The Mathematical Simulation of Information Interaction the Unmanned Aerial Vehicles

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***Abstract*— The article is devoted the control by group of unmanned aerial vehicles which can be used for search and rescue operation over the sea and land. There are the different control methods of the group unmanned aerial vehicles in article. The authors proposed the mathematic model of information interaction the unmanned aerial vehicles. This model allows to identify the parameters of timing interaction between elements of the group unmanned aerial vehicles. Particular attention is paid to reconfiguration of data exchange between unmanned aerial vehicles of the group at their failures. The results of the paper can be used for design of the software the control systems by unmanned aerial vehicles.**

***Keywords*— unmanned aerial vehicle; mathematical model; group management, information interaction, reconfiguration algorithm**

I. Introduction

Today unmanned aerial vehicles are widely used among aviation equipment, which are used for monitoring ground and air space. A separate place in the classification of such aircraft is occupied by small UAVs, the mass of which varies within the limits of 50 ÷ 500 kg, the flight time is 8 ÷ 9 hours, the flight altitude is up to 4 km. At the same time, the payload of the device is 50% of the total mass, which creates conditions for using them in search and rescue operations in all weather conditions. Moving the steering surfaces of the UAV is carried out by the helicopter control system, so the solution of the task of controlling the apparatus within the group must be performed by the computer software of the control system. At the same time, during flight of the aircraft, the coordination of the control system of the helicopter's executive mechanisms and the internal combustion engine control system should be ensured. In Fig. 1, an example of a small UAV is shown.

Considering that the search and rescue work areas can reach several hundred kilometers, there is a need for the use of UAV groups. Therefore, an important task is to manage unmanned aerial vehicles in the group. The flight of an aircraft in a group is a complex organizational and technical process, the management of which represents an independent scientific and technical task. The need for its solution is due to the increased requirements for the effectiveness of UAV applications, in particular, to the degree of accomplishment of the task posed to aircraft, to the optimization of flight routes, to the differentiation of tasks assigned to the UAV.

Currently, there are two main approaches to the management of a group of unmanned aerial vehicles, which are developed on the basis of "hard" control algorithms and artificial intelligence. In the first case, the group is managed by a single computing center (the "leading" aircraft), which receives commands from the operator from the ground and implements a predetermined flight program. Advantages of this method of control are relatively simple algorithms for flight of slave objects. However, the use of "hard" algorithms requires high computational power LA "lead", causes difficulty of organizing communication between the group members during the flight, results in loss of aircraft groups failure "lead" or communication channel. An example of such a control method is a group of robots [2], whose elements are moved by the commands of the master robot, which transmits the current location coordinates to other members of the group.

Fig. 1. Small unmanned aerial vehicle

An alternative solution to the task of managing a UAV group is to manage multi-agent systems [2–5], based on methods and algorithms of artificial intelligence. In such a system, each aircraft represents a separate element performing its own task, delivered by the developer (user). In this case, the actions of each member of the group is aimed at achieving a single goal, which creates prerequisites for the organization of data exchange between agents of the system. As an example of the use of a multi-agent system in the management of

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unmanned aerial vehicles, it is possible to defeat the enemy's ground or air targets. Thus, the use of artificial intelligence to control a UAV with the implementation of multi-agent system allows you to distribute operational functions between all the band members, as well as improve the effectiveness of its action in case of failure (loss) of some aircraft [5]. Significant disadvantages of this method of control are the absence of external control over the action of unmanned aerial vehicles and the need for high computational power of on-board equipment of an aircraft to organize the exchange of data between aircraft.

II. Characteristic of the multiclass control method of the UAV group

Among the methods of controlling the UAV group, it is also necessary to single out a multi-class control method, different from the others by dividing the aircraft of the group into classes. Each class unites 1 ÷ 5 apparatus, which allows to organize external control over the state and performance of the flight task of the group members. The structural scheme of multi-class control of a UAV group is shown in Fig. 2.

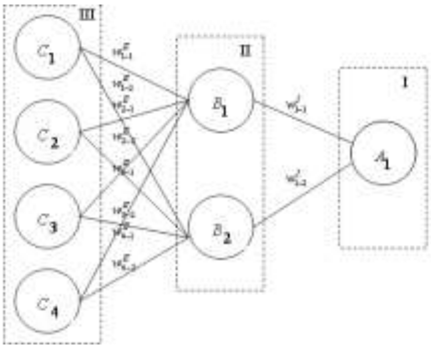

Fig. 2. Structural diagram of multiclass UAV control

The figure shows the following notation: where I ÷ III is the number of the class of the group, $A_1, B_1, B_2, C_1 \div C_4$ – the elements that make up the multiclass system, w^I_{1-1}, w^I_{2-1} – variables characterizing the exchange of data between the elements of the multisystem belonging to the I and II classes, $w^{II}_{1-1} \div w^{II}_{4-2}$ – variables characterizing the data exchange between the elements of the multisystem belonging to II and III class of the system.

It can be seen from the structural diagram that the system has a hierarchical construction in which commands and control signals are sent from the element of the senior class to the younger one. It should be noted that as the class level decreases, the number of elements belonging to this class increases. The number of elements of each class can be calculated by the formula (1).

$$k_n = 2 \cdot k_{n-1}, k_1 = 1, \tag{1}$$

Where k_{n-1} is the number of elements belonging to the previous class.

Note that each element in the current class controls two elements of the next. Then the distribution of information for the considered UAV group will take the following form (2):

$$\begin{gathered} A_1 \xleftrightarrow{w^I_{1-1}} B_1,\ A_1 \xleftrightarrow{w^I_{1-2}} B_2, \\ B_1 \xleftrightarrow{w^{II}_{1-1}} C_1, B_1 \xleftrightarrow{w^{II}_{2-1}} C_2, \\ B_2 \xleftrightarrow{w^{II}_{3-2}} C_3, B_3 \xleftrightarrow{w^{II}_{4-2}} C_4 \end{gathered} \tag{2}$$

The multi-class method of managing a group of unmanned aerial vehicles, allows to reduce the load of data exchange between group members and the computational costs that are incurred on the airborne equipment of an aircraft. Also, the presented control method provides constant monitoring of the operator over the group state, which is achieved by the data exchange of the "leading" group with the control center. A distinctive feature of multiclass control of a group of unmanned aerial vehicles from multi-agent systems is the organization of the interclass structure of data exchange between the group members.

III. Formulation of the problem

The purpose of this work is to develop a mathematical model of the information interaction of unmanned aerial vehicles in the group, which will allow us to determine the distribution of information flows between control objects in time, taking into account the delay in data transmission.

To achieve this goal, it is necessary to solve the following tasks:

1) identify the data exchange variables between the group members and the way they are transferred;

2) to construct a mathematical model of data exchange between the UAV group members;

3) to carry out modeling of information interaction of participants of a group of aircraft.

As a rule, interaction between the group members is carried out by the transfer of information containing the current position of the control object and the conditions of its flight through radio channels. Then, for the mathematical representation of the information exchange between the participants of the group, an infocommunication network model is required [6].

IV. Description of the variables that characterize the exchange of data between the group members and the way they are transferred

Variables characterizing the exchange between the elements of a multiclass system can be represented by the following dependencies (3):

$$\begin{gathered} w^I_{1-1} = [w^{I_{вых}}_{1-1}, w^{I_{вх}}_{1-1}],\ w^I_{1-2} = [w^{I_{вых}}_{1-2}, w^{I_{вх}}_{1-2}]; \\ w^{I_{вых}}_{1-1}(t) = w^{I_{вых}}_{1-2}(t), w^{I_{вх}}_{1-1}(t) = w^{I_{вх}}_{1-2}(t + \tau_{11}); \\ w^{II}_{1-1} = [w^{II_{вых}}_{1-1}, w^{II_{вх}}_{1-1}],\ w^{II}_{2-1} = [w^{II_{вых}}_{2-1}, w^{II_{вх}}_{2-1}]; \end{gathered} \tag{3}$$

$$w^{II}_{3-2} = [w^{II_{вых}}_{3-2}, w^{II_{вх}}_{3-2}],\ w^{II}_{4-2} = [w^{II_{вых}}_{4-2}, w^{II_{вх}}_{4-2}];$$
$$w^{II_{вых}}_{1-1}(t) = w^{II_{вых}}_{2-1}(t), w^{II_{вх}}_{1-1}(t) = w^{II_{вх}}_{2-1}(t+\tau_{21});$$
$$w^{II_{вых}}_{3-2}(t) = w^{II_{вых}}_{4-2}(t), w^{II_{вх}}_{3-2}(t) = w^{II_{вх}}_{4-2}(t+\tau_{22}).$$

where $\tau_{11}, \tau_{21}, \tau_{22}$ – the discrepancy of the time of data exchange between the elements of the group.

V. Construction of a Mathematical Model for Data Exchange Between UAV Group Members

During the flight of an aircraft, various external and internal factors, including random ones, that affect the transmission of the signal in time, affect it. Therefore, the mathematical description of the variable of data exchange between the elements of the system has the following form (4):

$$x(t) = A[s(t)\cos\varphi + \bar{s}(t)\sin\varphi] + n(t), \quad (4)$$

Where are $s(t)$, $\bar{s}(t)$ the Hilbert conjugation functions; φ – random initial phase, uniformly distributed over time $[0:2\pi]$; $n(t)$ Additive Gaussian noise.

$$\bar{s}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{s(\tau)d\tau}{t-\tau}, \quad (5)$$

Where τ is the time delay.

Using the formulas (3) and (4), one can obtain the expressions for information distribution between the UAV group members:

$$\begin{aligned}
w^{I_{вых}}_{1-1} &= A_{w^{I}_{1-1}}[w^{I_{вых}}_{1-1}(t)\cos\varphi + \bar{w}^{I_{вых}}_{1-1}(t)\sin\varphi] + n(t),\\
w^{I_{вх}}_{1-1} &= A_{w^{I}_{1-1}}[w^{I_{вх}}_{1-1}(t)\cos\varphi + \bar{w}^{I_{вх}}_{1-1}(t)\sin\varphi] + n(t),\\
w^{I_{вх}}_{1-2} &= A_{w^{I}_{1-2}}[w^{I_{вх}}_{1-2}(t)\cos\varphi + \bar{w}^{I_{вх}}_{1-2}(t)\sin\varphi] + n(t),\\
w^{II_{вых}}_{1-1} &= A_{w^{II}_{1-1}}[w^{II_{вых}}_{1-1}(t)\cos\varphi + \bar{w}^{II_{вых}}_{1-1}(t)\sin\varphi] + n(t),\\
w^{II_{вх}}_{1-1} &= A_{w^{I}_{1-1}}[w^{II_{вх}}_{1-1}(t)\cos\varphi + \bar{w}^{II_{вх}}_{1-1}(t)\sin\varphi] + n(t),\\
w^{II_{вх}}_{2-1} &= A_{w^{I}_{1-2}}[w^{II_{вх}}_{2-1}(t)\cos\varphi + \bar{w}^{II_{вх}}_{2-1}(t)\sin\varphi] + n(t)\\
w^{II_{вых}}_{3-2} &= A_{w^{II}_{3-2}}[w^{II_{вых}}_{3-2}(t)\cos\varphi + \bar{w}^{II_{вых}}_{3-2}(t)\sin\varphi] + n(t),\\
w^{II_{вх}}_{3-2} &= A_{w^{II}_{3-2}}[w^{II_{вх}}_{3-2}(t)\cos\varphi + \bar{w}^{II_{вх}}_{3-2}(t)\sin\varphi] + n(t),\\
w^{II_{вх}}_{4-2} &= A_{w^{II}_{4-2}}[w^{II_{вх}}_{4-2}(t)\cos\varphi + \bar{w}^{II_{вх}}_{4-2}(t)\sin\varphi] + n(t),
\end{aligned} \quad (6)$$

where $A_{w^{j}_{i-k}}$ is the amplitude of the signal belonging to the multiclass system.

Modeling of information interaction of participants of a group of aircrafts

Within the framework of the work, modeling of data exchange between the elements of a group of unmanned aerial vehicles was carried out. In the process of modeling the information interaction of the group members, the following assumptions were made:

1) Participants in the subclasses of the group receive information from the leading elements at the same time. For example, elements B_1 and B_2 simultaneously receive data from element A_1.

2) The leading elements of the group receive data from the slaves simultaneously for their own subclass. For example, B_1 receives data from C_1 and C_2 at the same time.

2) When exchanging data between group members, the value is.

The harmonic signal in the form of a cosine with an amplitude in the range of 5 ÷ 45 V and a frequency of 50 Hz was adopted as the initial data exchange signal. The results of modeling the data exchange between the group members are shown in Fig. 3.

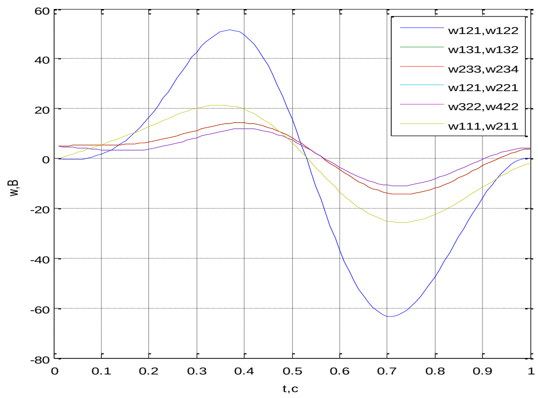

Fig. 3. Distribution of signals between group members

Fig. 3 shows that the offset of the transmission time interval between elements of different classes of the system is 0.1 s. And the time of data transfer from element A to elements C reaches 0.2 s. Therefore, in the process of organizing the distribution of information flows, it is necessary to take into account the time lag of data transmission from the leading elements to the slaves, which is expressed in the software and algorithmic support of the UAV control system.

Thus, expression (4) allows to represent mathematically the data exchange between the group members, which can later be used in the development process of the control system software for a group of unmanned aircraft.

VI. Development of an Algorithm for Reconfiguring the Interaction of Group Members

However, in the operation of aviation equipment, failures may differ with different consequences for the participants of the group, including the loss of one or more participants. Therefore, there is a need to develop an algorithm for reconfiguring the interaction of group members in order to maintain control and management over them. The process of reconfiguration of the elements of the system is a complex computational process aimed at changing the structure of the control system, which consists in the redistribution of the functions of its elements in the failure of other elements [7].

For the development of the algorithm, it is necessary to outline the main principles for reconfiguring the management of a group of unmanned aerial vehicles:

1) the appointment of a new lead remaining group;

2) changing data streams.

Consider an algorithm for reconfiguring the distribution of information between group members in the event of failure of the elements of the second class.

Stage 1. Initialization of control objects from the UAV group

Step 2. Verify the availability of data exchange between the elements of classes I and II.

Step 3. If there is no data exchange between one of the elements of class II and the leader of the group, the management is performed by the remaining participant in the class.

Step 4. Verification of the availability of data exchange between the elements of Class II and III.

Step 5. If the data exchange between the master and slave elements of the subclasses is carried out in accordance with the expression (3), then the control commands must be transmitted from the element in communication with the master group to the element with the failed communication over the reserve communication channels. Otherwise, the remaining element takes control of the elements of the next class. For example $B_1 \xleftrightarrow{w_{1-1}^{II}} C_1$, $B_1 \xleftrightarrow{w_{2-1}^{II}} C_2$, $B_1 \xleftrightarrow{w_{3-1}^{II}} C_3$, $B_1 \xleftrightarrow{w_{4-1}^{II}} C_4$, $B_1 \xleftrightarrow{w_{3-1}^{II}} C_3$, $B_1 \xleftrightarrow{w_{4-1}^{II}} C_4$ are backup data lines.

Step 4. If there is no data exchange between the group members from the II class with the leader, then the management of the third class should go to the leading group.

Thus, the proposed algorithm for the reconfiguration of a group of unmanned aerial vehicles will allow maintaining control functions in the process of the failure of its elements. Further development of the algorithm should be directed to its software implementation as part of the computer complex of the aircraft.

VII. Conclusions

As a result of the work done, a mathematical model of information interaction of the elements of a group of unmanned aerial vehicles operating in various weather conditions for search and rescue operations was obtained. Modeling of information interaction of participants of a group of flying vehicles is carried out. Also, an algorithm for reconfiguring its elements in the event of a failure of group members is proposed.

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