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The control system of a promising domestic unmanned aerial vehicle of the tactical management level

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ABSTRACT

The formation process of steel coatings by the supersonic method using the AAM-10 apparatus and an experimental sample of a metallizer with an adjustable electrode position was studied. It was found that the main parameters that determine the quality of the coating are the temperature and pressure of the gas in the spray head. The effect of these parameters on the size of dispersible particles, as well as their velocity in the jet and the effect of the flow of atomizing gas on the amount of oxygen in the coatings, was experimentally established. The density and adhesion of the coatings were obtained depending on the spraying distance and air flow. The influence of current strength on the quality of coatings is established. Rational spraying regimes are obtained.

Key words : supersonic speeds, atomizing gas, temperature, pressure, flow, porosity, performance.

1. INTRODUCTION

In the conditions of intensive development of automation systems and tools, robotization and intellectualization, the development of unmanned aerial vehicles is a dynamically developing direction[1].
1898-Nikola Tesla developed and demonstrated a miniature radio-controlled vessel[2].
1910-Charles Kettering developed an experimental unmanned "aerial torpedo", which became a precursor to cruise missiles. The unmanned vehicle was controlled by an inertial automatic control system.
After the start, powered by electricity from the engine, the gyroscope provided stabilization in the direction. The gyroscope was connected to a vacuum-pneumatic autopilot.
The simplest functions of the autopilot provided the Elevator control and the rudder, the counting of the distance travelled,the engine shut-off and vent wings.
The disadvantages of the control system were the problems of ensuring course stability and the possibility of only unidirectional flight from the start point to the goal[3].
The 30s of the XX century were marked by the appearance of radio-controlled aircraft.
Radio control allowed the drones to follow complex routes and perform complex maneuvers in the air. The devices were able to return to the starting position, which increased the number of their use.
Increased speed and range. However, the problem of increasing the altitude has not yet been solved. The equipment allowed effective use of UAVs only in the operator's field of view.
During world war II, Nazi Germany developed the V-1 projectile, a prototype of modern cruise missiles, as part of the "Weapons of retribution" project.
During the development of the project, it became necessary to introduce stabilizers and a gyroscope to stabilize the device during flight.
On the ground, before the launch, the drone was set the altitude and course values, as well as the flight range. Guidance was performed using a magnetic compass. After the launch of the device, the autopilot operated at a predetermined course and at a predetermined altitude. The course and pitch stabilization was based on the 3-power gyroscope readings: the pitch was summed up with the barometric altitude sensor readings; the course – with the values of angular velocities from two 2-power gyroscopes used to reduce projectile vibrations. Roll control was absent due to high stability around the longitudinal axis.
Currently, unmanned aerial vehicles are controlled by flight controllers, which are a control Board with a chip for connecting a microprocessor, sensors and other circuit

elements, as well as software that provides control logic and recognition of connected devices[3].

A promising unmanned aerial vehicle of the tactical control level that performs reconnaissance tasks should be of a multi-rotor type and have a miniature automated control system with the ability to switch to the following control modes:

1. manual operator control Mode.
2. Automated flight stabilization, altitude hold and geo-positioning mode.
3. Automatic return mode to the starting point.
4. Automatic mode for points on a pre-set route.
5. Automatic take-off and landing.

To increase the UAV's autonomy, it is necessary to provide the control system with the mathematical apparatus of the theory of artificial intelligence, including a computer vision system and adaptive control algorithms.

The automatic flight control mode must be performed in radio silence mode. This mode is necessary when the UAV is out of sight of the radio channel or under the influence of enemy electronic means.

In the case of GPS jamming (coordinate substitution), the device must switch to an inertial control system or magnetic compass [4].

In order to protect the radio channel from interception, radio suppression and exposure to radio-electronic means in urbanized areas, a mode of rapid pseudo-random adjustment of the operating frequency should be provided[5].

In General, the UAV control system of the tactical control level refers to an unmanned aviation system that includes on-Board UAV control systems, one or a group of aircraft with a payload, and a ground control system[6].

The composition of the Board of management shall enter:

Hardware and computing platform:

1. Flight microcontroller with connected modules:

Satellite navigation module-for receiving signals from the satellite navigation system and transmitting the values of geographical coordinates, track angle, magnetic declination and inclination to the unit for calculating orientation angles.

Spatial orientation module - for determining the position and stabilization of the UAV in flight with inertial measurement system sensors (accelerometer, gyroscope, magnetometer, barometer, electronic magnetic compass, etc.)

Module for storing and retrieving information about flight parameters and storing configuration files

2. The receiver for automated control of the UAV.
3. motor Controllers that receive pulse-width modulation signals.
4. External pulse width modulation input and output ports for recognizing signals from the receiver and controlling motor controllers.
5. UART ports for connecting GPS and wireless telemetry modules.
6. USB or COM port for debugging and testing software.
7. Li-polymer battery

The software in the UAV control logic should be responsible for providing computational processes:

- a set of libraries for working with the microcontroller's peripherals;
- a set of libraries for working with internal microcontroller devices (accelerometers, gyroscopes, magnetometer, barometer, GPS receiver, wireless telemetry module, memory card, etc.)
- operating system – program code in a high-level language.
- radio channel cryptographic protection system.
- The UAV payload must contain:
- devices for obtaining specific information:
- satellite navigation system (GLONASS / GPS);
- devices for radio lines of view and telemetry information;
- command and navigation radio line devices with antenna feeder device;
- command information exchange device;
- information exchange device;
- onboard digital computer (bcvm);
- device for storing species information.

As a ground control complex, a command and staff vehicle with equipment for receiving, processing, transmitting information and debugging control processes is offered.

The creation of a control system for a promising domestic unmanned aerial vehicle tactical control can be carried out using one of three approaches:

1) by developing the entire system "from scratch" in accordance with regulatory documents and standards;
2) by purchasing finished products;
3) combined approach:

- develop a schematic diagram of the control system components;
- create a 3D model of the hardware-computing platform Board;
- buy ready-made components for the Board in the electronic equipment market;
- manufacture the control Board with all the necessary electronic components;
- to develop software and "flash" in charge of hardware and computing platforms.

Research has shown that the best parameters of such the systems are achieved at a beacon radiation wavelength of 1.55 microns and radiation power over 1 W, with a decrease in the meteorological minimum is achieved by adjusting the power radiation depending on the transparency of atmospheric air, and also the illumination of the earth's surface.

By the centers of brightness of images of lighthouses on the photo matrix, coordinates of which (yn, zn), n = 1...3 are found during processing the spatial and angular position of the images are determined UAV regarding the beacon system. To describe the relative position of a system of beacons and UAVS let's introduce a horizontal rectangular system the OXYZ coordinate system associated with the radiation source system (basis i, j, k), the OX axis coincides with the runway centerline, the OY axis coincides with the vertical axis, and the Z axis forms the right coordinate system. System O of the coordinates X'y'z' – the movable system connected with the geometric center fotometrica, where the axis O X' directed along the optical axis lens, the axis O Y' pointing up perpendicular to the horizontal side fotometrica, the axis O'z' perpendicular to the axis O X' O Y', forming with them the right coordinate system represented by figure 1.

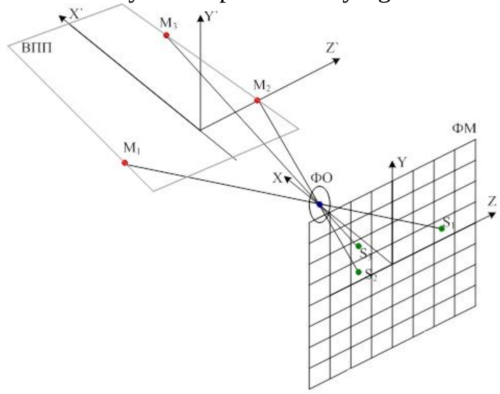


Figure 1: Relative position of the coordinate systems OXYZ and O'x'y'z'

The location of the Mn beacon in the OXYZ system is described coordinates (lxn, lyn, lzn), and its image S in the plane photo matrix-coordinates (yn, zn). System of equations, describing the angular and linear position of the UAV in the system the coordinates associated with the runway are as follows

$$
\begin{aligned}
&(a_{13}F + a_{11}z_1)(x_л - l_{x1}) + (a_{23}F + a_{21}z_1)(y_л - l_{y1}) + (a_{33}F + a_{31}z_1)(z_л - l_{z1}) = 0,\\
&(a_{12}F + a_{11}y_1)(x_л - l_{x1}) + (a_{22}F + a_{21}y_1)(y_л - l_{y1}) + (a_{32}F + a_{31}y_1)(z_л - l_{z1}) = 0,\\
&(a_{13}F + a_{11}z_2)(x_л - l_{x2}) + (a_{23}F + a_{21}z_2)(y_л - l_{y2}) + (a_{33}F + a_{31}z_2)(z_л - l_{z2}) = 0\\
&(a_{12}F + a_{11}y_2)(x_л - l_{x2}) + (a_{22}F + a_{21}y_2)(y_л - l_{y2}) + (a_{32}F + a_{31}y_2)(z_л - l_{z2}) =\\
&(a_{13}F + a_{11}z_3)(x_л - l_{x3}) + (a_{23}F + a_{21}z_3)(y_л - l_{y3}) + (a_{33}F + a_{31}z_3)(z_л - l_{z3}) = 0,\\
&(a_{12}F + a_{11}y_3)(x_л - l_{x3}) + (a_{22}F + a_{21}y_3)(y_л - l_{y3}) + (a_{32}F + a_{31}y_3)(z_л - l_{z3}) = (
\end{aligned}
$$

The resulting system of equations (1) with respect to the range L X , height L Y, lateral deviation L Z and matrix coefficients guide cosines ij a, depending on the yaw angles ψ, roll γ, and the pitch is not linear. The system of equations (1) can be solved by one of the numerical methods, provided that the coordinates beacons are known. All these methods have one common drawback, which consists in the need to perform multiple iterative computing, which significantly increases the requirements for computing resources of the onboard computer. However, in relation to the method of successive approximations, there is an important the moment that makes it more preferable compared to other methods. The point is that if you define it accurately enough zero approximation, the method provides a reliable and fast convergence to a solution (for practical purposes, just one iterations) with good accuracy. Using the measurement resultscoordinates of the images of lighthouses on the photo matrix can be enough accurately (1...2 %) and with low computational costs to determine zero approximation.

Consider this approach in relation to system (1) using Newton-Raphson method, a type of method consecutive approximations. As experience has shown, zero the approximation provides an error of no more than 5 %, and each

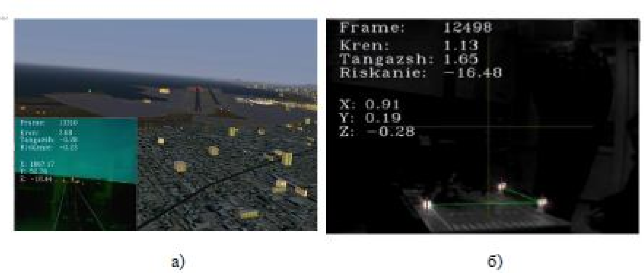
the subsequent approximation reduces it by another two orders of magnitude, so for practical purposes it is quite sufficient to stop at the first approaching. To find it, you need to solve the following problem a system of linear equations in matrix form linking zero and first approximation solutions of equation (1):

$$
\begin{aligned}
&\left[x_л^{(1)} \quad y_л^{(1)} \quad z_л^{(1)} \quad \gamma^{(1)} \quad \psi^{(1)} \quad \upsilon^{(1)}\right]^T =\\
&= \left[x_л^{(0)} \quad y_л^{(0)} \quad z_л^{(0)} \quad \gamma^{(0)} \quad \psi^{(0)} \quad \upsilon^{(0)}\right]^T - \Phi^{-1}\left[x_л^{(0)} \quad y_л^{(0)}\right.
\end{aligned}
$$

Moreover there is no need to write out the Jacobi matrix in analytical form if necessary, due to its bulkiness, and the calculation should perform in numerical form. The multifunctional vision system includes optoelectronic multifunctional measuring device, providing a breakthrough in solving the problem of automatic controls in various flight modes. Designed for development and debugging of algorithmic and software systems automatic landing, formation flight and refueling. Structure the system is shown in figure 2.

Figure 2: Block diagram of a multifunctional vision system

When developing a multi-functional maintenance system a simulation was conducted, which is based on a mathematical model of UAV flight dynamics was put in place, integrated with the UAV's onboard autopilot and flight simulator, to display a visual representation of the runway model (figure 3A).



a-semi-natural simulation, b-experiment using the runway layout

Figure 3: Automatic approach Tests

A mathematical model of flight dynamics generates the UAV movement parameters and transmits these data to the on-Board autopilot. The multi-functional optical-electronic system captures the position of the IR beacons on the screen, generates signals of the UAV's position relative to the runway, and transmits this data to the onboard autopilot. The onboard autopilot, in accordance with the established law of control, leads the aircraft along the glide path to land. In the future, a runway layout was developed with three IR beacons for conducting field tests (figure 3b). This layout allowed us to test the system in real conditions, conduct a series of experiments using various IR filters and LEDs.

To solve the problem of UAV flight control in the landing mode, an automatic control algorithm has been developed that ensures that the landing parameters are maintained with the specified accuracy. The automatic control algorithm is based on the following principles: hierarchical multi-level division of the flight task into flight stages, sections and phases; separation of continuous and discrete control channels [2].

Based on the formed set track angle, set trajectory tilt and set speed control program, taking into account the existing restrictions, the control law is formed in terms of a given roll and overload, which is the basis for the operation of the model of a standard UAV ACS. In the longitudinal channel, the ACS operation in landing mode is based on maintaining the set value of the pitch angle by means of the elevators and changing the engine thrust. To control the lateral movement of the UAV at the landing stage, an aerodynamic rudder and multi-section ailerons are used.

Based on the obtained control laws and the calculated mathematical model of UAV movement in landing mode, numerical modeling was performed, where the errors of deviation from the set control parameters were studied, shown in figure 4.

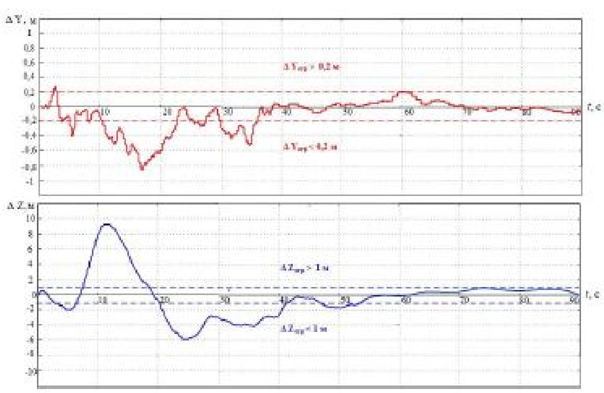


Figure 4: Aadjustment Errors for vertical ΔY and lateral ΔZ deviation under the influence of wind turbulence (σU=2 m / s, L=300 m)

The obtained simulation results show that the accuracy of measurement and adjustment of landing parameters is sufficient to solve the problem of performing automatic landing using the developed algorithmic software.

Thus, the use of the developed algorithmic support for a multifunctional optical system of technical vision has determined the prospect of practical application of the optical-electronic measuring system and ACS for safe automatic landing of UAVS on the aircraft runway.

A similar principle of operation of the system can be implemented in refueling and flight modes in formation. It is proposed to install IR tags on the refueling cone with active control when refueling (figure 4A); when flying in formation – on the tail and wing tips of the leading aircraft in a group (figure 4B). Thus, it is possible to expand the use of STZ for landing on an aircraft carrier, low-altitude flight, the task of preventing collisions with obstacles, and aiming at ground and air targets.

Figure 5: Various options for using the technical vision system:
a –in-flight refueling, b-group flight

5. CONCLUSION

The proposed system implements a number of patented technical solutions. It is possible to implement it using only domestic components. In 2016, a prototype of the system was produced, which is currently being used to work out a method for automatic landing on the runway in difficult weather conditions. It is proposed to set up experimental design work on the implementation of the proposed system in promising models of aviation equipment.

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