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Method of controlling a group of unmanned aircraft for searching and destruction of objects using artificial intelligence elements

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The article develops a method of controlling a group of unmanned aerial vehicles to search for and destroy enemy objects. The method is to recognize situations and adjust the actions of the group according to it. The basis of the method is the use of an intelligent decision support system. It provides situation recognition, using image recognition materials (intelligence materials), generalization of the obtained information and its comparison with the elements of the set of descriptions of typical situations. The method of controlling a group of unmanned aerial vehicles to search for and destroy enemy objects is built according to the concept of multi-agent systems — intelligent agents — UAVs. The information technology of processes of the method of control of a group of unmanned aerial vehicles according to the IDEF0 methodology is developed.

Keywords: *control system, multi-agent model, artificial intelligence, group of unmanned aerial vehicles, search for and destruction of objects, autonomous system, local rules of self-organization, situation recognition.*

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1. Introduction

The introduction of intelligent technologies into military systems is becoming more widespread. Thus, European countries and the United States are focused on the development and creation of robotic systems capable of performing tasks autonomously or in symbiosis with humans.

The robotization of the Armed Forces of Ukraine is an integral and necessary component for the creation of an effective, combat-ready and competitive army in the face of ever-increasing threats of the transition of the conflict in eastern Ukraine to an active phase of hostilities. In addition, robotics is a necessary condition for cooperation with NATO forces, which requires a clear plan for the development and implementation of modern methods and technologies in existing models of weapons and military equipment in the Armed Forces of Ukraine.

It should be noted that the military-industrial complex of Ukraine is working on the creation of its own robotic complexes and actively cooperates with partner countries. A number of land-based robotic complexes of Ukrainian production are being tested: "Hunter", "Piranha", "Phantom", robotic platforms "Laska" and "Scorpion" [1].

However, the greatest achievements were made by the developers in the field of unmanned aerial vehicles (UAVs). The Armed Forces of Ukraine are armed with UAVs "Raven", PD-1 "TOR", "Fury", ""Stork-100", "Bayraktar TB2" [2].

Given the tasks assigned to the Air Force, namely, providing reliable air cover for other types of troops, inflicting fire damage, conducting air reconnaissance, unmanned aerial vehicles are an integral part of combat operations.

Prospects for the use of robotic systems and technical equipment of UAVs of the Armed Forces of Ukraine encourage the development of methods for managing groups of disparate UAVs capable of acting autonomously in the face of enemy resistance.

Managing a group of UAVs to search for and destroy objects is a complex, poorly formalized task. It is solved under the condition of counteraction of the opposite party (conflict) and requires the use of methods, models and systems of artificial intelligence. These include: decision support systems, methods of presentation and formalization of knowledge, fuzzy set models, tools for the formation of multi-agent systems.

At present, in the practice of troops there are no methods of UAV control for autonomous search and destruction of objects, which determines the relevance of this study.

However, the Armed Forces of Ukraine lacks methods of controlling heterogeneous unmanned aerial vehicles capable of operating in the face of enemy resistance.

1.1. Problem analysis

Global trends in research in the field of control theory are concentrated in two areas — artificial intelligence and machine learning, robotics and decision theory. Military is no exception, where artificial intelligence technologies are being actively introduced and control systems are being developed to increase the effectiveness of combat systems and, above all, their autonomy.

The article [3] considers the principles of construction of a distributed system of external and onboard control components of a group of reconnaissance and strike unmanned aerial vehicles.

The paper [4] presents models of collective control of manned and unmanned aerial vehicles, developed methodological support for the training of aircraft control operators and engineers of air navigation systems.

In the article [5] a method for the coordinated control of swarms of miniature UAVs with a fixed wing was developed. The proposed method contains an algorithm for reconfiguring the UAV group formation scheme.

In the article [6] a fixed-wing UAV swarm control method based on a hierarchical architecture was developed. The method ensures the global asymptotic stability of the UAV swarm closed system under the incoming control system constraints.

In the article [7] a flight control algorithm based on artificial intelligence and game theory, aimed at increasing the autonomy of the UAV group was developed. This algorithm uses the local spatial, temporal and electromagnetic information of the UAV. Positioning is implemented by processing ad-hoc mobile network (MANET) information.

In article [8] the issues related to action planning, task distribution and communication organization of a group of robots are considered.

The work [9] is devoted to the study of tasks and approaches to the management of a group of aircraft in an antagonistic environment.

In the article [10] the analysis of an estimation of efficiency and criteria of reliability of group flights of UAVs is carried out. An algorithm for searching the central repeater of the UAV group to ensure the transmission of the control signal in the group has been developed.

The article [11] considers the advantages and disadvantages of centralized and decentralized architecture of UAV group management, presents tables of dependence of the level of onboard automation and the number of UAVs in the group.

The article [12] developed a method of planning the flight path of UAVs to search for a dynamic object in the forest-steppe area, taking into account possible options for its movement.

The work [13] is devoted to the development of a meta-model of a multi-agent system for searching and influencing a ground object by a group of unmanned aerial vehicles with a centralized control option. A base of inference rules for agents has been developed in accordance with the tasks to be solved and the role of the agent in the group, based on the use of the production model.

The work [14] is devoted to the development of a method for planning the UAV route when performing missions to search for a stationary object. The method makes it possible to take into account the probability distribution of the importance of the task area.

In the article [15] a method to substantiate the optimal route for conducting aerial reconnaissance was developed, indicators and a criterion for the effectiveness of conducting a search for a dynamic object were proposed.

In the article [16] the issues of the efficiency of decentralized control of a group of UAVs and the load of the operator when interacting with a decentralized scheduler are considered.

In the article [17] a methodology for assessing the level of risk of implementing business process reengineering projects based on the theory of fuzzy sets was developed. The risks in the project management system during organizational restructuring were identified and analyzed.

The work [18] considers modern approaches to modeling complex information systems at different levels of organization, taking into account the features of their further design, development and modification. To make optimal decisions, it is proposed to apply the mathematical apparatus of the theory of Markov chains.

The result of the literature analysis indicates the relevance and prospects of research in the direction of developing intelligent UAV control systems. Thus, the creation of group control methods with an intellectual component is a general way to increase the efficiency and autonomy of combat systems.

The developed method of group control of unmanned aerial vehicles for search and destruction of objects is based on works [12,13,15].

The purpose of the study is to develop a method of controlling a group of heterogeneous unmanned aerial vehicles when performing tasks to search and destroy objects in the face of enemy resistance using elements of artificial intelligence.

2. Main material

2.1. Model of situational analysis of the intelligence system

The difficulty of implementing UAV group management methods is to solve tasks related to planning the flight path of the group, communication between UAVs and the distribution of tasks and roles in the group.

The introduction of multi-agent systems (MAS) is promising in UAV control systems. This involves the creation of a system of many interacting agents [8,9]. The concept of MAS allows to implement the process of autonomous execution of tasks of each UAV group and decision-making within the overall mission.

The multi-agent approach to the organization of the UAV group will provide:

– adaptability of agents to the external environment;
– interaction with other agents of the system;
– replenishment and adjustment of the knowledge base in the process of work;
– identification of necessary actions to achieve the goal.

Determining the necessary actions to achieve the goal is provided by the situation recognition subsystem.

Under the recognition of the situation we will consider the process of evaluation and analysis of elements (objects) of the environment over time and forecast their state (behavior) in the future.

Figure 1 shows an object-oriented model of situational analysis of the reconnaissance system, which using a knowledge base, rules base and situation base can be implemented at control points or onboard UAV systems.

The tools of situational analysis for its implementation in the reconnaissance system of the UAV group when performing tasks are fuzzy neural networks (FNN). The use of FNN is possible both for image processing on board UAVs, recognition of images obtained by a group of UAVs, and for the synthesis of current information and situation recognition.

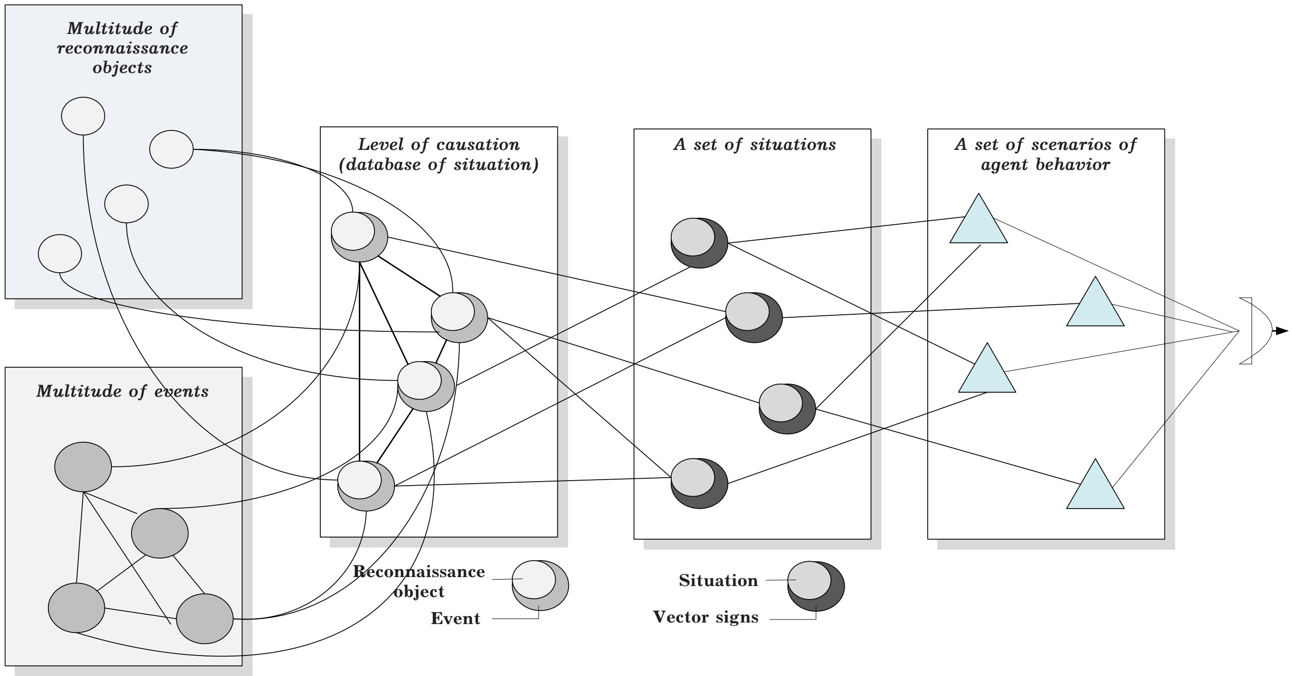

Fig. 1. Object-oriented model of situational analysis of the intelligence system.

For image recognition, as a rule, convolutional neural networks of the form R-CNN, Mask R-CNN, YOLO are used. They can be integrated into the UAV control system as a subsystem of image processing on pre-trained databases.

Graph Neural Network [19] or FrameNet [20] are used to recognize situations.

Given the meta-model of the multi-agent system of search and impact on the ground object by a group of unmanned aerial vehicles developed in [10], the organization of the multi-agent system should ensure the relevance of information in the system and clear order and efficiency of group tasks.

As a result, the functioning of a multi-agent group management system in recognizing the situation should be presented in the form of a cycle (Fig. 2), which consists of five stages:

– reconnaissance;
– generalization (processing) of data agents;
– formation of hypotheses;
– definition of actions;
– distribution of tasks.

Situation recognition is performed through operations with the database of intelligence objects, the database of events, the knowledge base of objects, relations (regularities), constants and the database of situations.

2.2. Model of intelligent decision support system situation recognition

The intelligence system, using software and hardware, implements the procedure of situational analysis through an intelligent decision support system (IDSS).

The developed model of IDSS situation recognition, shown in Fig. 3, has a multi level structure.

The first (preparatory) stage of the work of IDSS situation recognition is the formation of a database of situations and relevant rules for UAVs.

The database of situations contains a set $\{A_k\}$ of situations, each element of which is described by a vector of features.

The rule base contains a set $\{P_l\}$ of rules that define the actions of UAVs (UAV groups) such as: re-planning of the route, the composition of the group, the required additional payload, points and objects of monitoring.

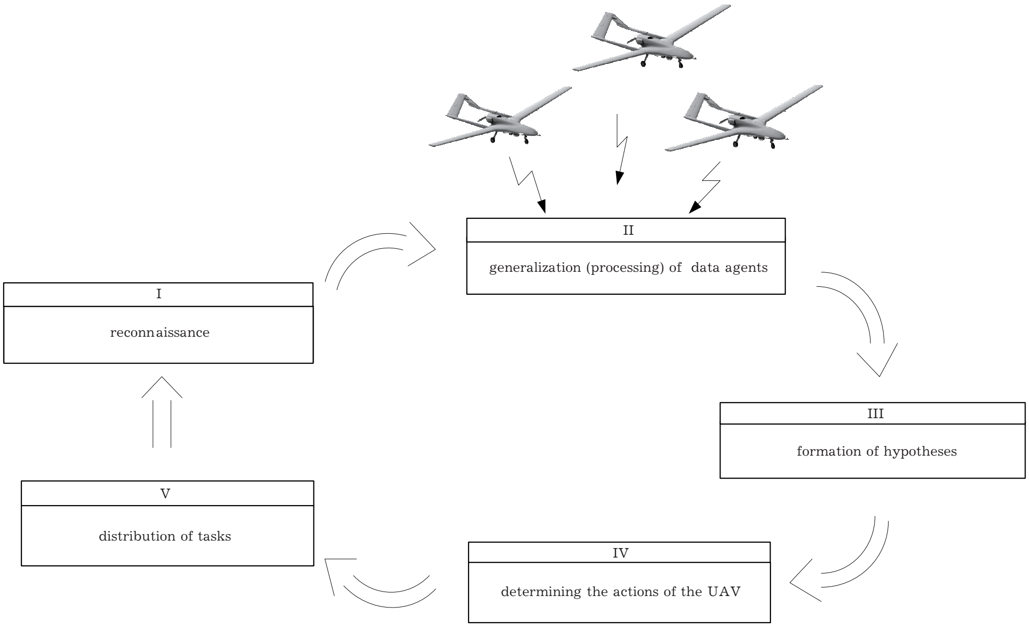

Fig. 2. Cycle of multi-agent group management system in situation recognition.

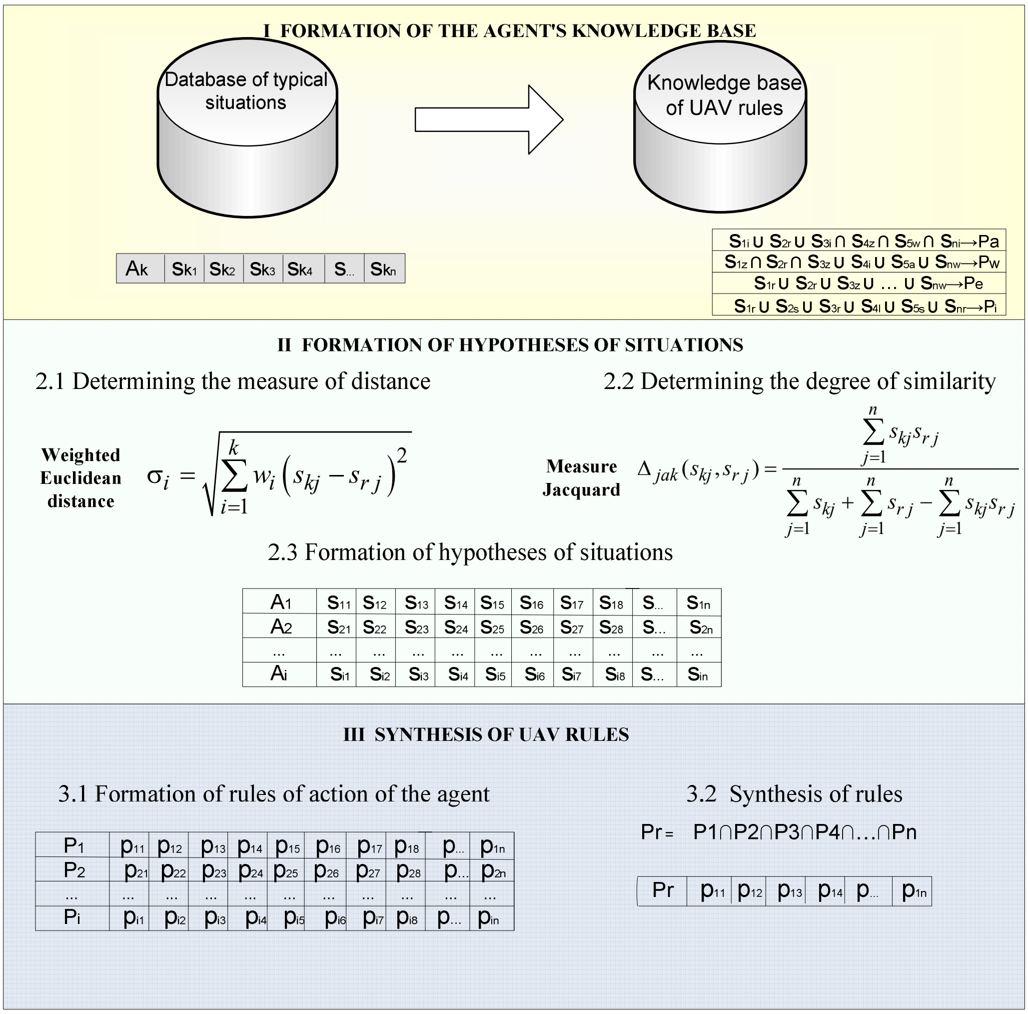

Fig. 3. Scheme of functioning of the intelligent decision support system for situation recognition.

For a holistic analysis of the received information, the situation recognition system should analyze not individual elements of information, but information structures to obtain the content of data.

The first level (preparatory) — formation of a base of situations and a base of rules for UAVs. The database of situations contains a set of situations, each element of which is described by a vector of features. The rule base contains a set of rules that define the actions of UAVs (UAV groups). These are re-planning of the route, redistribution of UAV tasks, necessary additional payload, points (sections) and objects of monitoring in the form of products.

Each element of the situation class can be represented as a point in n-dimensional space. Therefore, in the second stage, a metric is used to determine the difference between class objects, which determines the distance between the class element and the obtained data.

To determine the distance between the elements of the vector of signs obtained as a result of reconnaissance $\{A_r\}$, and the vector of signs of the base of situations $\{A_k\}$, it is advisable to use the weighted Euclidean distance, which is determined by the formula:

$$\sigma_i = \sqrt{\sum_{i=1}^{k} w_i \left(s_{kj} - s_{rj}\right)^2}, \tag{1}$$

where w_i — the weight of the sign, proportional to its importance in the structure of determining the situation;
s_{kj} — the value of the element of the feature vector of the situation $_{kj}$ base of situations
s_{rj} — the value of the element of the feature vector $_{rj}$ obtained in the process of exploration.

The weight of the signs w_i is determined by the method of expert assessments. It will identify the most priority features (which should be noted) in the overall system of situation recognition.

To weed out situations that have common feature vectors, but radically different values, we use a value σ', that is the level of selection of situations. The value σ' is calculated as $\sigma' = 0.5 * s_{kj}$ determined by simulation. If at least one element of the vector of signs of the situation does not satisfy the condition $\sigma' > \sigma_i$, it is considered impractical to consider it further.

The next step is to determine the degree of similarity between the hypotheses of situations and the base of situations. The Jacquard coefficient [16] was chosen to determine the degree of similarity of situation hypotheses, which is determined by the formula:

$$\Delta_{jak}(s_{kj}, s_{rj}) = \frac{\sum_{j=1}^{n} s_{kj} s_{rj}}{\sum_{j=1}^{n} s_{kj} + \sum_{j=1}^{n} s_{rj} - \sum_{j=1}^{n} s_{kj} s_{rj}}. \tag{2}$$

The Jacquard factor has a simple implementation and is used to determine the similarity of two objects. This allows you to rank and form a set of hypotheses of situations in the second stage.

The third level provides the selection of the rules of action of UAVs (groups) from the database of rules and their synthesis. The synthesis of rules is carried out by combining (generalizing) the rules of conduct of UAVs. This, due to synergies, will allow to form the priority measures necessary to confirm or refute the hypotheses.

2.3. The structure of the method of control of a group of unmanned aerial vehicles for search and destruction of the object

The general structure of the method of control of a group of unmanned aerial vehicles provides for the implementation of decentralized control and the transition to centralized control through the UAV of the leader with partial autonomy of each agent (Fig. 4).

In this case, the agent sensor information is sent to the leader's UAV. It uses IDSS to process materials and issue recommendations on the situation in the mission area.

Based on the research disclosed in [12,13], the general structure of the control method of a group of heterogeneous unmanned aerial vehicles was developed (Fig. 5).

The input data of the method are:

– type and number of UAVs;

– payload;

– pre-prepared knowledge base: (catalog of enemy objects, catalog of typical situations, catalog of standard rules of action, local rules of self-organization);

– knowledge base of causal relationships;

– geospatial data of the task area, forbidden zones.

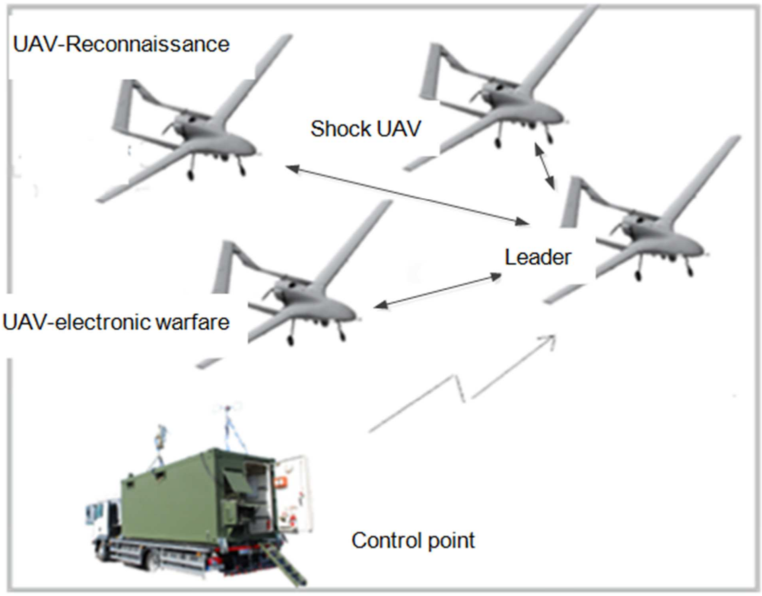

Fig. 4. The structure of centralized management through the UAV-leader.

The direct physical impact on the enemy object requires the approval of the control operator and the transition to centralized control. The corresponding procedure is provided by blocks 9 and 11 (Fig. 5).

In the event of UAV situations and actions that do not require impact on the object, the group autonomously carries out the flight route to implement certain actions due to the situation (block 10).

Thus, the division of management tasks into two levels is realized:

– higher level, cognitive management functions, performed by the operator (weapons, selection and priority of the target);

– lower level, UAVs are carried out autonomously (route planning, distribution of tasks, processing of reconnaissance materials, situation recognition, determination of UAV behavior, route re-planning).

2.4. Information technology of search and discharge planning on the enemy object by a group of UAVs

The complexity of the application of this method in the management of a group of UAVs requires the construction of appropriate information technology, which is presented in Fig. 6. The UAV group used the IDEF0 methodology to describe and formalize the processes of information technology of search and discharge planning on the enemy object [17].

As part of the process of performing tasks to plan the search and impact on the enemy object by unmanned aerial vehicles, the incoming flow of information is:

– task (mission) to find and influence the enemy object in a formalized form;

– the type and number of UAVs determined for the mission.

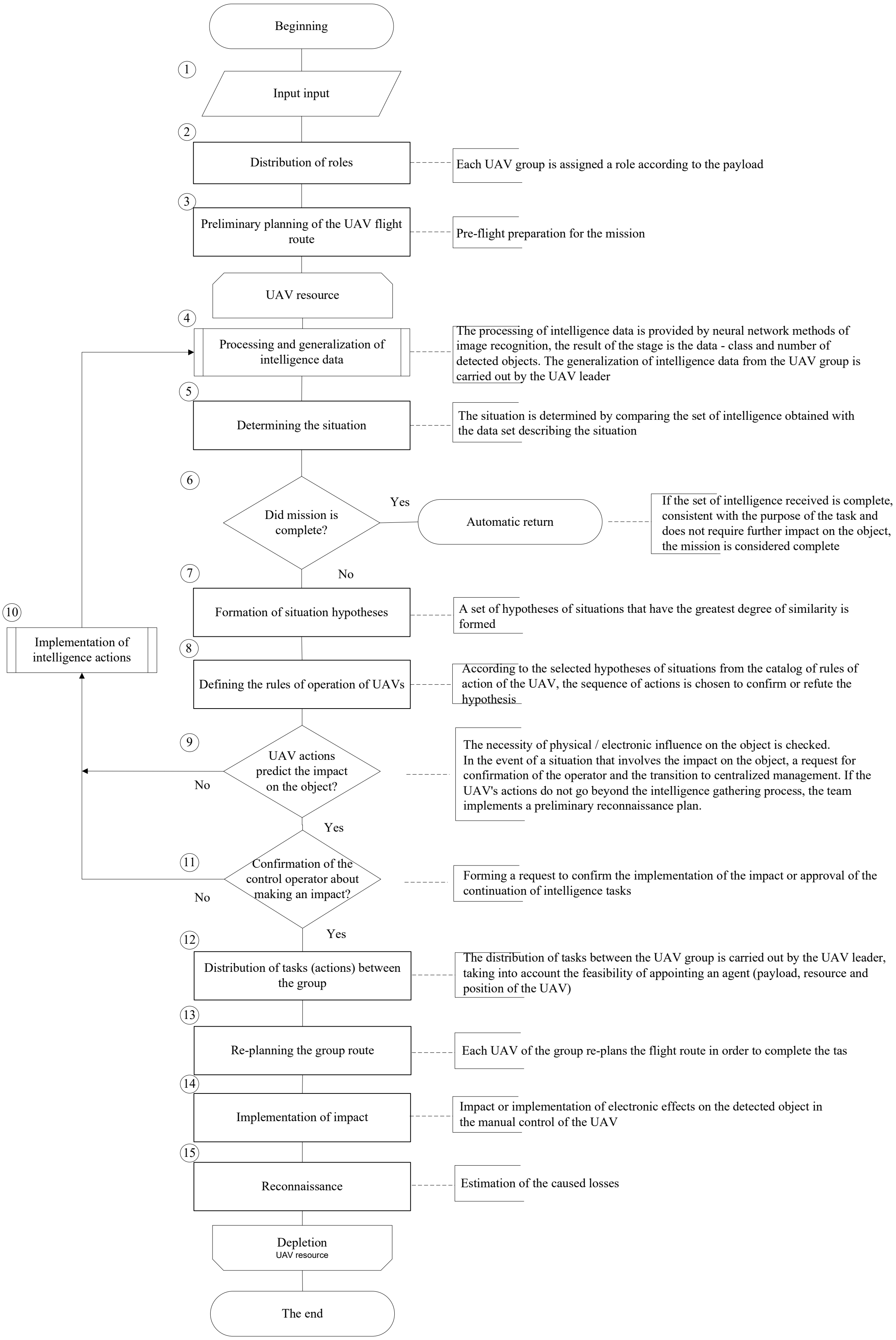

Fig. 5. General structure of the method of control of a group of unmanned aerial vehicles for search and destruction of objects.

The tools of information technology are:
– GIS software package;
– complex of meteorological data collection;
– database of technical characteristics of UAVs;
– database of UAV payload characteristics;
– database of enemy objects;
– database of cover objects;
– means of intelligence;
– knowledge base of objects, relations (regularities), constants;
– database of situations;
– base of fuzzy inference rules;
– base of UAV action rules.

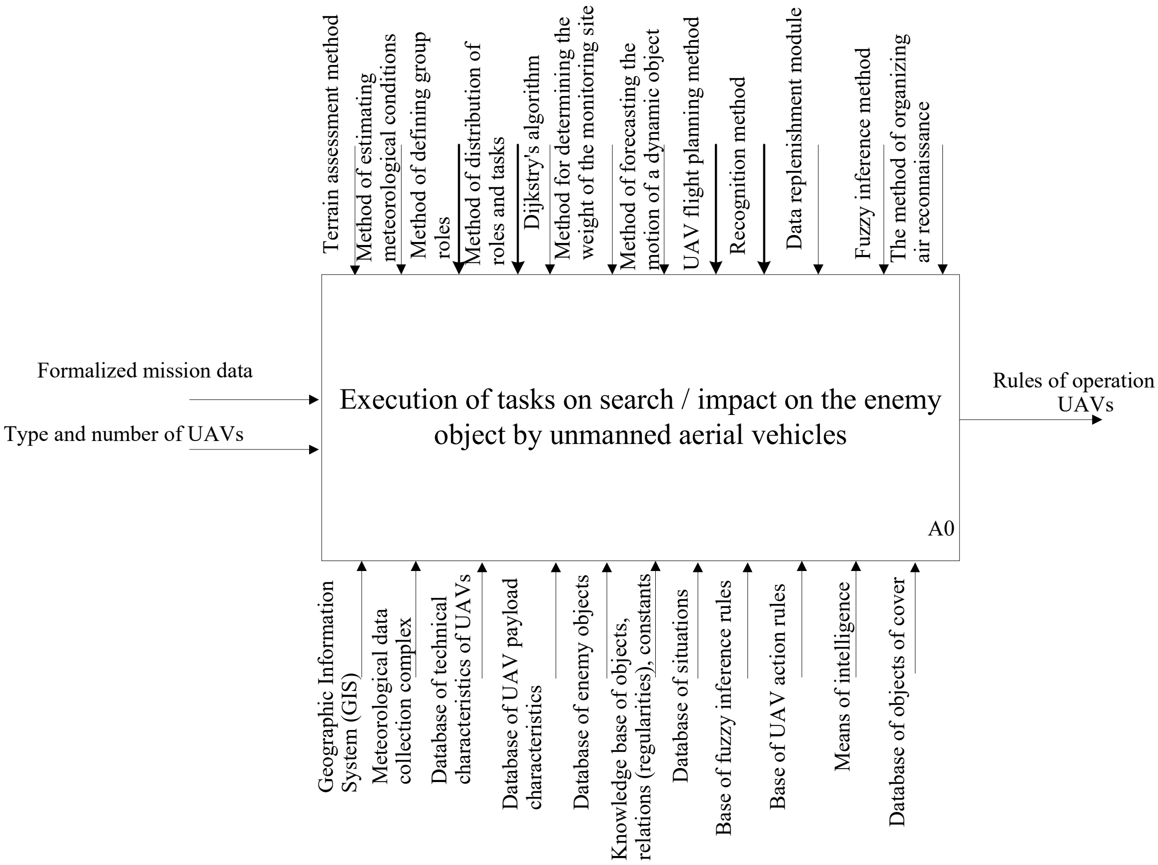

Fig. 6. IDEF0 diagram of planning the search and discharge on the enemy object by a group of UAVs.

Decisions in the IDSS of the control operator of the UAV group are formed as a result of special procedures of logical derivation of the knowledge base. Knowledge of the knowledge base are presented in a formalized form of products that contain a description of typical situations in the area of mission and standard rules of operation of UAVs.

The resulting output stream of information technology is the rules of operation of UAVs in the current situation.

The first level decomposition diagram is presented in Fig. 7 and shows the processing of information flows of information technology.

The task area assessment unit provides the system with geospatial data (boundaries of settlements, roads, restricted areas, objects of critical infrastructure, industrial facilities, hydrographic facilities and structures, type of terrain and relief) and coordinate data of the mission area. The toolkit of the unit is a geographic information system, the control mechanism — a method of assessing the area.

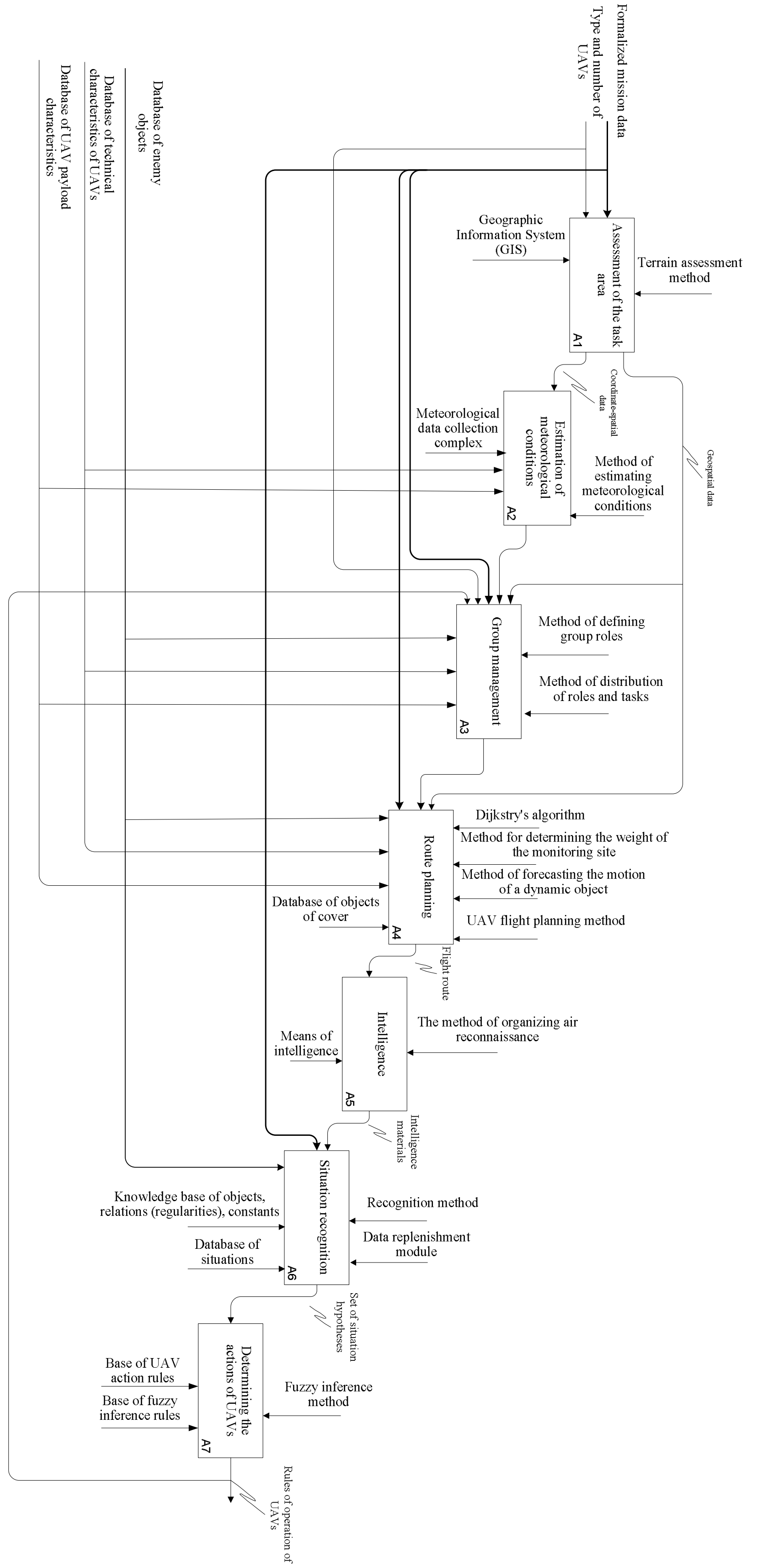

Fig. 7. Processes of information flow processing in information technology of mission execution by unmanned aerial vehicles.

The meteorological assessment unit provides control and forecast of meteorological conditions in the area of the task. The output stream of the block is the data that determines the possibility of the mission.

The decomposition of the UAV group control unit is shown in Figure 8 and consists of two processes. The first process is to determine the roles of the group required to perform the task, and the second — the distribution of roles between the UAVs into the group.

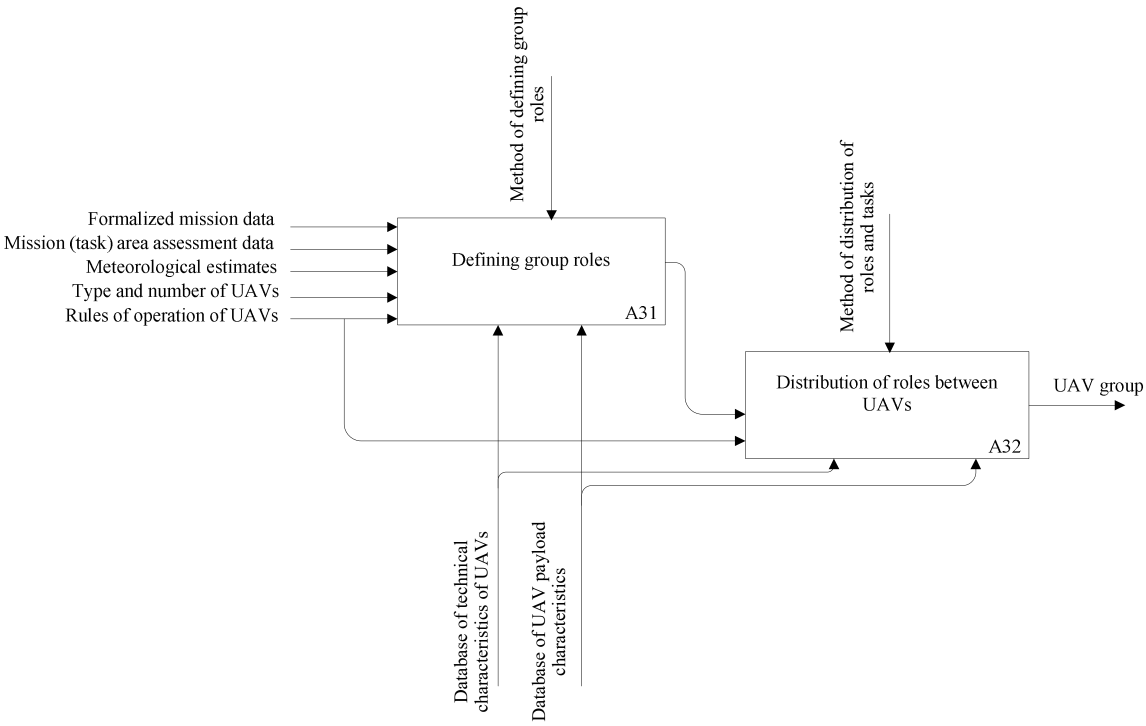

Fig. 8. Processes of processing information flows of the group control unit.

The output stream of the unit for processing information flows of the group management is the data of the UAV group, namely: the number of UAVs, payload, role and tasks in the mission.

The route planning unit provides pre-flight preparation — preliminary route planning and re-planning in the process of performing the task (Fig. 9).

The input information flows of the route planning unit are formalized mission data, geospatial data, output data of the group control unit. Formalized mission data can include tasks to find and defeat both dynamic and static objects. Therefore, the first block of the process of the route planning unit is to determine its type — stationary or dynamic.

The solution of the problem of finding a stationary object is considered in detail in [18]. The method of searching for a stationary object is based on the principle of flight on waypoints, which is usually solved by heuristic methods.

The tools of the route planning unit are the databases of cover objects, of UAV technical characteristics, of UAV payload characteristics and of enemy objects.

The control mechanisms of the route planning unit contain:

1. Dijkstra's algorithm, search of the shortest ways — for definition of probable routes of movement of dynamic object;
2. method of forecasting the movement of a dynamic object — provides data processing, determines the probable location of the dynamic object of the enemy;
3. method of determining the weight of the monitoring site;
4. method of UAV flight planning at given points (to search for a stationary object);

5. UAV flight planning method (for searching for a dynamic object) — provides the distribution of monitoring sites, taking into account the monitoring time and the weight of the sites.

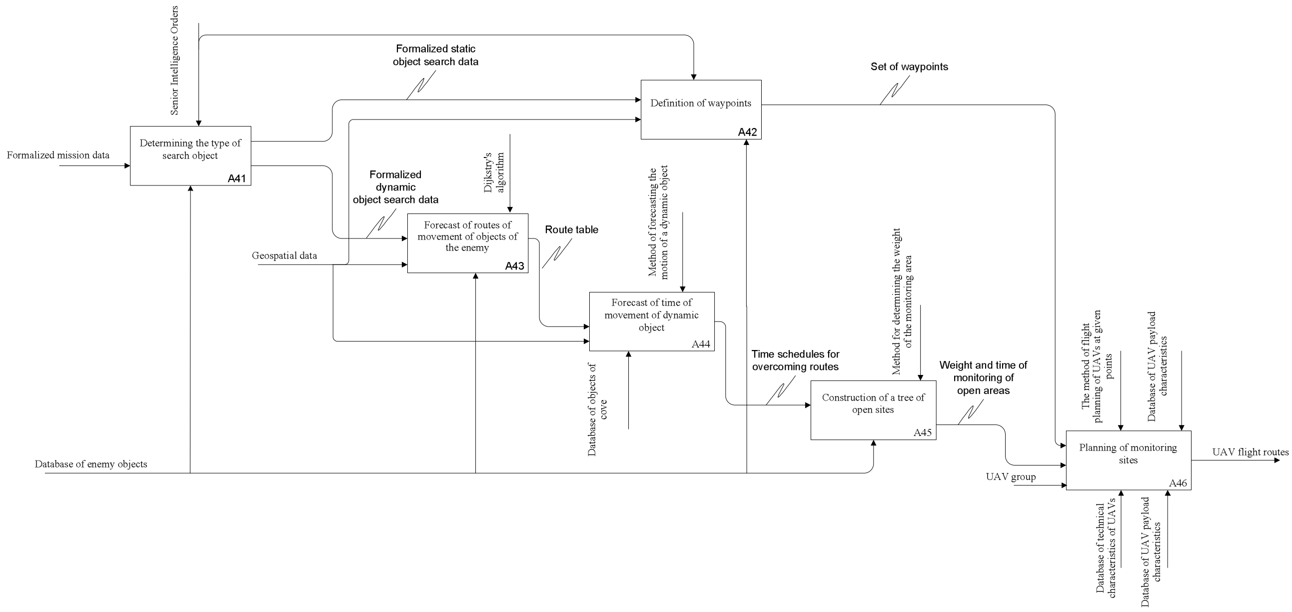

Fig. 9. Processes of processing information flows of the route planning unit.

The block of the intelligence process (Fig. 7). The incoming information flow is the route of the UAV flight. The reconnaissance process is provided by means of reconnaissance — optoelectronic equipment and means of radio technical reconnaissance. Reconnaissance is regulated by the method of organizing air reconnaissance. The source information of the unit is air reconnaissance materials.

The block of the process of recognition of situations consists of two processes — recognition of images of objects and recognition of situations. The decomposition of the block is shown in Fig. 10. The source information flow is a set of situation hypotheses.

The toolkit of the object recognition unit is the database of enemy objects, the incoming flow of information — formalized mission data and intelligence materials. The control mechanism of the unit is a method of recognition using a neural network. The source information flow is a vector of features: object class, number, location and time of detection.

The block of the process of recognizing situations forms a set of hypotheses of situations, which are ranked according to the similarity to the situations of the database and the knowledge base of objects, relations (regularities), constants.

The process of determining the action of UAVs is provided by the method of fuzzy inference, which operates with many hypotheses of situations (input information flow). The rules of operation of UAVs are generalized using the intersection of sets of rules, the most probable are determined. The toolkit of the unit is the base of UAV action rules and the base of fuzzy inference rules.

2.5. Analysis of the results

To determine the effectiveness of the developed method, a comparative table containing the following control options is given:

– several operators — several UAVs (V1),
– one operator — several UAVs (V2),
– one operator — several UAVs using the multi-agent model (V3).

As a rule, to meet the needs of search and destruction missions, a minimum group composition is required — four UAVs, due to the roles and payload.

Thus, we will assume that four UAVs are used in control methods.

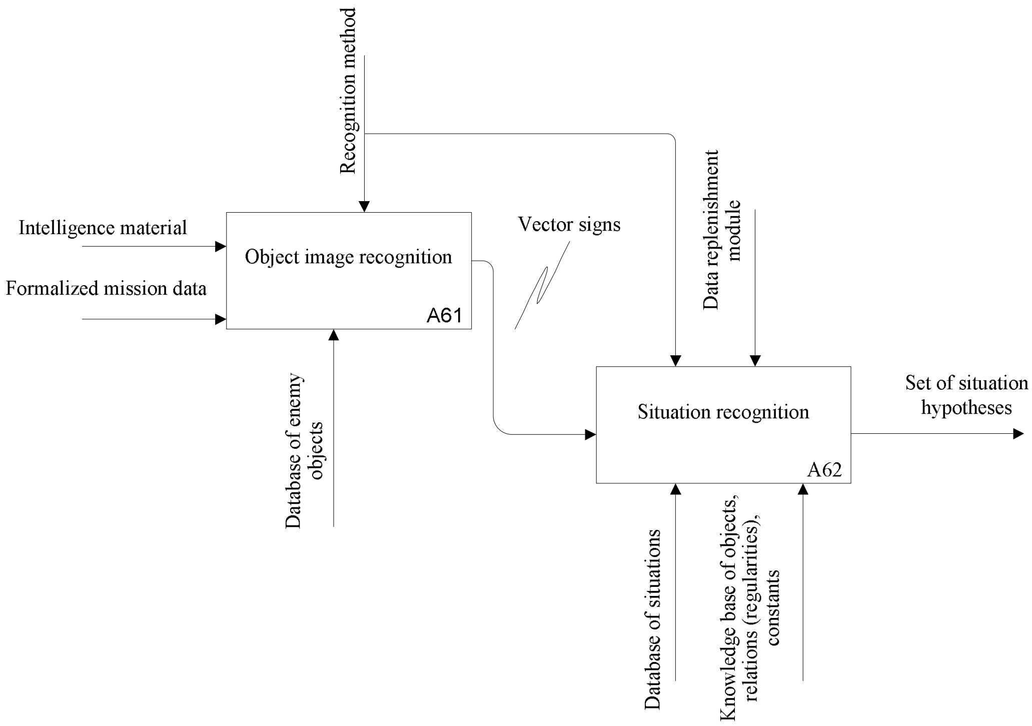

Fig. 10. Processes of processing information flows of the situation recognition unit.

Table 1. Advantages and disadvantages of management options.

	Cognitive load of the operator	Autonomy *	System response time *
V1	Medium	Low (10 – 15%)	Low 2 – 3 min.
V2	High	Medium (20 – 40%)	Medium 1 – 2 min.
V3	Low	High (more 60%)	High 0.17 – 0.5 min.

* under different conditions of the mission based on the simulation results.

To determine the effectiveness of group management options used indicators: cognitive load, autonomy and response time of the system.

The cognitive load of the operator when managing a group of UAVs means the load of the operator, which is reduced due to the autonomy of the UAV.

The autonomy of the UAV group is defined as:

$$K_{avt} = \frac{N_{SU}}{N_{\Sigma zag}}, \tag{3}$$

where N_{SU} — the number of operations performed by the UAV without operator intervention during the mission; $N_{\Sigma zag}$ — the total number of operations required to complete the mission.

The reaction time of the system ($T_{syst.}$) is determined by the expression:

$$T_{syst.} = T_{kom.} + T_{obrob.} + T_{rish.} + T_{zavd.}, \tag{4}$$

where $T_{kom.}$ — the time of transmission of information to the control operator; $T_{obrob.}$ — time of collecting and summarizing information; $T_{rish.}$ — time of decision making; $T_{zavd.}$ — time of distribution of tasks.

The results of the evaluation of control options are presented in Table 1.

Methods are evaluated by qualitative (high, medium, low) and quantitative (percentages and minutes) indicators.

According to these indicators, the control option V3 has a clear advantage over other options for group management.

The method developed in the work allows to implement the specified control option. To determine the effectiveness of the method, its evaluation was performed using the known methodology for evaluating staff models [25,26]. The defined technique allows to evaluate the quality of input data, namely the completeness of their consideration, which affects the overall efficiency of the control system.

To determine the effectiveness of management methods used the indicator of completeness of information, which is determined by the formula [27]:

$$R = 1 - \sum_{i=1}^{k} (\beta_j \cdot \alpha_i), \tag{5}$$

where k — the number of factors taken into account; α_i — weighting factor of the i-th parameter or factor, in relative units; β_j — the relative average value of the error, which is introduced into the calculations due to the generalized consideration of parameters and factors in the model by the j-th method of generalization, $j = 1, \dots, k$.

Ways to take into account the factors are as follows [21]:

$$\beta_j = \begin{cases} 0 - \text{ not taken into account} \\ 0.43 - \text{ taken into account in general} \\ 0.67 - \text{ accounted for indirectly} \\ 1 - \text{ is taken into account} \end{cases}$$

As a result, groups of factors are formed that should be taken into account when performing tasks to search and influence the enemy object and related to the stages of the mission: mission input, UAV group formation, launch site selection, route planning, route redevelopment and impact.

The factors of the above groups and their coefficients are shown in Table 2.

According to the results of expert assessments, a scale of advantages of groups of factors and their elements is formed. As a result, the values of the priority of some factors over others are obtained.

The generalized results of comparison of the methods received by a method of experimental estimation, with use of a method of the analysis of hierarchies [28], are resulted in Fig. 11.

The existing method of distributed control refers to the model (V1), which provides for the control of a group of UAVs by several operators connected by a communication system.

According to the results of the experiment, it was determined that the developed method of group management due to the subsystem of group management, route planning and situation recognition allows to take into account information for corrective actions during the mission, which is impossible to operate without automation. As a result, the total amount of information taken into account in the developed methodology is about 10% more compared to the existing system.

Thus, the results shown in Table 1 and Figure 11 indicate the advantage of the developed method of control of the UAV group.

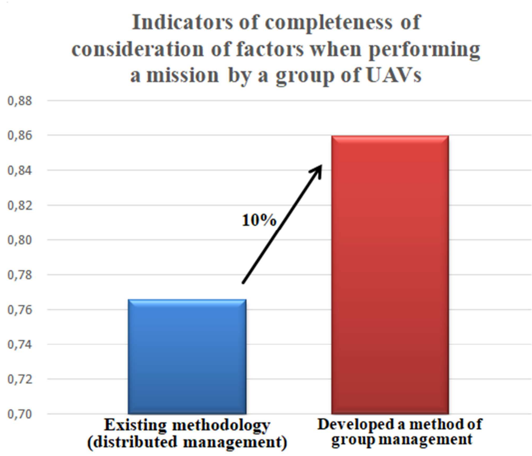

Fig. 11. Completeness of factors of group management methodology.

Table 2. Coefficients of consideration of factors at preparation and carrying out of tasks on search and influence on object of the enemy by various methods of management of group.

№	Factors that are evaluated	Weight W	Coefficient β^* Developed methodology	Coefficient β existing methodology	W · β^*	W · β
1	Mission area	0.2335	1	1	0.2335	0.2335
2	Mission start time	0.0282	1	1	0.0282	0.0282
3	Object of search and / or destruction of the enemy	0.2148	1	1	0.2148	0.2148
4	UAV readiness	0.0916	1	1	0.0916	0.0916
5	The number of UAVs	0.0105	1	0.43	0.0105	0.0045
6	Payload	0.0243	1	0.43	0.0243	0.0105
7	Specifications	0.0090	0.67	0.67	0.0060	0.0060
8	Areas of activity of enemy sabotage and reconnaissance groups	0.0091	0.67	0.67	0.0061	0.0061
9	No obstacles behind which a dead zone is possible	0.0155	0.43	0.43	0.0067	0.0067
10	Presence of mine fields and barriers	0.0037	0.67	0.67	0.0025	0.0025
11	No obstacles that affect flight safety	0.0075	0.43	0.43	0.0032	0.0032
12	The highest point of the terrain	0.0012	0.67	0.67	0.0008	0.0008
13	Access and access roads	0.0020	0.67	0.67	0.0014	0.0014
14	Location of enemy objects	0.0077	0.67	0.43	0.0052	0.0033
15	Number of enemy objects	0.0022	0.67	0.43	0.0014	0.0009
16	Type of enemy objects	0.0037	0.67	0.43	0.0025	0.0016
17	Location of starting positions	0.0032	1	1	0.0032	0.0032
18	Location of landing sites (landing)	0.0012	1	1	0.0012	0.0012
19	Open areas	0.0012	0.67	0.43	0.0008	0.0005
20	Forests	0.0011	0.67	0.43	0.0007	0.0005
21	The presence of corridors of the battle line	0.0050	1	1	0.0050	0.0050
22	Areas of counteraction of air defense means and electronic warfare of the enemy	0.0112	0.67	0.67	0.0075	0.0075
23	Prohibited areas (airfields. hydroelectric power plants)	0.0064	0.67	0.67	0.0043	0.0043
24	Weather conditions	0.0137	0.67	0.67	0.0092	0.0092
25	Time of day	0.0014	1	1	0.0014	0.0014
26	The number of UAVs in the group	0.0019	1	0	0.0019	0.0000
27	Tactical and technical characteristics of the UAV group	0.0033	1	0	0.0033	0.0000
28	Fortifications	0.0070	0.67	0.43	0.0047	0.0030
29	Air defense equipment. including electronic warfare stations	0.0070	0.67	0.43	0.0047	0.0030
30	Heavy vehicles	0.0749	0.67	0.43	0.0502	0.0322
31	Tank	0.1059	0.67	0.43	0.0709	0.0455
32	Armored personnel carrier \Infantry fighting vehicle	0.0529	0.67	0.43	0.0355	0.0228
33	Tanker	0.0172	0.67	0.43	0.0115	0.0074
34	Personnel	0.0070	0.67	0.43	0.0047	0.0030

3. Conclusion

Considering the trends in the development of unmanned aerial vehicles and the direction of development of the Air Force of the Armed Forces of Ukraine, the development of a control system for heterogeneous unmanned systems is promising and necessary in the context of the Joint Forces operation. To implement the group control of UAVs, the concept of multi-agent systems is used, the stages of operation of the control system of the UAV group in the form of a cycle are determined.

A method of controlling unmanned aerial vehicles for search and destruction of an object has been developed, based on the use of ISPPR and artificial intelligence methods at the stage of collection and processing of air reconnaissance materials. The model of ISPPR of recognition of situations which has to be integrated into the UAV control system and technically and programmatically implemented as an onboard component is developed.

An information technology for controlling unmanned aerial vehicles for searching and destroying an object has been developed.

The implementation of the developed management method meets modern needs: minimizes the participation of the operator in missions to search and destroy the object, reduces the cognitive load and increases the autonomy of UAVs, which increases the combat effectiveness of units.

Prospects for further research are the formation of a comprehensive base of rules of the knowledge base of ISPPR for missions in various physical environments, as well as the construction of special software and its testing.

[1] https://defence-ua.com/weapon_and_tech/bezdusha_sila_jak_vojujut_striljajut_jizdjat_nimetski_korejski_kitajski_ta_ukrajisnki-2572.html.

[2] https://drive.google.com/file/d/1N3tahxAhqpNUIoz-xbgVDKG-1YJmgpsK/view.

[3] Yevdokimenkov V. N., Krasil'shchikov M. N., Sebryakov G. G. Distributed intelligent control system for a group of unmanned aerial vehicles: architecture and software and mathematical support. Bulletin of the Southern Federal University. Technical sciences. No. 1. 174 p. (2016).

[4] Harchenko V. P., Shmel'ova T. F., Znakovs'ka Ye. A., Buhayko D. O., Luppo O. Ye., Lazorenko V. A., Kharchenko V. P. Methodology of situational collective control of manned and unmanned aerial vehicles in a single airspace: scientific materials. In 3 volumes. Volume 2. Integrated corporate models for collective management of manned and UAVs in a single airspace in conditions of risk and uncertainty. (2017).

[5] Wang X., Shen L., Liu Z. et al. Coordinated flight control of miniature fixed-wing UAV swarms: methods and experiments. Sci. China Inf. Sci. **62**, 212204 (2019).

[6] Hao C. H. E. N., Xiangke W. A. N. G., Lincheng S. H. E. N., Yirui C. O. N. G. Formation flight of fixed-wing UAV swarms: A group-based hierarchical approach. Chinese Journal of Aeronautics. **34** (2), 504–515 (2021).

[7] Kusyk J., Uyar M. U., Ma K. et al. Artificial intelligence and game theory controlled autonomous UAV swarms. Evol. Intel. **14**, 1775–1792 (2021).

[8] Kalyaev I. A., Gayduk A. R., Kapustyan S. G. Distributed Systems for Planning the Actions of Teams of Robots. M: Yanus-K, 2002. 292 p.

[9] Abrosimov V. K. Group movement of intelligent flying vehicles in an antagonistic environment, Moscow: Nauka, 2013. 168 p. (2013).

[10] Shmelova T., Bondarev D. Automated System of Controlling Unmanned Aerial Vehicles Group Flight: Application of Unmanned Aerial Vehicles Group. In Unmanned Aerial Vehicles in Civilian Logistics and Supply Chain Management (pp. 208–242). IGI Global (2019).

[11] Cummings M. L. Operator interaction with centralized versus decentralized UAV architectures. Handbook of Unmanned Aerial Vehicles, pp. 977–992 (2015).

[12] Tymochko O., Trystan A., Berezhnyi A., Sotnikov O., Matiushchenko O., Kryzhanivskyi I. Vehicles while Monitoring Behavior of Dynamic Objectsin a Forest–Steppe Area. International Journal of Emerging Trends in Engineering Research. **8** (7), 3208–3215 (2020).

[13] Matiushchenko O. H., Kadubenko V. S., Syedash S. P., Sizon D. O. Multi-agent model of group use of unmanned aerial vehicles when performing special missions. Polish Journal Of Science. **1** (35), 13–19 (2021).

[14] Yao P., Xie Z., Ren P. Optimal UAV Route Planning for Coverage Search of Stationary Target in River. IEEE Transactions on Control Systems Technology. **27** (2), 822–829 (2019).

[15] Tymochko O., Trystan A., Chernavina O., Berezhnyi A. The method of planning the flight route of unmanned aerial vehicles while monitoring the behavior of dynamic objects in the forest-steppe area. Information Processing Systems. **3** (162), 95–110 (2020).

[16] Cummings M. L., How J. P., Whitten A., Toupet O. The Impact of Human–Automation Collaboration in Decentralized Multiple Unmanned Vehicle Control. Proceedings of the IEEE. **100** (3), 660–671 (2012).

[17] Shpak N., Sorochak O., Hvozd M., Sroka W. Risk evaluation of the reengineering projects: A case study analysis. Scientific Annals of Economics and Business. **65** (2), 215–226 (2018).

[18] Shpak N., Odrekhivskyi M., Doroshkevych K., Sroka W. Simulation of Innovative Systems under Industry 4.0 Conditions. Social Sciences. **8**, 202 (2019).

[19] Russell S., Norvig P. Artificial intelligence: a modern approach (2002).

[20] Bugaychenko D. Yu. Development and implementation of methods of formal-logical specification of self-adjusting multi-agent systems with time constraints: dis. Candidate of Phys.-Math. sciences. St. Petersburg, 261 p. (2007).

[21] Al'pert S. I. Basic measures of similarity and new approaches to their application in the classification of hyperspectral space images. Mathematical machines and systems. **1**, 143–151 (2019).

[22] Presley A., Liles D. H. The use of IDEF0 for the design and specification of methodologies. In Proceedings of the 4th industrial engineering research conference (1995).

[23] Berezhnyy A. O., Kryzhanivs'kyy I. M., Barabash O. V. The method of automated route planning of unmanned aerial vehicles taking into account the detection of stationary objects. Telecommunication and information technologies. **4** (65), 90–98 (2019).

[24] Li R., Tapaswi M., Liao R., Jia J., Urtasun R., Fidler S. Situation Recognition with Graph Neural Networks. 2017 IEEE International Conference on Computer Vision (ICCV), Venice, Italy, pp. 4183–4192 (2017).

[25] Yatskar M., Zettlemoyer L., Farhadi A. Situation Recognition: Visual Semantic Role Labeling for Image Understanding. 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, pp. 5534–5542 (2016).

[26] Horodnov V. P., Drobakha H. A., Yermoshyn M. O., Smirnov Ye. B., Tkachenko V. I. Modeling of combat operations of air defense forces and information support of their management processes (theory, practice, history of development): Monograph, Kh.: Khark. viys'k. un-t., 410 p. (2004).

[27] Horodnov V. P., Malyuha V. H. Indicators and criteria for assessing the effectiveness of the structure of the Air Force control system. Honor and Law. **1** (64), 73–77 (2018).

[28] Saaty T. L. Decision making with the analytic hierarchy process. International journal of services sciences. **1** (1), 83–98 (2008).

Метод управління групою безпілотних літальних апаратів з метою пошуку і знищення об'єктів з використанням елементів штучного інтелекту

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У статті розроблено метод управління групою безпілотних літальних апаратів для пошуку та знищення об'єктів противника. Метод полягає у розпізнаванні ситуацій та коригуванні дій групи відповідно до неї. Основою методу є використання інтелектуальної системи підтримки прийняття рішень. Метод управління групою безпілотних літальних апаратів для пошуку та знищення об'єктів побудований відповідно до концепції мультиагентних систем. Розроблено інформаційну технологію процесів методу управління групою безпілотних літальних апаратів за методологією IDEF0.

Ключові слова: *система управління, мультиагентна модель, штучний інтелект, група безпілотних літальних апаратів, пошук та знищення об'єктів, автономна система, локальні правила самоорганізації, розпізнавання ситуації.*