Peculiarities of Remote-Piloted Vehicles On-Board Navigation Complex Construction

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Abstract.. The article dwells upon the peculiarities of on-board navigation complex construction. It is highlighted that the optimal method for constructing on-board navigation complex is integration into single complex of sensors and systems with the integration of measurement information. The core of on-board navigation complex should be built on the basis of free-form inertial navigation system. To ensure the piloting tasks, the on-board equipment includes system of air signals. On the basis of the air signals system and magnetic compass air course counting is performed, which together with the inertial calculation allow to obtain comprehensive solution in an autonomous mode. It is important to include in the on-board navigation complex receiver of GNSS signals. Thus, the ideology of constructing the on-board navigation complex initially consists in the integration of measurements from the sensors and systems that make up its structure. It is emphasized that directly on-board navigation complex consists from inertial sensors, GNSS and magnetic compass receivers and also interface with air signal system. Specific types of sensors and systems are selected in accordance with the requirements of software and algorithmic support of on-board navigation complex.

Keywords: Remote-piloted vehicle, On-board navigation complex, Navigation system, System sensors.

1 Introduction

Robotic technologies are widely used in various types of air, land and sea transport, in agriculture, extraction of minerals and development of natural resources. At the same time, the market of robotic aircraft is developing very dynamically. As the total number of unmanned aerial vehicles grows, the task of integrating them into the common space with manned aircraft becomes urgent. It is possible only when the specified determination quality of remote-piloted vehicles parameters including precision and interference immunity is achieved. Operational standards are under development by the authorized civil aviation authorities and are likely to repeat similar requirements for on-board equipment of civil aircraft.

It is emphasized that total number of remote-piloted vehicles have increased so that the task of their integration into the common space with manned aircraft becomes urgent. It is possible only when the specified quality of the remote piloted vehicle movement parameters have been determined, including accuracy and interference immunity. It has been highlighted that remote-piloted vehicle equipment is subject to stringent requirements for minimization of cost, mass and size characteristics and power consumption, which are often mutually contradictory, and their implementation in general leads to deterioration of accuracy and interference immunity. The problem of ensuring accuracy and noise immunity when using the general-purpose element base becomes urgent.

Nowadays, international market do not offer specialized serial navigation systems for unmanned aircraft, especially small and medium-sized classes that meet the safety requirements in the general airspace. There are strict requirements for the on-board equipment of remote-piloted vehicle concerning minimizing of costs, weight and size characteristics and power consumption, which are often mutually contradictory, and their implementation in general leads to deterioration of accuracy and interference immunity. That is why the problem of ensuring accuracy and noise immunity when using the general-purpose element base is urgent [6,15,16,22].

To achieve this goal it is important to develop the concept of constructing the on-board navigation complex and increase noise immunity with variable structure.

2 Peculiarities of on-board navigation complex construction.

Specificity of remote-piloted application without terrestrial support under low-altitude flight, while reducing the visibility of signals of navigation satellites of global navigation satellite systems complicates the problem of accuracy and interference immunity provision.

The solution of the problem is possible in two ways [1,5]:

- use of the equipment used in manned aircraft (advantage of this approach is the use of waste products and technologies, disadvantage is ignoring the remote-piloted vehicle specificity that makes practically impossible to use it as a part of the remote-piloted vehicle of small and middle classes
- creation of specialized navigation systems of small and middle-class remote-piloted vehicle in which it is possible to apply inexpensive general-purpose sensors (possibility to maintain algorithms software, and apparatus core of remote-piloted on-board navigation complex based on to the inertial navigation system)

It is necessary to substantiate the concept of construction, development of software and algorithmic support and hardware solutions to improve accuracy, as well as to study the properties of on-board navigation complex with high interference immunity with variable structure for remote-piloted vehicles.

At the first stage of development of on-board navigation complex it is necessary to justify its structure in accordance with the requirements for the accuracy of determining orientation and navigation parameters, to propose the concept of the

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development procedure, operation modes, to develop the structure of algorithms for complex information processing, orientation and navigation algorithms, justify the choice of the hardware of on-board navigation complex.

The basic requirements for the accuracy and range of measurements of orientation and navigation parameters of the on-board navigation complex correspond to the requirements of the inertial-satellite navigation system [5, 27].

The traditional approach to the design of the remote-piloted vehicles involves the following:

- selection of measurers
- development of orientation and navigation algorithms based on measurer values
- development of algorithms for complex processing of information.

The use of such an order is due to the small volume of sensors, high cost of products. However, more flexible and productive is the reverse order:

- requirements
- modes of operation
- measurements
- development of algorithms for complex processing of information.
- development of orientation and navigation algorithms based on measurer values
- selection of measurers

It is more convenient due to the lack of mandatory requirements for remote-piloted vehicle navigation equipment and, accordingly, the absence of the need for certification, which gives advantages in the development of algorithmic support and choice of measurers.

When creating remote-piloted vehicle, it is necessary to take into account such critical factors as ensuring the accuracy levels established by the technical specification while minimizing the cost, weight and size characteristics and energy consumption. From this point of view, the optimal method for constructing on-board navigation complex is integration into single complex of sensors and systems with the integration of measurement information. The core of on-board navigation complex should be built on the basis of free-form inertial navigation system. To ensure the piloting tasks, the on-board equipment includes system of air signals.

On the basis of the air signals system and magnetic compass air course counting is performed, which together with the inertial calculation allow to obtain comprehensive solution in an autonomous mode (without the use of GNSS). It is important to include in the on-board navigation complex receiver of GNSS signals. Thus, the ideology of constructing the on-board navigation complex initially consists in the integration of measurements from the sensors and systems that make up its structure. Directly on-board navigation complex consists from inertial sensors, GNSS and magnetic compass receivers and also interface with air signal system[2,3,4,15].

Specific types of sensors and systems are selected in accordance with the requirements of software and algorithmic support of on-board navigation complex.

It is based on the sequence of stages (requirements - operating modes - measurements - development of algorithms for complex processing of information - development of orientation and navigation algorithms based on measurer values - selection of measurers).

The navigation system of remote-piloted vehicle is depicted in Fig.1[3, 13, 18, 19].

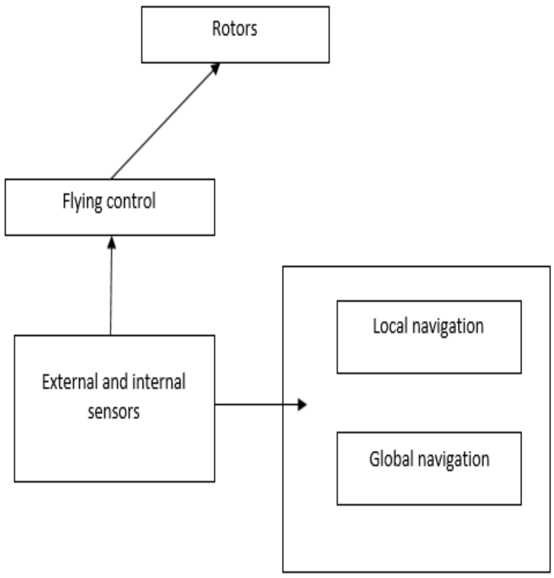

Fig. 1 Navigation system of remote piloted vehicle

Self-positioning and modeling of environment relative to the local coordinate system is under control of local navigation. 3D information is formed based on a set of flat images, forming 3D map of the studied surface. Block "Global navigation" presents the positioning of the remote-piloted vehicle by using the constructed 3D model of the external environment.

This technique allows to solve the problem of positioning in the condition of absence of GNSS signals. Local positioning system takes into consideration the onboard sensors indices, external sensors and position change data from the camera, which after processing by the filter of Kalman-Bucy solve the problem of orientation in space of dense urban development[7,8,9].

For the practical implementation of the proposed algorithm of the selection of a preferred profile of detection is necessary to ensure the adequacy of the technological process of production of photographs using the remote-piloted vehicle. For this purpose it was necessary to develop the methodology. Significant differences of this method consist in the use of on-Board 4-processor vector computer capable of processing images. The compute engine also provides automatic flight of the remote-piloted vehicle in the absence of GNSS data reception, focusing on the testimony of the inertial block, which includes a combination of accelerometers and gyroscopes.

For processing data from the sensors responsible for the positioning, was used an iterative formula to calculate the Kalman-Bucy coefficient[17, 20, 21, 24]:

$$E(e_{n+1}^2) = \frac{\sigma \frac{2}{k}(Ee_n^2 + \sigma_m^2)}{Ee_n^2 + \sigma_m^2 + \sigma_k^2}$$

where e_n^2 and e_{n+1}^2 – square of failures in n i n+1 moment of time accordingly; Ee_n^2 and $E(e_{n+1}^2)$ – expected value square of failures in n i n+1 moment of time accordingly; $\sigma_m^2 + \sigma_k^2$ – dispersion of positioning inertia block values and receiver of GNSS signals respectively.

By storing in the automated system of retrospective spatial data it is possible to set the flight mission, specifying only the name of the study area. By applying to the obtained areas data filter of Kalman-Bucy, it is possible significantly to improve the accuracy of the inertial navigation system due to the complete independence of measurement errors by these methods[23,25].

The use of the two-level scheme for the implementation of the prototype has allowed to implement a secure debug mode, because MultiWii allows the remote-piloted vehicle to hover or return to the starting point by the elementary route in the case of a failure in the block of "Remote-piloted vehicle navigation". The application in this mode of ultrasonic sensor allows to avoid collision with an obstacle by the elementary route. Operational adjustment of parameters takes place via radio or GPS in flight. At the time of the remote-piloted vehicle positioning on the landing pad are loaded the initial flight assignments and uploaded the collected information on the ground station via WiFi network.

The high speed of errors accumulation in inertial systems of positioning is caused by error of measurements of the used integrated accelerometers and the need to calculate the integral, leads to the multiplication of errors and does not allow to obtain positioning accuracy comparable with the accuracy of GNSS [8, 18,19].

The positioning of remote-piloted vehicle is made on the basis of the analysis of the location of ground objects and pre-designed models of environment. The block "Flying task and control" is responsible for the collection and processing of the 2D images obtained through the onboard camera, and solves such important tasks:

- adjustment of coordinates of an inertial positioning system;
- stabilization with respect to a predetermined position;
- safe landing of remote-piloted vehicle.

The on-board navigation complex has three main modes: "Initial parameters", "Navigation", " Attitude-and-heading reference" and four auxiliary modes: “Test Control", "Deviation", "Calibration", "Axis Coordination" (Fig. 2).

Modes "Deviation", "Calibration" and "Coordination of axes" can not work simultaneously and outside the mode " Attitude-and-heading reference ". In the "Test-control" mode, the other modes are not working.

In the "Navigation" mode on-board navigation complex generates and outputs navigation parameters with the required level of accuracy and in full volume. For successful operation of the regime, stable reception of GNSS signals and / or air signal system is required. In the absence of reception of GNSS and / or air signal system during a time interval of a predetermined duration, on-board navigation complex switches to the operation mode of Attitude-and-heading reference. In this mode, according to the navigation parameters, there are signs of failure, and the UAV orientation parameters are determined with increased errors [26, 27,28].

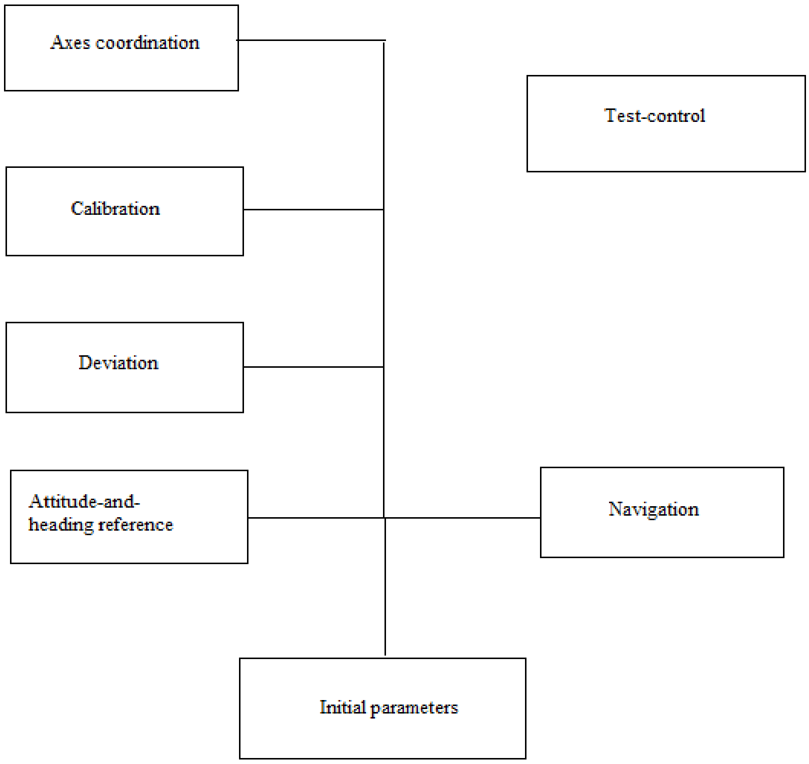

Fig.2 On-board navigation complex operation modes structure

In the Attitude-and-heading reference mode, the angular position of the remote-piloted vehicle relative to the vertical is determined by the measurements of the accelerometers. The error in determining the angles in this mode depends on the flight mode of the remote-piloted vehicle, the maximum accuracy is achieved with a flight close to a straight uniform. In the modes of intensive maneuvering of the remote-piloted vehicle, an error is accumulated, the magnitude of which depends on the duration and intensity of maneuvering. After the reduction of the effect of accelerations and angular velocities, the errors decrease. When start receiving GNSS signals again, the "Navigation" mode is restored. The proposed structure and logic of switching modes fully meets the requirements of the on-board navigation complex and makes it easier to conduct routine maintenance[3,5].

3.1. On-board navigation complex hardware

It is necessary to determine the structure of on-board navigation complex. It includes sensors and systems that allow constructing complex that meets the minimum requirements for determining the orientation and navigation parameters: the inertial module, the satellite navigation receiver GPS and magnetic compass[10,11].

The output information of the inertial module are three projections of the absolute angular velocity of rotation and three projections of the apparent acceleration onto the orthogonal axes of the coordinate system. At the same time, it is required to provide a range of measured angular velocities.

The choice of the on-board navigation complex calculator is carried out taking into account the requirements for the interaction interfaces and the functional load [5, 12,13,14]:

- control, monitoring and signaling functions for all elements (basic and
- optional) that are part of the on-board navigation complex;
- collection, processing and transmission of data on internal and external data buses;
- functions for synchronizing the operation of sensors, systems and algorithms;
- implementation of algorithms for orientation, navigation and auxiliary algorithms;
- recording and storage in the non-volatile memory of initial and current settings of parameters of system.

Interfaces of on-board navigation complex interaction should provide reception and transfer of single discrete commands and data packets exchange with the onboard equipment. In on-board navigation complex should be implemented:

- four digital inputs: "Chassis compression" signal, "Axes coordination" command, "Test control" command, "Calibration" command;
- four discrete outputs: signals "Serviceability", "Readiness", "Power", "Error";
- channel for monitoring and controlling GNSS receiver parameters;
- channel for the exchange of data packets with on-board equipment;
- channel designed for high-speed transmission of measurements of inertial sensors, measurements of GNSS receivers in consumer equipment;
- channels designed for receiving and transmitting data to onboard equipment of the remote-piloted vehicle.

The "Chassis compression" signal is used to indicate the mode of stop or the movement of remote-piloted vehicle over the runway. "Axes coordination” is designed to provide a command for coordinating the axes of the magnetic compass. The "Calibration" command is used when calibrating inertial sensors. Integral signal "Serviceability" is formed on the basis of information about internal control of the status of subsystems, if one of the elements fails, the active signal level is not formed.

The "Readiness" signal is integral, the active state is formed when there is minimum information for measuring the implementation of one of the main modes and the end of the initial exhibition. The "Power" signal is used to indicate the presence of power. The "Error" signal is used when diagnosing the program error of the on-board navigation complex with built-in monitoring functions.

The proposed hardware structure allows to obtain the entire required volume of measurement information for the implementation of orientation and navigation algorithms.

4. Conclusions

Nowadays remote-piloted vehicles are widely used in different spheres of life, particularly in the area research. They have a lot of advantages: high economic efficiency; low altitude of aerial photoshooting; aerial photoshooting exactness.

But also here are some hindrances at any height, in particular, if take into account low-level remote-piloted vehicles. Then the flight is complicated due to the high turbulence of the atmosphere and the inability to track the change in the altitude, as on small unmanned aerials, the device for measuring the relative altitude is used for landing or absent altogether. Therefore, it is necessary to increase the height of the automatic flight and thus reduce the efficiency of the accomplishment of the tasks .

The conception of constructing on-board navigation complex is the following: determination of requirements, operating modes, selection of measurement types, development of algorithms for complex processing of information, development of orientation and navigation algorithms based on readings of measurers, the choice of measurers. This approach allows to get the desired result with the reduction of time and material costs.

The structure of algorithmic support of complex processing of information, solving problems of navigation and orientation of the on-board navigation complex, allowing to obtain the required characteristics while minimizing the cost of development and the product as a whole, is developed.

The hardware composition and interfaces of the interaction of the on-board navigation complex, which allow implementing the proposed algorithmic support structure, are proposed.

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