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Decentralized Control Of Complex Technological Systems

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Abstract: The present level of the organization of industrial production implies an integrated approach to process control with full coverage of all the elements of a unified automated system of optimal control. Such a control system has to create by combining existing local management systems, which leads to a problem, because it is a very laborious task [1]. A similar problem also occurs when you include in the functioning of the process new technological devices and systems that have built-in autonomous control systems that is becoming common practice for manufacturers of process equipment. Solution to this problem could be the creation of decentralized control systems with a hierarchical structural organization [2], in terms of effective processes class of complex technological systems (CTS). Multi-element technological processes with complex structure [3] include in CTS, typical for large industrial facilities, completed production or manufacturing units.

Keywords: Decentralized control systems, complex systems, decomposition; situational decomposition method

1 Introduction

Facilities of management of CTS class are quite widespread, especially in the chemical, petrochemical and allied industries. These industries are characterized by the production of multi-element and multi-step process in which a large number of processing raw materials are implemented into multiple end products with multiple and complex manufacturing operations.

Such objects are often found in other industries, which makes the relevance of the development of common management principles of CTS. Scientific and methodological basis of decentralized optimal control of CTS constitute decomposition methods of control problems [4,5,6,16].

They assume the original task of management to the equivalent aggregate of more than simple control tasks to be solved together. Typically, such decision is realized within a two-level hierarchical procedure of iterative interchange by values of considered data.

Objectives of the lower level represent a local management tasks for individual structural elements (subsystems) as part of the CTS. Global challenges of coordination of local problems solution is being solved on the upper level.

Simultaneous solution of these problems lies in the fact that the local control problems accounted for given values of coordinating parameters chosen in the process of solving the problem of coordination.

The solution of the problem of coordination are those values of its variables, in which the solutions to the local problems are responsible for the solution of the original problem of CTS management in general.

If necessary, local control tasks can also be applied decomposition procedure. In this case, the number of levels of hierarchy of control problems encountered will increase, causing the multilevel control structure of CTS.

Decomposition methods are developed primarily for static control problems [7,8,15] whereas for dynamic problems, they are practically unknown. The universal method applicable for both dynamic and static control problems of CTS.

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2 The main part

The optimal control problem of CTS in general can be formulated as follows:

$$F(x,u,y,t) \to \max_{u(t)\in U}$$

$$U = \{u : g(x,u,y,t) = 0; h(x,u,y,t) \geqslant 0\}, \quad (1)$$

where x - vector of disturbances; u - the control vector; y - the vector of outputs; t - the physical time; F - the objective function; g and h - set of vector-valued functions in the mathematical model of CTS and constraints of the problem.

Mathematical models and restrictions recorded in the problem (1), are of the nature of integro-differential equations and inequalities. For industrial facilities of CTS class, their number is usually large, and their constituent vector variables have a greater dimension. All this results in extremely high complexity of the problems of CTS control for which reason their solution in the automatic control system operating in compliance with the requirements imposed as a rule, is substantially hindered or even impossible.

To resolve these difficulties for reducing the original dynamic problem to a sequence of static problems is proposed, which reflect the current situation in the facility management at the time of the adoption of the control solution. As a result, the problem under consideration is decomposed by situations. At the same time, a simplified, sometimes significantly, static control problems may correspond to a considering situation.

We show the legitimacy and validity of such approach. Let us accept the assumption that the function disturbance $x(t)$ has the nature of a piecewise constant functions. This assumption is quite justified, because the main perturbations in the management objects of the class CTS usually occur due to changes in indicators of quality of the feedstock, when there is a transition from one party to the other raw materials or changing loads on the technological units. And in both cases, the disturbance variables retain their values unchanged for quite a long time until the next change.

Based on this assumption, during the steady-state values $x(t)$, it is possible to mix the dynamic control problem (1) to sequentially solved static problems of the form

$$F(x,u,y) \to \max_{u\in U}$$

$$U = \left\{ u : \begin{matrix} g(x,u,y) = 0 \\ h(x,u,y) \geqslant 0 \end{matrix} \right\} \quad (2)$$

for different values $x = const$. Problem management (2), at the time of the adoption of managerial decisions, may be modified in composition variables, objective function, the mathematical model and the constraints by taking into account the situation in the CTS. As a result of such a modification a substantial simplification of the problem can be achieved, by minimizing the number of variables and the corresponding conversion function and the target carried conditions. In this modified problem can maintain equivalence of the original problem. Modified in such way the problem can be made available for effective solutions using traditional methods of nonlinear programming [9] without imposing specific requirements for the performance of computing devices used.

In this case, the managerial decisions made on the basis of solving the problem of management (2) of variable structure. In this case, we can talk about its kind of decomposition, since the original control problem is reduced to a set of simplified private problems solved separately, and their coordination corresponds to the choice of a particular problem at the time of the adoption of the control solution. It should be noted that this modification of the original control problem (2) and its transformation into a simpler particular problem, of course, means its coarsening. In the general case, we can not guarantee complete agreement between solutions of the original and the modified problems. It is only possible with a certain accuracy. Therefore, speaking about the equivalence of these problems, it should be borne in mind that it refers to a certain extent and can be evaluated according to various indicators of compliance.

This circumstance, however, is not an obstacle to the practical use of the proposed method. In the numerical solution of similar problems in control systems is usually determined not desired optimum, but its some approximation, in the form of an arbitrary point in a given neighborhood, i.e. the solution is always sought with some error. Therefore, differences in the solution of the original and the modified problems are quite acceptable. It is important that it does not exceed the specified limit. In addition, in the real world obtaining control problems with high accuracy is not needed either because their playback in the facility management with automatic control systems and technical actuators always carried out with an error, significantly exceeding the error control problems.

When modifying the control problem (2) it is proposed to take into account situations developing in the CTS at the time of the adoption of the control solution [10]. Under the situation, in the broadest sense, a generalized description of the current state of the control object is understood. It can be determined the set of values of state coordinates, the composition of their elements, having got the increment, the magnitude and sign of the increment, the extent to which the estimated values of the parameters of the actual state of the object, the degree of compliance with applicable restrictions and others.

Various ways assessing the situation are possible in specific management problems. In the simplest cases, when managerial decisions associated only with the emergence of disturbances on the object, as an estimate of the situation, the current value of the input variable x can be used. Based on an analysis of the current situation, for the modified problem (2) the composition of effective variables corresponding to the structure of the objective function, a mathematical model of CTS and conditions in constraints can be determined. As a result, all irrelevant variables are discarded, the objective function, models and constraints are simplified, which leads to simplification of the control task.

An important advantage of this method is that it does not impose any special requirements for the structure of the control problem, its objective function and considering conditions, in contrast to the known decomposition methods, which require mandatory compliance with the conditions of problem [8] separability. The main requirement is reduced only to the possibility of separating and recognizing situations in the facility management. In connection with this method can be used virtually in any optimal control problem.

Principle of governance called situational decomposition method can be considered as an analogue of adaptive control [11,12,13] in which there is also a modification of the control problem. However, with adaptive control modification is carried out only in part of the accounted mathematical model of control object, and is performed in case of violation of the adequacy of the model. The structure of the models and problems in management as a whole remain unchanged. Only the model of parameters in the form of the coefficients of the variables are changed. Situational decomposition method differs in that instead of identifying the mathematical model of control object, allows identification of the situation at the site, followed by the replacement of the original problem of management modified the problem corresponding to considered situations. In this modified structure of control problems may be different in all components. As a result, the control system, provides a solution to this problem, becomes a variable structure.

Let's consider the content side of the proposed method of situational decomposition. Since the original control problem (2) is reduced to a set of private sub problems, there is the additional problem of recognition of the current situation in the facility management. This problem manages the appeal to private sub problem in the development of the current control solutions. The problem of recognition of situations is treated as a problem of coordination, whereas private sub problem is considered as an analogue of a local problem management in a decentralized management system.

The problem of recognition of the current situation is formulated as follows:

$$(\overset{0}{x},\overset{0}{u},\overset{0}{y}) :\overset{R}{\to} i, M_i, \tag{3}$$

where $(\overset{0}{x},\overset{0}{u},\overset{0}{y})$ - specific values of the input variables x, controls u and output y of the control object, respectively, i -number situation, M_i − many variables of control problem (3), taken into account in the i- situation, $M_i \subset M = X \cup U \cup Y, X, U, Y$- many variables x,u,y respectively, R operator of display vector $(\overset{0}{x},\overset{0}{u},\overset{0}{y})$ into a pair i, M_i

The meaning of the problem (3) is that the current values of the variables x,u,y at the time of the adoption of the control solutions are displayed by the operator R in i -number situation and many M_i variables of the problem (2), effective in this situation. The values of the functions f,g and h, are not taken into account, as uniquely determined by the values of its arguments x,u,y.

Private or local problem is formulated as:

$F_i(x_i,u_i,y_i) \to \max\limits_{u_i \in U_i \subset U}$

$$U_i = \left\{ u_i : \begin{array}{c} g_i(x_i,u_i,y_i) = 0 \\ h_i(x_i,u_i,y_i) \geqslant 0 \end{array} \right\} \tag{4}$$

$\cup U_i = U$

i=1,2,..,N

Here i number of current situation, N the number of potential situations, x_i,u_i,y_i - modified vectors of inputs and outputs, object controls, F_i modified objective function, U_i modified many of acceptable solutions to the problem caused by the modified vector-valued functions g_i,h_i,U many of acceptable solutions to the original problem.

Problems (3-4) suggest a two-tier scheme of managerial solutions. The corresponding control system acquires the structure shown in Figure 1.

Here CTS_i, $i = 1,2,,N$ CTS, modified taking into account i- situation; CB coordinating body, CS controlling system, solving modified problem of control. In the given management system, CB evaluates the current situation in the CTS by its identification on the set accounted situations and forms the structure of the modified problem (4) on the basis of problems (3), by eliminating the variables in its small significance.

Exploded composition vectors of variables x_i,u_i,y_i in (4) can be different and represent a subset of the set Mi of the whole M variables. Thus selected components of the vectors x_i,u_i,y_i are the most effective in this situation.

The considered control system is a system with variable structure. It is the centralized and decentralized simultaneously, combining the principle of centralized management within the current situation with decomposition of the control object on situations and causes decentralization of management as a whole.

The problem (4) will obviously be less complex than the problem (3). However, some of them can be quite complex and their use in control systems will be difficult in terms of time solutions that fit into the spaces between the emerging situations. In such cases, it is possible that the problem is solved in advance, and the result is stored in computer memory. If necessary, it is played without direct solution of control problems. Similarly, we can deal with recurring situations. Due to this, control system becomes self property, i.e. it becomes an element of intelligence.

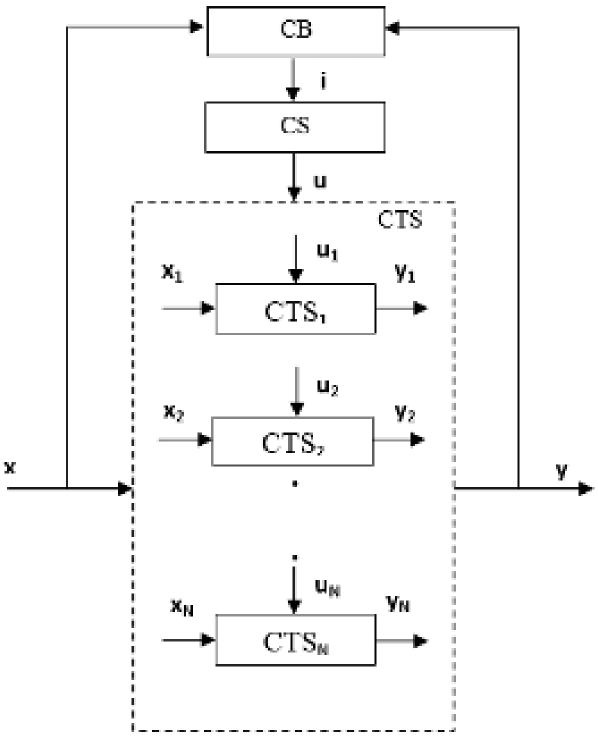

Fig. 1: The structure of the control system that operates under the scheme of situational decomposition

The main problem with the implementation of this approach is to construct the operator R mapping to identify the current situation. Its task is in analytical form, in particular, as a function of $R(x,u,y)$ as a rule, it is not possible, because it is difficult to identify patterns that connect continuously changing values of the variables of the problem with the discrete values of the number of the situation. For this reason, the main way to specify the use of R becomes numerical procedures of selective feature of selection situations. Since, in general, the number of possible situations is extremely high, despite the fact that the complete specification of each situation requires consideration of a large number of features, this leads to complex computational schemes or the need to build expert systems.

Another problem is the allocation of the aggregate significant variables to be taken into account in the modified problem (4) for each number of situation i. This separation is to measure the sensitivity of the output variables y_i on permissible in the i- situation of change control variables u_i at a given value xi, any additional tasks of identifying model of control object with the determination of its optimal structure.

When development of control solutions is associated with the occurrence of disturbances, the evaluation of situations can be according to the values of the variable x. In such method of evaluating situations, their possible number N in the general case is sufficiently large, as it is determined by the number of possible combinations of components of the vector x, and the number of possible values of the discrete components for each x_i. Thus, if the dimension of the vector x, is n, and the number of possible discrete values for each component is equal to m, the number of situations to be counted, will be determined by the ratio

$$N = \sum_{i=1}^{n} i \cdot m \frac{n!}{i!(n-i)!} \tag{5}$$

Identification of the number of possible situations turns into intractable problem complicating the practical application of the method. To solve this problem, we propose to consider not all possible situations, but only types that are much smaller. Emerging current situations relate to typical and, under certain conditions, equal to the specific types of situations.

A typical situation is characterized by the fact that it is effective only certain components of the control vector u, i.e. only these components have an impact on the control object and included as variables, whereas the rest are given constants. For typical situations, the problem (4) can be simplified, sometimes significantly, by reducing the number of variables taken into account, the corresponding simplification of the objective function, a mathematical model and constraints. As a result, the solution of this problem is simplified and the management of the facility as a whole.

In terms of actual production systematization of typical situations is usually possible and it is related to managerial solutions for a particular object. In addition, for each typical situation modified control problem can be formalized (4), which takes into account only the effective variables and conditions in the restrictions.

Simultaneously, the system can be constructed signs, which identifies specific types of situations. In this case, a sequential scan system features of typical situations, guarantees the identification of the current standard situation.

Control using typical situations is close to the management principles of industrial and technological processes implemented by man. Using the whole control parameters are observed more in exceptional cases than in normal practice. At the same time, making a decision, the person is guided by the lessons learned and is systematized by the typical situation, which relates the current situation arising.

The normal course of processes is evaluated as a set of full-time, i.e. typical situations for which an efficient algorithm response and decision-making are known and worked out. Emergency situations shall be considered as exceptional, requiring an appropriate algorithm for finding response and produce the control solutions. Such algorithms are typically based on a combination accounting standard situations. If the constructed solution algorithm is effective, it is stored and the corresponding situation translates into the category of staff. Thus, over time, the number of possible contingencies is reduced, and management approaches action under only nominal situations. The latter may be attributed to the absolute advantage of situational management principle, and to characterize it as the management of the accumulation of information about the behavior of the control object. Management system that implements this principle, intellectual property becomes a self-learning system.

Quality of control can be enhanced by the simultaneous consideration of two or more types of situations when the current situation cannot be unambiguously assigned to typical situations. This case should be a mechanism to identify common variables for intersecting situations, which make up the structure of the variables of modified management problems, with the addition of private variables of accounted situations.

Formalize now considered principle of control. We denote by D - many situations considered in the problem (5), each of which corresponds to a part of the effective variables. Suppose that the set D can be partitioned into L subsets D_k , $k = 1,2,,L$, corresponding to typical situations. All of the current situation are estimated to belong to a certain set D_k, $k = 1,2,,L$, and the problem (5) is replaced by the equivalent problem for the typical situation Dk .

Partitioning of D into subsets D_k, $k = 1,2,,L$, can be carried out based on the formation of the hallmarks of typical situations. As such signs, except the values of the components of x, number of the component can also be used by incremented part, the magnitude and sign of this increment, other quantitative assessment. In the simplest case allocated typical situations will not have intersections, i.e.

$$D_k \cap D_j = ø, k = 1,2,..,L; j = 1,2,..,L; k \neq j \quad (6)$$

This means that only certain typical situations in pure form will take place in the control process. However, this distinction is the exception rather than the rule. In the more general case, the condition (6) is not satisfied, i.e. typical situations may overlap on certain grounds. Then the problem should be taken into account all the typical situations in which there is a crossing.

The assignment of the current situation to the standard is based on the calculation of all the hallmarks of the current situation, and then comparing them with systems of signs for particular types of situations. It will meet such a typical situation for which there is a match on all grounds. The absence of such a typical situation would mean the current situation belongs to the intersecting typical situations, i.e. presence of distinguishing features of the current situation, which simultaneously belong to different typical situations.

Under these circumstances the problem of coordinating the most general case can be formulated as the problem of determining the distinctive features of the current situation, belonging to different types of situations, and then combining intersecting situations. This problem can be formulated as follows:

$$d = 0; a_j = 0, j = 1,2,..,L;$$
$$\exists k = 1,2,..,L; p_s \in P_k, s = 1,2,..,S \Rightarrow$$
$$\Rightarrow d = 1; b_{ks} = 1; a_k = 1 \quad (7)$$

$$\bar{D} = \cup \bar{D}_j, j = 1,2,...,L \quad (8)$$

where d, b_{ks} and a_j- auxiliary variables used as indicators; $p_s - s$- feature of the situation; $\underline{P}_k$ - the set of the hallmarks of the k typical situation: D the set of variables taken into account in the modified control problem; - $\bar{D}_j$ - intersecting sets of typical situations for $a_j \neq 0$.

In the absence of intersecting signs, the problem reduces to a sequential scan system of typical situations features P_k with the objective of finding the system, identical to the signs of the current situation. This problem can be formulated as:

$$d = 1 \Rightarrow \sum_{s=1}^{S} b_{ks} \to \max_{k}, k = 1,2,..,L; \bar{D} = D_k \quad (9)$$

The solution to this problem is $k = k^*$ for which the sum of the significant features of typical situation $\sum_{s=1}^{S} b_{ks}$ maximum. Accordingly, the set of variables accounted for the modified problem management - is $D_{k^{**}}$ Local task of the second level in this case can be written as:

$$F_i(x_i, u_k, y_i) \to \max_{u_k \in U_k}$$
$$U_k = \left\{ u_k : \begin{matrix} g_k(x_i, u_k, y_i) = 0 \\ h_k(x_i, u_k, y_i) \geqslant 0 \end{matrix} \right\}$$
$$\cup U_k = U$$
$$i = 1,2,,..,N \quad (10)$$

where i- number of the current situation, k - number of typical situations $i \in 1,2,..,N, k \in 1,2,..,L$ The proposed method of solving the problem of optimal control CTS (3) can be described as a decomposition method for typical situations. Accordingly, a control system that implements this method is a decentralized system of situational management. The method can also be seen as a way of projection of the original problem in the subspace of equivalent subtasks for specific situations, or projection of the set of feasible solutions of the original problem U into subsets $U_k, k = 1,2,,L$.

3 Conclusion

The proposed method of situational decomposition can be considered new, as previously unknown approach to solving decentralized problem of optimal control CTS (3) is used. The method is very promising, as applicable to the management problems of both dynamic and static nature. At the same time it incorporates the principle of making operating decisions, close to the principles of natural management of human use. The latter circumstance contributes intellectualization of management systems, giving them greater flexibility and increase the number of degrees of freedom in decision making.

An important advantage of the method is that it does not impose any special requirements for the structure of the control problem, in contrast to the known methods of decomposition. In this regard, its application field can be considerably wider.

The main difference between situational decomposition method from classical decomposition methods is that it assumes that only one local control tasks, which can change its structure. This does not exclude the possibility of using the principles of decentralized management with respect to the modified object. In this case, there is a combined control system, which implements the spatial-temporal decomposition of CTS management tasks.

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