on their dimensionality, the impossibility of guaranteed obtaining better results in comparison with fixed packages for different values of the input parameters of the problem. In the article, the author solved the problem of optimizing the composition of job packages running in multi-stage systems using the branch and bound method. Research has been carried out on various ways to form package execution orders tasks in multi-stage systems (heuristic rules for ordering packages tasks in the sequence of their execution on MS devices). A method has been determined ordering packages in the sequence of their execution (heuristic rule), ensuring minimization of the total time for implementing actions with them on devices Based on the obtained rule, a method is formulated for ordering task types, according to which their packages are considered in the method procedure branches and boundaries. A mathematical model of the process of implementing actions with packages on the devices of the system, which provides calculation of its parameters.*

Key words: *analysis, management of multistage processes (MSP), flotation, optimization, automated control system, digital technologies.*

Annotatsiya: *Ko'p bosqichli tizimlarda vazifalar paketlarini bajarishni rejalashtirish muammolarini hal qilishning zamonaviy usullari ularning o'lchamlari bo'yicha cheklovlar mavjudligi, kirish parametrlarining turli qiymatlariga yega bo'lgan sobit paketlarga nisbatan kafolatlangan yaxshi natijalarga yerishishning mumkin yemasligi bilan tavsiflanadi. muammolar. Maqolada muallif ko'p bosqichli tizimlarda bajariladigan vazifalar paketlarining tarkibini filiallar va chegaralar usuli bilan optimallashtirish muammosini hal qildi. Ko'p bosqichli tizimlarda paketlarni bajarish uchun buyurtmalar vazifalarini shakllantirishning turli usullarini o'rganish (paketlarning vazifalarini MS qurilmalarida bajarish ketma-ketligida buyurtma qilishning yevristik qoidalari) amalga oshirildi. Paketlarni ularni bajarish ketma-ketligida buyurtma qilish usuli (yevristik qoida) aniqlanadi, bu ular bilan qurilmalarda harakatlarni amalga oshirish uchun umumiy vaqtni minimallashtiradi. Olingan qoida asosida vazifa turlarini buyurtma qilish usuli shakllantiriladi, unga ko'ra ularning paketlari usul protsedurasining tarmoqlari va chegaralarida hisobga olinadi. Tizim qurilmalarida paketlar bilan harakatlarni amalga oshirish jarayonining matematik modeli, uning parametrlarini hisoblashni ta'minlaydi.*

Kalit so'zlar: *tahlil, ko'p bosqichli jarayonlarni boshqarish (MSP), flotatsiya, optimallashtirish, avtomatlashtirilgan boshqaruv tizimi, raqamli texnologiyalar.*

Аннотация: *Современные методы решения задач планирования выполнения пакетов задач в многоступенчатых системах характеризуются наличием ограничений на их размерность, невозможностью гарантированного получения лучших результатов по*

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сравнению с фиксированными пакетами при разных значениях входных параметров. проблемы. В статье автор решил задачу оптимизации состава пакетов заданий, выполняемых в многоступенчатых системах, методом ветвей и границ. Проведены исследования различных способов формирования задач приказов на выполнение пакетов в многоступенчатых системах (эвристических правил упорядочивания задач пакетов в последовательности их выполнения на устройствах MS). Определен метод упорядочивания пакетов в последовательности их выполнения (эвристическое правило), обеспечивающий минимизацию общего времени реализации действий с ними на устройствах. На основе полученного правила сформулирован метод упорядочивания типов задач, согласно которому их пакеты учитываются в ветвях и границах процедуры метода. Математическая модель процесса реализации действий с пакетами на устройствах системы, обеспечивающая расчет ее параметров.

Ключевые слова: *анализ, управление многостадийными процессами (МСП), флотация, оптимизация, автоматизированная система управления, цифровые технологии.*

Introduction

For a wide class of mathematical models of complex systems, in particular, MSPs, the presence of a relationship between measurements and noise is characteristic; therefore, the identification of an object by traditional methods of mathematical modeling [1,3,4, 7, 11] often leads to mixed estimates, regardless of the number of observations. At the same time, the objects under study are not stable, which is why the mathematical model cannot describe the behavior of the identified object with the required accuracy over a long period of time.

Material and Methods

In this regard, there is a need to develop and apply adaptive identification algorithms that allow, both at the initial stage of modeling and during the operation of the model, to appropriately adapt the working model of the object to the changing characteristics of the control object by adjusting the model parameters at each control step.

Adaptive methods are used in the construction of:

- optimal automated process control systems for which there is no complete information about their mathematical model;

- optimal systems for automated process control with parameters that are available in time due to changes in conditions and modes of operation.

There are various methods and algorithms for adapting mathematical models that differ in scope, the amount of information required, the speed of convergence, the required amount of PC storage and other characteristics.

In various MSP management systems, different indicators can be limiting, as a result of which it is impossible to specifically specify the general criterion for the quality of the algorithm and the corresponding adaptation algorithm. The criterion for the quality of the algorithm in most cases, both for stationary and non-stationary processes, is the minimum of the root-mean-square error of the product of the output indicator of the process [2, 3]:

$$Q(a) = \mathcal{M}\{g^2\} = \mathcal{M}\left\{\left(y - f(x, a^*)\right)^2\right\} \rightarrow min \quad (1)$$

Here, the value $Q(a)$ characterizes the degree of discrepancy between the outputs of the object and the model and depends on the parameters of the model; $\mathcal{R}^{\mathcal{K}} - \mathcal{K}$ –dimensional Euclidean space of vectors a^*. If the model structure is chosen correctly, the f residual function (1) is equal to zero, i.e., the model is adequate to the object.

In most cases, the correction of the coefficients of the MRP mathematical model is carried out by one of the following recursive relations:

$$a^*_{j,\ \mathcal{N}+1} = a^*_{j,\ \mathcal{N}} + \gamma_r \left(\sum_{i=1}^{n} a_{i,\mathcal{N}+1} x_{i,\mathcal{N}+1} - \sum_{i=1}^{n} a^*_{i,\mathcal{N}} x_{j,\mathcal{N}+1} \right) x_{j,\mathcal{N}+1} \quad (2)$$

$$a^*_{j,\ \mathcal{N}+1} = a^*_{j,\ \mathcal{N}} + \frac{\sum_{i=1}^{n} a_{i,\mathcal{N}+1} x_{i,\mathcal{N}+1} - \sum_{i=1}^{n} a^*_{i,\mathcal{N}} x_{j,\mathcal{N}+1}}{\gamma_r + \sum_{i=1}^{n} x^2_{i,\mathcal{N}+1}} \cdot \ x_{i,\mathcal{N}+1}. \quad (3)$$

Here $\mathcal{N}$ –is the number of the corresponding iteration; $x_{i,\mathcal{N}+1}$-value of input parameters at $\mathcal{N} + 1$the -th step of integration; $a^*_{i,\mathcal{N}+1}$- the value of the coefficients of the mathematical model at $\mathcal{N} + 1$the -th step of integration: i- the number of inputs; γ_r- some positive number, taking into account the influence of interference.

The value $\mathcal{X}_i$when calculating the free member $a_0$always takes equal to one.

The convergence of these adaptation algorithms was proved in [2, 5, 6, 9, 12, 15]. The value of the parameter $\gamma_r$can be detailed based on the analysis of previously obtained arrays x and $y$based on the condition of minimizing the residual variance. In general, the parameter value $\gamma$is defined as follows:

for the algorithm (2)

$$\gamma = \frac{1}{m},$$

and for (3)

$$\gamma = \sum_{i=1}^{m} \mathcal{D}_{xi},$$

where $\mathcal{D}$is the dispersion symbol, $m$is the number of input variables.

Often the characteristics of continuously functioning MSPs are described by nonlinear equations $y = f(x_1, x_2, \ldots, x_n, a_1, a_2, \ldots, a_m)$,. In such cases, correction of the coefficients of equation $y = f(x_1, x_2, \ldots, x_n, a_1, a_2, \ldots, a_m)$, by direct application of the adaptation algorithm (2), (3) is impossible. Therefore, before correcting the coefficients of mathematical models of the form $y = f(x_1, x_2, \ldots, x_n, a_1, a_2, \ldots, a_m)$, it is necessary to bring them to a linear form

$$y = a_0 + \sum_{i=1}^{n} a_i x_i.$$

In the adaptation algorithm, at each moment of time, the output of the process and the output of the model are compared, while the square of the difference in outputs is minimized by an appropriate choice of the parameters of the model operator (Fig. 1). Then the model will constantly adjust to the object so that the reactions to the same input at each moment of time differ minimally.

Results and Discussion

The principle of constructing an adaptive control system for an MSP with an identifier consists in parametric compensation in the adaptive controller of parametric disturbances affecting the control object. At the same time, an identifier is a kind of sensor for deviations of object parameters from their nominal values.

An adaptive control system is a set (complex) of algorithms that provide real-time solution of problems of structural and parametric adaptation, as well as software and hardware tools that implement them. Conventionally, management $\mathcal{U}$ can be divided into management of the structural $\mathcal{U}_S$ and parameters $\mathcal{U}_n$ of the system.

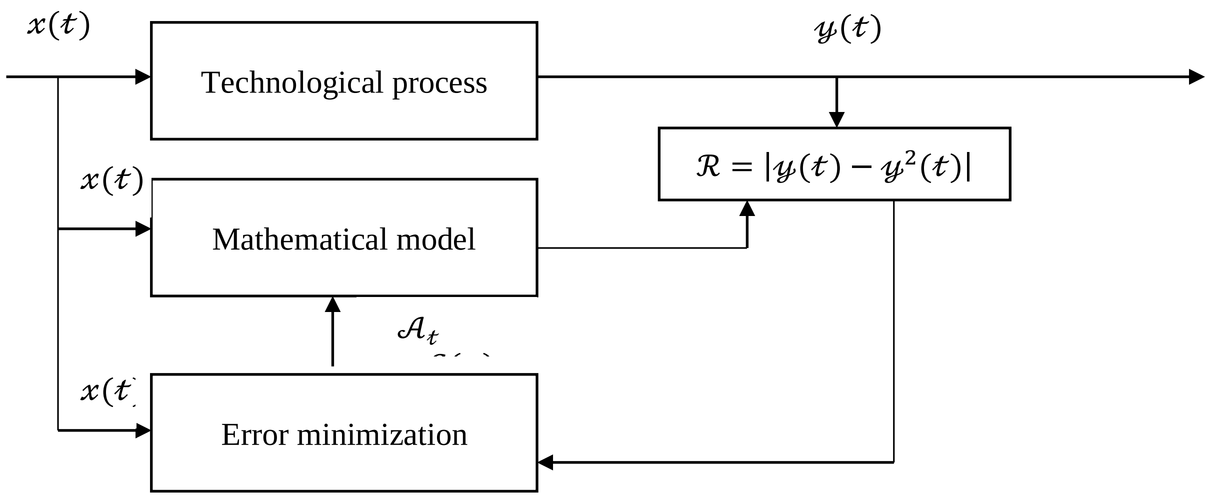

Fig.1. Scheme of adaptation of the mathematical model of MSPs.

The choice of control system means the choice of adaptive control algorithms$\{\mathcal{A}_S,\ \mathcal{A}_n\}$ and the corresponding functional parameters $\{\ \varphi(\mathcal{A})\}$, as well as algorithms (procedures) for identifying (predicting) the corresponding characteristics of input actions $\{\mathcal{R}_x,\ \mathcal{R}_z\}$, and, if necessary, identifying the state and the generalized functional operator of the system functioning φ, $\{\mathcal{R}_{\mathcal{H}},\ \mathcal{R}_{\psi}\}$. Identification procedures $\mathcal{R}$should provide control algorithms $\mathcal{A}$service information necessary for their effective operation (development of control decisions) and in a form convenient for use in the control system.

A complex adaptive system can be represented by a set of two subsystems: controlled (control object - CO) and controlling (control system - CS) (Fig. 2), interconnected and based on common organizational and technical principles of construction and operation.

d-sensors of the state of the environment, the system and the quality of functioning.

Where OS is the control object; $\mathcal{R}_1$, $\mathcal{R}_2$ - control devices in the forward circuit and in the feedback circuit, respectively; $\mathcal{A}$- an adaptation device that identifies and generates control parametric and signal actions based on information from input, control, disturbing actions and output processes.

To solve the problem, the control system should be endowed with the following properties: identify the parameters of input influences (beneficial x and interfering z) forming a set of conditions $Y = (x, z)$based on the use of a priori and accumulated in the process of statistical information $\mathcal{Y}$.

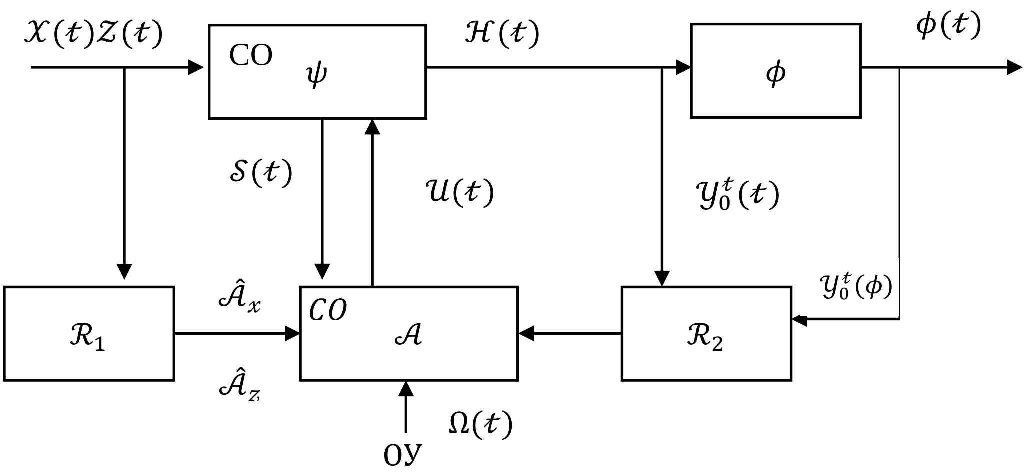

Fig. 2. Generalized structural-functional diagram of an adaptive system

Identify the state of the managed object $\mathcal{H}$, including the integrity of the functional structure (links) < $\mathcal{S},\mathcal{F}$> of the system, and quantify the quality functional ϕ.

Possess an internal goal (criterion ϕ), which ensures the ability of the system to form a purposeful activity.

Thus, the control system must have the means to control input actions $\mathcal{X},\mathcal{Z}$, the state of the system $\mathcal{H}$, structure $\mathcal{S}$and quality ϕ, and have two algorithms: structural and parametric adaptation.

When constructing adaptive control systems, two approaches are possible [8, 12]: the decomposition of an adaptive control device into an optimal controller and a self-tuning device; and the second, the use of dual control algorithms, i.e. algorithms that carry out both the control of the object and its study.

An adaptive system of the first type consists of two circuits (Fig. 3.): self-tuning and the main one. The self-tuning loop performs three main operations: it determines the current dynamic response of the system, generates a self-tuning signal, and rebuilds the controller parameters in accordance with the selected self-tuning criterion.

The self-tuning loop includes a process analyzer (PA), an impact analyzer (IA), a computing device (CD), an executive element (EE).

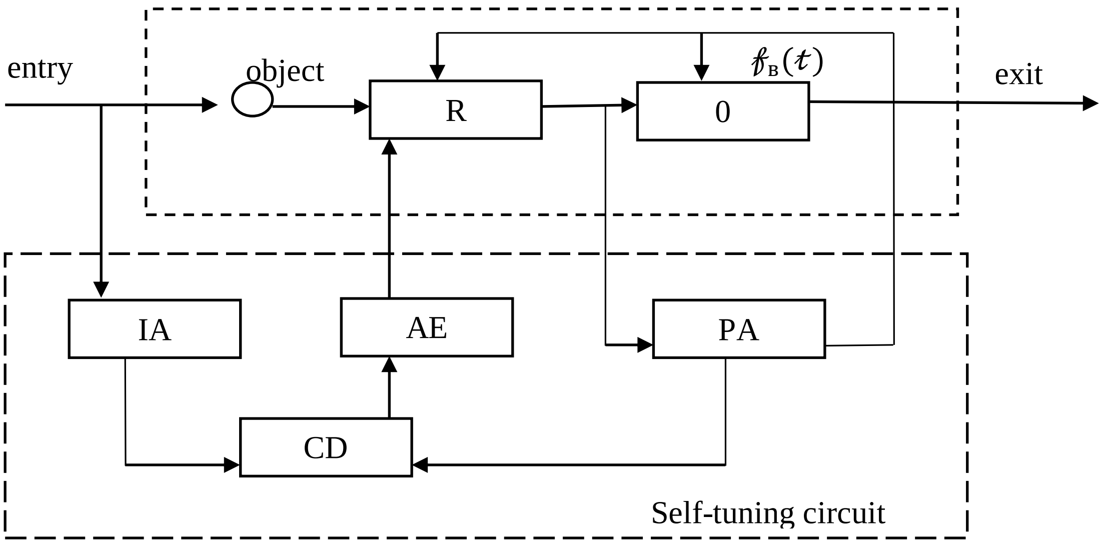

Fig.3. Structural diagram of a self-tuning system: R-regulator; O-object; PA - process analyzer; IA impact analyzer; CD-computing device; EE-executive element; $f_B(t)$- disturbing effect.

The process analyzer is used to fully or partially determine the dynamic properties of an object based on current information about the object. When the normal operating signal of the system is not sufficient to obtain the necessary information for process evaluation, then the PA includes a test signal generator. IA determines the reason for the deviation of the process from the specified (optimal) value. The self-tuning condition (criterion) is stored or generated in the CD. The EE transmits the necessary action from the output of the self-tuning loop to the changing part of the regulator. The considered elements of a self-tuning system are not strictly required, their number can be increased or decreased depending on the degree of perfection of the self-tuning system and the optimization criterion.

The central point in constructing an adaptive mathematical model of the system is to find a generalized functional operator for the functioning of systems ψthat establishes the quality functional $\phi$and the characteristics of input actions $\mathcal{X}$ и $\mathcal{Z}$for the selected control $\mathcal{U}$, i.e.

$$\phi(t) = \psi(\mathcal{X}, \mathcal{Z}, \mathcal{U}, t)$$

Given the random nature of the input parameters $\mathcal{X}$and $\mathcal{Z}$the control object is stochastic, and the operator $\psi$is probabilistic.

For structurally complex stochastic systems, the ambiguity of the results of functioning is characteristic due to a certain technical imperfection of the system itself, the complexity of the tasks being solved, the random nature of the complex of functioning conditions $\mathcal{Y} = (\mathcal{X}, \mathcal{Z})$. As a result, the system functioning process provides a sequence of different system states $\mathcal{H}$, in each of which the system performs the specified functions with a certain quality level ϕ, depending on the current state of the system. The state $\mathcal{H}$can be understood as the state of health and throughput of various elements of the system structure, the degree of their load, etc.

Dependence ϕon the state $\mathcal{H}$is a mathematical model of the quality of the system functioning, set by the operator ψ_1, i.e.

$$\phi(t) = (\mathcal{H}(\mathcal{Z}), \mathcal{U}(\mathcal{Z}))$$

The law of change in time of the vector $\mathcal{H}(t)$ is a mathematical model of the system functioning process. The set of possible states of the system $\mathcal{H}$ forms the phase space of states $\Omega(\mathcal{H})$.

A functional description can be built on the basis of an experimental study (evaluation) of the system operator ψ(identification of an object in the process of its operation) or on the basis of a preliminary mathematical modeling (description) of the system operation, using its monographic image and informational description[6, 16].

Conclusion

Thus, the adaptation algorithm, based on current information about the input and output parameters, should bring the behavior of the model closer to the behavior of the object. The resulting model parameters are estimates of the object parameters.

The advantages of systems using the method of adaptive models are visibility, speed and versatility, the main disadvantage is the complexity of ensuring the conditions for the systems to work, since the identification algorithms in them are directly dependent on the accuracy of assessing the state of the control object at each moment of time and the presence of any errors and measurement leads to the need to reconfigure the model parameters.

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