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Development of algorithms of optimization of adaptive neural flight control system of UAV on the basis of pseudosspectral Gauss method

Systematization of development and optimization of design parameters of unmanned aerial vehicles were performed. Equations for lifting force, aerodynamic resistance, thrust and pitch moment are constructed for the mathematical model, which became the basis for differential equations of the state were plotted. A mathematical apparatus for calculating the average value of the power consumed by the driving system and the power of the system of electric batteries is suggested. The application of Gauss pseudospectral method by conducting the sampling procedure and introducing appropriate restrictions is suggested.

Aerodynamic diagnostics system.

Determining the basic model of the UAV, which is quite simple in construction, but at the same time adequately reflects the aerodynamic characteristics of the aircraft, which can be used for most typical tasks, necessitates the introduction of a number of restrictions. In the framework of this study, it is suggested to consider the model of winged UAV, characterized by (i) a large value of wing elongation; (ii) a flat symmetrical shape of the fixed wings; (iii) low speed of flight in the horizontal and vertical plane without performing complex maneuvers that include a scaffolding or roll of the aircraft; (iv) constant value of the total mass of the aircraft. According to these limitations, it is possible to simplify the mathematical model, eliminating from it the calculation of the moment of inertia of the UAV, which arises from a number of reasons and depends on the design of the aircraft and the flight mode, the incorrect consideration of the planet's surface as an inertial system, etc. At the same time, it is suggested to build a mathematical model in such a way that, if necessary (according to the task on which a separate type of UAV specializes, which is subject to analysis and improvement of structural characteristics) it can be modified.

The basic mathematical model for determining the aerodynamic properties of the winged UAV according to the specified restrictions (Figure 2) should be based on the equations for lifting force F_L (lift force, LF), aerodynamic resistance F_D (drag force), thrust F_T (thrust force), that is calculated on the basis of lifting force and aerodynamic resistance, as well as the M_P pitching moment (MP):

$$\begin{cases} F_L = q \cdot k_L \cdot S_W \\ F_D = q \cdot k_D \cdot S_W \\ M_P = q \cdot k_P \cdot l_{AF} \cdot S_W \ , \\ F_T = F_L \cdot \dfrac{k_D}{k_L} \end{cases} \tag{1}$$

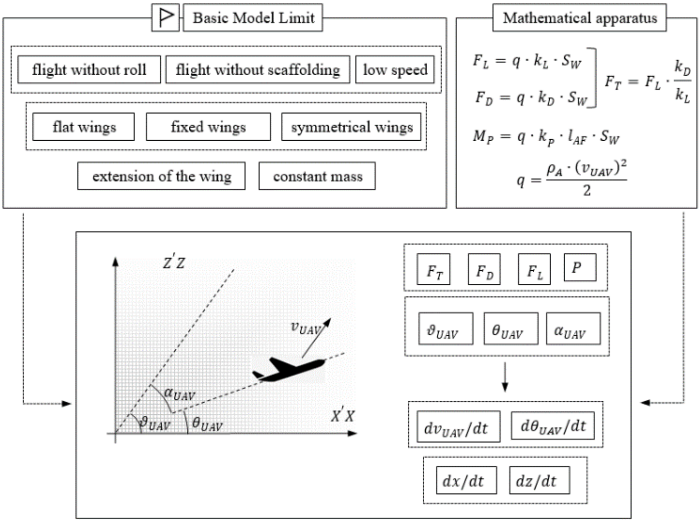

Figure 2. Algorithm of construction of basic model for determining the aerodynamic properties of UAV.

where q — free flow pressure, S_W — total area of wings k_L — coefficient of lifting force k_D — coefficient of aerodynamic resistance, k_P — coefficient of pitching moment, l_{AC} — length of aerodynamic profile chord (airfoil chord). The free flow pressure is determined on the basis of the air density values ρ_A depending on the altitude of the UAV flight and the speed of the devicev_{UAV}:

$$q = \frac{\rho_A \cdot (v_{UAV})^2}{2} \ . \tag{2}$$

Due to the fact that the aircraft maneuvers are considered only in the vertical plane, for further modelling and optimization of the trajectory of UAV motion by mathematical methods, it is sufficient to construct differential equations for changing the speed of the aircraft dv_{UAV}/dt and the pitch angle $d\theta_{UAV}/dt$. To do this, one introduces the concept of the angle of attack α_{UAV} and the angle of inclination of ϑ_{UAV} the UAV, and $\vartheta_{UAV} = \alpha_{UAV} + \theta_{UAV}$. From these equations, through definitions θ_{UAV}, one can go to navigation differential equations for dx/dt and dz/dt, where the axis $X'X$ corresponds to the horizontal motion of the UAV, and $Z'Z$ — to the vertical:

$$\begin{cases} \dfrac{d\theta_{UAV}}{dt} = \dfrac{F_T \cdot \sin(\alpha_{UAV}) + (F_L - P \cdot \cos(\theta_{UAV}))}{m_{UAV} \cdot v_{UAV}} \\ \dfrac{dv_{UAV}}{dt} = \dfrac{F_T \cdot \cos(\alpha_{UAV}) - (F_D + P \cdot \sin(\theta_{UAV}))}{m_{UAV}} \end{cases} \rightarrow \begin{cases} \dfrac{dx}{dt} = v_{UAV} \cdot \sin(\theta_{UAV}) \\ \dfrac{dz}{dt} = v_{UAV} \cdot \cos(\theta_{UAV}) \end{cases} \quad (3)$$

where m_{UAV} - the mass of the UAV, and $P = m_{UAV} \cdot g$ — its weight.

Also, for the construction of a mathematical model, it is important to determine the first and second derivative of the angle of inclination as the angular speed ω_y along the axis $Y'Y$ and the ratio of the pitch moment and the moment of inertia I_y:

$$\begin{cases} \dfrac{d\vartheta_{UAV}}{dt} = \omega_y \\ \dfrac{d^2}{dt^2}\vartheta_{UAV} = \dfrac{M_P(y)}{I_y} \end{cases} \cdot \quad (4)$$

For most tasks, the flight of the UAV can be considered as such that during the maintime occurs in a horizontal mode. In this case, the value of the angle of attack and the angle of inclination of the aircraft can be specified as close to zero. This greatly simplifies differential equations (3) for derivatives on the angle of pitch and velocity and can be used in the development of mathematical apparatus for calculating the parameters of the subsystem of solar cells of the power supply system of the device:

$$\begin{cases} \dfrac{d\theta_{UAV}^{+}}{dt} \approx \dfrac{F_L - P \cdot \cos(\theta_{UAV})}{m_{UAV} \cdot v_{UAV}} \\ \dfrac{dv_{UAV}^{+}}{dt} \approx \dfrac{F_T - F_D - P \cdot \sin(\theta_{UAV})}{m_{UAV}} \end{cases} \rightarrow \begin{cases} \dfrac{d\theta_{UAV}^{+}}{dt} \approx \dfrac{g \cdot (k_{NO} - \cos(\theta_{UAV}))}{v_{UAV}} \\ \dfrac{dv_{UAV}^{+}}{dt} \approx g \cdot \left(\dfrac{F_T - F_D}{P} - \sin(\theta_{UAV})\right) \end{cases} \quad (5)$$

where $k_{NO} = F_L/P$ — coefficient of normal overload (normal overload, NO).

Specification of the constructed model according to the power scheme allows to optimize the trajectory of UAV autonomous flight by means of methods of numerical analysis.

The analysis provided an opportunity to systemize the process of development and optimization of UAVs by building an appropriate research methodology, which consists of the stages of setting the problem, determining the functionality of the apparatus, determining the basic characteristics of the design of search methods for their optimization and refinement of the task. The classification of the typical tasks solved by the developers of UAVs and functional capabilities of the apparatus and the basic characteristics of the aircraft that correspond to them was carried out. In particular, the same groups of parameters as aerodynamic parameters of the device depending on the flight altitude, the time of autonomous flight according to the power supply system of the apparatus and flight conditions, the flight control system and the precision positioning of the device and the lifting force of the UAV are selected. The basic model was characterized by a number of restrictions, so the winged UAV was considered in the paper, characterized by a large value of the wing elongation; flat symmetrical shape of fixed wings, low flight speed in the horizontal and vertical plane (without scaffolding or roll), and constant value of the total mass of the aircraft. In accordance with this, equations for lifting force, aerodynamic resistance, traction and pitch moment were constructed for the mathematical model, which became the basis for differential equations of the state describing the processes of changing the pitch angle, velocity and position of the UAV. The next stage for calculating the level of solar irradiation in accordance with the geographical position of the apparatus and the position of photocells was constructed a system of equations for the angle of the Sun's elevation and the angle of inclination of the Sun, as well as the transition matrices from the geographical coordinate system to the system coordinates of the UAV and from the UAV coordinate system to the coordinate system of the solar cell. A mathematical apparatus was also suggested for calculating the average value of power consumed by the driving system of power of the system of electric batteries. The task of optimizing the mode of functioning of UAV was reduced to the mathematical problem of finding the maximum of the target function of the index of efficiency of accumulation and consumption of energy, which was proposed to solve on the basis of pseudospectral Gauss method, after the sampling procedure and introduction of appropriate restrictions. Thus, the practical implementation of the proposed approach is to optimize the design parameters of UAV in accordance with the experimental dependencies for the angle of tanging, the speed of the UAV, the thrust, the charge of the battery and the coefficient that determines the ratio of charge to the capacity of the battery.

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