Multi-Agent Group Application Model of Unmanned Aircrafts and Unmanned Ground Vehicles During Special Mission Execution

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Abstract

Analysis of the experience of unmanned aircrafts and vehicles group application shows the imperfection of methods that would meet the requirements for special missions, namely the lack of control systems for unmanned vehicles in various environment (air and ground) that would take into account situations which arise during missions' execution.

In order to increase the efficiency of special mission execution, there was developed a model of a multi-agent search and impact system on a ground object by a group of unmanned aircrafts along with unmanned ground vehicles under different control options with regard to the conditions of the antagonistic environment. The roles of agents and their tasks in the group are determined in accordance with the payload and operational characteristics. This study also depicts an example of formation of knowledge database and database of unmanned aircrafts and vehicles; specifies rules of coordination of multiple-type unmanned systems for achievement of the special mission purpose.

Keywords

Agent, multi-agent systems, systems for unmanned, database, command structure, principles and methods of collective command, management of a group of technical objects

1. Introduction

At present, the Armed Forces of NATO member states are aimed at integration of unmanned aircrafts and vehicles and systems into military formations in the capacity of full-fledged units capable of acting individually and in symbiosis with humans.

The use of such systems has a potential with relation to the solution of various problems when the exploitation of the manned aviation or equipment is impossible or impractical. For example, in conditions of strong resistance to enemy air defences, radiation, chemical or bacteriological contamination of the air and terrain, in conditions of high risk of complement loss or the need for an object to be under observation for a long period of time.

The main advantages of using unmanned aircrafts and vehicles compared to the conventional ones are as follows: manoeuvrability, low operating costs, small size, stealth capability and zero risk to the control operator (crew).

In view of the technical features of unmanned aircrafts and vehicles, they are most commonly effective when used in small areas and are widespread in various fields of human activity: agriculture (planting monitoring, tillage), road traffic control, state border control, emergency prevention, provision of state security and national defence.

At the same time, modern unmanned systems perform various tasks, for example: intelligence (aerial surveillance, fire adjustment by ground-mounted destroyers, strikes evaluation, air guard duty over the assigned sectors), attack and fighter (land-based, surface- and air- launched target destruction) and special (electronic counter measures to enemy fire and support resources,

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complication of the air environment through the use of unmanned systems as aviation erroneous targets, relay of information and battle commands, investigation of buildings and terrain pinpoints).

Taking into consideration the potential of engagement of unmanned (robotic) aircrafts and vehicles in various physical environments, it seems advisable to introduce the concept of Unmanned Vehicle (hereinafter UV) in this research paper. UV means a set of software and hardware capable of performing tasks autonomously, according to a pre-prepared program or by remote control through communication channels.

UV implies the following:

- unmanned aerial vehicle (hereinafter UAV);
- unmanned ground vehicle (hereinafter UGV);

Integrated use complex.

2. Presenting main material

The difficulty of implementation of the UV collective control methods resides in solution of problems related to the planning of tasks and flight (relocation) of the group, communication, distribution of tasks and roles in the group.

In the process of UV group control the external and onboard control systems must perform different tasks which are shown in Fig. 1.

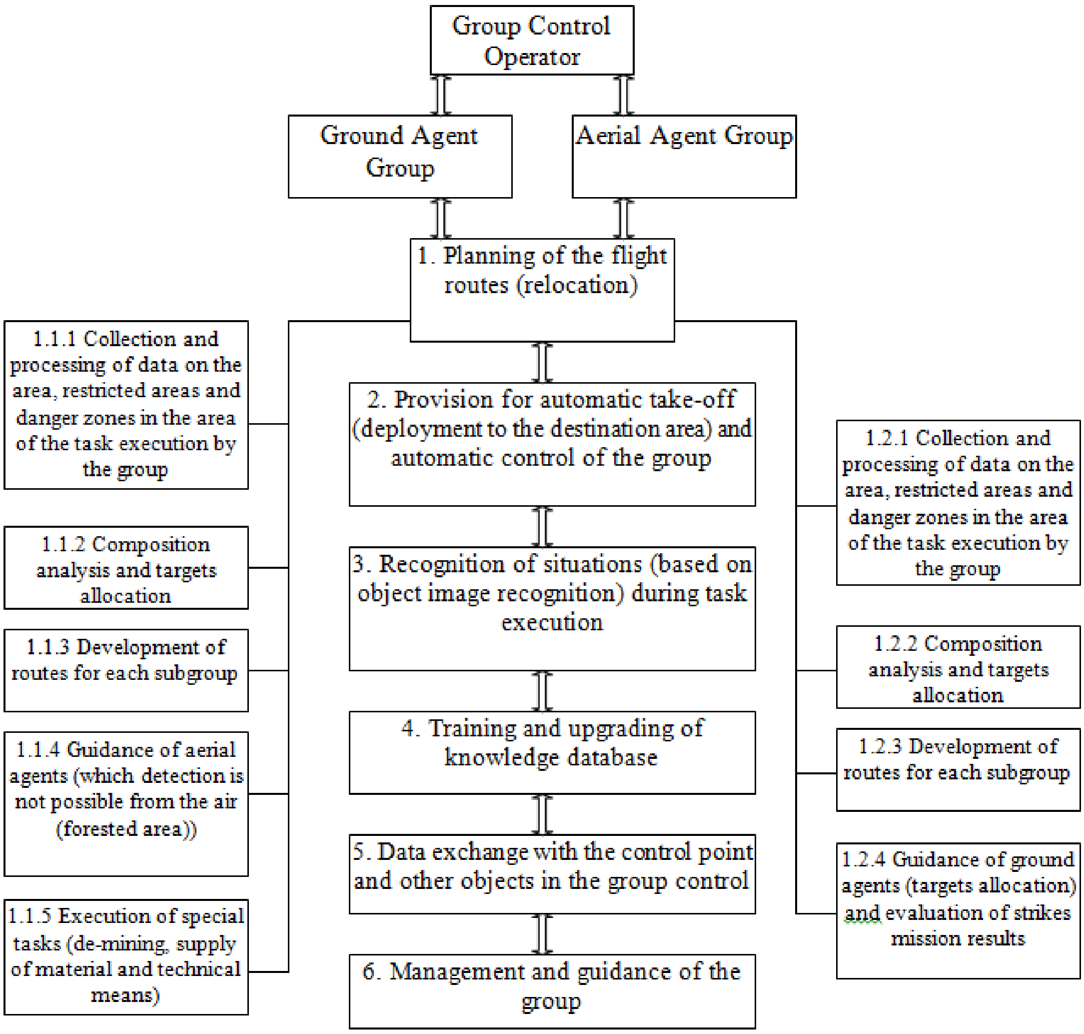

Figure 1: Tasks of the unmanned aerial vehicle (group) and unmanned ground vehicle (group) control system

The introduction of multi-agent systems (MAS) has a certain potential in UV control systems. This is largely due to the widespread use of MAS in various fields, including the development of automated control systems, automatic adjustment of neural recognition networks, formation control, overload control in communication networks, interaction of groups of drones, relative alignment of satellite groups, control of mobile robot groups' movement, synchronization in power systems [5].

The purpose of the MAS is a fundamentally new method of solving problems. In contrast to the classical method with the search for a well-defined algorithm that allows you to find the best solution to the problem, MAS gives the automatic solution as a result of the interaction of many independent goal-oriented software modules - software agents.

The agent has the ability to function fully without outside interference and to control the internal state and its actions. Unlike some adaptive systems, the agent has the ability to learn. Therefore, during changes in the external environment, it will be able to replenish its basic knowledge, which will help in the future to find better solutions to problems and will give more alternatives if one of them does not work.

The advantages of using MAS are as follows [6]:

- adaptability of agents to the environment conditions;
- interaction with the other agents of the system;
- up-grading and adjustment of the knowledge database in the process of work;
- identification of actions required to achieve the goal.

MAS involves the operation of two or more intelligent agents. Thus, there is a problem of coordination between agents, which can be solved by self-organization of the system.

The process of self-organization of the IAS is the internal order, coherence, interaction of more or less differentiated and autonomous agents of the multi-agent system, due to its structure.

As a result, in the MAS several agents can exchange information, interact with each other and solve the set task. In such a system the tasks are distributed among agents, each of which is considered as a group member. The division of tasks involves assigning roles to each member of the group, determining the degree of its "responsibility" and the requirements for its "experience".Table 1 identifies the main roles and tasks in the group in the search and impact mission

Additionally the following can be engaged in the group: diverting, erroneous, unmanned vehicle – a victim, which actions are aimed at execution of special tasks [11].

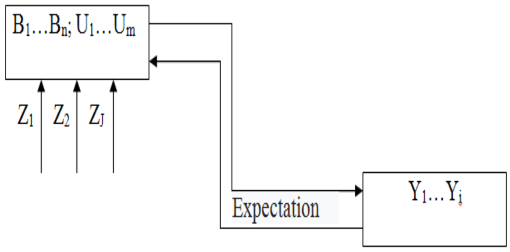

Figure 2: Scheme of interaction of 3 types of agents of a multi-agent system

The distribution of roles in the group is carried out according to the UV payload. The unmanned vehicle – LEADER - is determined from among the unmanned vehicles – SCOUTS, so in case of loss of communication with the Leader, its role can be performed by an agent- Scout.

The number of unmanned vehicles as leaders or scouts is calculated according to the area of the mission territory and is comprised of at least two units due to the necessity to re-monitor the objects and with regard to the time required to make a decision. Thereat, the payload of such unmanned vehicles should be the same [11].

The group realization requires the availability of at least three types of intelligent agents (Figure 2). Agents of the first type (Scout) assess the quality of system control and its state by measuring a set of parameters $B_1 \ldots B_n$; $U_1 \ldots U_m$ - some characteristics of the system that describe its operation [3].

Agents of the second type (Leaders) after detection of any suspicious changes as a result of external flight (relocation) $Z_1, Z_2, \ldots Z_j$ by the first type agents (Scouts), (for example, the appearance of new fire resources, enemy's ambush forces or surveillance systems), analyse and predict different solutions of the problem by forecasting the future behaviour of the system $Y_1 \ldots Y_i$.

Table 1
The roles of unmanned vehicles and their tasks in the group

Agent Role Head 1	Payload	Task in the Group
Leader	Computer systems for monitoring data pre-processing, Data capture sensors, laser radar, automation systems of processes as to detection, recognition and identification of objects, optoelectronic equipment, means of communication	– route planning (re-planning); – monitoring; – allocation of targets; – integration of information and specification of the scenario communication with the control point
Scout	Computer systems for monitoring data pre-processing , Data capture sensors, laser radar, automation systems of processes as to detection, recognition and identification of objects, optoelectronic equipment, means of communication	– monitoring; – identification and classification of objects; – guidance and adjustment ; – re-monitoring ; – analysis of the strikes mission results; – Investigation of buildings, facilities and separate objects.
Special tasks	Electronic counter measures systems, radio engineering reconnaissance systems, means of communication, systems for detection, recognition and identification of de-mining objects, system of delivery of necessary material and technical means to the points of destination	– radio engineering reconnaissance ; – jamming of counter measures to the UAV group during the mission; – detection, investigation and de-mining; – supply of material and technical means to the points of destination
Physical effect	Systems and means of destruction; guidance system, means of communication	– monitoring; – destruction of an object, restrike

It should be noted that the process "on hold" shown in the figure is a special case of adaptation, when the system through the exchange of information between intelligent agents forecasts changes and regulates its behaviour to respond to failure. This approach protects the entire system comprehensively rather than its individual components, and assists in reporting the problem to the control point and resolving it.

Thus, the MAS is able to solve tasks and organize its activities independently and perform the task as intended, forecast the work of all members of the group and control the stages of the task completion without human intervention.

The UV group control models are considered in Figure 3. The following models are defined for the control of intelligent UV in the group: centralized, decentralized and combined.

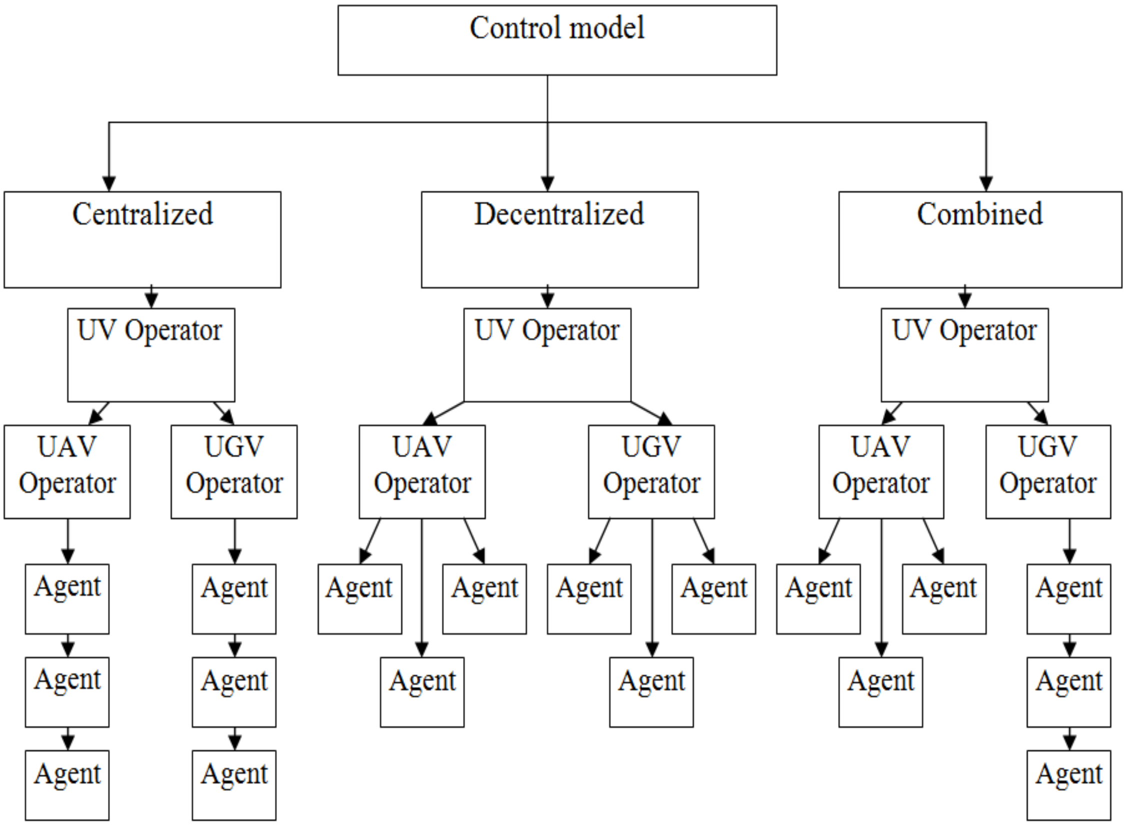

Figure 3: Unmanned vehicles group control models

Centralized control strategies can be divided into single-level and hierarchical.

Single-level control supposes that the commander's or operator's group has a control device which performs the functions of planning and group control. Its advantage is the simplicity of organization and algorithmization. Disadvantages include the long decision-making time because only one operator solves the task how to optimize all members of the group to achieve the group target and fragility.

Hierarchical control supposes that the operator or commander has the control device, which controls a small number of subordinates; each of them has its own group of controlled objects. This, compared to the single-level control, significantly simplifies the task to be solved by an individual commander or operator, but the complexity of the management structure can lead to delays or failures in the transmission of commands from top to bottom level.

Decentralized control strategies are divided into collective and gregarious.

Collective control supposes that there is no commander or operator of the control device in the system, all devices are equal and each member of the group makes decisions independently, trying to make the maximum possible contribution to the group target, and while doing that all exchange information about selected actions with each other. Due to the fact that each device solves the optimization problem only for itself, and does not try to coordinate the actions of the whole group, optimization is significantly simplified, so the task can be performed quickly, in real time.

However, group control complicates algorithmization, which requires software and hardware to ensure and maintain a high "intellectual level". If this requirement is not met, the ability of agents to understand the group task and be able to choose the actions that lead to the best performance of the mission in view of the effectiveness of the group is significantly reduced or limited.

In gregarious control there is no commander or control operator in the system, all units are equal and each device makes its own decision, trying to make the maximum possible contribution to the group target, but there is no exchange of information between the group members and each object coordinates its actions on the basis of indirect information, following the activities of others.

Under a centralized single-level strategy, the operator of the control device makes the optimal decision and the time for its adoption depends exponentially on the number of objects in the group.

In this case, it is possible to get the best solution, because the operator performs the optimization of all group actions as a whole. Under the hierarchical strategy the time for decision-making is reduced by breaking down the tasks which are solved by separate subgroups.

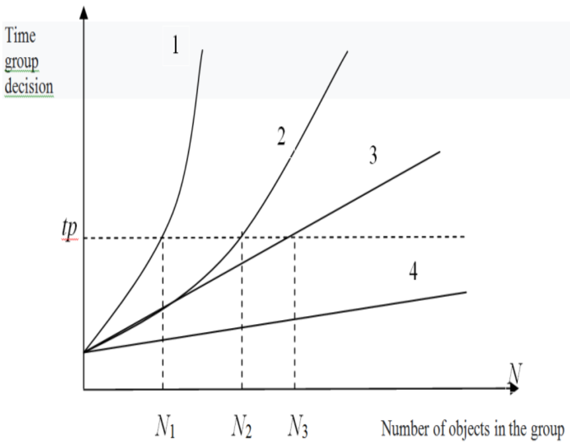

Figure 4: Group decision time for different control strategies: 1 - strategy of single-level control; 2 – strategy of hierarchical control; 3 - strategy of collective control; 4 - strategy of gregarious control

Under a decentralized collective control strategy each object of the group makes decisions independently and informs others about its intentions to optimize joint actions, so the time for decision-making increases linearly depending on the number of objects in the group.

The gregarious strategy achieves the shortest time of decision-making, because each object of the UV group takes it independently, basing only on indirect signs, so this time is slightly dependent on the number of objects in the group. However, it is clear that the gain in time is achieved by deteriorating the quality of the task execution. Accordingly, the highest quality is obtained when using a single-level control [7,17].

Basing on Figure 4 it is possible to determine the type of strategy that is most optimal in each particular case. To do this, you need to know the required group decision time tp and the number of objects in the group N. For example, if you know tp, and the number of objects in the group is less than one, it is better to use a centralized strategy, because it provides the best result. If (with known tp) the number of objects in the group ranges from one N to two N, it is advisable to use a hierarchical control system. With two N - three N the use of collective strategy will significantly reduce time expenditures compared to centralized control systems.

If the number of objects in the group is more than three N, and the time tp is limited, it is advisable to use a gregarious control system, because in this case the decision time does not depend on the number of objects in the UV group. In turn, the value of tp depends on the conditions in which the group must operate. If they are determinated and practically there is no restriction on time of the task decision in the group it is possible to make the program in advance and to put it in memory of each object of the group [16].

Provided that the situation changes slowly, for example, when drawing a map of the area, it would be more acceptable to use a hierarchical strategy, when commands (tasks) come from the control point for separate UV groups, each of which has its own local commander, who effects control within the group. If the situation changes very quickly, as in the case of military operations, the decision on group actions shall be made immediately, often without paying attention to quality, in which case one of the strategies of decentralized control is suitable: collective or gregarious [13].

The practical implementation of the above models of group control necessitates the implementation on one functional basis under different conditions and different organizational structure of the UV (single-level, hierarchical, collective or gregarious).

Figure 5 shows a schematic meta-model of the search and impact system on the object by the UV group.

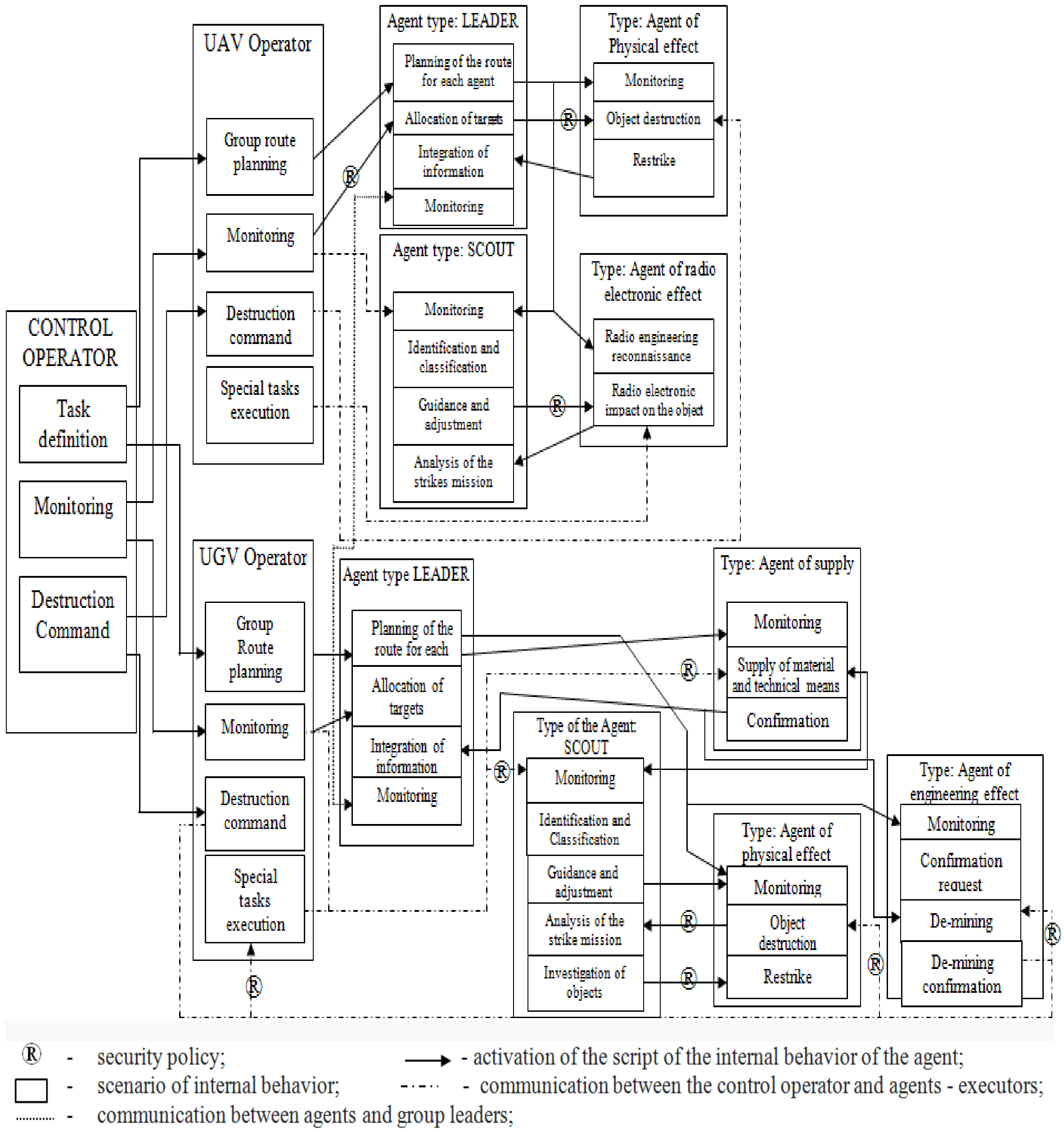

Figure 5: Meta-model of the system of search and impact on the object by a group of unmanned vehicles

The dotted broken line shows the relationship between the executing agents used in centralized control. When the communication with operator is lost, the control model is shifted to a decentralized control model via a leader agent.

The meta-model contains two types of internal scenarios of agent behaviour: scenarios that are executed when information is received from other agents; and scenarios that are executed by the agent as a result of processing information from its own sensors and detectors [12]. For example, a Scout agent activates an identification scenario when an object is detected, while activating a detection scenario requires a control command message from the Leader agent.

MAS functioning as to object search and impact is activated by control operators and begins with a preliminary search plan for a specific object, which includes route planning for each agent (to be made by a Leader agent) and countdown of the start time of the task execution, which is synchronized between groups of agents.

The data obtained from the sensors of the agents get into the general information field, so the system obtains information about the environment and the information remains constantly updated.

Since the MAS concept provides for partial awareness of information by each agent, it is logical that each agent has its own knowledge dataBase (KB) capable of operating knowledge that corresponds to the role of the agent, and "higher" level KB, which operates knowledge of each type agents – KB of the Leader agent [11].

For efficient functioning of MAS of search and impact on the object by UV group it is necessary to define rules and strategies of the agents' behaviour that will correspond to the MAS application environment and role of each agent. The rules added to the MAS KB will allow agents to respond correctly and effectively to situations.

KB of an UV agent can be conveniently divided into three blocks:

knowledge added during preparation for the task execution, namely: data of the geographic information system (GIS), the area of the task execution, the catalogue of objects;

sensor information: information obtained from the system's own sensors and detectors;

current information: information received from group control points.

Each system agent A_i has its own initial KB, which contains data about the environment:

- the area of the mission territory (S);
- its location ($x_{A_i} y_{A_i}$);
- location of other agents ($x_{A_j} y_{A_j}$), where, $j \in [1...N]$, N is number of agents, $i \neq j$;
- restricted areas defined by polygons (set of points) Z_k , where $z = \{z_{1...} z_m\}$, m is the number of points in the polygon, $m \in \{1...M\}$, where M is the number of polygons;
- catalogue of objects K_i , where $i \in [1...\mathrm{X}]$, where X is the number of objects;
- agent behaviour strategies H_i , where $i \in [1...\mathrm{M}]$, where M is the number of possible agent behaviour strategies.

During the task execution, the agent expands and updates its own knowledge database through data obtained from other agents (location, restricted areas) or from its own sensors. Thus, the KB is filled with data obtained as a result of logical inferences.

The facts database and knowledge database of physical effect agents are specified in detail in the research paper [11]. With regard to peculiarities of the use of UAVs and UGVs, we will consider the fact database and knowledge database for the engineering effect agent and the support agent.

Table 2 shows an example of the knowledge database of engineering effect and support agents, the rules database (Table 3) of the engineering effect agent and the rules database (Table 4) of the support agent.

Table 2
Facts database of engineering effect and support agents

No	Exposition	Interpretation
1	$x_{A_i} y_{A_i} \subset S$	The current coordinates of the agent $x_{A_i} y_{A_i}$ are located within the task execution area (S)
2	$x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset S$	The coordinates of the object $x_{\mathrm{K}_i} y_{\mathrm{K}_i}$ are located within the task execution area S
3	$\mathrm{K}_p \subset \mathrm{K}_i$	The object catalogue K_i contains the defined object of impact K_p
4	$\mathrm{K}_n \subset \mathrm{K}_i^{\alpha}$	Object K_n is one of the tasks that group K_i^{α} can perform
5	$x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset Z_k$	The coordinates of the object $x_{\mathrm{K}_i} y_{\mathrm{K}_i}$ are located within the restricted zone Z_k
6	$\mathrm{B} = 1$	Actions comply with security protocol (B)
7	$\mathrm{B} = 0$	Actions do not comply with security protocol (B)
8	$\mathrm{H} = 0$	A control command (H) is received from the Leader agent or control point for monitoring
9	$\mathrm{H} = 1$	A control command (H) is received from the Leader agent or control point for de-mining

No	Exposition	Interpretation
10	$\mathrm{H}=2$	A control command (H) is received from the Leader agent or control point for supply of the material and technical means
11	$\mathrm{A}=1$	Confirmation (A) is received for demining from the Leader agent or control point
12	$\mathrm{A}=0$	No Confirmation (A) is received for demining from the Leader agent or control point
13	$\mathrm{I}=1$	Confirmation (I) of demining completion and report to the Leader agent or control point
14	$\mathrm{I}=0$	No Confirmation (I) of demining completion (demining is still in process)
15	$\Upsilon=1$	Confirmation (Υ) is received for supply of the material and technical means
16	$\Upsilon=0$	No Confirmation (Υ) is received for supply of the material and technical means from the Leader agent or control point
17	$T_r < T_{\max}$	Time for the task (work) execution (T_r) does not exceed the resource ($T_{\max}$) of the agent
18	$T_r > T_{\max}$	Time for the task (work) execution (T_r) exceeds the resource ($T_{\max}$) of the agent

Table 3
Behaviour scenario of the Engineering effect agent

No	Notation	Interpretation
1	H_1	Monitoring
2	H_2	Formation of confirmation request
3	H_3	De-mining
4	H_4	Confirmation of de-mining completion

Rule 1

$$((x_{A_i} y_{A_i} \subset S) \cap (\mathrm{B}=1)) \cup ((\mathrm{H}=0) \cap (\mathrm{B}=1)) \rightarrow \mathrm{H}_1$$

Rule 2

$$(x_{A_i} y_{A_i} \subset S) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset S) \cap (\mathrm{K}_p \subset \mathrm{K}_i) \cap$$
$$\cap (\mathrm{K}_n \subset \mathrm{K}_i{}^{\alpha}) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \not\subset Z_k) \cap (\mathrm{B}=1) \cap$$
$$\cap (T_r < T_{\max}) \rightarrow \mathrm{H}_2$$

Rule 3

$$(x_{A_i} y_{A_i} \subset S) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset S) \cap (\mathrm{K}_p \subset \mathrm{K}_i) \cap$$
$$\cap (\mathrm{K}_n \subset \mathrm{K}_i{}^{\alpha}) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \not\subset Z_k) \cap (\mathrm{B}=1) \cap$$
$$\cap (T_r < T_{\max}) \cap ((\mathrm{H}=1) \cup (\mathrm{A}=1)) \rightarrow \mathrm{H}_3$$

Rule 4

$$((x_{A_i} y_{A_i} \subset S) \cap (\mathrm{B}=1)) \cup ((\mathrm{I}=1) \cap (\mathrm{B}=1)) \rightarrow \mathrm{H}_4$$

Table 4
Behaviour scenario of the Supply agent

No	Notation	Interpretation
1	H_1	Monitoring
2	H_2	Formation of confirmation request
3	H_3	Supply of the material and technical means

Rule 1

$$((x_{A_i} y_{A_i} \subset S) \cap (\mathrm{B}=1)) \cup ((\mathrm{H}=0) \cap (\mathrm{B}=1)) \rightarrow \mathrm{H}_1$$

Rule 2

$$(x_{A_i} y_{A_i} \subset S) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset S) \cap (\mathrm{K}_p \subset \mathrm{K}_i) \cap$$
$$\cap (\mathrm{K}_n \subset \mathrm{K}_i{}^{\alpha}) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \not\subset Z_k) \cap (\mathrm{B}=1) \cap$$
$$\cap (T_r < T_{\max}) \rightarrow \mathrm{H}_2$$

Rule 3

$$(x_{A_i} y_{A_i} \subset S) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \subset S) \cap (\mathrm{K}_p \subset \mathrm{K}_i) \cap$$
$$\cap (\mathrm{K}_n \subset \mathrm{K}_i{}^{\alpha}) \cap (x_{\mathrm{K}_i} y_{\mathrm{K}_i} \not\subset Z_k) \cap (\mathrm{B}=1) \cap$$
$$\cap (T_r < T_{\max}) \cap ((\mathrm{H}=2) \cup (\Upsilon=1)) \rightarrow \mathrm{H}_3$$

3. Conclusions

The formation of a group of agents with the organization of group control (ground and aerial groups) allows ensuring the joint solution of a set of tasks that cannot be solved in the case of non-collective behaviour.

Analysing the existing systems, principles and methods of UV groups' collective control, we can come to a conclusion that the issues related to the development of group control systems for functioning in various environments, separately ground and aerial, are quite well elaborated and implemented in practice as specific specialized systems. At the same time, the complexity of the tasks of UV groups' control, which are engaged in execution of special missions, has been growing significantly. The greatest difficulty of the tasks of UV joint use in various environments is the implementation of control in conditions of an organized counter measures, when decisions shall be made within a short time, close to real time, and the actions of separate groups may not necessarily be optimal. Thus, there is a need to combine the capabilities of two groups of agents with different environments for the effective solution of the problems.

The conducted researches resulted in development of a multi-agent model of UV group application during execution of special missions. This research paper has examined centralized, decentralized and combined models of multi-agent systems control. It also gives the conclusions as to the use of each control model.

A differentiating feature of this model is the consideration of the option of centralized control with a leader and decentralized control.

The choice of decentralized group control strategies increases the efficiency of functioning and probability of achieving a system-wide target, as well as the performance of the task by a separate object. The application of gregarious principles of control is expedient in the conditions of purposeful actions aimed at destruction by the opposing force.

The developed knowledge database of UV agents is based on productive rules of inference and takes into account the given situation. The synthesis of this model allows developing a system of rules and describing the UV behaviour during execution of special missions to find an appropriate method of group control.

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