УДК 629.782

PRINCIPLES OF TERMINATION CONTROL OF UNMANNED AERIAL VEHICLES FLIGHT PATH

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Розглянуто реалізацію управління спуском з траєкторії польоту в заданий район простору планерувального літального аппарата, запропоновано принцип його неавтономного управління. Показано спосіб управління, визначені мета, задачі синтезу і командна програма управління.

For realization of control of gliding aircraft descend from the flight path to the defined area of the space let's propose its non autonomous control principle. The method of control is shown, a goal, tasks and command control program are defined.

The overview of the last international aviation shows conclusively indicate that unmanned aerial vehicles (UAV) every year take more and more important role in the civil and military sphere. It is explained by the fact that many tasks assigned to manned aviation may be successfully done by UAV. Thus, according to the prognosis of Forecast International, USA during following 10 years not less than 30 % of manned special-purpose aircrafts have to be replaced by UAV. The growth trend of the segment of unmanned aviation, including domestic development, is observed broadly in Russia, Western Europe, and also in countries of Middle East, China, India. Programs of modernization and design of new UAVs remain first-priority and their financing is not reduced, but continuously increases [1].

Active development of UAVs is caused by number of their important advantages. First of all, it's absence of crew, comparatively small cost of UAVs, small operating costs, ability to carry out in-flight maneuvers with acceleration exceeding possible for human, greater duration and distance of a flight because of absence of crew tiredness factor and other advantages comparatively to manned aviation.

During the next decades an air and informational spaces will be mastered by UAVs with unprecedented temps, due to presented and developed new technologies of processing and transfer of information with high rate and accuracy for large distances.

Experts mark out main existing tasks for UAVs (classification by destination):

- by overall-weight characteristics — diminutive, minute, small, medium, large;
- by reusability — reusable and disposable;
- by aerodynamical scheme — airplane and helicopter like;
- by takeoff way — eject type, as a variant — hurled by hand, with takeoff from runway (airfield);
- by landing method — by airplane way (with a landing run), descended by parachute (paraglider), caught up with different implements (nets etc.);
- by the method of control — controlled by operator by communication lines (channels), with automatic control (by program), with combined control system;
- by launcher bases location — land-based, aerial, sea-based;
- by use altitudes — minute altitude, small altitude, middle altitude, high altitude;
- by action radius — minute range, small range, middle range, high range;
- by flight endurance — small duration, medium duration and high duration.

Guidance of UAVs to the specified point in space by termination principle on whole active part of trajectory may provide:

- more complete use of the energy resources in a flight;
- improvement of accuracy of motion by the trajectory;
- broadenening of quick redirection abilities;
- adaptability to new conditions of implementation and possible improvement of UAV;

Complex of UAV control, providing operation of termination control system, considered in this research paper, may be presented as a self-contained arrangement [2], consisting of: UAV with airborne equipment — receiver of satellite navigation system and range radar, ground-based equipment — a radio beacon/repeater, a radio direction-finder station, a communication line «air-surface-air».

Features of unmanned aviation. Let's point out a number of essential aspects, which characterize special features of unmanned aviation. Their essence may be reduced to following.

Firstly, technologies of design of having prospects unmanned aircrafts do not require long development and installation of expensive and reliable life support system for a pilot on the board of an aircraft. It considerably lowers as temporal, so price cost of design of unmanned items.

Secondly, «operational» costs of organization and realization of the processes of control of unmanned aerial vehicle are also considerably decreased. It's explained in a following way. Group formations of unmanned aerial vehicles are controlled from ground or aerial control stations. And one operator (pilot) can control several aircrafts simultaneously.

Thirdly, cost of these operators training is sharply decreased. It is just necessary to have simulators in training centers, in which imitational models of supposed functional actions are realized.

Fourthly, in prevailing majority all unmanned aerial vehicles do not need construction of expensive airports. In fact for their majority airports are not necessary at all. They are necessary, as a rule, for unmanned versions of aircrafts, in compliance with requirements of which they are planned to be adopted. For example, space vehicle «Buran» («Буран», USSR), which have flown only one time, also may be considered as unmanned. On the trajectory of cosmic flight it has been controlled from the ground control stations. At the landing stage the control was carried out from a pilot aircrafts which tracked it.

Fifthly, unmanned aerial vehicles are more manoeuvring than piloted ones. They can to perform aerobatics, g forces acting at which cannot be borne even by the most high-qualified pilots, who have gone through appropriate training. So, particular modern airplanes — fighters by their constructional abilities can bear g forces up to 20 units (20g). A biological limit of possibilities of bearing of g forces action bearing by pilot is about 8…9 units (8…9g). It is clear, that potential performance capabilities of manned aircraft are considerably restricted for this reason, especially when realizing maneuver for going off, for example, from missile attack.

At the same time, for a complex understanding of the peculiarities and specificity of design and application of unmanned aerial vehicles it is necessary to consider that facts, which, as a rule, in prevailing majority, are absent in an analogous situations with manned aircrafts. Let’s accentuate more attention at those ones. Firstly, it is supposed functioning of at least two (main) communication channels, when using remote manned vehicles for organization of feedforward and feedback connection with the control stations. Along with it, the channels of video signals, transmitted from the unmanned aerial vehicles, must to have necessary throughput.

Secondly, for effective application of unmanned aerial vehicles should be created, and productively work, a highly reliable, functionally steady, situational control system. It is known that an expenses for modern UAV’s control system developing at cost and time are almost commensurable with expenses for the body of device development. But these expenses are justified by necessity of achievement of needed parameters of efficiency of its application.

Thirdly, application of formations of unmanned aerial vehicles assumes for decision-making by the person-operator which is functionally integrated into this big organizational system, presence of artificial intellect control systems. For this purpose it is supposed to create a new technology of information gathering, storing, generalisation and the system analysis of the information received by the person through its organs of perception of an external world. On the basis of it typical situational models of behavior of the person-operator of difficult technical systems in cases of making of control decisions. It is supposed to take such models for a basis at creation of algorithm of control systems of unmanned aerial vehicles (UAVs).After realization in the programs of operation of the on-board and ground automatic and automated systems it will allow providing a high efficiency control in all the possible situations for organization of application of the unmanned aerial vehicles.

In such way, to take into account these peculiarities in a process of design of unmanned aerial vehicles, we can point out that for synthesis of control systems for unmanned aerial vehicles it is reasonable to use new information systems technologies.

When organizing technologies of design of communication channels between unmanned aerial vehicles, and also with control stations it is reasonable to us, for example, wide-range connection to provide protection. And also for researching of perspective techniques of creation, and especially principles of application of UAV’s, it is expedient to use well proved imitating modelling of functioning of difficult technical systems.

So, taking into an account at creation of domestic perspective UAVs of noted features and aspects will allow reaching, in particular, desirable results.

Problem definition. Controlled descent (flight) to the specified area of earth surface (circumterrestrial space) of unmanned gliding aerial vehicle (UAV) with a large lift-drag ratio ($K > 1$) is considered. Such vehicles by means of aerodynamic maneuver in the atmosphere can significantly change their descent (flight) trajectory.

The problem of the control is guidance of the vehicle to the point with specified geographical coordinates in presence of random disturbances acting on the UAV during the descent (flight). That’s why the most reasonable is termination control of UAV, based on prediction of coordinates of a point of landing (flight).

Because of this reason on sizeable part of the starting trajectory the control of UAV is autonomous. Prediction is realized by integration of system of differential equations of motion with initial conditions, determined by autonomous navigation system. Accumulated, as a result of control synthesis during landing (flight), navigation errors lead to appearance of not excluded by control system dispersion of landing (flight) points.

Nowadays designed methods of forming of non-autonomous control are based on principle of tracking of a priori given nominal programs of relative motion of aircraft and destination point parameters change [3].Concerning the task of landing these methods, particularly the method of proportional approach, even with nominal conditions of motion, doesn’t provide necessary accuracy of guiding because of necessary overload exceeding of G tolerance in neighborhood landing spot and breach of convergence of control correction processes [4].

To increase accuracy of UAV guidance at the final part of landing (flight) non-autonomous control is reasonable, using information about relative position and motion of aircraft and destination point. At this paper the method of synthesis of non-autonomous termination dual-channel control of UAV $U = f(\gamma_a, K)$ by dynamic roll angle $\gamma_a(t)$ and aerodynamic characteristic $\mathrm{K}(t)$ under guidance to omnidirectional beacon situated in defined point of space [5—8].

The method of non-autonomous multistep adaptive termination control of flying vehicle . To provide guidance of the vehicle with sufficiently high accuracy method of non-autonomous multistep adaptive termination control in a zone of close-range guidance, starting at the moment of grabbing of beacon signal by radio equipment of the vehicle.

At the moment of grabbing on a board of UAV inertial coordinate system $0x_i y_i z_i$ is formed, an origin of the system matches with center of inertia of the vehicle, axis $0y_i$ is directed by radius-vector $\vec{\mathbf{r}}$, and vertical plane $0x_i z_i$ is superposed with radio beacon at a landing point $C(\varphi_c, \lambda_c)$ with geographic latitude φ_c and longitude λ_c. In this system processing of data for control synthesis is carried out.

Direction vector sight line $\vec{\mathrm{D}}^0(t)$ and pointing direction distance to it $D(t)$ are external information. Internal information is a vector of current phase coordinates of the vehicle

$$\mathbf{x}^{\text{н}} = (V_{\text{к}}^{\text{н}}, \theta^{\text{н}}, \psi^{\text{н}}, h^{\text{н}}, \varphi_{\text{ц}}^{\text{н}}, \lambda^{\text{н}})$$

which is determined in autonomous regime by navigation system and includes earth speed $V_{\text{к}}^{\text{н}}$, slope angle of trajectory $\theta^{\text{н}}$, track angle $\varphi^{\text{н}}$, altitude $h^{\text{н}}$, geocentric altitude $\varphi_{\text{ц}}^{\text{н}}$ and latitude $\lambda^{\text{н}}$ (fig. 1).

The procedure of multistep control synthesis of close zone guidance. For realization of multistep synthesis the initial length of guidance $T_0 = t_{\text{к}0} - t_0$ from moment of beacon gripping t_0 to predicting moment $t_{\text{к}0}$ of reaching by vehicle the guidance sphere of radius $r_c = R_0 + h_{\text{к}}$ on the surface, which is located on a height $h_{\text{к}}$ above the surface of the Earth with rits radius R_0 the beacon is located, is divided on N_0 intervals

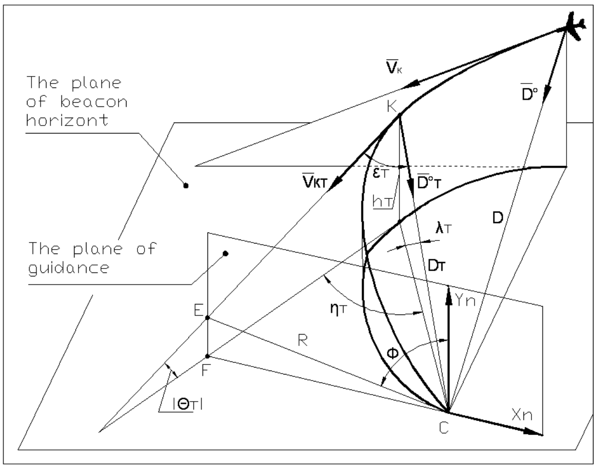

Fig. 1. Scheme of descent

$$\Delta T_\nu = t_\nu - t_{\nu-1},\ \nu = \overline{1, N_0},\ t_{N0} = t_{\hat{e}0},\ T_0 = \sum_{\nu=2}^{N_1+1} \Delta T_\nu .$$

In the end of the interval ΔT_1, analyzing the predicted time $t_{\text{к}j}$ of guidance sphere reaching, the descent duration $T_1 = t_{\text{к}1} - t_1$ is divided on N_1 intervals

$$\Delta T_\nu = t_\nu - t_{\nu-1},\ \nu = \overline{2, N_1 + 1},\ t_{N1} = t_{\text{к}1},\ T_1 = \sum_{\nu=1}^{N_0} \Delta T_\nu .$$

Thus for each current moment of correction t_j the rest predicted duration of descent $T_j = t_{\text{к}j} - t_j$ divided on N_j intervals

$$\Delta T_\nu = t_\nu - t_{\nu-1},\ \nu = \overline{j+1, N_j + j},\ t_{Nj} = t_{\text{к}j},$$

$$T_j = \sum_{\nu=j+1}^{N_j + j} \Delta T_\nu .$$

In the end of each interval the correction of control program is done and in the rest interval $t \in [t_j, t_{kj}]$ a descent is performed with help of command program

$$\mathrm{u}_{\text{ком}}^{(j)}(t \ge t_j) = (\gamma_{a\text{ком}}^{(j)}(t \ge t_j), \mathrm{K}^{(j)}(t \ge t_j)).$$

The aim of control on each step ΔT_j, $j = 1, 2, \ldots$ is forming of trajectory, going through the point of landing C in predicted moment of time of descent t_{kj} to the surface of the sphere. In case of two-parametric control deviation of predicted final position of the vehicle from the required one is recorded on plane of guidance by two coordinates — distance R and angle Φ (see fig.), which define the position cross point of a vector of velocity of the vehicle $\vec{\mathrm{V}}_{kt} = \vec{\mathrm{V}}_k(t_{kj})$ with this plane. The plane of guidance is perpendicular to both the plane of the horizon of a beacon and projection of a vector of velocity of the vehicle on this plane at the final moment of a descent. In the guidance plane an orthogonal system of coordinates $Cx_{\text{п}} y_{\text{п}} z_{\text{п}}$ is built, axes $Cy_{\text{п}}$ of which is directed by radius-vector of a point C.

The task of control synthesis is formed by the following way. For each discrete moment of time

ISSN 2075-0781. Наукоємні технології, 2009. № 2

t_j, $j = 1,2,\ldots$ is needed to determine the optimal command control

$$u_{ком}^{(j)}(t \ge t_j) = (\gamma_{аком}^{(j)}(t \ge t_j), K^{(j)}(t \ge t_j)).$$

For whole rest interval of descent $t \in [t_j, t_{kj}]$, minimizing a predicted length R at the final moment of time of descent on a destination sphere

$$u_{ком}^{(j)}(\gamma_{аком}^{(j)}, K_{ком}^{(j)}) = \arg\min_u R(y(t_{kj}), u).$$

Conclusions. In the result of multistep correction the command program of control is formed in a form of sequence of intermediate programs $u_{ком}(t \ge t_0) = (u_{ком}^{(0)}, u_{ком}^{(1)} u_{ком}^{(2)}, \ldots, u_{ком}^{(j)}, \ldots)$.

Here $u_{ком}^{(0)}(t \ge t_0) = (\gamma_a^{(0)}(t \ge t_0), K^{(0)}(t \ge t_0))$ is a command program, formed in the end of the zone of autonomous control.

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Стаття надійшла до редакції 04.03.09