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DEVELOPMENT OF RESOURCE DISTRIBUTION MODEL OF AUTOMATED CONTROL SYSTEM OF SPECIAL PURPOSE IN CONDITIONS OF INSUFFICIENCY OF INFORMATION ON OPERATIONAL DEVELOPMENT

У роботі розглянута задача розподілу ресурсів автоматизованої системи управління спеціального призначення в умовах недостатності інформації про розвиток оперативної обстановки. Об'єктом дослідження є автоматизована система управління спеціального призначення в умовах невизначеності оперативної обстановки та обмеженості обчислювальних ресурсів. Одним з найбільш проблемних місць при розподілі ресурсів автоматизованої системи управління є низька якість планування, розподілу та використання ресурсів автоматизованої системи в умовах недостатності інформації про оперативну обстановку та відсутність можливості прогнозування дій противника. Це знижує ефективність як самої системи, так і її застосування. Наукове завдання вирішено за дпомогою розробки моделі розподілу ресурсів системи за умови можливої появи на вході безлічі збурень, що враховує особливості поточної оперативної обстановки протікання збройного конфлікту та дозволяє провести прогнозування стану автоматизованої системи управління. В ході проведеного дослідження авторами роботи були використані основні положення теорії масового обслуговування, теорії автоматизації, теорії складних технічних систем, а також загальнонаукові методи пізнання, а саме аналізу та синтезу. Новизна запропонованої моделі полягає в тому, що вона дозволяє обґрунтувати декомпозицію системи. Це дозволяє представити рішення векторного завдання оптимізації в бінарних відношеннях конфлікту, сприяння та байдужності. А також враховує оперативну обстановку та дозволяє провести прогнозування стану системи з урахуванням зовнішніх впливів, побудувати функції корисності та гарантованого виграшу, а також чисельну схему оптимізації на цій множині. Запропонована модель дозволить підвищити оперативність обробки інформації за рахунок її розподілу та раціонального використання наявних обчислювальних ресурсів. Результати дослідження доцільно використовувати під час планування конфігурації системи передачі даних та на етапі оперативного управління ресурсами зазначених систем.

Ключові слова: *системи управління, оперативна обстановка, якість планування, бінарне відношення конфлікту, оперативність передачі інформації.*

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1. Introduction

The distribution of resources of the special-purpose automated control system (ACS) is a function of the system to regulate the use of its resources in the presence of uncertainty about the nature of the conflict using various means of confrontation (destruction of targets). And also because of the inconsistency of the current operational situation with the planned method of using ACS as the most effective for a certain time.

The allocation of resources provides a series of techniques that help the decision-making element (DME) in achieving the best results. In this case, the task of the DME is to find ways to respond flexibly to changes in the operational environment in order to minimize the impact of the current situation on the automated control system using the means of distributing its resources.

However, existing approaches to the allocation of resources do not satisfy the requirements that apply to them, namely:

– great computational complexity [1, 2];
– need to know complete information about the state of the system and the actions of the enemy [3, 4];
– inability to predict the actions of the enemy on the state [5–7].

In this regard, it is necessary to develop a model for the distribution of ACS resources in conditions of insufficient information on the operational situation, taking into account the essential features of the course of the armed conflict in a specific situation. So, *the object of research* is an automated control system for special purposes in the face of uncertainty in the operational environment and limited computing resources. And *the aim of research* should be considered to increase the efficiency of the ACS functioning by increasing the efficiency of the distribution of ACS resources.

2. Methods of research

The resulting control u, which affects the control object, is formed by two components, such as software (plan x), and corrective (operational control c) [1, 2]. This type of control can be represented in different ways: as the sum of two components, or some other given by their function:

$$u = x + y \text{ or } u = F(x, y). \quad (1)$$

The operating party must ensure that all conditions of admissibility of the resulting control are met, can be briefly written as follows:

$$u \in U(\varepsilon), \quad (2)$$

where U – a given set in the functional space of controls, depending on perturbations ε. In addition, the operating side is trying to maximize the quality criterion of controls, which is also affected by perturbations:

$$J(u, \varepsilon) \to \max. \quad (3)$$

Records (2), (3) show a significant feature of ACS in conditions of insufficient information on the development of the operational environment: the quality criterion and the conditions for admissibility of control depend on perturbations.

Then, the inverse influence of the control on the set of expected perturbations Ξ_0 is taken into account. Based on a priori information $I(\Xi)$ about perturbations, the operating side determines the plan x in advance:

$$x = X(I(\Xi)). \quad (4)$$

The next step will be to consider two options for a priori awareness [7, 8]:

- only a lot of future perturbations Ξ_0 are known, which is set, for example, by the limiting values of perturbations;
- only a distribution function of perturbations $\mu(\Xi)$ are known, that is, the probability with which perturbations can fall into any subset Ξ of the original set Ξ_0.

Operational control is formed after planning, in the process of functioning, using information $i(\varepsilon)$ about the perturbation. This makes it possible to compensate for some unwanted effects:

$$y = Y(x, i(\varepsilon)). \quad (5)$$

By operational control algorithm is meant a complete list of actions for each of the existing implementations $\varepsilon \in \Xi_0$. The construction of such algorithms is not considered in this case, therefore, let's consider the operator (5) as given. When the information at the given moment of time is complete, that is $i(\varepsilon) = \varepsilon$, it is possible to analytically create the optimal operational control algorithm in some solved quasistatic problems [9, 10].

To complete the operational task, a certain set of resources is needed, part of which is in the ACS, and the other in the higher system (super-system), the volume of centralized replenishment of the ACS x resources is planned to be operated by the party – ACS operator in advance. The ACS operator can't exert any influence on the volume and availability of resources of a higher supersystem ε, and also, when planning, the value ε is unknown, that is, it is in the category of perturbations.

The total amount of resources $x + \varepsilon$ consists of two parts, one is transferred to the ACS and has a single capacity, the other may be, depending on the operational situation, in a passive reserve with a capacity r, or be ready for use by a higher system [3]. On the other hand, the total amount of resources $x + \varepsilon$ should be enough for the ACS in the conditions of insufficient information on the development of the operational situation, together with a higher system, to be able to carry out the necessary opposition to the enemy. To do this, it is necessary to provide an initial i-th share of the maximum (single) complex of ACS resources $(0 < \upsilon < 1)$. The missing amount of resources can be filled with the redistribution of ACS resources or with the actions of a higher system. The operational control effect in this consists in the redistribution of ACS resources to perform a partial task.

The operational control effect in this consists in the redistribution of ACS resources to perform a partial task. Positive values of the control action correspond to the replenishment of the stock necessary to achieve a partial goal, negative – the reduction of the necessary stock of the resource [2].

The resulting control (1) is equal to the sum of the planned x and operational in terms of:

$$u = x + y, \quad (6)$$

which in the current setting are not vector functions of time, but simply scalar parameters that the DME of the operating side selects.

The set (2) of possible resulting controls is determined by the ACS resource reserves reduced to unity, the minimum allowable amount υ, and also the size r of the passive reserve. Such a set significantly depends on perturbations – the quantities ε and u are taken under conditions of admissibility of control on equal rights:

$$u \in U(\varepsilon) = \{x, y : x \geq 0, |y| \leq r, \upsilon \leq x + y + \varepsilon \leq 1\}. \quad (7)$$

The control quality is assessed by the quality of the task, which linearly depends on all three types of resources: centralized x (ACS resources), decentralized ε (supersystem resources) and compensating y (redistributed) [1, 3]:

$$J = x + qy + g\varepsilon \to \max, \quad (8)$$

where $g \geq 1 \geq q \geq 0$.

Different values of the coefficients g, q reflect the mismatch of the confrontational situation, which for simplicity is considered already known at the planning stage. According to the above, operational control y is carried out according to reliable information about perturbations ε and plan x. So, from the admissible set (7), it is possible to choose the value y, maximizing the criterion (8):

$$y = Y(x, \varepsilon) = y_u = \{1 - x - \varepsilon, r\} \geq y_l = \max\{\upsilon - x - \varepsilon, -r\}. \quad (9)$$

Expression (9) is an operational control algorithm (5), according to which the compensating amount of resources is always equal to the maximum possible: $y = y_u$. This either ensures the full use of ACS resources, if $y = 1 - E - \varepsilon \le r$, or completely exhausts the supply of resources of the supersystem, if $y = r \le 1 - x - \varepsilon$. The lower bound y_u is involved only in creating conditions for the admissibility of algorithm *Y*; close relation (9). The admissibility of operational control is guaranteed by choosing the plan *x*.

Given the planning of the operational control algorithm *Y*, condition (2) for the admissibility of the resulting control must be fulfilled only by choosing the plan *x*. This provides an adequate supply of regulatory resources.

Conditions (2), reflected in the space of plans *x*, can be divided into three types:

1. Conditions that are independent of the perturbation, as well as the conditions of integer or, in the general case, discreteness of some components of the plan vector *x*:

$$x \in X_1 = \bigcup_{n=0}^{N} X_1^n,\ X_1^n \cap X_1^{n'} = \varnothing \text{ for } n \ne n'. \quad (10)$$

Expression (10) shows the process of constructing a set X_1. This is the union of a finite number of independent subsets X_1^n, each of which is possibly compact and depends on the number *n*. Allowed and purely discrete options when the subsets X_1^n are finite or pairwise.

2. Conditions that depend on the perturbation, but according to their purpose, must be realized for all a priori possible implementations of the perturbation:

$$x \in X_2(\varepsilon) = \{x : G_i(x,\varepsilon) \ge 0, i \in I_2\}, \forall \varepsilon \in \Xi_0(x). \quad (11)$$

3. Conditions depend on the perturbation:

$$x \in X_3(\varepsilon) = \{x : G_i(x,\varepsilon) \ge 0, i \in I_3\}, I_2 \cap I_3 = \varnothing. \quad (12)$$

In (11) and (12) $G_i(x,\varepsilon)$ is reflections, which are synthesized from the initial reflections that define expression (2) in the space of the resulting control *u*. After which the expression occurs through the planned *x* and correcting to the component and the subsequent exclusion in using the operational control algorithm *Y*. Conditions (11) and (12) are systems of inequalities. They are identical in ε and can't be satisfied due to the choice of *x*, due to the fact that the planned component, in comparison with the corrective one, can change depending on the perturbation at a given time. Deviation from this rule takes place only when the operational control algorithm reliably reflects perturbations for any initial data. But in this case, the mappings $G_i(x,\varepsilon)$ corresponding to them are transformed no longer actually depend on ε and belong to the category of conditions (10) in which both equalities and inequalities are solved.

Conditions (11) that are satisfied under any perturbations of $\Xi_0(x)$ both probabilistic and guarantee deliveries can be assigned to expression (10), which has no perturbation, due to the equivalence of two inequalities:

$$G_i(x,\varepsilon) \ge 0\ \ \forall \varepsilon \in \Xi_0(x) \Leftrightarrow \inf_{\varepsilon \in \Xi_0} G_i(x,\varepsilon) \ge 0, \quad (13)$$

in the absence of dependence on the perturbation ε in terms of *x*. As a result, the condition for the simultaneous execution of expressions (10) and (11) can be reflected in a simpler form:

$$x \in X_0 = \{x : x \in X_1, G_i(x) \ge 0, i \in I_2\}. \quad (14)$$

For the convenience of further reasoning, the perturbation vector ε is divided into two subgroups – continuous (η) and discrete (χ):

$$\varepsilon = (\eta,\chi) \in \Xi_0(x) \Leftrightarrow \chi \in Z_0 = \{\chi_1, \chi_2, \ldots\}, \eta \in H_0(\eta,\chi). \quad (15)$$

Discrete perturbations χ included in a finite or computational set Ξ_0 are responsible for spasmodic changes in the situation at a given time. Such perturbations are caused, for example, by new restrictions that arise after the completion of the planning stage.

The implementation of discrete perturbations χ_i can affect the set H_0 of future values of continuous perturbations η. Plan *x* is selected depending on the structure of the set H_0. In principle, there are no contradictions for dependence $Z_0(x)$. Sets Z_0 and H_0 of future discrete (η) and continuous (χ) perturbations are considered known at the beginning of the planning stage [4].

Then, for each value of discrete perturbations χ_j, according to the guaranteed payoff model:

$$\varphi = \sum_{\{\text{ACS},\,\zeta_n\} \in \{\overline{>\text{I}}\}} \alpha_n \left(q_{ACS}^r - q_{ACS}^0\right) + \sum_{\{\text{ACS},\,\zeta_n\} \in \{>\text{I}\}} \beta_n \left(q_{ACS}^r - q_{ACS}^0\right),$$

where α_n, β_n – the weights of the corresponding properties of perturbations ξ_n from the standpoint ACS,>I,$\overline{>\text{I}}$ – the relation of assistance and conflict, respectively; q_{ACS}^0 – expected utility function.

Let's introduce the set H_j^+ of favorable continuous perturbations η. Perturbations η are considered favorable if they do not violate the condition of admissibility of the resulting control for a fixed plan *x* and enable the implementation of the $\widetilde{J}$ quality criterion, do not fall below the required level *c*:

$$H_j^+(x,c) = \left\{ \begin{matrix} \eta : \eta \in H_0(x,\chi_j), G_i(x,\eta,\chi_i) \ge 0, \\ i \in I_2, J^*(x,\eta,\chi_j) \ge c \end{matrix} \right\}, \quad (16)$$

where $J^* = J\left(F\left(x, Y\left(x, i(\eta, x_j)\right)\right), \eta, \chi_j\right)$.

Other perturbations with H_0/H_j^+ are unfavorable. Thus, the set Z^+ of favorable discrete perturbations χ consists only of those χ_j for which (16) is a nonempty set, i. e.:

$$Z^+(x,c) = \{\chi : \chi = \chi_j \in Z_0, H_j^+(x,c) = \varnothing\}, \quad (17)$$

perturbations remaining χ belong to adverse.

3. Research results and discussion

The separation of all possible perturbations into disjoint subsets of favorable and unfavorable perturbations is performed for a fixed set of plans *x* and a fixed lower bound for the implementation $\widetilde{J}$ of the quality criterion for the resulting control.

It is clear that for the subsequent consideration, plans that correspond to the conditions (17) of the perturbations, do not include perturbations are important.

The remaining conditions (15) of the admissibility of the plan are realized only on the set of favorable perturbations. If the estimate increases, the set of favorable perturbations will narrow (or rather, not expand), and for all c exceeding a certain critical level, it will be empty. But from the point of view of choosing a plan, interest is not «depletion» of set of favorable perturbations, but its «completeness» is necessary. The guaranteeing and probabilistic statements differ in the requirements for completeness of the set of favorable perturbations.

In the assignment on ACS resource management, the amount of resources of a higher system ε is a continuous variable. By the beginning of planning, it is estimated only from above by the value d, so that $\Xi_0 = [0, d]$.

The sets (16), (17) (Fig. 1) of favorable perturbations for each fixed x on the basis of expressions (7)–(9) are represented by segments of the following form:

$$\Xi^+(x,c) = \left[\varepsilon_l^+,(x,c),\varepsilon_u^+(x)\right], \quad (18)$$

where

$$\varepsilon_l^+ = \max\{\varepsilon_{l0},\varepsilon_{l1},\varepsilon_{l2},\varepsilon_{l3}\}; \quad \varepsilon_u^+ = \min\{\varepsilon_{u0},\varepsilon_{u1}\};$$

$$\varepsilon_{l0} = 0; \quad \varepsilon_{l1} = 1 - r - x; \quad \varepsilon_{l2} = \frac{1}{g}(c - x - qr);$$

$$\varepsilon_{l3} = \frac{1}{g-q}\left(c - (1-q) - x - g\right);$$

$$\varepsilon_{u0} = d, \ \varepsilon_{u1} = 1 + r - x.$$

In (18) and in Fig. 1 is indicated by:

ε_{u0} – upper a priori estimate of perturbations;

ε_{u1} – maximum perturbation in terms of resources allowed by the supersystem;

ε_{l0} – lower a priori estimation of perturbations;

ε_{l1} – minimal perturbation, permissible on condition of loading;

ε_{l2} – minimal perturbation, provides the expected result c with the possibility of a free set of resources;

ε_{l3} – minimum perturbation, provides the expected result c in the presence of the remaining resources.

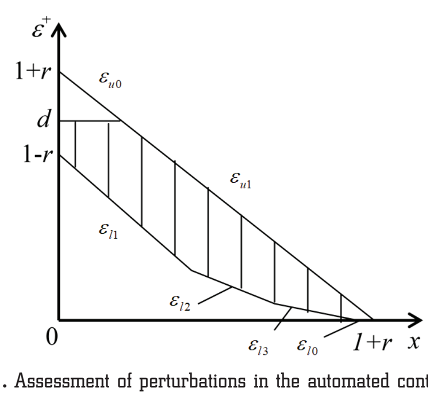

Fig. 1. Assessment of perturbations in the automated control system

With increasing intensity of the confrontation c, the lower bounds ε_{l2} and ε_{l3}, are raised, while others remain constant. In accordance with this, the range of favorable perturbations (18) narrows, degenerating in a certain sense value c into an empty set. This is a general property of the sets of favorable perturbations (16), (17).

Next, problematic questions arise related to the assessment of the influence of perturbations on the effectiveness of counteraction, which allows the use of the research results in models of supporting decision-making.

4. Conclusions

During the study, the authors developed a model for the distribution of ACS resources under conditions of insufficient information on the development of the operational environment. The novelty of the proposed model is that it:

- allows to justify the decomposition of the system, allows to imagine a solution to the vector optimization problem in the binary relations of the conflict, assistance and indifference;
- takes into account the operational environment;
- allows to predict the status of the system, taking into account external influences;
- allows to build utility functions and guaranteed payoff, as well as a numerical optimization scheme on this set.

The proposed model will improve the efficiency of information processing due to its distribution and rational use of available computing resources.

It is advisable to use the results of the study when planning the configuration of the data transmission system and at the stage of operational control of the resources of these systems.

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