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SYNTHESIS OF THE MODEL OF MANAGEMENT OF COMPLEX DYNAMIC OBJECTS TAKING INTO ACCOUNT THE EVENTS OF THEIR SECURITY

The rapid development of complex, decentralized, non-linear technical structures - robotic means urgently requires the creation of an optimal algorithmic support for an automatic situational control system of such dynamic objects, taking into account the possibility of increasing the safety of their operation. This will be a guarantee, and as a result, a significant increase in the efficiency and quality of the tasks assigned by the specified technical structures. For the practical implementation of this task, it is advisable to comprehensively consider the nonlinear model of the processes of changing the state of a complex dynamic object. It is advisable to take into account the possibility of operational automatic compensation of dangerous incidents. Such a model will become the basis for the synthesis of nonlinear synergistic situational laws of management of these structures. The difference of the proposed approach is the consideration of the influence of intensive variations of incident flows in the state management laws of nonlinear dynamic objects. Emphasis on promising areas of research, namely: the application of the obtained results to justify the requirements for the design characteristics of control systems and their algorithmic support from the point of view not only of increasing their safety of operation, but also of ensuring the specified performance indicators of a wide range of possible tasks. One of these tasks is the provision of departmental communication (for the collection, processing, storage, protection of information and its operational transmission) in the case of the use of dynamic objects as mobile aerial platforms (unmanned aerial systems (UAVs)) for the placement of special electronic communications devices.

Key words: control model, situational control, aerial platform, nonlinear optimization, compromise scheme, special electronic communication, unmanned aerial systems, incident.

Statement of the problem in a general form. Taking into account the special specifics of the requirements for the provision of departmental communication, the possibility of placing electronic means for its implementation on aerial platforms is being considered. As these platforms, it is expedient to use modern unmanned aerial vehicles with effective on-board computers of automatic control, the software of which takes into account the ability to process a wide range of incidents that affect the safety of their functioning when performing assigned tasks.

Therefore, we focus on the specific features of the combined use of unmanned aerial vehicles (UAVs) as part of groups. This approach will make it possible to implement the stability and uninterrupted functioning of the mobile departmental communication network in the case of placement and "dispersal" of special electronic means on board each aircraft of the group – UAV. Therefore, for the organization of special communication, it is advisable to focus on the specifics of the use of UAVs and the features of the management of these means, taking into account the implementation of the possibility of compensating for the consequences of dangerous incidents.

Management of complex dynamic objects, taking into account the possibility of effective compensation of the consequences of accidents dangerous for their operation, is an urgent problem for all classes of such structures. Special attention is paid to critical infrastructure facilities, aircraft, computer systems and all special electronic communications.

Today, a significant advantage of using UAS – modern UAVs in groups is a significant increase in the probability and efficiency of their performance of assigned tasks, while the disadvantage is the impossibility of ensuring the necessary (given) level of flight safety during intensive maneuvering under the influence of the atmosphere, and especially fluctuations in speeds and directions wind currents. A promising approach to eliminating this shortcoming is the appropriate organization of the process of managing the simultaneous use of a large number of UAVs in a group flight. The term "group flight" reflects the process of simultaneous, compatible, coordinated, synergistic (organizationally interconnected) application and operation of several aircraft (which, as a rule, have different flight and technical characteristics, loads, functional purpose, on-board equipment, etc.) with a clearly defined purpose of the flight task. Today, the current flight tasks, the efficiency of which is significantly increased by the group use of UAVs, include: surveillance with the accumulation or operational transmission in real time of the necessary service information about ground and air objects; search and detection of objects, constant observation of them with the necessary and possible information-energy or other influence on their functioning; transportation of oversized cargo; performance of aviation and chemical works; fire extinguishing; carrying out special monitoring; retransmission, switching, routing and conversion of departmental radio communication signals; solving applied scientific problems on the study of the earth's surface; patrolling etc.

Implementation of the proper management organization of the process of simultaneous use of a large number of UAVs in a group flight with the provision of a given level of flight safety during intensive maneuvering under the influence of the state of the atmosphere is proposed to be ensured through the creation of algorithms for the control system of these moving objects. Today, appropriate automated control systems for the group use of UAVs (complexes of mobile aviation systems) are being developed. But, according to the authors, it is advisable to focus special attention on the task of significantly increasing the level of flight safety during intensive maneuvering under the conditions of constant influence of changes in the state of the atmosphere, and especially fluctuations in speed and direction. wind currents. Therefore, this scientific article is devoted to the solution of this actual theoretical and applied problem.

Analysis of recent research and publications. A significant amount of fundamental and applied scientific research, the results of which are reflected in many publications, is devoted to the modeling of the management processes of complex, dynamic, large organizational objects, which undoubtedly include groups of UAVs, and especially unmanned ones. Attention is focused on the most relevant of them. During the analysis, scientific articles from [1] to [12] were considered. Let's consider the results of this analysis.

For example, in [1], an approach to planning the flight path of the UAS is described and a model of the AC group is given. Takes into account the possibility of modeling movement along trajectories approximated by arcs of constant and variable curvature, as well as Pythagorean hodographs. The advantages and disadvantages of UAVs motion modeling and the conditions of application of the mentioned approaches for the approximation of trajectories are shown.

In the scientific paper [2], an analysis of existing approaches and features of UAVs control was carried out, its mathematical model was described, and a number of different approaches to the control of such aircraft were proposed. The main ideas, terms of use, advantages and disadvantages of the proposed approaches are illustrated and discussed. The structural schemes of the UAVs as a control object are considered. The architectural components of its pilotage and navigation equipment are described.

The scientific article [3] is devoted to the consideration of possible methods of evaluating the effectiveness of the use of UAVs and offers an improved methodology for evaluating the effectiveness of the use of group formations of UAVs in conditions of unauthorized influence of various factors not only directly on the devices themselves during their flight tasks, but also on the entire UAVs group. It is indicated that since the UAVs control process is stochastic, it is suggested to use probabilistic indicators to evaluate the effectiveness of the use of these aircraft, namely: the probability of successful completion of flight tasks, the guaranteed probability of completing tasks, the probability of completing a number of tasks from the total number of them, the average guaranteed result, mathematical expectation of the number of successfully completed flights by UAVs.

In a number of scientific works, namely [4]–[6], scientists comprehensively considered the important features and specifics of group use of UAVs. The authors of these works proposed a probabilistic method of justifying the choice of a UAS group control system, which is based on Markov probabilistic models of changes in discrete states in continuous time. The possibility of differentiating the intensity of event flows depending on the states of the UAS is taken into account. The difference between the obtained scientific results is the consideration of the widest possible range of situations of possible application of UAS. An important requirement for the stable operation of the “UAV group – application object” system is proposed to ensure compliance of the random flow of events with Markov conditions.

The article [7] presents approaches and research results of effective operational planning of UAVs logistics in emergency situations. These studies are based on the use of algorithms for the optimal allocation of the UAVs resource for the implementation of optimal compensation processes for the consequences of dangerous incidents.

Approaches to the synthesis of the UAVs control and monitoring subsystem are proposed in [8] and a protected automated voice control system for this aerial object is described in [9].

Scientific works [10]–[12] are devoted to the construction of mathematical models of the movement of UAVs as complex nonlinear dynamic objects, taking into account the flight and technical capabilities of the aircraft for the synthesis of the control system with decision support.

Thus, a comprehensive analysis of theoretical and applied results obtained in the latest scientific research shows that scientists are currently paying considerable attention to the problems of organizing optimal control of UAVs and synthesis of control systems for these structures. But the approaches to ensuring a given level of flight safety of UAS groups by compensating dangerous incidents in situational control systems, which provide for the possibility of compensating the incidence of wind effects on the maneuvering of such air vehicles are not sufficiently covered in the known works.

The purpose of the article is the theoretical substantiation of the synthesis of management models of complex dynamic objects (large technical and information systems) on the example of the functioning of stable organizational structures, namely: the combined use of UAS taking into account the incident danger – turbulent phenomena in the atmosphere. Emphasis will be placed on the formation of non-linear models which should be implemented in the algorithmic and software of synergistic situational systems of automatic control of UAS to organize their safe movement management for a significant increase in the efficiency of task performance. by appointment.

Presentation of the main research material. Non-linear models which sufficiently fully and accurately describe the processes of UAS functioning in combined application and which as research shows are used for the synthesis of situational nonlinear laws of control of these complex dynamically dispersed objects, appropriately take into account the situational factor – the impact of a dangerous event, namely: changes in atmospheric processes or wind flows [1].

As the analysis of the experience of the combined use of air defense systems shows the influence of intense fluctuations in the air environment causes instantaneous but as a rule not always predictable changes in the aerodynamic forces and moments of aircraft. As a result it significantly affects the efficiency of managing these air assets. To compensate for this incident, the main emphasis should be placed on the organization of ensuring their flight safety with joint (group) use to realize the possibility of performing tasks by UAS formations [2]–[7].

It is known that the variation (dynamics) of atmospheric processes is influenced by a large number of factors [13], [14]. It is proposed to take into account the most significant of them for conducting research, namely: the geographical position of the area of the combined use of air defense systems, the features of the earth's surface, the altitude of the aircraft, the season, time of day, air temperature fluctuations [8], [9], [13]. This indicates that the air environment is a complex non-linear object, for which it is problematic and not always possible to synthesize an adequate and accurate model of atmospheric processes during the organization of compatible (synergistic) situational control of air defense systems [5], [6], [10].

Conducted theoretical and experimental studies show that existing turbulent phenomena in the atmosphere can be represented by appropriate nonlinear mathematical models. Among them, according to the authors, the greatest interest for achieving the goal of nonlinear synthesis of situational and synergistic control systems of UAS is represented by mathematical models in which, using the method of express measurement of the state of complex systems using a parametric indicator [13] it is sufficient to take into account intensive variations in atmospheric turbulence, which significantly affect the change in wind flow profiles. As a rule,they are characteristic of fast-flowing air currents near the Earth's surface [14].

The study of the reaction of UAS when used in combination with fast-moving situational factors of intense variations of atmospheric turbulence was based on the theory of statistical dynamics and stochastic optimization [15]. For a complete, accurate and adequate description of possible control situations, in which the influence of existing factors of atmospheric turbulence is taken into account, models of the UAS group in the form of nonlinear differential equations are used. It is taken into account that in addition to the dynamic states in flight of these aerial objects, they also describe their propulsion systems and servo drives (for control). This made it possible to synthesize the functioning algorithms of the system of synergistic situational management of the UAS group as a single dynamic structure. The implementation of these algorithms in on-board digital computers of control systems will ensure self-organization of situational control by taking into account the features of various options for using the UAS [11], [12].

When solving this problem, one of the possible approaches to assessing the impact of air turbulence is proposed. We will use the obtained results to describe the general patterns and determine the necessary requirements for the synthesis of situational control systems of the UAS.

When conducting analytical studies we will consider the air environment to be homogeneous and isotropic. Then, for all points of the air space near the earth's surface, in which the application of the UAS group is predicted, such characteristics as the mathematical expectation, dispersion and density of the distribution of the random component of the wind speed will be the same.

It is known that variations of the longitudinal component u_x changes in the speed of the UAS taking into account the influence of a homogeneous isotropic medium along the trajectory L the movements of this aerial vehicle should be represented by spectral density

$$S_1(\omega) = \frac{2\delta_u^2 L V^{-1}}{1+\omega^2 L V^{-2}}, \tag{1}$$

where δ_u^2 – dispersion of the velocity of the longitudinal component of the wind flow;

V – speed of UAS movement;

ω – the frequency of the components of a random signal adequate to the change in the speed of the wind flow which can take a value $\omega = [0, \infty]$;

L – the distance traveled by the plane.

Vertical u_y and lateral u_z component changes in UAVs speed, taking into account the effects of intense variations in atmospheric turbulence (normal to the UAS trajectory vector and lying in its structural plane of symmetry and in the plane of its wing), are characterized by spectral density and are determined from the expression

$$S_2(\omega)=\delta_u^2 LV^{-1}\left(\frac{1+3\omega^2L^2V^{-2}}{\left(1+\omega^2L^2V^{-2}\right)^2}\right). \tag{2}$$

To describe the variance dependence D_{ij} signals X_i (which identify a group of airborne aerial platforms – UAS as a complex dynamic nonlinear large organizational technical system) from the spectral density S_0 of the “white noise” type coming to j the input of this system and the corresponding integral quadratic estimate of the pulses of these signals, we will use the classical statistical dynamics mathematical model

$$D_{ij}=S_0 I_{ij}. \tag{3}$$

Using the mathematical expression (3) in the synthesis of the laws of situational synergistic control, it is proposed to create models that describe the forming filters of the transformation of control signals with the spectral densities described by the expressions (1) and (2). It is also proposed to simplify theoretical studies to present a model of a dynamic system containing nonlinear equations of the combined motion of a UAS in a group of two aircraft. In this model it is advisable to include equations that describe the processes of signal processing in the shaping filter, taking into account the intensity of variations in wind disturbance and the predicted control of the UAS pair. In order to simplify analytical modeling it is assumed that the management processes of such structures are stable. Acceptance of such assumptions will allow to determine integral quadratic estimates during analytical research I_{ij} which characterize signal processing in UAS control systems.

Amplitude-phase characteristics $W_1(j\omega)$ i $W_2(j\omega)$ forming filters for signal processing in UAS control systems that correspond to spectral densities $S_1(\omega)$ i $S_2(\omega)$ described by the functions of the species

$$S_i(\omega)=\left(W_i(j\omega)\right)^2 S_x(\omega), \tag{4}$$

where $S_x(\omega)$ – spectral density of the input signal of the shaping filter.

Taking into account (4) and accepting $S_x(\omega)=1$ we find dependencies for determining the amplitude-phase characteristics of the shaping filters of signal processing in the computers of the airborne control systems of the UAS

$$\left|W_1(j\omega)\right|^2=S_1(\omega),\ \left|W_2(j\omega)\right|^2=S_2(\omega). \tag{5}$$

Then the differential equation describing the state of the first signal processing filter will have the form

$$\dot{u}_x=-VL^{-1}u_x+\delta_u\sqrt{2VL^{-1}}\xi, \tag{6}$$

For the second filter the mathematical model will look like this

$$\begin{vmatrix}\dot{Y}_1\\ \dot{Y}_2\end{vmatrix}=\begin{vmatrix}0 & -V^2L^{-2}\\ 1 & -2VL^{-1}\end{vmatrix}\begin{vmatrix}Y_1\\ Y_2\end{vmatrix}+\begin{vmatrix}\delta_u\left(VL^{-1}\right)^{\frac{3}{2}}\\ \delta_u\left(3VL^{-1}\right)^{\frac{1}{2}}\end{vmatrix}\left|\xi\right|, \tag{7}$$

where $Y_2=u_y$, $Y_1=2V\left(LV_2\right)^{-1}+\dot{Y}_2-\delta_u\left(3VL^{-1}\right)^{\frac{1}{2}}$.

The output signal for the second filter, which will transmit wind flow signals to the input of control object models u_y is signal Y_2. The input signal of both filters as well as in extended models of control objects is a signal which we denote ξ.

It is advisable to first present the model of UAVs application processes in a general form

$$\dot{X} = AX + Gu, \tag{8}$$

where X – vector of the state of the UAS group, consisting of the parameters of their single use and the parameters of the coordinates of the relative position of these aerial platforms when used together;

A – matrix of coefficients which describes UAS as a complex dynamic object of management;

G – the matrix of coefficients of the effectiveness of the influence of control signals on the implementation of maneuvering processes of the UAS;

u – vector of UAS control signals.

In equation (8) of the matrix A i G let's present it in this form

$$A = \begin{vmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ A_{31} & A_{31} & A_{31} \end{vmatrix}, \quad G = \begin{vmatrix} G_1 & 0 \\ 0 & G_2 \\ 0 & 0 \end{vmatrix}. \tag{9}$$

Taking (9) into account, let's convert expression (8) into the following systems of equations. The first of them will look like

$$\begin{gathered} \dot{X}_1 = A_{11}X_1 + G_1u_1, \\ \dot{X}_2 = A_{22}X_2 + G_2u_2, \\ \dot{Y}_{om} = A_{31}X_1 + A_{32}X_2 + A_{33}Y_{om}. \end{gathered} \tag{10}$$

Equations (10) denote:

X_1, X_2 – n- measurement vectors that reflect the state of autonomous movement of the first and second UAS, respectively;

Y_{om} – μ- measurement vector of coordinates of the relative position of the UAS;

u_1, u_2 – r- measurement vectors of control influences – control signals;

$A_{11}...A_{33}$ – matrices of coefficients that characterize “internal connections” in the UAS model;

G_1, G_2 – matrices of coefficients that are included in the block matrices of the form (9) for the mathematical model (10) and characterize the efficiency of UAS management.

Let's supplement the mathematical model (10) with a system of equations which is represented by dependencies of the form

$$\begin{gathered} X_{C1} = A_{11}X_{C1} + G_1u_1; \\ X_{C2} = A_{22}X_{C2} + G_2u_2. \end{gathered} \tag{11}$$

It consists of isolated equations of motion of an individual UAS in a group.

To compile a complete mathematical model of the movement of aerial platforms of the UAS using (10) and (11), let's transform the expressions that describe the structure of matrix elements included in these equations from the parameters of the movement of these unmanned aerial vehicles.

For example, let's consider the most typical variants of flight situations of the use of a group of UAVs as aerial platforms for placing special mobile means of electronic communications, namely: the mode of longitudinal movement and simultaneous turning in the horizontal plane.

In longitudinal motion, the vectors of their state, which correspond to the equations of autonomous motion, are represented by matrices of the form

$$X_1 = \left[\bar{n}_1 \ V_1 \ \theta_1 \ \omega_{z1} \ \nu_1\right]^T, \tag{12}$$

$$X_1 = \left[\bar{n}_2 \; V_2 \; \theta_2 \; \omega_{z2} \; \nu_2\right]^T . \tag{13}$$

The UAVs control vectors in the group will be presented in the form

$$u_1 = \left[\delta_{1\text{дв}}\varphi_1\right], \tag{14}$$

$$u_2 = \left[\delta_{2\text{дв}}\varphi_2\right]. \tag{15}$$

In expressions (12), (13), (14) and (15) symbols $\bar{n}_1$ and $\bar{n}_2$ marked increases in the relative frequency of rotation of the rotors of power plants (for the implementation of the UAS movement), equivalent to the increase in their thrust; $\delta_{1\text{дв}}$, $\delta_{2\text{дв}}$ – deviation from the balancing provisions of the management bodies of these installations; φ_1, φ_2 – deviation from the balancing provisions of the UAS stabilizers. The rest of the designations in model (12) and (13) correspond to those adopted in the aerodynamics of aircraft [15], [16].

Identical in matrix structure A_{11} and A_{22} whilst G_1 and G_{21} included in the mathematical model (10) we will present it in the form

$$A_{11} = \begin{vmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 & a_{25} \\ a_{31} & a_{32} & a_{33} & 0 & a_{35} \\ 0 & a_{42} & a_{43} & a_{44} & a_{45} \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix}, \tag{16}$$

$$G_1 = \begin{vmatrix} g_{11} & 0 \\ 0 & g_{22} \\ 0 & g_{32} \\ 0 & g_{42} \\ 0 & 0 \end{vmatrix}. \tag{17}$$

The elements of matrices (16) and (17) are determined by numerically differentiating the complete nonlinear equations of the air movement of unmanned aerial platforms by the elements of its state vector under their flight parameters. It is known that these parameters adequately correspond to variations in the current values of the AC balancing process.

We focus special attention on the fact that intense changes in wind speed u_x are taken into account in models (11)–(17) in the second column of the matrices A_{11} і A_{22}.

Let's introduce vectors to take into account these influences, marking them χ_{v1}, χ_{v2}. At the same time the influence of the vertical component of the wind speed is described in the mathematical model (15) by the fifth column.

The possibility of describing this action is based on the fact that the equations that describe the movement of the UAS are compiled in the speed coordinate system of the movement of the aircraft [15], [16].

Taking this into account the angle of attack of the AC will be determined from

$$\alpha = \upsilon - \theta + \alpha_{в},$$

where $\alpha_{в} = u_y V^{-1}$.

Mathematical models (10) and (11) describing the combined movement of aerial platforms, taking into account the possibility of implementing the processes of managing their state as well as signals u_x which are adequate to variations in the horizontal component of wind flows we will present in the form

$$\begin{vmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{Y}_{om} \end{vmatrix} = \begin{vmatrix} D_{11} & 0 & 0 \\ -G_2K_{21} & D_{22} & -G_2K_{23} \\ A_{31} & A_{32} & 0 \end{vmatrix} \times \begin{vmatrix} X_1 \\ X_2 \\ Y_{om} \end{vmatrix} + \begin{vmatrix} \chi_{V1} & \chi_{\nu 1} \\ \chi_{V2} & \chi_{\nu 2} \\ 0 & 0 \end{vmatrix} \times \begin{vmatrix} u_x \\ \dfrac{u_y}{V} \end{vmatrix}, \tag{18}$$

where $D_{11} = A_{11} - G_{11}K_{11}$, $D_{22} = A_{22} - G_{22}K_{22}$ – dimensional matrices $n \times n$ models that describe the autonomous controlled movement of the aerial platform.

It is appropriate to present the model (18) in the form

$$\dot{Z} = DZ + \chi_V u_x + \chi_\nu \frac{1}{V} u_y, \tag{19}$$

where $Z = \left[X_1^T \ X_2^T \ Y_{om}^T \right]^T$ – dimension vector $2n+\mu$ state of the closed air platform control system;

$\chi_V = \left[\chi_{V1}^T \ \chi_{V2}^T \ 0 \right]^T$ and $\chi_\nu = \left[\chi_{\nu 1}^T \ \chi_{\nu 2}^T \ 0 \right]^T$ – vectors of control coefficients for unmanned aerial platforms taking into account the horizontal and vertical components of wind speed u_x and u_y;

D – matrix of coefficients of the closed air platform control system.

In order to take into account in the UAS control model the influence of a random signal on the flight, which is adequate to the variations of wind disturbances, let's transform (18) and (19) into the first extended model of the form

$$\begin{vmatrix} \dot{Z} \\ \hline u_x \end{vmatrix} = \begin{vmatrix} D & \chi_V & Z \\ 0 & -VL^{-1} & u_x \end{vmatrix} + \begin{vmatrix} 0 \\ g_\Phi \end{vmatrix} |\xi|, \tag{20}$$

where $g_\Phi = \sigma_u \sqrt{2VL^{-1}}$ – coefficient of effectiveness of the influence of a “white noise” type signal.

We will evaluate the results of the action of a random wind disturbance signal taking into account (18) and (19) on the basis of the second extended model, namely:

$$\begin{vmatrix} \dot{Z} \\ \dot{Y}_1 \\ \dot{Y}_2 \end{vmatrix} = \begin{vmatrix} D & 0 & \chi_\nu V^{-1} \\ 0 & 0 & -V^2L^2 \\ 0 & 1 & -2VL^{-1} \end{vmatrix} \begin{vmatrix} Z \\ Y_1 \\ Y_2 \end{vmatrix} + \begin{vmatrix} 0 \\ g_\Phi \\ g_\Phi \end{vmatrix} |\xi|, \tag{21}$$

where $g_\Phi = \left[\sigma_u \left(VL^{-1} \right)^{\frac{3}{2}} \sigma_u \left(3VL^{-1} \right) \right]^T$ – vector of coefficients characterizing the effectiveness of the influence of a “normalized white noise” type signal.

For the convenience of simplifying analytical studies, let's present equations (20) and (21) in the form

$$\dot{Z}_n = D_n Z_n + g_n \xi. \tag{22}$$

When calculating the values I_{ij} included in expression (3) it is suggested to use the following approaches.

The first of them is that in equation (22) the action of the signal $\xi = \delta(t)$ is replaced by a non-zero initial condition $Z_n(t_0) = g_n$ and grades are determined $I_{ij} = \int_0^\infty Z_{ni}^2 \mathrm{d}t$ along the trajectory of free movement of the system (21).

To calculate the value I_{ij} matrix is given B_i with a single non-zero element the location of which corresponds to the location of the coordinates Z_{ni} in the vector Z_n.

After that the matrix equation is solved

$$P_1 D_n + D_n^T P_i = -B_i . \tag{23}$$

Then the value of the estimate I_{ij} is determined from the dependence

$$I_{ij} = Z_n^T\left(t_0\right) P_1 Z_n\left(t_0\right). \tag{24}$$

In the general case equation (22) must be solved $2n+\mu$. At the same time at each step of the solution, new values of matrix elements are set B_i.

The second (simplified) approach to solving this problem, which consists in solving the following equation instead of equation (22)

$$\overline{P} D_n^T + D_n \overline{P} = -Z_n\left(t_0\right) Z_n^T\left(t_0\right). \tag{25}$$

Then the score we are looking for is determined from the expression

$$I_{ij} = B_i \otimes \overline{P} . \tag{26}$$

Let's consider the fairness of such an approach. We substitute the expression to define the matrix B_i with (23) in (24) and we get

$$I_{ij} = -\left(P_1 D_n + D_n^T P_i\right) \otimes \overline{P} . \tag{27}$$

After the appropriate transformation (27) we obtain the following equation

$$I_{ij} = -\left(\overline{P} D_n^T + D_n \overline{P}\right) \otimes P_i = Z_n\left(t_0\right) Z_n^T\left(t_0\right). \tag{28}$$

The conducted analytical studies confirm that to determine the elements of the matrix $\overline{P}$ it is enough to solve equation (27) once. In this matrix the first $2n$ its diagonal elements are equal in magnitude I_{ij}, $\left(j = 1, 2, ..., 2n\right)$. At the same time, the proposed and considered approach allows to algorithmically take into account in situational synergistic systems of automatic control of the combined movement of unmanned aerial platforms the influence of such incidents of danger as variations in the turbulence of atmospheric flows.

Conclusions. Thus, the conducted analytical theoretical research on the features of the combined (group) use of UAS under the influence of atmospheric variations allows us to draw the following conclusions. Thus, a necessary condition for improving the safety of group piloting of aircraft is to take into account variations in the speed and direction of wind flows (with the possibility of their adaptive compensation) in the algorithms of the functioning of the situational synergistic automated control system for the group application of UAS. To fulfill this requirement, nonlinear mathematical models of the flight of a group of unmanned aircraft are proposed.

Based on these models the possibility of compensating wind flow variations is taken into account when synthesizing the laws of maneuvering control of the UAS. This makes it possible to form a priori the requirements for the structure of the algorithmic and software of automated control systems for their group application to specify the technical tasks for carrying out research and development works on the creation of situational control systems to form potential opportunities for the use of nonlinear models for the study of complex processes of group application of UAS and organization of management of this application.

According to the authors of the article it is promising to further use the obtained results to justify the optimal functionality of the group's devices the requirements for the design characteristics of the flight information sensors of the UAS from the point of view of increasing not only the safety of their flights in group formations but also a significant increase in the efficiency of performing a wide range of possible tasks the purpose of such air objects and especially for the implementation of a mobile air network of special electronic communications.

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СИНТЕЗ МОДЕЛІ УПРАВЛІННЯ СКЛАДНИМИ ДИНАМІЧНИМИ ОБ’ЄКТАМИ З УРАХУВАННЯМ ПОДІЙ ЇХ БЕЗПЕКИ

Стрімкий розвиток складних, розосереджених, нелінійних технічних структур – безопараторних (роботизованих) засобів нагально вимагає створення оптимального алгоритмічного забезпечення автоматичної системи ситуаційного керування такими динамічними об’єктами з урахуванням можливості підвищення безпеки їх функціонування. Це стане запорукою, а як наслідок, значного підвищення ефективності та якості виконання цими технічними структурами поставлених завдань. Для практичної реалізації поставленого завдання доцільно комплексно розглянути нелінійну модель процесів зміни стану складного динамічного об’єкта. Доцільно враховувати можливість швидкої автоматичної компенсації небезпечних інцидентів. Така модель стане основою для синтезу нелінійних синергетичних ситуаційних закономірностей управління цими структурами. Відмінністю запропонованого підходу є врахування впливу інтенсивних варіацій набігаючих потоків на закони керування станом нелінійних динамічних об’єктів. Акцент зроблено на перспективних напрямах досліджень, а саме: застосування отриманих результатів для обґрунтування вимог до проектних характеристик систем керування та їх алгоритмічного забезпечення з точки зору не лише підвищення безпеки їх функціонування, а й забезпечення заданих показників ефективність виконання широкого кола можливих завдань. Одним із таких завдань є забезпечення відомчого зв’язку (для збору, обробки, зберігання, захисту інформації та її оперативної передачі) у разі використання динамічних об’єктів як мобільних літальних платформ (безпілотних авіаційних комплексів) для розміщення спеціальних пристрої електронного зв'язку.

Враховуючи особливу специфіку вимог щодо забезпечення відомчого зв’язку цими засобами зв’язку, розглядається можливість розміщення радіоелектронних засобів його реалізації на повітряних платформах. В якості таких платформ доцільно використовувати сучасні безпілотні літальні апарати з ефективними бортовими комп’ютерами автоматичного керування, програмне забезпечення яких враховує здатність опрацьовувати широкий спектр інцидентів, що впливають на безпеку їх функціонування під час виконання завдань за

призначенням. Тому зупинимося на особливостях комбінованого використання безпілотних літальних апаратів (БПЛА) у складі груп. Такий підхід дозволить реалізувати стабільність та безперебійність функціонування мобільної відомчої мережі зв’язку у разі розміщення та “розосередження” на борту кожного літака групи – БПЛА спеціальних радіоелектронних засобів. Тому для організації спеціального зв’язку доцільно орієнтуватися на специфіку застосування БПЛА та особливості управління цими засобами з урахуванням реалізації можливості компенсації наслідків небезпечних подій.

Ключові слова: модель керування, ситуаційне керування, аероплатформа, нелінійна оптимізація, компромісна схема, спеціальні електронні комунікації, безоператорські повітряні системи, інцидент.

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