MODELS OF CONFLICTS IN MOTION CONTROL SMALL UAV

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Abstract: The paper deals with the formalization of conflict patterns that arise in the management of the movement of small UAVs. The stages describe the conflicts, their classification. Model description of the conflict involves two tasks: the formation of the desired type of UAV flight path and forming the vector control or self-propelling UAVs along such a trajectory. The proposed models of conflicts include the impact of the flight environment, the presence of the path of the UAV prohibited areas that arise when flying at low altitudes static, but on the entire range of performance of the flight task - dynamic objects. These conflicts system models can be used to find estimates of permissible boundaries of the vector values of UAV motion parameters in order to predict the probability of performing the flight task, allowing to make the appropriate adjustments in the theory of intelligent control of the UAV and a part used for its implementation of the airborne and ground systems.
Keywords: conflict, conflict model, small UAV, conflict-resistant systems, managed model aircraft movements, the flight task, the flight path, conflict situation, UAV control.

Introduction

The central problem in the development of the methodical device substantiation requirements for the systems of different purpose is the construction of adequate and accurate mathematical model of the object of research. The particular importance such models get during the design of complex conflict-resistant systems designed to operate in conditions of dynamic interaction (conflict) with poorly predictable behavior of the opposing (conflicting) sides. Such systems are complex dynamic object management system, in particular - small UAV.

The management issues conflict-resistant robotic systems, including UAVs, are engaged in both native and foreign scientists.

Thus, in (Pshihopov, 2013) the positional-trajectory management system with unstable regimes in solving obstacle avoidance task in an uncertain three-dimensional environment is investigated. Bypass obstacles is carried out by introducing an unstable regime in a neighborhood of obstacles. The structure of the position-trajectory control system with unstable regimes is presented.

. The results of numerical modeling of the mobile object management system in an environment with fixed obstacles with unstable regimes are given.

In (Beloglazov, 2014, Chowdhary, 2013, Kanatnikov, 2012, Pshikhopov, 2012) describes a mathematical model of the motion of the UAV with the presentation method for solving the problem of movement of the terminal using the time polynomials and an example of its use. Planning for UAVs maneuvers is based on one of the proposed heuristic algorithms. The simulation results show that the proposed scheduling algorithm generally copes well with the task.

In (Alejo, 2009, Hua, 2009, Leatherland, 2011, Manathara, 2011) the authors deals with the conflicts and clashes of robotic systems, mainly UAV. The decentralized autonomous decision-making approaches for avoiding collisions and other typical conflict of flight models are proposed.

Method

The initial stage of drawing up a model system of any conflict is to determine on the basis of the morphological representation system its basic characteristics Q_i (quality indicators), on the basis of which the phase variables are determined, forming a functional space of the functioning processes p_i. In the next stage the relationship between the levels of quality and processes in the system are set, as well as forming of the criterion efficiency E. The third phase establishes the relationship between the values of processes at certain times and their rate of change $\dot{p}_i$. It ends with the establishment of the system v definition model of governance u (with the opposing side) and self-government in the system and its influence on the rate of change processes.

As the resulting, such, the system model of conflicts is the basis for the formal description.

In order to formalize the conflict arising in the management of the robotic system is useful to consider the abstract conflict, as the interaction of multiple systems without any restrictions on the nature of the processes and systems resources (Moiseev, 2013).

General view of the equation for the *i*-th operation process:

$$\dot{p}_i(t) = f_i\left[t, \{p_k(t)\}, \{J_k(t)\}, u_i(t, \tau_{ui}, Z_i), \{v_j(t, \tau_{vj}, Z_j)\}\right], i, j, k = \overline{1, N}, i \neq j \qquad (1)$$

where:

N - The number of processes in the system;

$J_i(t)$ - A function of time delay;

$\tau_{ui(vj)}$ - Control delay (self-government);

Z_i - target the process function, $Z_i = Z_i\left(p_i(t), T_i\right)$.

In the specific case, the use of differential equations results in an exponential increase in the number of variables with increasing complexity of the problem. Typically, the conflict is challenging. The problem of aggregation of variables arises, but the task after drawing up a system of equations becomes unsolvable. (Kanatnikov, 2012).

The main issue of the first phase of system research of the conflict is the choice of the system of equations describing the system operation processes. The well-known works of Caste and Lange proposed the set of elements of a deterministic system, which in some way related.

The functional dependence of the mathematical model of the conflict $f_i(\cdot t)$ are formed on the set of variables of the functional space of the system $\{p_i\}$, taking into account departments u_i and municipalities v_i. Besides, office and government have physical limitations U_i and V_i. Also, the self-models are included in which known delays τ_i. Each variable function space (state variable) $\dot{p}_i(t\cdot)$ is described by the time variation with data functional dependences. The decision of the system of differential equations with retarded argument functions $J_i(t\cdot)$ (defined for follow-up on the initial function φ), is a system of functional relationships for the phase variables in the model. This completes the stage of formalizing the process.

The stage of description of operations and statement of the problem begins with the formulation of objectives of the operation and construction of model-based target function (s) Z_i. The final formulation of the optimization problem is carried out after the formalization of methods time-

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consuming T_i and w_i resource active with the relevant restrictions T_i' and W_i, as well as most of the criterion of efficiency E_i.

The third stage of purely mathematical - the solution of the optimization problem as finding the extremum of the objective function with the assessment of the efficiency by varying municipalities on the condition of optimal control on the opposite side - the participant of the conflict (Moiseev, 2013).

There we consider the conditions for the functioning of small UAVs in carrying out flight missions. UAV movement is seen in a rectangular geographic coordinate system (see fig. 1) and the information on the location of the UAV gets from navigation satellites (GPS), or using a mobile GSM communication system for an active navigation (A-GPS) (Chowdhary, 2013).

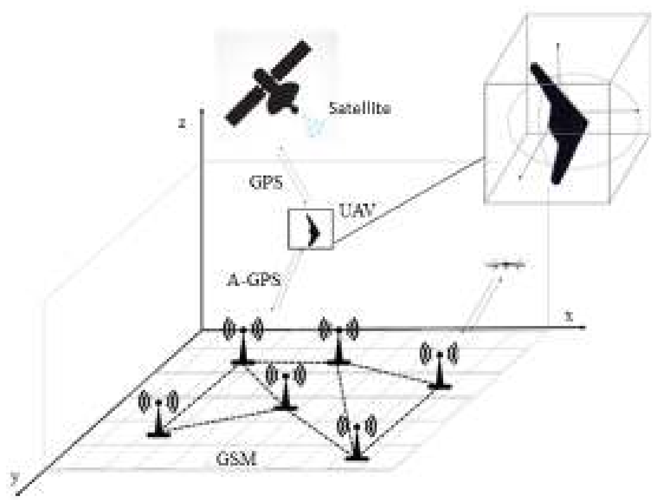

Figure 1. Determination of the current position of the UAV in flight

To describe the motion of the UAV in the space x, y, z the common managed model aircraft movements is used, which in vector form is written as:

$$\dot{x} = f(x,u,t), t \in [t_0, t_k]; x(t_0) = x_0 \quad (2)$$

where $x = (x_1, x_2, ..., x_n)$ - the state vector of the UAV, called the vector of phase coordinates; $u = (u_1, u_2, ..., u_m)$ - the control vector; $f = (f_1, f_2, ..., f_n)$ - vector-function of its arguments; $[t_0, t_k]$ - the time interval on which the flight of the UAV.

On the UAV control imposed constraints of the form:

$$u_{\min} \le u(t) \le u_{\max}, t \in [t_0, t_k] \quad (3)$$

To reduce the complexity of calculating the vector $u(t)$ are generally used simplified models motion of the center of mass of the UAV, as follows:

$$\begin{cases} \dot{V} = f_1(V,\theta,\psi,y,u); t \in [t_0,t_k]; \\ \dot{\theta} = f_2(V,\theta,\psi,y,u); \\ \dot{\psi} = f_3(V,\theta,\psi,y,u); \\ \dot{x} = V\cos\theta\cos\psi; \\ \dot{y} = V\sin\theta; \\ \dot{z} = V\cos\theta\sin\psi. \end{cases} \tag{4}$$

where $V = V(t)$ - the velocity of the UAV at a time $t \in [t_0,t_k]$; $\theta = \theta(t)$ and $\psi = \psi(t)$ - the angles of inclination and rotation of the UAV trajectory; $x = x(t)$, $y = y(t)$ and $z = z(t)$ - UAV geographical coordinates in the coordinate system. Thus, the phase vector coordinate UAV consists of a set (V,θ,ψ,x,y,z) (Beloglazov, 2014).

Software control of the UAV motion reduces to the determination of the vector control $u(t)$ using model (1) - (3) and the formation of self-vector $v(t)$ describing the laws of changing the position of the UAV controls while driving, which are calculated using a vector of values $u(t)$ of the phase coordinates $V(t),\theta(t),\psi(t),x(t),y(t),z(t)$, the torque and the design of UAV characteristics .

For the general case we represent the vector control of the UAV aircraft type in the form of:

$$u(t) = \big(P(t),\alpha(t),\beta(t),\gamma(t)\big), \tag{5}$$

where $P(t)$ - the power of the UAV engine thrust; $\alpha(t),\beta(t),\gamma(t)$ - angles of attack, slip and roll in the UAV $t \in [t_0,t_k]$.

UAV self-vector will be:

$$v(t) = \big(\delta_P(t),\delta_B(t),\delta_H(t),\delta_Э(t)\big), \tag{6}$$

where $\delta_P(t)$ - law changing the position of the governing body of the UAV power plant; $\delta_B(t),\delta_H(t),\delta_Э(t)$ - laws deviation elevators, ailerons and direction in the range $t \in [t_0,t_k]$ (Manathara, 2011).

In addressing the UAV control tasks on a time interval $t \in [t_0,t_k]$ you can identify the main stages (see fig. 2.)

1. The rise and set of a predetermined altitude for a time $[t_0,t_1]$ zone performing the flight task.
2. The horizontal flight in the area performing the flight task in the time interval $[t_1,t_2]$.
3. Implementation of the flight task in the time interval $[t_2,t_3]$.
4. The flight to landing zone in the time interval $[t_3,t_4]$.
5. Reducing and landing UAV in the time interval $[t_4,t_5]$ [3].

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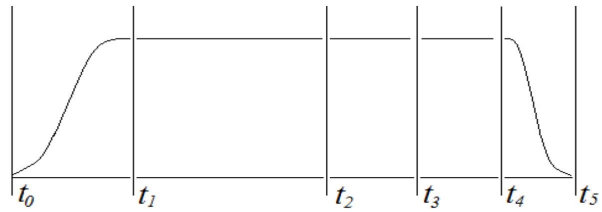

Figure 2. Stages of the UAV flight assignment

To build a model of conflict situations that may arise at each stage of the flight of the UAV is necessary to solve two problems: the formation of the desired type of UAV flight path and the formation of the control vector $u_1(t), u_2(t), \ldots, u_5(t)$, providing UAV movement on this path at intervals $[t_0, t_5]$.

The analysis of possible conflicts that arise during the flight of the UAV it helps to identify the following basic model:

1. The model takes into account the disturbing effects of the environment on the flight path of UAV.
2. The model of accounting forbidden areas when planning the route of the UAV.
3. The model, taking into account possible collisions with static obstacles that may arise during the UAV flight at low altitudes.
4. The model account possible collisions with dynamic objects in the path of motion of the UAV (with other aircraft, UAVs) (Aleshin, 2011).

We describe each model of conflict in more detail.

The conflict situation **"UAV - aircraft"**. The most direct impact on the dynamics of motion of the UAV has the wind, forming a jet and turbulent movement of air masses.

The common quantitative characteristic of the current wind is a vector of its velocity (w_x, w_y, w_z). With the known values of the components of the value of the current wind speed is calculated as:

$$W = \sqrt{w_x^2 + w_y^2 + w_z^2}. \quad (7)$$

Vector UAV track speed $\overline{V}_{\Pi}$, so called velocity relative to the earth surface, is defined as the vector sum

$$\overline{V}_{\Pi} = \overline{V} + \overline{W}, \quad 8)$$

where $\overline{V}$ - velocity vector relative to the air.

If the vector $\overline{V}$ and $\overline{W}$ parallel, depending on the direction of the UAV fuel consumption is estimated as

$$q = \frac{q_ч}{3.6(V \pm W)}, \quad (9)$$

where $q_ч$ - the fuel consumption per hour of flight of the UAV (kg/h); V - the value of UAV air velocity (m/s); W - the velocity of the wind (m/s).

Definitions dependencies $w_x(t)$, $w_x(t)$ and $w_z(t)$ components of the wind velocity vector involves the use of meteorological data service in the area of implementation of the UAV flight missions.

Due to the wide spread of GPS satellite navigation systems such as the opportunity to use their information for the measurement of the velocity of the current wind.

We consider the general case of arbitrary influence of wind perturbations described by vector $\overline{W} = (w_x, w_y, w_z)$ to the vector of phase $(V, \theta, \psi, x, y, z)$ coordinates of the general model of UAV movement managed.

The wind effect on the change of the spatial coordinates of the position of the UAV is described as

$$\begin{cases} \dot{x} = V\cos\theta\cos\psi \pm w_x; \\ \dot{y} = V\sin\theta \pm w_y; \\ \dot{z} = V\cos\theta\sin\psi \pm w_z. \end{cases} , \quad (10)$$

The integration of the equations for the given dependencies $V = V(t), \theta = \theta(t), \psi = \psi(t)$ allows you to build a perturbed trajectory $x = x(t), y = y(t), z = z(t)$ of UAV motion.

For terms and conditions $\sin\theta \approx \theta; \cos\theta \approx 1; \sin\psi \approx \psi; \cos\psi \approx 1$:

$$\begin{cases} V_{П} = \sqrt{V + 2V(\pm w_x \pm w_y\theta \pm w_z\psi) + w_x^2 + w_y^2 + w_z^2}; \\ \theta_{П} = \arcsin\left(\dfrac{V\theta \pm w_z}{\sqrt{V^2 + 2V(\pm w_x \pm w_y\theta \pm w_z\psi) + W^2}}\right); \\ \Psi_{П} = arctg\left(\dfrac{V\psi \pm w_z}{V \pm w_x}\right). \end{cases} \quad (11)$$

Angered by the trajectory of the UAV, with regard to (11) takes the form:

$$\begin{cases} \dot{x}_{П} = V_{П}(t)\cos\theta_{П}(t)\cos\psi_{П}(t); \\ \dot{y}_{П} = V_{П}(t)\sin\theta_{П}(t); \\ \dot{z}_{П} = V_{П}(t)\cos\theta_{П}(t)\sin\psi_{П}(t), \end{cases} \quad (12)$$

with the initial conditions $x_{П}(t_0) = x_0, y_{П}(t_0) = y_0, z_{П}(t_0) = z_0$.

The influence of meteorological data on vector UAV motion parameters is a high priority of the route planning and the described model is the basis for building models of other conflicts.

The conflict situation **"UAVs - the restricted."** This conflict situation in terms of the calculus of variations occurs if the UAV movement route in the horizontal field may be restrictions prohibiting the movement through a point of the area G defined by the curve $y = \varphi(x)$.

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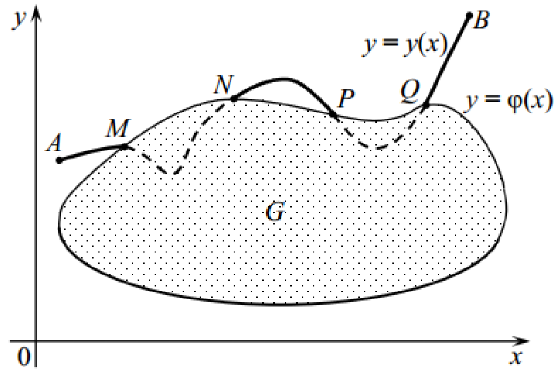

Figure 3. Route UAV traffic passing through the restricted area

In such a situation, the movement route can take place outside the area G, or consist of arcs lying outside the boundaries G and borders of parts of the area.

The conflict situation **"UAV - obstacle."** The emergence of such a situation is primarily due to the use of drones at low altitudes and describes the required views of flat trajectories.

In (Pshihopov, 2013)UAV is considered as a rigid body having six degrees of freedom, in which implemented 3 types of progressive influences its center of mass and 3 types of rotational movements with respect to the center of mass.

The dynamic equations of motion have the form of UAVs

$$\begin{cases} m\dot{V} = \sum F_x; \\ m\dot{V}\varpi_ц = \sum F_y; \\ m\dot{V}\cos\theta\varpi_ц = \sum F_z, \end{cases} \quad (13)$$

where: m - the mass of the UAV; $\dot{V} = \dot{V}(t)$ - the time derivative of the speed of UAV (acceleration at time t); $\theta = \theta(t)$ - the angle of inclination of the trajectory; $\sum F_x, \sum F_y, \sum F_z$ - the sums of the projections of all forces acting on the UAV axis;

Dynamic UAV rotation equations is generally described as:

$$\begin{cases} J_x\dot{\varpi}_x + (J_z - J_y)\varpi_z\varpi_y = M_x; \\ J_y\dot{\varpi}_y + (J_x - J_z)\varpi_z\varpi_x = M_y; \\ J_z\dot{\varpi}_z + (J_y - J_x)\varpi_x\varpi_y = M_z. \end{cases} \quad (14)$$

where: w_x, w_y, w_z - angular speed of rotation of the UAV relative to its own axis of the coordinate system; M_x, M_y, M_z - the sum of the moments of the projections on these axes are all acting on the UAV forces withrespect to its center of mass; J_x, J_y, J_z - the principal central moments of inertia of the UAV (Aleshin, 2011).

The assumption of ideal UAV control system (transient time through the channels of pitch, yaw and roll is negligible) allows to consider it without inertia rotating object, for which $J_x = J_y = J_z = 0$ and $M_x = M_y = M_z = 0$.

This assumption allows the present system (13) as:

$$\begin{cases} m\dot{V} = \sum F_x; \\ mV\dot{\theta} = \sum F_y; \\ mV\cos\theta\dot{\psi} = \sum F_z. \end{cases} \quad (15)$$

Given that UAVs are gravity during the flight $G = mg$; engine thrust P; drag force X, the conflict model **"UAV - obstacle "** provides a description of the model of the motion in the vertical plane (set altitude) in the interval (L_1, L_2) for which the UAV must get an altitude, allowing fly obstacle height $(h_2 - h_1)$ (fig. 4).

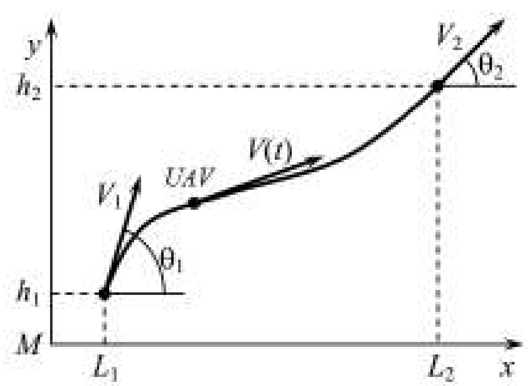

Figure 4. Set the height of the UAV flyby of obstacles located at L_2 with height $(h_2 - h_1)$

The equations of motion take the form:

$$\begin{cases} \dot{V} = \dfrac{P - X(V,\alpha,y)}{m} - g\sin\theta; t_1 < t < t_2; \\ \dot{\theta} = \dfrac{P(\alpha + \varphi_{дв}) + Y(V,\alpha,y)}{m} - \dfrac{g}{V}\cos\theta; \\ \dot{x} = V\cos\theta; \dot{y} = V\sin\theta. \end{cases} \quad (16)$$

Optimizing UAV height of the recruitment process can be solved by two criteria: the sets of altitudes with minimal consumption of resources and maximizing the value of the velocity at the end point climb. To determine the optimal trajectories in the vertical plane variational problems are used, which are the functional approximation of integral estimation of change overload values in the interval $[L_1, L_2]$ (Saati, 1977)

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The conflict situation **"UAVs - aircraft (UAV)"** occurs in the case of falling objects in the air piloting a secure area of the UAV. This area, which cross section depends on the maneuvering characteristics of the UAV and the type used on its bot control equipment (radio, optoelectronic, acoustic and other means) may take the form shown in fig. 5.

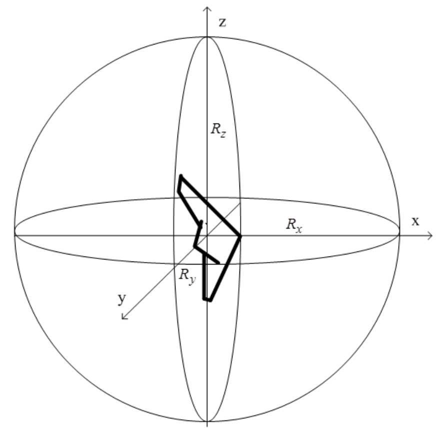

Figure 5. Safe piloting UAV's zone

We represent the boundary of the dangerous proximity of the radius of the sphere $R = \min\{R_x, R_y, R_z\}$. Then in the process of UAV flight in the interval of time $t \in [t_0, t_k]$ we will have a moving sphere (figure 6.), described by the inequality:

$$\left(x_1(t) - x_2(t)\right)^2 + \left(y_1(t) - y_2(t)\right)^2 + \left(z_1(t) - z_2(t)\right)^2 < R^2 \quad (17)$$

where $x_i(t), y_i(t), z_i(t)$ - the coordinates of approaching objects.

In the case of convergence with other UAV aerial objects at a distance of less R essential issue of the control action, which may be represented by the equations of motion, described in the event of a conflict situation **"UAV - obstacle"** in the vertical and horizontal planes.

Results

Thus, the described models in the management of conflicts of UAV motion allow to take into account the influence of the flight environment, the presence on the path of the UAV prohibited areas that arise when flying at low altitudes static, but on the entire range of performance of the flight task and dynamic objects. The practical application of the resulting studies described conflict models for specific UAV is finding estimates of permissible boundaries of the vector values of UAV motion parameters in order to predict the probability of performing the flight task, which will make the appropriate adjustments in the theory of intelligent control UAVs, and in part used for its implementation airborne and ground systems.

Discussion

One of the main directions of further development of the application of UAV control theory is a statement of system optimal control problems various types of UAVs, covering all phases of flight from the start (taking off) before landing, taking into account all sorts of random factors (effect of wind with random values of the components of the velocity vector, UAV designs dispersion values starting characteristics and equipment obtained during their production, etc.).

A separate area of multi-criteria optimization problem are the UAV control, the solution of which will allow to select from a plurality of paretooptimal UAV control options option that best matches the specific conditions of the current situation.

References

Alejo, D. (2009). Multi-UAV collision avoidance with separation assurance under uncertainties. Mechatronics.

Aleshin, B., Suhanov, V. (2011). Obespechenie bezopasnosti poletov bespilotnyh aviacionnyh sistem v edinom vozdushnom prostranstve. Uchenye zapiski CAGI, pp. 73-83.

Bachrach, A. et al. (2011). RANGE–robust autonomous navigation in GPS denied environments. Journal of Field Robotics, 28(5), pp. 644 - 665.

Beloglazov, D. et al. (2014) Intellektual'noe planirovanie traektorij podvizhnyh ob#ektov v sredah s prepjatstvijami. Moscow: Fizmatlit.

Chowdhary, G. et al. (2013). GPS-denied indoor and outdoor monocular vision aided navigation and control of unmanned aircraft. Journal of Field Robotics, 30(3), pp. 415–437.

Demidova, A. and Semenchev, E. (2012). Imitacionnaja model' peremeshhenija intellektual'nyh avtonomnyh ob#ektov v prostranstve s prepjatstvijami na osnove universal'nogo algoritma. Izvestija TulGU. Tehnicheskie nauki, 2 (12), pp.284-291.

Hua, M.-D.(2009). Contributions au contrôle automatique de véhicules aériens. PhD thesis, Université de Nice SophiaAntipolis.

Kanatnikov, A. et al. (2012). Dopustimye prostranstvennye traektorii bespilotnogo letatel'nogo apparata v vertikal'noj ploskosti. Nauka i obrazovanie. MGTU im. N. Je. Baumana. Jelektron. zhurn., (3), pp. 1-15.

Leatherland, A. (2011) Pilot training considerations for a whole new world. UAS Annual Conference. Royal Aeronautical Society.

Manathara, J. and Ghose, D. (2011). Reactive collision avoidance of multiple realistic UAVs. Aircraft Engineering and Aerospace Technology, 83 (6), pp. 388 – 396.

Moiseev, V. (2013) Prikladnaja teorija upravlenija bespilotnymi letatel'nymi apparatami: monografija. GBU «Respublikanskij centr monitoringa kachestva obrazovanija» (Serija «Sovremennaja prikladnaja matematika i informatika»).

Pshihopov, V. et al. (2013). Sistema pozicionno-traektornogo upravlenija robotizirovannoj vozduhoplavatel'noj platformoj: matematicheskaja model'.Mehatronika, avtomatizacija i upravlenie, (6), pp. 14 – 21.

Pshikhopov, V. et al. (2012) The design of helicopter autopilot.. SAE Technical Papers 5. doi: 10.4271/2012-01-2098.

Saati, T. (1977) Matematicheskie modeli konfliktnyh situacij. Moscow: Sov. Radio.