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DETERMINATION OF UNCERTAINTY IN THE FLIGHT MOTION OF AN UNMANNED AERIAL VEHICLE BY MEANS OF REGULATOR SYNTHESIS

РЕТТЕГІШ СИНТЕЗІНІҢ КӨМЕГІМЕН, ҰШҚЫШСЫЗ ҰШУ АППАРАТЫНЫҢ ҰШУ ҚОЗҒАЛЫСЫНДАҒЫ БЕЛГІСІЗДІГІН АНЫҚТАУ

ОПРЕДЕЛЕНИЕ НЕОПРЕДЕЛЕННОСТИ В ЛЕТНОМ ДВИЖЕНИИ БЕСПИЛОТНОГО ЛЕТАТЕЛЬНОГО АППАРАТА С ПОМОЩЬЮ РЕГУЛЯТОРНОГО СИНТЕЗА

Abstract. This article highlights the fact that the development of unmanned aerial vehicles (UAVs) is a dynamically developing direction, which has recently been of particular interest to UAVs, as well as a number of their features and application areas. The main direction in the development of UAVs is to increase the autonomy of flights, which in turn increases the reliability of the device, provides ease of operation without requiring a high level of qualification of the operator, as well as reduces the overall cost of completing the task. We show the control system of an unmanned aerial vehicle, the impact of obstacles in the flight of an unmanned aerial vehicle and the presence of difficulties arising in the landing conditions.

Keywords: unmanned aerial vehicle, unmanned aerial vehicle control system, unmanned aerial vehicle movement model, system of equations.

Аңдатпа. Бұл мақалада ұшқышсыз ұшу аппараттарын (ҰҰА) әзірлеу қарқынды дамып келе жатқан бағыт болып табылатыны, соңғы уақытта ҰҰА деген ерекше қызығушылық пен олардың бірқатар ерекшеліктері мен қолдану салалары атап айтылады. ҰҰА-н әзірлеудегі негізгі бағыт ұшу дербестігін арттыру болып табылады, бұл өз кезегінде аппараттың сенімділігін арттырады, оператордың жоғары біліктілік деңгейін талап етпей, пайдаланудың қарапайымдылығын қамтамасыз етеді, сондай-ақ тапсырманы орындауға жұмсалатын жалпы шығындарды азайтады. Ұшқышсыз ұшу аппаратының басқару жүйесін, ұшқышсыздардың ұшу барысындағы кедергілердің әсері мен қону жағдайында туындайтын қиындықтардың болуын көрсетеміз.

Түйін сөздер: ұшқышсыз ұшу аппараты, ұшқышсыздарды басқару жүйесі, ұшқышсыз ұшу аппаратының қозғалысының моделі, теңдеулер жүйесі.

Аннотация. В данной статье отмечается, что разработка беспилотных летательных аппаратов (БЛА) является динамично развивающимся направлением, в последнее время особый интерес представляют БЛА и ряд их особенностей и областей применения. Основным направлением в разработке БЛА является повышение самостоятельности полетов, что в свою очередь повышает надежность аппарата, обеспечивает простоту эксплуатации, не требуя высокого уровня квалификации оператора, а также снижает общие затраты на выполнение задания. Покажем систему управления беспилотным летательным аппаратом, влияние препятствий на полете беспилотников и наличие трудностей, возникающих в условиях посадки.

Ключевые слова: беспилотный летательный аппарат, система управления беспилотниками, модель движения беспилотного летательного аппарата, система уравнений.

Introduction. As science and technology advance day by day, the conquest of new milestones in human history is revived. Today, science has reached many heights, and drones are proof of that.

Let's briefly touch on the variety of drone types: there are different types of drones by design. UAVs are classified according to interrelated parameters such as weight: flight time, range and flight height.

We know that UAVs are widely used in military defense, surveying and civilian programs. It also contributes to scientific research, such as the use of drones in environmental research. Due to the rapid development of drone technology that has become available over the past decade, they are in high demand in wildlife research, especially aerial photography. Scientists have determined the effectiveness of drones compared to planes for marine fauna studies taking aerial photographs of the sea [1]. Scientists from Calvin University studied the impact of drones on the bird world and they showed that drones do not cause the birds stress, making drones a better option for studying them. [2].

Materials and methods. In the case of information uncertainty, the synthesis of software control of an unmanned aerial vehicle is carried out. On the basis of the mathematical model of the UAV guidance described in the discrete-variable coordinate system the method of analytical synthesis of the UAV control law according to the given quality criterion at guidance along the trajectory passing through the given points of space which is characterized by the solution of the optimization problem is offered which allows to form the optimal control law in changing conditions of the UAV application. On the basis of a fuzzy regulator formulated methodology for the formation of the control signal of the UAV autopilot, which includes algorithms for forming the optimal trajectory of the UAV, phasing of random input signals, calculation of control parameters and obtaining the control signal. signals of the UAV autopilot, which allows it to provide the necessary quality control in terms of information uncertainty [3].

Of particular importance is the development of domestic unmanned aerial vehicle (UAV) control systems, which belong to the class of structures that are subject to the influence of random external forces, measurement noise, and other perturbations. UAV manufacturers, due to changes under the influence of unknown parameters in a wide range, the synthesis of high-precision systems requires the search for solutions from the class of modern control systems.

The development of modern control theory began with works in the field of adaptive, interval (interval-determined), uncertain and stochastic (uncertain and stochastic systems) systems.

The means to improve the effectiveness of UAV control in the face of obstacles to the UAV control system are described. It is duplicated by local radionavigation systems based on false satellites to improve the immunity from interference of satellite radionavigation systems. In order to improve the accuracy of positioning of aircraft, the possibility of using a combined method of spatiotemporal and spatial-frequency processing of navigation signals is defined [4].

If we synthesize UAV motion under uncertainty. For different levels of research uncertainty, the mathematical model of the UAV is provided with lower control accuracy compared to the proportional regulator with constant coefficients obtained for the model.

Results and Discussion. In estimating the vector state, we consider the coefficients of the equations of linear motion of the aircraft simultaneously with the vertical-horizontal flight algorithm.

Let us write the longitudinal model taking into account the wind acceleration, motions in the state space:

$$\dot{X} = AX + BU + \xi \qquad (1)$$

Here is the vector state;

$X = [\Delta V\ \Delta\theta\ \Delta\vartheta\ \Delta\omega_z\ \ \Delta H]^{\mathrm{T}}$ - velocity stabilization errors, angles

$\Delta V\ \Delta\theta\ \Delta\vartheta\ \Delta\omega_z,\ \Delta H$ - trajectory and pitch angles, angular velocity, and pitch altitude;

U- control of the helicopter

$\xi = [\xi_1\ \xi_2\ \ 0\ \xi_4\ 0]^T$ - vector of random wind gusts

A- matrix state; B- control matrix

The elements of matrix A and B depend on airspeed and inertial-mass characteristics.

We derive the estimation parameters A and B from the state vector and its derivative [5]. From this we obtain 2 measurement equations:

$$Y_1 = AX + BU + \xi + \xi_{y1},$$
$$Y_2 = X + \xi_{y2}$$

Here Y_1 and Y_2 are the measurement vectors of the components of the state vector and its derivative; the component of the measurement vector is the noise vector $\xi_{y2} = [\xi_V\ \ \xi_\theta\ \ \xi_\vartheta\ \xi_{\omega z}\ \xi_H]^T$ the state vector is the product of the noise vector of the state measurement component $\xi_{y1} = [\xi_{\dot V}\ \xi_{\dot\theta}\ \xi_{\dot\vartheta}\ \xi_{\dot z}\ \xi_{\dot H}]^{\mathrm{T}}$

In the tracking device algorithm, the vector U* is used not only as a part of the measurement vector, but also as a control vector. If separate sets of sensors are used, then for X and their noises can be considered independent. As a result, the control process looks as follows:

$$\dot{X} = U^* + \xi$$
$$\dot{A} = 0$$
$$\dot{B} = 0 \qquad (2)$$

or if we introduce an extended state vector

$$X^* = [X^T\ a^T]^T$$

where the equations-columns of the vector-coefficients written in the order a-(1), i.e., the rows of matrices A and B,

$$X^* = [X^T\ a^T]^T \qquad (3)$$

In the control process equation (3), the extended input control vector $U^{**} = [U^{*T}\ \ 0]^T$and the extended deviation vector $\xi^* = [\xi^T\ \ 0]^T$

Measurement equation:

$$Y = \left[\frac{Y_1}{Y_2}\right] = \left[\frac{AX+BU}{X}\right] + \left[\frac{\xi+\xi_{y1}}{\xi_{y2}}\right] \qquad (4)$$

Or $Y = F + \xi_y$

Here $F = \left[\frac{AX+BU}{X}\right],\ \xi_y = \left[\frac{\xi+\xi_{y1}}{\xi_{y2}}\right]$

The nonlinear Kalman filter algorithm can now be used for the control process (3) and control conditions (4) [5]:

$$\dot{\hat{X}} = U^{**} + P\left(\frac{\partial F}{\partial \hat{X}}\right)^T\ S_y^{-1}(Y - F(\hat{X}, U)) \qquad (5)$$

• equation of the control device;

$$\dot{P} + P\left(\frac{\partial F}{\partial X^*}\right)^T S_y^{-1}\frac{\partial F}{\partial X^*}P = S_{x^*} \qquad (6)$$

• the equation of the correlation error matrix P.

Estimation of the $\hat{X}$ extended state vector in the algorithm (5), (6).

S_y is the matrix of measurement noise intensity ξ_y;

S_{x^*} - intensity matrix of random perturbations ξ^*;

$$\frac{\partial F}{\partial X^*} = \begin{bmatrix} A & \frac{\partial}{\partial a}(AX + BU) \\ I & 0 \end{bmatrix}$$

I-unit matrix.

For the model of longitudinal motion of the UAV described by system (1), when using only the altitude rudder as the control system

$$\frac{\partial}{\partial a}(AX + BU) =$$

$$= \begin{bmatrix} \Delta V & \Delta\theta & \Delta\vartheta & \Delta\delta_в & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \Delta V & \Delta\theta & \Delta\vartheta & \Delta\delta_в & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \Delta V & \Delta\theta & \Delta\vartheta & \Delta\omega_z & \Delta\delta_в & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \Delta\theta \end{bmatrix}$$

$\frac{\partial F}{\partial X}$ if we take into account linear independence of matrix columns.

Algorithm of joint evaluation and identification of equations (5) and (6).

To verify the performance of the algorithm (5), (6), mathematical modeling was conducted using the Matplotlip Python Plotting program.

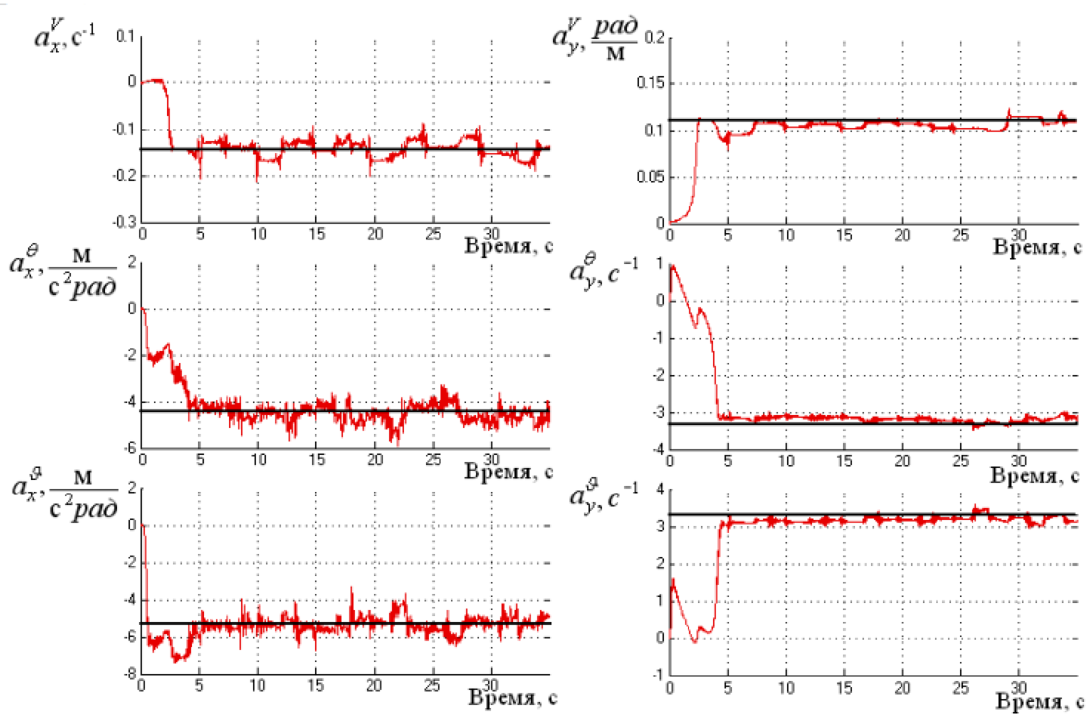

Figure 1. Coefficients of the first and second rows of the UAV longitudinal motion state matrix.

At the same time, the estimation of the motion parameters and the determination of the parameters of the light UAV model were performed simultaneously. The object under study turned out to be a completely nonlinear system of equations of motion. The flight of the aircraft was simulated taking into account the random noise of the sensors.

Synthesis of a controller. The control law can be obtained by synthesizing optimal controllers based on analytical theory [2, 4, 5]. For a linear object (1) is optimal in terms of minimum functionality.

$$I = \int_0^\infty X^T Q X dt + \int_0^\infty U^T R U dt \quad (7)$$

Manager $U = -R^{-1} B^T S X$

The solution of the algebraic S-Riccati equation of this

$$\dot{S} + S\hat{A} + \hat{A}^T S - SBR^{-1}B^T S = -Q \quad (8)$$

In the last expression $\hat{A}$-algorithm (5), (6) is evaluated using the state matrix; Q, R are matrices of positively determined coefficients defining the ratio of control accuracy requirements and the amount of control of individual state parameters.

Simulation of the synthesized adaptive regulator was performed under various conditions of uncertainty, and its results (Fig. 2) indicate significant limitations of using such an approach.

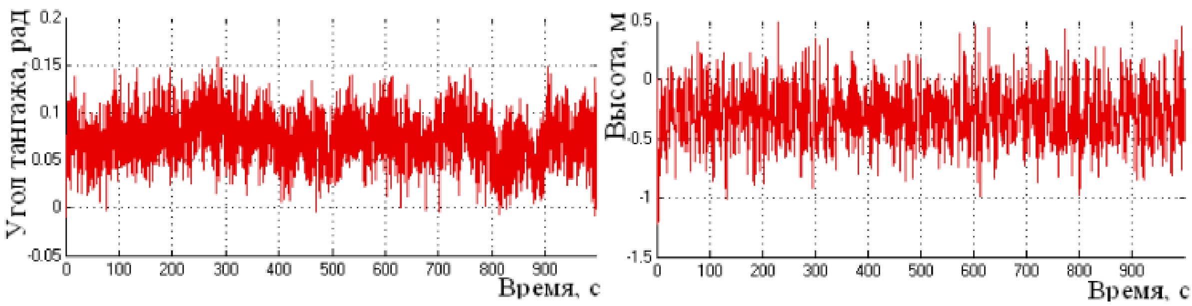

Figure 2. Adaptive errors in UAV control based on the nonlinear controller (5), (6).

Fig. 1 and Fig. 2 show the motion parameters of the UAV, which were in error under a wind speed of 20 km/h and a moment of inertia of 20%. In this case, if the airspeed is known to an accuracy of 3 km per hour. In the absence of airspeed information, the control algorithm is unprofitable because of the long transitions of the identification algorithm

Conclusion. Determining the effects of the natural environment on drones in different situations. Observing the motion of UAVs under conditions of uncertainty. Estimating the vector of state, the coefficients of the equations of linear motion of the aircraft, while considering the algorithm of vertical-horizontal flight. We write a longitudinal model, taking into account the wind excitation, situation, and get the drone motion in space.

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