INFORMATION SUPPORT OF UNMANNED AIR VEHICLE BY USING THE SPECIALIZED AUTOMATIC CONTROL SYSTEM

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ABSTRACT

In the process of obtaining a theoretical model and developing an automatic control system for an atmospheric satellite in the form of an unmanned air vehicle (AS UAV), methods of mathematical and simulation modeling, software tools and environments for modeling, developing on-board monitoring and control systems and for performing engineering calculations were used in the constructing and designing of UAVs. In the process of developing an automated control system for AS UAVs received the following developments: compiled a program code and a prototype autopilot; composed program code and prototype of the control system for the power plant, servos and camera; compiled program code and prototype of the power management subsystem; developed the structure and composition of the automated AS; developed the structure and composition of information support; developed virtual on-board instruments. Main design and technical - operational indicators: reduced measurement errors on-board devices, created by the influence of internal electromagnetic fields from electronic equipment. Applying area: main areas of application of unmanned systems in the form of AS UAVs will be border and law enforcement, anti-terrorism measures, detection of emergency situations and liquidation of their consequences, environmental monitoring and protection of natural resources, monitoring of industrial facilities, transport and energy infrastructure, as well as agricultural land. Development of the system of control, management and information support of AS UAVs will allow the country to create and manufacture domestic integrated, mobile navigation and control stations of UAVs for various purposes. Use of UAVs as an aerial platform has great prospects when shooting small area objects and linear objects.

Keywords: *Air Vehicle, Atmospheric Satellite, Unmanned Air Vehicle, Electromotor Glider, Automatic Control System, Information system, Automated Workplace, Glider, Aerodynamics, Theoretical Model, Mathematical Model, On-Board Devices, Autopilot*

1. INTRODUCTION

Currently, creation of atmospheric satellites is an urgent and promising task, because these air vehicles relative to orbital space satellites are more economical in terms of design, equipment and do not require high costs for to required altitude. Despite the simple design of atmospheric satellites in the form of unmanned air vehicles, they are able to perform the same tasks that are assigned to orbiting space satellites. Of course, there are certain advantages and disadvantages of atmospheric

satellites relative to orbital space satellites, there are problems in the development of such air vehicles, etc [1].

All existing problems, advantages, disadvantages and ways of solving were considered the following types of work: conducted a review of created and existed models atmospheric satellites in the form of unmanned air vehicles (AS UAVs) in abroad; produced the choice of AS UAVs models based on mathematical models and simulation; completed engineering calculations to determine the geometric, structural and technical characteristics of the model; performed calculations and modeling of aerodynamic characteristics of the model; developed drawings and 3D models of UAVs based on the obtained geometric, structural, technical, aerodynamic and strength characteristics; conducted the choice of power plant and electronic equipment on the basis of obtained results in the process of calculations and modeling; additional theoretical research and refinement of theoretical models; development of information support; development of UAV control and management systems; development of the operator's workstation (information and data exchange system between the UAV and the operator); development of prototype systems; creating of a prototype installation; conducting comprehensive laboratory testing.

The developed prototypes (models) of atmospheric satellites (AS) UAVs are mainly their designs are electric-powered unmanned gliders with flexible or carrier wings equipped with solar cells. Modern composite materials are used in the design and manufacture of UAV components [2]. To reduce the take-off weight of the UAV AS, various designs of wings, feathers, stabilizers and fuselage are used.

2. INFORMATION SUPPORT OF UAV

Depend on the purpose of using an atmospheric satellite in the form of an unmanned air vehicle (UAV) structure and composition of information support may differ from each other. In our case AS UAV performs video surveillance on a given flight route. Accordingly, developed information support should perform the following functions and tasks: navigation; orientation; movement; processing and transmission of video information; processing and transmission of flight parameters; receiving, processing and implementation of data received from the operator. Optimal functioning of AS UAV is possible and is

provided by a specialized automatic control system (ACS).

Developed information support of ACS (ACS IS) consists of the following software modules and complexes, see figure 1.
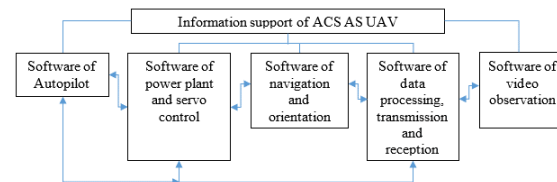

Figure 1: Structure And Composition Of IS AS UAV

In this case, AS UAV controlled by ground services the operator, respectively, the automated workplace (AWP) of the operator equipped with the appropriate software, see figure 2.
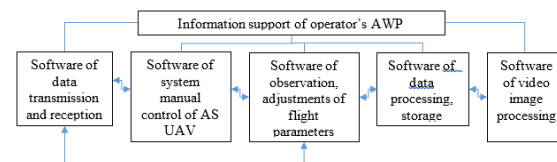

Figure 2 Structure And Composition Of AWP Of The Operator

Control of AS UAV carried out by two operators. Functions of the first operator conclude of observe the parameters of the flight, its adjustment and, in necessary, switch to manual control. Functions of the second operator conclude of observe video images, control the camera, process and store video data.

In the development of IS AS UAV used the following software environments:

- mikroBasic PRO for PIC and C++ - for developing programs and firmware these programs into microcontrollers;

- MatLab / Simulink –for modeling, conducting calculations, calibration of onboard devices and sensors;

- LabVIEW – for creating the interface of ACS AS UAV and AWM operator's;

- ZUAVVideo - for processing video signals and video images;

- ZUAV GCS - for archiving, storage of ACS data and video images;

- AutoCAD – for designing of components and node's;

- Multisim – for designing and testing of electronic circuits.

2.1 Control and management systems of UAV

The control subsystem of power plant and servos together with the software (figure 3) provides control of speed of the flight, control of ailerons and rudders. Autopilot (further consider its technical composition) together software autopilot, software of navigation and orientation provides a stable flight on a given route.

The use of wings with a large span, in which there are no elements such as ailerons, flaps, etc. ACS AS UAV (autopilot) contains special software capable of controlling the flight of multi-engine UAV turns adjusting the thrust of the corresponding electric motors. Also, to save power, the UAV cyclic AS goes into the planning state, i.e. after climbing, the electric motors are turned off, and the AU must plan until it drops to a certain height at which the UAV electric motors are turned on [3]

Whereas, flexible solar cells installed on the surfaces of the wings, inside of fuselage batteries, optimal and efficient power management of all AV subsystems during the day and night is required.

Communication management subsystem together with the corresponding SOFTWARE provides data exchange between the UAV and operator workplace.
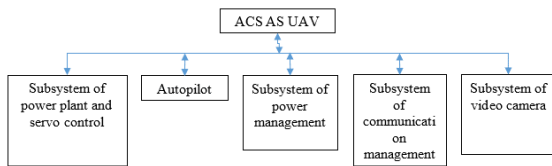
Figure 3: Structure And Composition Of IS AS UAV

3.   EXPERIMENTAL MATERIALS

This diagram (figure 4) reflects the location of electronic and microprocessor units ACS UAV, power plant, communication subsystem, power subsystem. With the help of specialized symbols displayed in the drawing on-Board control systems, regulation and logic control elements. Available on Board sensors, actuators using the same symbols are shown to which microcontrollers are connected. Also, the drawing shows control and management systems located in the operator's workplace. In the right corner above main inscription of the drawing is a table, which summarizes the name, position and quantity of equipment of UAV, management units, control, communication, power supply [3].
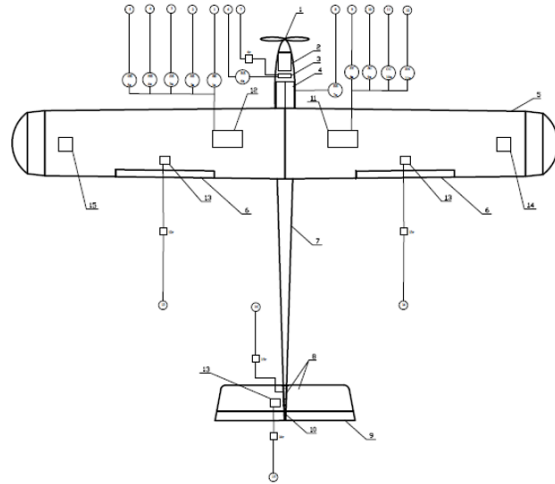
Figure 4: Functional Diagram Of Automation AS UAV

With the development of network and telecommunication technologies are widely used in modern automated systems means of wireless communication between sensors, converters and industrial logic controllers. These devices are small and can be built directly into the primary automation tools. To reduce the power consumption of electricity in the UAV power supply system, energy-saving wireless devices should be used [3,4,6,7]. The intelligent solar cell model system in automated operating mode can increase about 13% of the annual power output of the UAV.

3.1 Functional diagram of automation AS UAV

The following sensors and devices are connected to the autopilot microcontroller:

- magnetometer – performing the role of on-Board digital compass;

- gyroscope - performing the functions of the airborne horizon and device for measuring angular velocity;

- accelerometer - acting as an on-board device for measuring heading speed and vibration;

- pressure sensor - acting as a device for measuring flight altitude and air mass pressure overboard;

- temperature sensor - an on-board device for measuring temperature overboard.

Also, magnetometer has built in temperature sensor, which measures the temperature of on-Board measuring systems.

Autopilot performs function of stable flight AS UAV by controlling the yaw, roll, pitch and heading speed of the Air Vehicle.

Schematic diagram of the connection of the autopilot sensors has shown in figure 5.
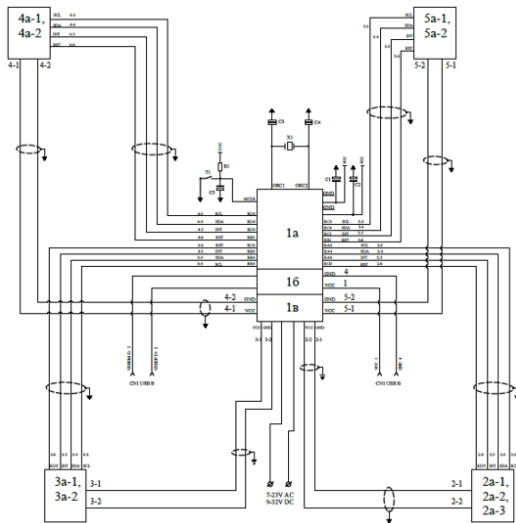

Figure 5: Functional Diagram Of Automation AS UAV

Power supply of all electronic and microprocessor systems of ACS, servos and sensors is carried out with the help of an electronic DC stabilizer, its schematic diagram is shown in figure 6. The power plant AS UAV is powered by another regulating electronic circuit
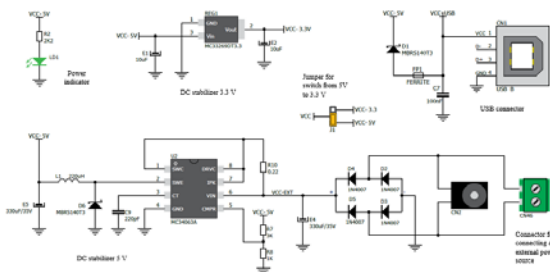

Figure 6: Schematic Diagram Of The Power Stabilizer

External power supply can be AC – 7...23V or DC – 9...32V. In our case, the external power sources are solar panels which composed of flexible solar photovoltaic cells and a battery.

All electronic and microprocessor subsystems, ACS AS UAV servos are powered by 5V, and sensors are powered by 3.3 V.

USB connector designed to supply an external power supply, for separate diagnostics, debugging or re-firmware of the microcontroller program, for example for autopilot.

Since on Board the AS UAV are sensitive to electromagnetic interference, noise and radiation, on-Board devices such as accelerometer, gyroscope, compass, power and signal wiring and cables are selected with a shielded braid. Additionally, the bundles are wrapped with thin foil for General shielding.

Electronic and microprocessor units, transceivers are also shielded by a thin foil. To avoid contact of foil with electronic elements on printed circuit boards, as well as from the influence of humidity, ambient temperature, they are coated with a special varnish. Shielding electronic components with tin cases, we refused, because we are fighting to reduce the weight of AS UAV. Also, the power plant, battery and servos wrapped with thin foil. All shielding elements connected to each other by grounding wiring.

Equipment, software, algorithm of work, tests of separate blocks of system of automation we will consider below in the subsequent paragraphs.

In our case, navigation and control station AS UAV is a field portable mini station automated operators' workplace. This includes the following hardware, accessories, inventory, and software:
- field tent;
- fuel electric generator;
- autotransformer (to stabilize the AC);
- three uninterruptible power supplies;
- four laptops with appropriate software and operating systems;
- two joysticks;
- portable remote control flight AS UAV, own program code, with built-in liquid crystal display (LCD) and transceiver;
- the remote control of the camera AS UAV with integrated transceiver;
- two passive antennas;
- router;
- server with software and operating system;
- network and communication cables;
- portable weather station with software and built-in wireless communication;
- two folding chairs;
- two folding tables;
- accessories.

The remote-control flight designed for manual implementation of the following flight maneuvers:
- takeoff;
- landing;
- adjustment of the course of the flight;
- switching to manual control in case of emergency.

The remote control connects to the laptop of the first operator via a USB port and thus carries

out radio communication, reception and transmission of flight parameters from the operator's workplace.

The camera remote control unit designed to receive a video signal and transmit command signals to the camera control module. The remote control connects to the laptop of the second operator via a USB port and thus carries out radio communication, reception and transmission of flight parameters from the operator's workplace.

The first operator's laptop screen displays the map interface and the moving interface on-Board devices, temperature condition of the onboard systems, temperature and pressure air masses.

The second operator's laptop screen displays the interface horizontal and vertical angular position of the camera relative to the fuselage guide of the AS UAV and the interface of the video image of the terrain being flown.

Each operator on its workplace performs certain functions, which we will consider later.

Portable weather station designed to measure the parameters of the environment. It measures the following environmental parameters.
- atmospheric pressure;
- air humidity;
- air temperature;
- dew point;
- consumption of precipitation;
- illumination (daylight, ambient light)
- infrared radiation;
- wind direction;
- wind speed.

This weather station with a laptop and software automatically keeps statistics of weather and environmental parameters. Communication with the laptop is carried out wirelessly. The laptop screen communicating with the weather station displays all the measured parameters of the environment and weather in a convenient form for observation.

1 – laptop; 2 – flight remote control; 3 – joystick; 4 – receiver (video signal receiver and control command transmitter); 5 – four channel router; 6 – server; 7 – uninterruptible power supply; 8 - single phase AC autotransformer; 9 – gasoline single-phase electric generator; 10 – portable weather station with wireless connection

Figure 7 shows the relationship of all the listed modules, units, equipment and computer equipment included in the operator workstation.

The remote control 2 equipped with its factory standard software, which is stitched into the MC. For the laptop of the first operator, the program code writes in C#, this program is at the stage of completion. For the laptop of the second operator used open-source FlightGear which the identification of the image of the terrain is carried out, it also allows you to set the field of vision of the camera, create and manage the route of the Air Vehicle. Mathematical software for image processing implemented through the library of OpenCV [5]. Transceiver 4 equipped with standard program code, which is stitched in the MC. Database formation, its collection, processing and storage is carried out using the MySQL software environment with open source. This software environment installed from disk into the server of operating system. Weather station 10 equipped with own factory software, which is installed from the disk into the operating system of the laptop.

3.2 Development of Prototypes of automation systems of AS UAV

Under the development of prototypes of systems, refers to the development, commissioning and laboratory testing of all subsystems of ACS AS UAV. In view of the requirements, we will consider the autopilot development process in more detail, and for the rest of the ACS subsystems we will present the final results.

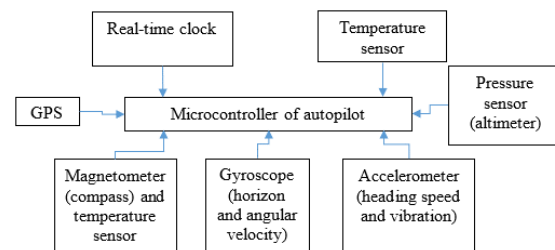Figure 8 shows the structure of the developed autopilot.

Figure 7: Interconnection Of Operator Workplace Equipment

Figure 8: Structure Of The Autopilot

The magnetometer has a built-in temperature sensor that measures the temperature inside the magnetometer chip. This temperature sensor is used as a device for measuring the temperature of all electronics on Board. I. e. with the help of this sensor will be evaluated influence of ambient temperature (air mass) on the electronics that located on board the AV. Separately, a temperature sensor connected to the MC which measures the temperature of the air mass flow. Pressure sensor in autopilot will be used to measure atmospheric pressure and measure flight altitude. Purpose of remaining sensors and devices connected to the autopilot MC is, in fact, clear.

a - board with microcontroller; b - three-axis magnetometer with built-in accelerometer and temperature sensor; c - three-axis gyroscope; d - pressure sensor; e - accelerometer; f - real-time clock; g - GPS / GLONASS receiver; h - temperature sensor.
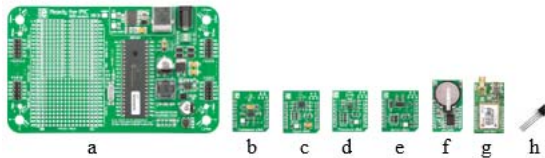

Figure 9: Technical Composition Of Autopilot

The Board MC autopilot installed PIC18F87K22 microcontroller with five I/o ports, also has an electronic stabilizer DC 5 and 3.3 V and USB UART port.

Sensors are specialized, were designed and manufactured by Mikroelektronika D. O. O. for unmanned systems (cars, air vehicle, robotic systems). Technical characteristics of these sensors and devices are presented on the website https://www.mikroe.com/.

Schematic diagram of the sensors and devices connection to the autopilot MC has shown in figure 10.
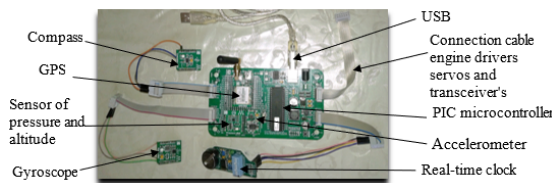

Figure 10: Autopilot Collection

Figure 10 shows the autopilot collection. The two sensors are specifically placed outside the MC Board whereas they are sensitive to electromagnetic interference and must also be placed in certain positions.

When designing and modeling the autopilot of an air vehicle of the type of aircraft is used the method of sequential closure of feedback loop. To use this method, flight equations of flight, which consists of twelve nonlinear differential equations, should transformed and linearized to obtain lower-order transfer functions, and more acceptable models in the state space for the development of an automatic flight control system for an air vehicle.

4. RESULTS AND ANALYSIS

With the help of the MatLab/Simulink software environment, we will develop an autopilot model based on the above linear models of transfer control functions.

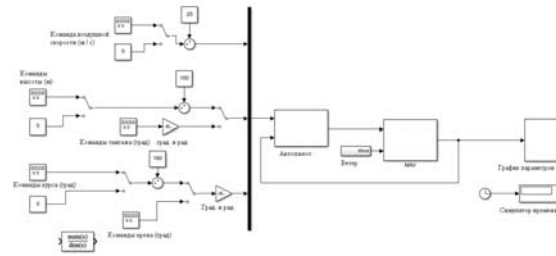Figure 11 shows a block diagram of the simulation model of the autopilot, formed in Simulink.

Figure 11: Model Simulation Of Autopilot

Run Simulink, the simulation window opens, where with the help of engines we change the parameters of the roll, height, air speed, as well as change the parameters of disturbing factors.

The Figure Windows display graphs of changes in the parameters of the Air Vehicle flight, these include:
- airspeed;
- angular airspeed;
- flight altitude;
- change roll (tilt).

It should be noted that the work on modeling and simulation of the AS UAV flight continues and at the moment a model of autopilot is being developed in the simulation, which should display the onboard instruments and the process of flying the air vehicle in the airspace.

So, according to the simulation model, calculate limit values of the angles of rotation of the ailerons, rudders and height, speed, angle and altitude characteristics, the calculation of the frequency parameters of internal and external

circuits and the gain of each link of the PID controller.

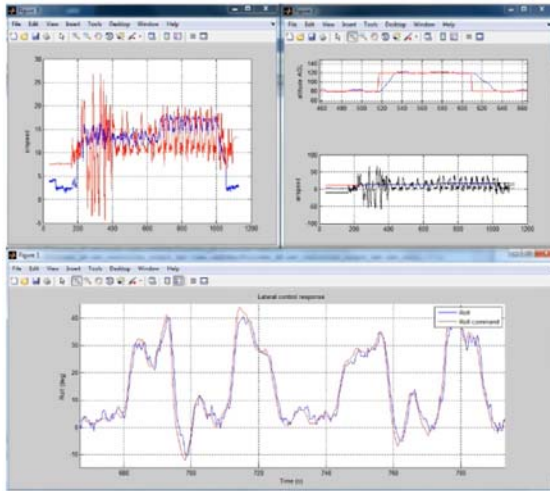Figure 12 shows the results of the flight simulation of the Air Vehicle.

Figure 12: Model Simulation Of Autopilot

During the flight of the AS UAV, the operator on his AWP monitors the following on-board devices:

- magnetic direction of the Air Vehicle relative to the Earth;

- heading airspeed;

- position of air vehicle in airspace relative to horizon;

- flight altitude;

- coordinates of the location of air vehicle;

- vibration of the Air Vehicle body (wing, fuselage, rear tail);

- temperature atmospheric pressure airflow;

- temperature of the onboard electronic and microprocessor devices.

In reality, on Board the experimental model AS UAVs are not installed on-Board devices, they are not necessary. On-board device is a sensor that is connected to autopilot MC. Data from the autopilot in a certain sequence is transmitted by the radio transmitter (receiver) to the radio receiver of the operator's remote control. Next, MC remote control via USB UART port sends data from the autopilot to the PC. Program code installed in the laptop AWP of the first operator displays on the LCD screen the readings of all virtual on-Board devices

On-board compass is a three-axis magnetometer sensor and its schematic diagram, figure 13.

As can be seen from figure 13, the onboard compass is assembled on the lsm303dlh chip,

which is a 6D sensor module that contains a 3D magnetometer, a 3D accelerometer and a temperature sensor built inside the chip.
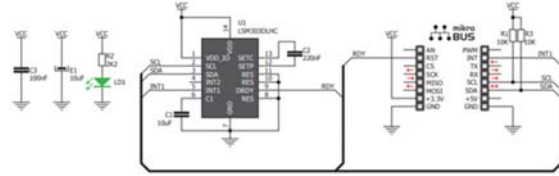

Figure 13: Schematic Diagram Of Digital Compass On Chip LSM303DLHC

In this section, we will only view at the 3D magnetometer. 3D accelerometer and temperature sensor will be used for other on Board devices listed above. This sensor is connected to the autopilot MC. Module of program code which is stitched in MC of the autopilot processes data of the magnetometer. It should be noted the autopilot MC in a certain sequence polls data from the onboard sensors. So, in the same sequence, the program code procedures of the autopilot MC process data from sensors and generates commands for the power plant drivers and servos of ailerons, elevators and directions, as well as in the same sequence sends data from the sensors to the MC transceiver installed on Board the AS UAV.

Flight course determined with the help of a digital compass, in automatic or remote mode. As is known, the flight course of the Air Vehicle (AV) is constantly changing, which requires its constant adjustment in automatic or remote mode (or combined mode). Consider what factors affect the course of flight AV. This is important, because in the process of developing a digital compass, it is necessary to take into account all the factors that negatively affect the operation of the compass and the AV.

The AS UAV is an airplane-type electric glider; thin, flexible plate solar cells are installed on the upper surface of the wing by gluing. The AS UAV course is the angle between two directions in the horizontal plane, of which one serves as a guide for determining the other. Depending on the meridian with respect to which they are reporting, four types of courses are distinguished in air navigation that determine the direction of flight:

- True Heading (TH) - the angle between the north direction of the true meridian and the longitudinal axis of the AS UAV (counted in the direction of clockwise movement from 0 to 360º);

- magnetic course (MC) - the angle between the north direction of the magnetic meridian and the

longitudinal axis of the AS UAV (counted clockwise from 0 to 360º)

- compass heading (CH) - the angle between the north direction of the compass meridian and the longitudinal axis of the AS UAV (measured in the direction of clockwise movement from 0 to 360º);

- conditional course (CC) - the angle between the conditional direction and the longitudinal axis of the AS UAV;

Courses listed above related by the following relationships:

$$TH = MC + (\pm\Delta m); \quad MC = CH + (\pm\Delta k);$$
$$TH = CH + (\pm\Delta) = CH + (\pm\Delta k) + (\pm\Delta m); \quad (1)$$
$$CC = TH + (\pm\Delta a).$$

Where, Δm – magnetic declination: angle between northward direction of true and magnetic meridians (angle is positive if the magnetic meridian is deviated to the right and negative if it is deviated to the left of the true meridian); Δa - azimuthal correction: angle between conditional and true meridian (Δa is counted from the conditional meridian clockwise with a plus sign, counterclockwise with a minus sign); Δk - deviation: the angle between the north direction of the magnetic and compass meridians (the sign of Δk depends on the deviation relative to the magnetic meridian); Δ - variation: the angle between the north direction of the true and compass meridians (the sign of Δ depends on the deviation relative to the true meridian); $\Delta = (\pm \Delta m) + (\pm \Delta k)$.

From the above-considered ratios of courses, it can be seen that the true flight course of the AV is influenced by magnetic declination and deviation, which can vary from the trajectory, flight range, etc. Below we consider the physical, mechanical and electrical processes that affect the course flight parameters, AS UAV.

During the flight of an AV, a practical occurrence of errors and errors in the reading of the magnetic compass, and in our case a digital electronic compass, constantly occurs.

The on-board compass (digital electronic compass) is affected by the AS UAV's magnetic field (metal parts made of soft and hard metal, the electromagnetic field generated by electrical and electronic devices, electromagnetic noise from signal and power conductors, cables, electromagnetic waves emitted and received by transceiver devices and other). Compass error caused by magnetic field.

The on-board compass (digital electronic compass) is affected by the AS UAV magnetic field (metal parts made of soft and hard metal, the electromagnetic field generated by electrical and electronic devices, electromagnetic noise from signal and power conductors, cables, electromagnetic waves emitted and received by transceiver devices and other). Compass error caused by the magnetic field of the AV, itself is called deviation. Dependence of the deviation on the magnetic course of AS UAV in horizontal flight without acceleration is expressed by the following formula:

$$\Delta K = A + B \times sinMC + C \times cosMC + D \times sin2MC + cosE \times cosMC, \quad (2)$$

Where: A - constant deviation; B and C are approximate coefficients of semicircular deviation; D and E are approximate quarter deviation coefficients.

AS UAV course coincides with the direction of movement only with complete calm. The angle between the flight path of the AV and the geographical meridian (north) is called the track angle (TA), and the angle between the flight path of the AV and the magnetic meridian is called the magnetic track angle (MTA). The angle measured on the map between the meridian and the desired flight line is called the set track angle (STA). During the flight AS UAV are influenced by air masses and currents, this direction and wind speed, air density. The wind blows the aircraft away from the taken flight direction. Between the direction of the AV axis (the vector of its airspeed) and the direction of its actual path (the vector of the ground speed of the AS UAV) there is an angle called the drift angle (DA). Knowing the DA, the actual flight direction, i.e. actual magnetic track angle (AMTA), which is calculated by the following expression:

$$AMTA = MC + DA. \quad (3)$$

A negative effect on the operation of the on-board compass influenced by changes in pitch, roll and yaw of the AV. This negative effect called the error from the slope and in the transverse roll of the AS UAV is determined by the following formula:

$$\Delta\Psi = MC - arctg(tgMC \times cos\gamma - ((tg\theta \times sin\gamma)/cosMC)), \quad (4)$$

where: $\Delta\psi$ – error from tilt (roll); θ – angle of magnetic inclination; γ – roll angle; MC – magnetic course.

Vibration and chatter in flight naturally have a negative effect on the compass. Also, the compass

magnetic field has a negative effect on the on-board compass reading.

Where, the magnetic field of the compass, is error of indication arising from magnetic noise created during the operation of electronic elements and devices in the compass, as well as the influence of the properties of the magnet-soft-iron and magnet-hard-iron, i.e. conductors and elements made of non-ferrous and steel metals, which are contained in the compass and can create magnetic, electrical and electromagnetic noise.

In the following paragraphs, we consider methods and measures for performing compensation and reducing the influence of negative processes and factors on the on-board compass.

Before connecting the magnetometer sensor to the autopilot MC, it is necessary to calibrate it. I.e., convert the data to normalized values, set the measurement range, determine the measurement error, eliminate or reduce the above negative factors (noise) affecting the measurement. To do this, each on-Board sensor separately with the help of special technical means, we will conduct their calibration and testing.

With the help of the development Board, figure 14, and a special device with which the magnetometer sensor can be rotated along the X-axis, the Y-axis and the Z-axis, we will calibrate the sensor
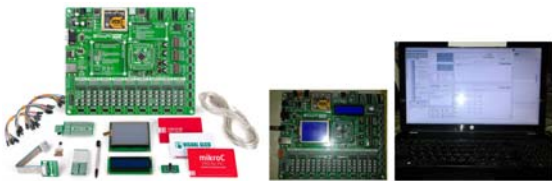

Figure 14: Professional Development Board Easypic PRO V7

Sensor calibration refers to the conversion of the initial data into normalized values for calculating the course and roll of the AV.

4.1 Development of a virtual onboard compass

The magnetometer sensor Connect to MC development of Board, and connect the development Board itself via a USB cable to the PC.

Let's debug the program code, after the syntax and algorithmic errors are eliminated, compile the program, and then perform the procedure of firmware of the MC development Board (programming the MC). As soon as the compiled

(in machine code) program code is loaded into the development Board MC, the automatic MC will start working. Read data from the magnetometer sensor can be viewed in the USB UART port window. Reading data from the magnetometer sensor MC is carried out continuously for six bytes per cycle and the data are expressed on each axis X-Y-Z in numerical values of voltage. Magnetometer scale is set by the program code for setting the registers CRA_REG_M (00h) and MR_REG_M (02h) and has a full-scale value of ±1.3 Gauss and ODR at a frequency of 30Hz. This data need to convert to degrees and set the measurement range from 0 to 360 degrees. To do this, we will add the previously written program code to the function of converting and setting the measurement range.

Created a picture of the front panel of the onboard compass in the graphics editor, figure 14

The onboard compass works as follows. When the course of flight of the AV changes, for example, under the influence of a crosswind, the dial of the compass turns to the appropriate angle. The compass needle remains in place does not turn.

To perform the animation of the onboard compass figure 14.

Figure 14: Front Panel Of Onboard Compass

Now, if these figures in a cycle relative to some Central point, displays on the monitor screen in a certain sequence and the dial in each cycle will be rotated, for example, one degree, then after ten cycles, the dial will rotate ten degrees relative to the center, and thus, the effect of animation of the onboard compass will be created. If you now record the above procedure in a frame animation film, for example, the rotation of the compass dial clockwise and counterclockwise from 0 to 360°, then this frame film (in one frame captured the rotation of the dial by one degree), you can use a virtual instrument. When a signal is received from the magnetometer sensor, for example, 20°, turn on the film scrolling for 20 frames in the appropriate direction of rotation of the dial.

On the basis of the above we will make the program code of animation of operation of the onboard compass,

```
f1=zeros(380,380);
im = imread('C:\Users\SicoMAZ_hp
\Documents\MATLAB\project_2019
\Fig_Compass\Chkala_001.jpg','jpg');
im1 = imread('C:\Users\SicoMAZ_hp
\Documents\MATLAB\project_2019
\Fig_Compass\Strelka_001.jpg','jpg');
im2 = imread('C:\Users\SicoMAZ_hp
\Documents\MATLAB\project_2019
\Fig_Compass\Air_001.jpg','jpg');
im3 = imread('C:\Users\SicoMAZ_hp
\Documents\MATLAB\project_2019
\Fig_Compass\Kvadrat_001.jpg','jpg');
figure('Color','w');
figure(1), imshow(im);
hold on
for j=1:1:20
chk = imrotate(im,j,'bilinear','crop');
% the default method is 'nearest', but 'bucubic'
is much better!
figure(1), set(1,'Color','w','MenuBar','none');
imshow(chk);
image (im1, 'XData', [184 184],
'YData', [67 67]), figure(1),
image(im2, 'XData', [106 106],
'YData', [106 106]);
buff(j)=getframe;

end
movie(buff,1)
movie(mov, j);
montage(MX);
h=montage(MX)
clc;
clear all;
clear buf
```

Development of other onboard devices is similar in structure and algorithm. All listed onboard devices are displayed in real time on the monitor screen of the first operator's workplace.

4.2   The algorithm of the movement between waypoints

One of the common and proven guidance methods for tracking the movement of the AIRCRAFT along the trajectory, is the movement of the AIRCRAFT on a predetermined series of waypoints. The algorithm with the implementation of the movement of the Aircraft on the waypoints is shown below. The advantages of this algorithm are its simplicity, the disadvantage is that the Aircraft does not pass directly through the waypoint, since an arc is added at the end of the trajectory to rotate, and in some cases it is required to pass any waypoint to the end.

Algorithm: Follow the waypoint with rounded:

Input: a trajectory with waypoints $w = \{w_I, \dots, w_N\}$, the situation Aircraft $p = (p_n, p_e, p_d)^T$, radius of curvature R.

1: If a new waypoint of the route has been reached W, then

2: Initialize the index of the waypoint: $i \leftarrow 2$, and the finite state machine state$\leftarrow 1$.

3: end if

4: $q_{i-1} \leftarrow (W_i - W_{i-1})/\|W_i - W_{i-1}\|$

5: $q_i \leftarrow (W_{i+1} - W_i)/\|W_{i+1} - W_i\|$

6: $\varrho \leftarrow < cos^{-1}(-q_{i-1qi}^T)$

7: if state=1, then

8: *flag $\leftarrow$ 1*

9: $r \leftarrow W_{i-1}$

10: $q \leftarrow q_{i-1}$

11: $z \leftarrow W_i - (R/tan(\varrho/2))q_{i-1}$

12: if $p \in H(z, q_{i-1})$, then

13: *state $\leftarrow$2*

14: end if

15: otherwise, if state=2, then

16: *flag$\leftarrow$2*

17:     $c \leftarrow W_i - (R/sin(\varrho/2))(q_{i-1} - q_i)/\|q_{i+1} - q_i\|$

18: $c \leftarrow R$

19: л$\leftarrow sign(q_{i-1,n}q_{i-1,e}q_{i,n})$

20: $z \leftarrow W_i + (R/tan(\rho/2))q_i$

21: if $p \in H(z, q_i)$, then

22: *i $\leftarrow$(i+1)* until, *i=N-1*

23: *state$\leftarrow$1*

24: *end if*

25: *end if*

26: return flag, r, q, c, ρ, λ.

Elimination of the above drawback of the algorithm is possible with the addition of the Dubins trajectory to this algorithm. In this case, computing processes are significantly increased, which for our microcontroller in autopilot will be difficult to implement in time and memory. In the future, during laboratory and field tests of the experimental model of the UAV AS, it will be found out whether there is a need to add an additional MC and a memory chip to the autopilot circuit to perform the above computational processes.

5. CONCLUSIONS AND FUTURE DIRECTIONS

The following results were obtained from the work done:

- developed structure and composition of ACS and AWM operators AS UAV;

- developed the functional scheme of automation, basic electric and electronic schemes of automation, schemes of traces of electric and signal wires and cables;

- developed transfer functions and linear models in the space of States of lateral and longitudinal motion of AV with a constant wing area;

- designed the autopilot for the AS UAV and software codes;

- developed virtual onboard devices and their program codes;

- structured and defined mathematical models for flight parameters control (course, pitch, roll);

- structured and defined mathematical models for linear and circular motion control AV;

- developed algorithms for route management subsystem;

- разработаны алгоритмы для подсистемы управления маршрутом

Experimental prototype AS UAV made in LLP "SP RoboAvia" according to the designed drawings. This enterprise is located in the industrial zone of Shymkent city (Kazakhstan). As the manufacture of separate knots and blocks of enterprise LLP " SP RoboAvia " will be conduct laboratory tests. Measuring instruments, test benches for laboratory tests are available.

At the moment, developed on-Board devices have been prepared for laboratory tests. As well as work has begun on testing the gyroscope.

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