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ADAPTATION OF A PREDICATE MODEL IN CONTROL PROBLEMS OF NONSTATIONARY STATIC OBJECTS

Abstract. *When controlling static objects at the optimization level, pattern recognition methods are used that allow partitioning the factor space into elementary subdomains in the form of n-dimensional hyperparallelepipeds. One of the main elements of the control structure for this approach to control is the adaptation algorithm, that makes it possible to refine the description of a static object under nonstationarity conditions. Repeated use of the adaptation algorithm to refine the model leads to an unjustified complication of its logical structure and the accumulation of information that has lost its relevance. The paper proposes a method for minimizing the description of images of technological situations, that makes it possible to overcome the indicated disadvantages. The method is based on the property of invariance of the number of parameters defining the hyperparallelepiped to the size of the described area in the factor space. This made it possible to identify significant boundary sub-areas in the description of the image of technological situations and, by their subsequent combination in the direction of the feature axes, to select a description with a minimum number of sub-areas. When performing these operations, "outdated" information is removed and the logical structure of a static control object is simplified as much as possible. The paper shows the possibility of implementing an algorithm for minimizing the description of images on the basis of α-algebra, that makes it possible to integrate its control structures using relational data models. The effectiveness of the proposed algorithm is confirmed by computational experiments in the control of the process of lump crushing for the conditions of a mining and processing plant.*

Keywords: *controlling static objects, α-algebra, method for minimizing the description of images, information, adaptation algorithm*

Introduction

Adaptive control systems capable of functioning effectively in unstable environments remain an important area of modern scientific research. In particular, predicate models — logical knowledge representation models based on predicates (mathematical logic formulas) — and their adaptation for solving control tasks of technical objects are being actively studied [1]. Predicate models make it possible to describe the states and interrelations of an object in the form of logical statements (predicates), which ensures flexible decision-making based on knowledge. However, for their effective application in real-time systems, such models require mechanisms for adaptation to changing operating conditions of the controlled object.

Ukrainian researchers have made a significant contribution to the development of this area. Thus, the authors in [2] proposed a predicate model for selecting protection devices for asynchronous motors operating under unstable power supply conditions. It has been shown that the energy-economic model of the motor can be represented as a disjunction of predicates, and pattern recognition algorithms can be applied to this model for decision-making regarding motor protection. An important advantage of this approach is the openness of the model and the possibility of accumulating knowledge about the equipment [3]. Based on the classical algorithm of statistical optimization of nonlinear objects represented by a set of predicates, the authors in [2, 3] achieved an effective search for solutions according to the principle of local gain. Further research by these authors was aimed at accelerating the development of predicate models and ensuring their structural adaptation. In particular, methods for reducing the description of features made it possible to build a model faster at the training stage and subsequently perform the necessary structural transformations during adaptation while maintaining the accuracy of describing the interrelations [4, 5]. This made it possible to take into account the technical and economic performance indicators of the equipment under various conditions (with or without protection devices) and to ensure the optimal choice of a solution [2-5].

In addition to recent works, it is worth noting earlier studies that laid the foundation for the development of adaptive predicate models. The author in [6] proposed a method of adapting the description of patterns in the algorithm of recognizing production situations as early as 1984. The author in [7] in 1982 developed a method for describing technological situations for process control using state predicates, optimizing the description by reducing redundant information.

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These studies [6,7] demonstrated the possibility of encoding the states of technological objects in the form of numerical predicates and their use in control systems. These fundamental studies, although conducted several decades ago, remain relevant as examples of knowledge formalization about the control object and their gradual refinement (adaptation) during operation.

In parallel with Ukrainian research, approaches to adaptive control based on logical models are also actively developing in the global scientific community. For example, the authors in [8] compared the capabilities of classical predicate logic, fuzzy logic, and non-monotonic logic as methods of knowledge representation for control systems. They demonstrated that each approach has its strengths: predicate logic ensures strictness and unambiguity of conclusions; fuzzy logic provides flexibility in conditions of uncertainty; and non-monotonic logic enables the revision of previously made conclusions when new information becomes available. Modern studies often combine these approaches to achieve greater adaptability of control systems.

Scientific literature emphasizes that effective control of non-stationary objects requires the use of models capable of being updated in real-time and of taking into account changes in system parameters during operation. Such models reflect both the current state of the object and the rules of response to changes (for example, exceeding parameter thresholds).

Once a sufficient amount of reliable and accurate information about the main disturbing factors and external influences affecting the technological object is collected, it becomes possible to significantly improve the quality of control over such systems. In particular, the availability of detailed data on the characteristics and behavior of the controlled object under varying operating conditions allows for the development and implementation of highly effective control strategies. These strategies are aimed at ensuring stable operation of the object, minimizing negative effects from disturbances, and maintaining optimal performance indicators.

In order to achieve such a high level of control, it is necessary to determine optimal control actions that are adequate to the current operational state of the object and the nature of the influencing disturbances. The formation of these optimal control actions can be carried out in different ways, depending on the peculiarities of the technological process and the available computational resources.

One of the possible approaches is to establish the dependence of the control actions on the changing disturbances directly in the course of the control process. In this case, optimal solutions are determined in real time using optimization algorithms based on the current values of disturbances and object parameters. However, this approach often requires considerable computational resources and time, especially when the system is complex or when the object is influenced by a large number of rapidly changing factors. Moreover, the resulting dependence of optimal control actions on disturbances usually cannot be expressed explicitly in a simple analytical form due to the complexity of the object’s behavior.

Alternatively, the dependence of control actions on disturbing factors can be formed in advance, during the design or configuration phase of the control system, based on a mathematical model of the object obtained from previous studies or experimental data. In this case, the optimization calculations are carried out beforehand for different scenarios of possible disturbances, and the results are stored in the form of precomputed functions, lookup tables, or control charts. These stored solutions are then used during the operation of the system for quick selection of control actions without the need for repeated optimization computations.

Both of these approaches are conceptually similar, as they are based on the idea of optimizing control actions in accordance with the characteristics of the object and the nature of the disturbances. However, they differ primarily in the frequency and timing of optimization calculations. In the first approach, the calculations are performed continuously or at the rate at which the disturbances change, ensuring an adaptive response of the control system to real-time changes. In the second approach, all necessary computations are performed offline, prior to the control process, and the system uses the prepared data during its operation.

Regardless of the chosen approach, in both cases the task of determining optimal control actions is solved using well-known mathematical programming methods. These include various techniques of linear, nonlinear, and dynamic optimization, which are widely used in control theory for static or quasi-static objects [9, 10]. These methods allow for formalizing the control problem, taking into

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account existing constraints and optimization criteria, and finding the most effective control actions that ensure stable and efficient functioning of technological objects under variable external conditions.

Static optimization methods are widely recognized as an effective tool for solving a broad spectrum of practical problems in the field of control of technological processes and technical systems. These methods make it possible to determine optimal operating modes, resource allocation, or control strategies under given conditions and system constraints. The choice of a particular optimization method, as indicated in [11], is largely determined by the availability of a well-defined mathematical description of the process or object to be controlled.

Indeed, the presence of a reliable and sufficiently accurate mathematical model of the object is a key prerequisite for the successful application of most static optimization techniques. Such a model serves as the basis for formulating the optimization problem, setting the objective function, and defining the system constraints.

However, in many real-world cases, obtaining a mathematical model of a complex technological object is associated with significant challenges. This is especially true for industrial processes characterized by high variability, nonlinearity, or the influence of many uncontrolled factors. A typical example of this is the process of lump crushing at ore-dressing and processing plants, where the dynamics of the process are determined by a large number of random and difficult-to-measure parameters.

The development of a mathematical model for such objects using traditional approaches — such as experimental research, statistical data analysis, or physical modeling — requires considerable financial investment, as well as substantial time and human resources. These costs may become even more substantial when considering the fact that in real operating conditions, the parameters and characteristics of the process often change over time due to wear of equipment, changes in raw material properties, or varying external influences.

Consequently, it is necessary not only to develop the initial mathematical model but also to regularly update or refine the model coefficients to maintain its relevance and accuracy. This model adjustment is essential to ensure the correctness of the optimization results and the effectiveness of control decisions. However, periodic model identification or recalibration requires additional measurements, data collection, and computational resources, which further increases the overall economic and labor costs associated with the modeling and optimization process.

Therefore, when selecting optimization methods for practical application, it is very important to take into account not only the accuracy requirements for the mathematical description of the process but also the cost-effectiveness of obtaining and maintaining such a model. In some cases, it may be reasonable to use simplified models, heuristic methods, or knowledge-based approaches that require less detailed information about the object but still provide acceptable quality of optimization and control solutions.

One of the possible and widely recognized approaches to overcoming the aforementioned difficulties associated with obtaining mathematical models of complex technological processes is the use of adaptive identification methods. These methods are designed to automatically adjust the parameters of the model during the operation of the control system based on real-time measurement data. This approach makes it possible to significantly reduce the cost and time associated with traditional offline modeling procedures, especially in cases where the system operates under conditions of uncertainty or frequent changes in its parameters.

Among the existing adaptive identification methods, the most commonly used is the least squares method, which has proven to be highly effective in many engineering applications. This method provides parameter estimation by minimizing the sum of squared deviations between the measured output data of the system and the corresponding values calculated from the model. Its widespread popularity is explained by its relatively simple mathematical implementation, stability of results, and the possibility of its application in both static and dynamic systems.

In addition to the least squares method, various modifications of the stochastic approximation method are also used quite successfully for solving identification tasks, especially in situations where the measurement data are subject to significant noise or when the system parameters vary in a random manner [12]. These methods allow for a gradual refinement of parameter estimates through iterative procedures

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based on incoming measurement data, which ensures the adaptability of the model to changing external and internal conditions of the technological object.

However, despite the obvious advantages and the wide range of proposed methods for adaptive identification, it should be noted that the practical application of this approach is not without significant limitations and challenges. One of the main problems is that, although the theory of identification provides a large variety of mathematical tools, algorithms, and procedures for parameter estimation, it does not offer clear recommendations regarding the rational choice of the model structure itself or the optimal identification criteria.

In other words, the main focus of identification theory is on the mathematical aspects of parameter estimation within an already defined model structure, while the issue of selecting the appropriate structure of the model — that is, the set of variables, their interrelationships, and the form of the model equations — often remains outside the scope of this theory. Additionally, there is a lack of universally accepted criteria for evaluating the quality of identification results and for choosing the most suitable identification algorithms for a specific object or control task.

As a result, as noted by experts in this field [13], the process of selecting appropriate adjustable models and corresponding algorithms for their identification is often based not only on strict scientific principles but also on the experience, intuition, and creative approach of the developer or system designer. Therefore, it is quite fair to state that "the choice of tunable models and algorithms is more an art than a science" [13], reflecting the fact that successful implementation of adaptive identification methods in practice requires not only theoretical knowledge but also a deep understanding of the specific features of the controlled object, the nature of the disturbances, and the requirements of the control system.

In addition, the model of an object in analytical form has a significant drawback: the invariability of its structure. The constancy of the structure of the mathematical model leads to a loss of accuracy in describing a real process. Pattern recognition methods have much greater flexibility in terms of improving the model, that is, clarifying its structure.

Recognition methods are widely used in process control. They are mainly used for predicting its course, that is, predicting the parameters characterizing the process, or assigning the expected mode to one of the predetermined classes - typical modes. It is obvious that optimization methods and recognition methods complement each other, and only their combined application can improve the efficiency of technological processes control.

In [14, 15], this approach is applied to the choice of technical means of protection of an induction motor in electrical networks with low-quality electricity. At the same time, a predicate adaptive model of the following type was chosen as a mathematical model reflecting the regularities of the influence of the indicators of the electrical network and the cost indicators of protective equipment on the economic efficiency of operating an induction motor:

$$Z_e\left[\overrightarrow{X},\overrightarrow{U}\right]=\mathop{V}_{p=1}^{q}\left\{\left[\mathop{V}_{l=1}^{\lambda_p+s_1} Z_{pl}\left[\overrightarrow{X},\overrightarrow{U}\right]\right]\wedge\left[\overline{\mathop{V}_{h=1}^{s_2} Z_{pl}\left[\overrightarrow{X},\overrightarrow{U}\right]}\right]\right\} \quad (1)$$

where $\overrightarrow{X},\overrightarrow{U}$ – are the vectors of power quality indicators and cost indicators of protective equipment, respectively; s_1 and s_2 – the number of results obtained for the recognition of contradictions of the first and second kind, respectively; q – the number of images of economic situations; λ_p – the number of predicates describing l - the pattern at the end of the pattern recognition learning procedure; ; $\wedge,\vee$ – logical operations of disjunction and conjunction, respectively.

Model (1) can also be applied to optimize static technological processes, if vectors of perturbing and control quantities are considered as vectors $\overrightarrow{X}$ and $\overrightarrow{U}$. However, continuous refinement of this model will inevitably lead to an increase in conjunction and disjunction operations in its right-hand side and, as a consequence, a complication of the structure and the need to adjust the algorithm for choosing the optimal control actions. This circumstance limits the application of the considered approach to the control of technological processes with constant parameters.

Purpose of paper. This paper is aimed at substantiating the possibility and determining the stages of identical transformations of the predicate model in order to prevent the complication of its structure.

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The main material

The optimal control of static and case-static modes of robots of technological objects is based on the pattern recognition method, which allows partitioning the factor space into elementary subdomains. The essence of the algorithm for recognizing static optimization of nonlinear objects is as follows.

In the process of learning recognition by elements of the sample population $(\overrightarrow{X_1},\ldots,\overrightarrow{X_u})$, it is necessary, by setting different values of the control criterion y in the interval $y_{\max} \div y_{\min}$, to split the factor space $\{x_1,\ldots x_n\}$ into two images: M_1, if $y_{\mathrm{j}} \le y$ and M_2, if $y_{\mathrm{j}} > y$ $(j=\overline{1,v})$, where v – sample size. If, in this case, the value of the control criterion is changed with the interval Δy, then $m = entier((y_{\max} - y_{\min})/\Delta y) + 1$ of the separating images of hypersurfaces will be obtained, which, in accordance with the method of analytical description of objects by methods that allow partitioning the factor space into elementary regions, can be specified in the form of predicate equations Z_i. If a controlled value can be selected as a quality, then Δy is the accuracy of its control.

A significant advantage of constructing a mathematical model of a complex and heterogeneous technological process within a unified mathematical framework is that such a model inherently incorporates the basic constraints and limitations imposed by the physical nature and operating conditions of the process itself. These built-in constraints reflect the fundamental technological requirements, safety regulations, operational limits, and resource restrictions that must be respected during the control of the object.

When the technological process is adequately described within a single modeling approach — for example, using unified mathematical equations or a generalized set of dynamic relationships — it becomes possible to significantly simplify the development of the control system. This is because the restrictions that normally require separate consideration in optimization problems are already implicitly present in the mathematical representation of the process.

As a result, there is no need to formulate an additional system of external constraints or perform complex analytical transformations to account for them during optimization. The constraints are naturally integrated into the model structure through the interconnections between variables, technological balances, and functional relationships governing the process behavior.

This modeling feature provides a unique opportunity to design control algorithms that do not require the application of conventional, often resource-intensive, optimization methods. Instead of resorting to classical optimization procedures — such as linear programming, nonlinear programming, or multi-criteria optimization — the control problem can be solved using relatively simple computational procedures based on the existing model.

In such cases, the optimal control actions are generated directly within the control algorithm as a result of the model's structure and its inherent properties. The system automatically respects all process limitations without the need for additional computational steps for constraint handling.

Thus, the use of a unified mathematical model for describing heterogeneous technological processes allows for the implementation of straightforward and computationally efficient control algorithms. These algorithms ensure optimal or near-optimal control performance while significantly reducing the complexity of the control system and minimizing the computational burden compared to traditional optimization-based control approaches.

This modeling strategy is especially relevant in real-time control tasks or in systems with limited computational resources, where the simplicity and speed of the control algorithm are critical factors for its practical implementation.

Of the factors influencing the process, controllers $x_1 \div x_v$ are distinguished and the full range of their changes is presented as a series of values with an interval Δx. Thus, all possible controls can be specified as combinations of these values. Then, based on the values of the disturbing factors $x_{v+1} \div x_n$, it is sufficient to determine the truth of the predicate Z_1 for all possible controls. The optimal control is the one that ensures the truth of the predicate. If the optimal combination is not found by the predicate Z_1, then it is necessary to expand the investigated zone of the factor space by passing to the predicate Z_2, etc.

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When constructing mathematical models of complex systems or when solving control and optimization problems, it is often necessary to partition the n-dimensional factor space into simpler geometric regions for the purpose of analysis, classification, or decision-making. In this context, one of the most convenient and widely used geometric objects for representing an elementary domain in an n-dimensional factor space is the hyperparallelepiped.

A hyperparallelepiped is a generalized geometric figure in multidimensional space, which is a direct extension of a parallelepiped in three-dimensional space to higher dimensions. Its structure is defined by specifying the lower and upper boundaries along each of the n coordinate axes corresponding to the factors or variables under consideration.

Mathematically, such an elementary domain can be very conveniently and compactly described using a two-valued logical predicate function, which allows one to determine whether a given point in the factor space belongs to this region or not. In other words, the hyperparallelepiped is defined as a set of all points whose coordinates satisfy a system of inequality constraints that specify the minimum and maximum permissible values for each factor.

This two-valued predicate takes the value "true" (or 1) if the point lies within the specified limits along all coordinate axes, and "false" (or 0) if at least one of the constraints is violated. Such a representation is not only mathematically rigorous and unambiguous but also very convenient for practical implementation in algorithms of control, identification, classification, or optimization.

Moreover, using a hyperparallelepiped as an elementary domain in the factor space offers a number of advantages from the computational point of view. The simplicity of the mathematical expression that defines its boundaries allows for fast checking of point membership, which is critical in real-time control systems or in optimization algorithms where a large number of such checks may be required.

In summary, the hyperparallelepiped provides a universal and efficient geometric structure for partitioning the factor space in multidimensional modeling tasks. Its formal description through a two-valued logical predicate ensures clarity, ease of implementation, and high computational efficiency, making it one of the most suitable elementary domains for use in control theory, decision-making systems, pattern recognition, and various engineering applications:

$$Z\left[\vec{X}\right]=\frac{1}{2^n}\prod_{j=1}^{n}\left\{1+\operatorname{sgn}\left[(X_j-X_{j\min})(X_{j\max}-X_j)\right]\right\} \quad (2)$$

where

$$\operatorname{sgn}\left[(X_j-X_{j\min})(X_{j\max}-X_j)\right]=\begin{cases}1, & if\ \left[(X_j-X_{j\min})(X_{j\max}-X_j)\right]\geq 0\\ -1, & if\ \left[(X_j-X_{j\min})(X_{j\max}-X_j)\right]<0\end{cases}, \quad (3)$$

$X_{j\min}, X_{j\max}\,(j=\overline{1,n})$ – parameters of an elementary hyperparallelepiped that determine its dimensions; n – the number of input quantities (disturbing and controlling); x_j – current values of input quantities; $\prod$ – mathematical multiplication operation.

If the current technological situation $\overrightarrow{X}(x_1, x_2, \ldots, x_n)$ falls inside the hyperparallelepiped (the technological situation is recognized), then $Z\left[\vec{X}\right]=1$, otherwise $Z\left[\vec{X}\right]=0$ (the technological situation is not recognized).

Then the whole p - image can be represented as a logical sum of predicates:

$$Z_p\left[\vec{X}\right]=\bigcup_{l=1}^{\lambda_p} Z_l[\overrightarrow{X}], \quad (4)$$

where λ_p – the number of predicates that determine the p - image.

The set of n - dimensional hyperparallelepipeds that define the p - image in the feature space have a random arrangement - they may intersect or have no common points at all.

The mathematical model of the controlled object, presented in the form of m - images, will take the form:

$$Z_m\left[\vec{X}\right]=\bigcup_{p=1}^{m} Z_p\,[\overrightarrow{X}], \quad (5)$$

In the process of control, it is possible to refine the model (5). So if for the current technological situation the optimal control values have not been found

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(error of the first kind), then predicate (2) is formed based on the control result with the current control values and is included in (4). If, for the current situation, the optimal control values are determined, but the control result does not correspond to the expected (error of the second kind), then the corresponding predicate in (4) is further considered false and a new alternative image is formed, and the mathematical model takes the form (1). A simple removal of the false predicate from (4) is impossible, since it defines a set of technological situations that fall inside some n-dimensional hyperparallelepiped.

Obviously, when controlling a non-stationary static or quasi-static object, such refinements can be performed many times, which will lead to a structural complication of the mathematical model (1) and, as a consequence, to the loss of the control algorithm performance. Structural changes (1) should be limited.

It is proposed to solve the problem of limiting structural changes in the predicate model of technological situations on the basis of the invariance of the number of parameters of the hyperparallelepiped to the size (volume) of the region specified by it in the feature space. A set of randomly located p-image hyperparallelepipeds can be represented as ordered hyperparallelepipeds differing in size (Fig. 1). The hyperparallelepipeds located on the border of the image will have the smallest dimensions, since they determine the accuracy of the dividing function. In Fig. 1 they are shaded.

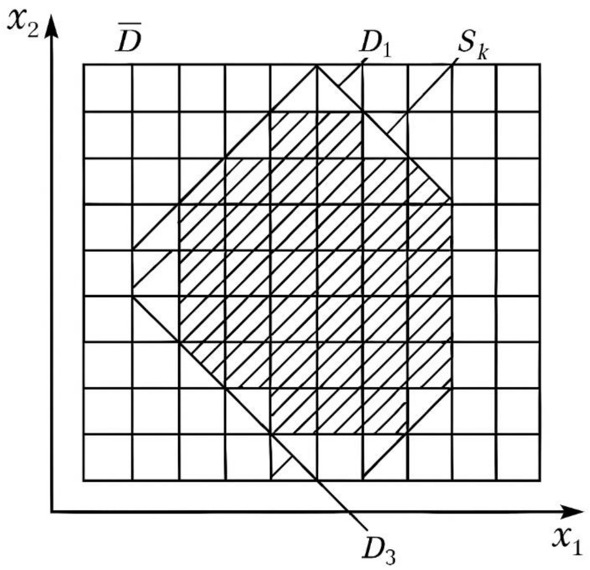

Figure 1 - Location of Boundary Subareas

If we combine the shaded boundary sub-areas in the direction of one of the feature axes, for example, x_1, we get different-sized sub-areas that completely describe the image. Thus, the union of the subdomains D_1 and D_2 is of interest, since the resulting subdomain D_{12} includes, in addition to D_1 and D_2, one more internal subdomain of the image S_k. Combining the D_1 and D_3 subdomains into the D_{13} subdomain will allow simultaneously describing four more internal subdomains.

It is easy to see that the combined subregions differ only in the parameters of one projection. This allows us to propose a simple condition according to which two boundary subdomains are to be united if all internal subdomains located between them belong to the image $x^1_{j\min} = x^2_{j\min};\ x^1_{j\max} = x^2_{j\max}$ under $j = \overline{1,n};\quad j \neq r$, where $x^1_{j\min}, x^2_{j\min}, x^1_{j\max}, x^2_{j\max}$ – parameters of function (2) describing two combined subdomains; r is the number of the feature axis in the direction of which the union is performed. For the resulting subdomain, the unknown minimum and maximum value of the m-feature is defined as $x^{12}_{m\min} = \min\left\{x^1_{m\min}, x^2_{m\min}\right\};\ x^{12}_{m\max} = \max\left\{x^1_{m\max}, x^2_{m\max}\right\}$.

Obviously, the considered unification of the boundary subareas does not lead to a change in the location of the image in the feature space, since the boundary areas do not change their location - they are only united by oppositely located boundary subareas. This transformation of the image is identical. It can be performed immediately upon the occurrence of the previously mentioned contradiction of the second kind. Then the complication of the structure of model (5) is not required.

It should be noted that the number of enlarged subregions obtained as a result of merging is already more than two times less than the number of boundary subregions. These joins can be continued in the remaining n - 1 directions. If you change the sequence of combining along the attribute axes, you can get n!, separating functions, from which the minimum in terms of the number of constituent subdomains is selected.

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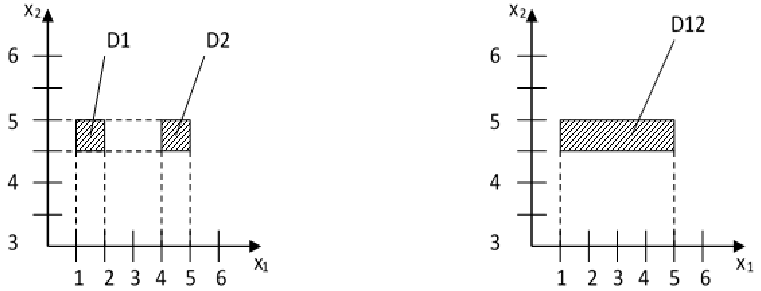
Practical implementation of the minimization algorithm

The set of technological situations given by predicates (2) are combined into classes depending on the values of the control criterion. Each class is determined by the disjunction of predicates. The use of such a model involves arranging its elements in the form of a two-dimensional table. And in its columns values $X_{j\min}^{pl}, X_{j\max}^{pl}$ are placed, and the line corresponds to some predicate.

It is easy to see that the columns of the table have different names and are homogeneous, all rows are unique and have the same structure. The order of the lines is not significant and only affects the speed of access to each of them. Given also that the information in the columns is atomic, we can conclude that this table satisfies the conditions and constraints that allow us to consider its relationship as a relational data model [16-18]. The sequence number of the relation tuple (table row) uniquely identifies the current technological situation. The set of attributes (columns of the table) determines the scheme of the relationship. It is clear that the set of relations M_k, each of which describes a certain class of technological situations, completely determine the model of the technological process. Here $k = \overline{1, \mathrm{q}}$, where q is the number of relationships.

Operations on relations are determined by α-algebra. Consider the application of α-algebra to implement the procedures of the proposed minimization algorithm.

Algorithms for minimization and accelerated learning are based on combining two subregions D1 and D2 in factor space (Fig. 2).



D_1

X1 min	X1 max	X2 min	X2 max
1	2	3	4

D_2

X1 min	X1 max	X2 min	X2 max
4	5	3	4

Projection

Projection

D_1MN

X1 min	X1 max	X2 max
1	3	4

D_1MX

X1 min	X2 min	X2 max
2	3	4

D_2MN

X1 min
4

D_2MX

X1 max
5

Cartesian multiplication

D_12

X1 min	X1 max	X2 min	X2 max
1	5	3	4
4	2	3	4

Filtration

D_12

X1 min	X1 max	X2 min	X2 max
1	5	3	4

Figure 2 - Defining a tuple that defines a merged area

The tuples of relations that define these subdomains differ in the value of the two attributes $x_{l\min}, x_{l\max}$ (x_1 is the sign axis in the direction of which the union takes place. Selection of these tuples D_1 and D_2 is achieved by the filtering

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operation. To obtain a tuple D_12 that defines the combined region D_12, the relation D_1 is first decomposed into the relation D_1MX without the attribute $x_{1\min}$ and the relation D_1MN without the attribute $x_{1\max}$, and the relation D_2 into the relation D_2MN with a single attribute $x_{1\min}$ and the relation D_2MX with a single attribute $x_{1\max}$.

This decomposition is achieved by the projection operation. In the future, performing the Cartesian multiplication operation $D\_1MX \otimes D\_2MN$ and $D\_1MN \otimes D\_2MX$, two tuples of the relation D_12 with a complete set of attributes are formed, from which the desired D_12 is selected by filtering under the condition $x_{1\min} < x_{1\max}$.

Conclusions

1. The proposed minimization algorithm provides a robust mechanism for stabilizing the structure of the predicate model, which is particularly important when dealing with nonlinear and nonstationary objects. By systematically reducing the uncertainty and variability inherent in such systems, the algorithm ensures the consistency and adaptability of the model structure over time. This, in turn, allows the refined predicate model to be effectively utilized for solving optimal control problems, enabling improved decision-making, better system responsiveness, and enhanced performance in dynamic and complex environments.

2. Identical transformations applied to the predicate model, which are grounded in the principle of invariance of the number of predicate parameters with respect to the size of the region in the n-dimensional factor space that the model characterizes, enable a significant simplification of the model structure. This invariance implies that the complexity of the model does not necessarily have to grow with the expansion of the factor space, allowing for a more efficient representation of the system's behavior. As a result, it becomes possible to systematically reduce the number of predicates without losing the descriptive power or accuracy of the model. Such a reduction contributes to improved computational efficiency, enhances interpretability, and facilitates the application of the model to

real-time or large-scale control and decision-making tasks in dynamic environments.

3. Representation of elements of the predicate model in the form of a relational data model allows to describe the minimization procedure on the basis of a single mathematical apparatus of α-algebra. Given that relational data models are supported by database management systems, the proposed algorithm can be easily integrated into the information and software structures of existing management systems.

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АДАПТАЦІЯ ПРЕДИКАТНОЇ МОДЕЛІ В ЗАДАЧАХ КЕРУВАННЯ НЕСТАЦІОНАРНИМИ СТАТИЧНИМИ ОБ’ЄКТАМИ

Анотація. *У даній роботі розглянуто актуальну науково-практичну задачу підвищення ефективності управління статичними та квазістатичними технологічними об’єктами в умовах їх нестаціонарної поведінки та мінливості зовнішніх впливів. Особлива увага приділяється застосуванню предикатних моделей, які дозволяють формалізовано описувати різноманітні технологічні ситуації, стани та взаємозв’язки параметрів об’єкта управління за допомогою логічних конструкцій. Такі моделі є гнучким інструментом для представлення знань про об’єкт і забезпечують можливість адаптації до зміни параметрів у процесі експлуатації.*

Запропоновано новий підхід до побудови та адаптації предикатної моделі на основі алгоритму мінімізації опису образів технологічних ситуацій. Його сутність полягає у виявленні та видаленні з моделі інформації, що втратила *актуальність, а також у спрощенні логічної структури моделі без втрати якості її опису. Важливою особливістю даного підходу є використання властивості інваріантності кількості параметрів, що визначають гіперпаралелепіпед у факторному просторі незалежно від його розмірів. Це дозволяє суттєво зменшити кількість предикатів у моделі та знизити складність обчислювальних процедур у системах автоматизованого управління.*

Методика побудови моделі передбачає розбиття факторного простору на елементарні підобласті - гіперпаралелепіпеди, які дозволяють гнучко формувати опис різних ситуацій. При цьому граничні підобласті, що мають найменші розміри, визначають точність роздільної функції. Об'єднання таких підобластей у напрямку осей ознак дозволяє оптимізувати структуру моделі та спростити процес прийняття рішень в системах управління.

Особливу увагу в роботі приділено можливості практичної реалізації алгоритму мінімізації на основі апарату α-алгебри. Це забезпечує інтеграцію моделі до інформаційних систем на основі реляційних моделей даних, які підтримуються сучасними системами управління базами даних. Такий підхід дозволяє підвищити універсальність та зручність використання запропонованого методу у складі існуючих автоматизованих систем управління технологічними процесами.

Показано, що використання моделі з мінімізованим описом дозволяє забезпечити високу якість управлінських рішень, адаптивність до зміни характеристик процесу та стабільність функціонування системи в умовах впливу зовнішніх та внутрішніх факторів невизначеності.

Таким чином, представлений у роботі підхід до побудови предикатної моделі та її адаптації шляхом мінімізації опису образів технологічних ситуацій є універсальним інструментом для управління нестаціонарними статичними об'єктами. Запропонований алгоритм може бути використаний для створення інтелектуальних систем підтримки прийняття рішень, автоматизованих систем оптимального управління, а також інформаційно-аналітичних систем промислових підприємств.

Ключові слова: *управління статичними об'єктами, предикатна модель, α-алгебра, мінімізація опису образів, адаптація моделі, інформація, нестаціонарні технологічні процеси, реляційна модель даних, автоматизовані системи управління.*

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