DEVELOPMENT OF ON-BOARD VIRTUAL INSTRUMENTS FOR THE ATMOSPHERIC SATELLITE

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ABSTRACT

The article deals with the development of an onboard digital compass of an atmospheric satellite in the form of an unmanned aerial vehicle, which is determined by the course of flight. The factors, physical, mechanical and electrical processes that affect the readings of a digital compass and, accordingly, the course of the aircraft, which must be taken into account in the process of developing and calibrating the digital compass are also considered. This is, for example, the magnetic field of an unmanned aerial vehicle itself, that is, the magnetic field, the field arising from metal parts, the electromagnetic field generated by electrical and electronic devices, the electromagnetic noise from signal and supply conductors, cables, the electromagnetic waves emitted and received by transceiver devices, etc. It is explained the negative influence of changes in the flight of an unmanned vehicle on an electronic compass. The article presents a schematic diagram of the digital onboard compass.

Key words: atmospheric satellite, aircraft, course of flight, magnetic compass.

INTRODUCTION

With the help of a digital compass, in automatic or remote mode, the course of flight of aircraft is determined. As you know, the course of flight of the aircraft due to the influence of various factors can change, which requires constant adjustment in automatic, remote or combined mode.

Consider the factors that affect the digital compass readings. This is of paramount importance, because in the process of developing and calibrating a digital compass, it is necessary to take into account all these factors that directly affect the operation of the compass and, accordingly, the course of the aircraft.

The onboard compass is a three-axis magnetometer sensor assembled on the lsm303dlh chip, which is a 6D sensor module consisting of a 3D magnetometer, a 3D accelerometer and a temperature sensor integrated into the chip (Fig. 1). The 3D accelerometer and temperature sensor included in the chip are used for other onboard instruments.

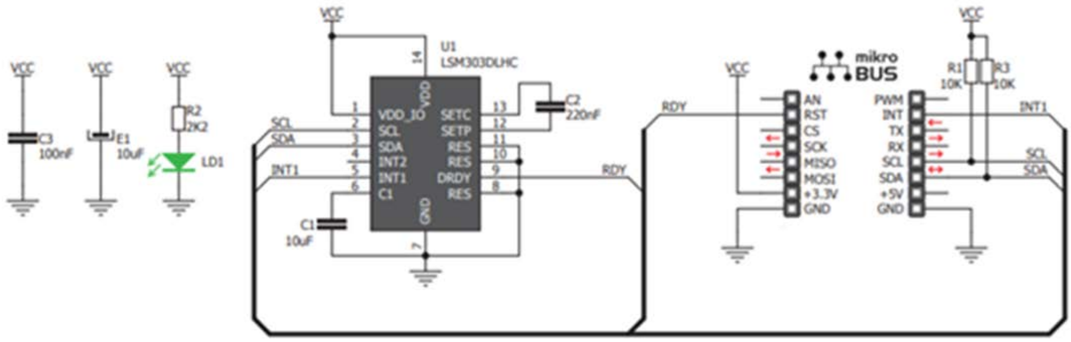

Fig 1. Schematic diagram of the digital compass on the chip LSM303DLHC

MATERIALS AND METHODS

The autopilot microcontroller (hereinafter MC) processes the data of the magnetometer connected to it. It should be noted that the autopilot microcontroller interrogates and processes all onboard sensors in a certain sequence. Based on this data, the microcontroller generates commands for the power plant drivers, Aileron servos, Elevator and rudders, and sends data from the sensors to the transceiver installed on Board the atmospheric satellite.

The course of an atmospheric satellite in the form of a UAV is the angle between two directions in the horizontal plane, of which one serves as a guide to determine the other. Depending on the Meridian with respect to which the report is conducted, in air navigation there are four kinds of courses that determine the direction of flight (Fig. 2).

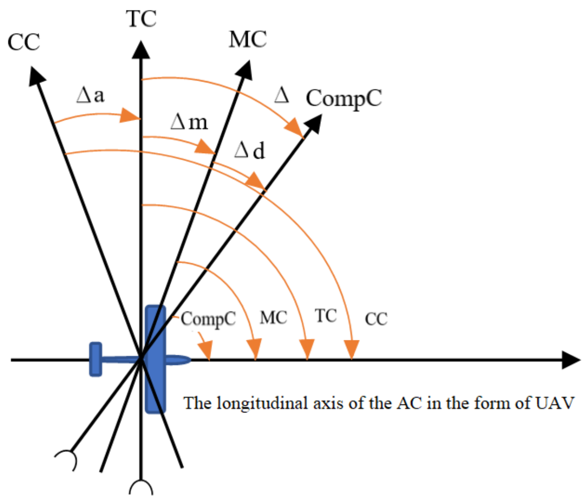

Fig 2. UAV Courses

TC-true course-the angle between the North direction of the true Meridian and the longitudinal axis of the UAV (measured in the direction of clockwise movement from 0 to 360º);

MC-magnetic course-the angle between the North direction of the magnetic Meridian and the longitudinal axis of the UAV (measured clockwise from 0 to 360º);

CmpC-compass course-the angle between the North direction of the compass Meridian and the longitudinal axis of the UAV (measured in the direction of clockwise movement from 0 to 360º);

CC-conditional course-the angle between the conventional direction and the longitudinal axis of the UAV AU.

The above courses are linked by the following relationships:

$$\begin{aligned} &TC = MC + (\pm\Delta m); \\ &MC = CmpC + (\pm\Delta d); \\ &TC = CmpC + (\pm\Delta) = CmpC + (\pm\Delta d) + (\pm\Delta m); \\ &CC = TC + (\pm\Delta a). \end{aligned} \tag{1}$$

Where, Δm is the magnetic declination: the angle between the North direction of the true and magnetic meridians (the angle is positive if the magnetic Meridian is deflected to the right and negative if it is deflected to the left of the true Meridian);

Δa -azimuthal correction: the angle between the conditional and the true Meridian (Δa is counted from the conditional Meridian clockwise with a plus sign, counterclockwise with a minus sign);

Δd -deviation: the angle between the North direction of the magnetic and compass meridians (Δd sign depends on the deviation relative to the magnetic Meridian);

Δ-variation: the angle between the North direction of the true and compass meridians (sign Δ depends on the deviation relative to the true Meridian); Δ = (±Δm) + (±Δd).

From the above considered ratios of courses it is clear that the true course of flight of the aircraft 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 of the atmospheric satellite in the form of a UAV.

During the flight, the aircraft is practical constantly, there is an occurrence of errors and errors of the magnetic compass, and in our case, a digital electronic compass. The indication of the onboard digital electronic compass is influenced by the magnetic field of the UAV itself, i.e. arising from metal parts, the electromagnetic field generated by electrical and electronic devices, electromagnetic noise from signal and supply conductors, cables, electromagnetic waves emitted and received by transceivers, etc. Compass error caused by the magnetic field of the aircraft is called deviation. The dependence of the deviation from the magnetic course of the atmospheric satellite in the form of a UAV in horizontal flight without acceleration is expressed by the following formula:

$$\Delta d = A + B \times \sin MC + C \cos MC + D \sin 2MC + \cos E \cos MC, \tag{2}$$

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

The course of the atmospheric satellite in the form of a UAV coincides with the direction of its movement only when there is no wind. The angle between the path line of the aircraft and the geographic Meridian (North) is called the track angle (TA), and the angle between the path line of the aircraft and the magnetic Meridian is called the magnetic track angle (MTA). The angle measured on the map between the Meridian and the required flight line is called the specified path angle (SPA). The atmospheric satellite in the form of a UAV during the flight is influenced by air masses and flows, this is the direction and speed of the wind, the density of the air. The wind blows the aircraft away from the taken direction of flight. Between the direction of the axis of the aircraft-the vector of its air speed and the direction of its actual path - the vector of the ground speed of the aircraft, there is an angle called the drift angle (DA). Knowing the drift angle and the magnetic course (MC), we calculate the actual direction of flight, i.e. the actual magnetic track angle (AMTA), according to the following expression:

$$AMTA = MC + DA \tag{3}$$

The negative impact of these factors on the operation of the onboard compass is manifested in the process of changing the pitch, roll and yaw of the aircraft. This negative effect is called the error of the slope and the transverse roll of the atmospheric satellite in the form of a UAV and is determined by the following formula [1]:

$$\Delta\psi = MC - arctg(tgMC \times \cos\gamma - (\frac{tg\theta \times \sin\gamma}{\cos MC})), \tag{4}$$

where: $\Delta\psi$-the error of the slope (roll), θ – the angle of magnetic inclination, γ – the angle of the roll, MC – the magnetic course.

Vibration and turbulence in flight naturally has a negative impact on the compass reading. Also, the magnetic field of the compass has a negative impact on the reading of the onboard compass. Error readings arising from magnetic noise generated 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, ie conductors and elements made of non-ferrous and steel metals contained in the compass and can create magnetic, electrical and electromagnetic noise.

RESULTS AND DISCUSSION

Before connecting the magnetometer sensor to the autopilot MS, 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 calibrate and test them.

Using the development Board (Fig. 3) and a special device with which the magnetometer sensor can be rotated along the X-axis, Y-axis and Z-axis, we will calibrate the sensor.

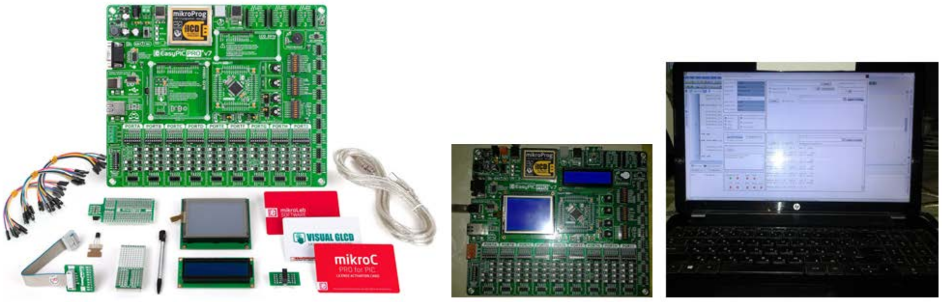

Fig 3. EasyPIC PRO v7 Professional development Board

Sensor calibration refers to the conversion of input data into normalized values to calculate the course and roll of an aircraft.

To do this, the magnetometer sensor is connected to the microcontroller of the development Board, and the development Board via a USB cable to a PC.

Next, the program code is compiled to read data from the magnetometer sensor in the software environment mikroBasic PRO for PIC. The program code is debugged, after syntax and algorithmic errors are eliminated, the program is compiled, and then the procedure of firmware of the microcontroller of the development Board (programming of the microcontroller) is performed. The microcontroller will automatically start working as soon as the machine-compiled program code is loaded into the microcontroller of the development Board. Read data from the magnetometer sensor can be viewed in the USB UART port window. Reading data from the magnetometer sensor by the microcontroller is carried out continuously for six bytes per cycle and the data is expressed on each axis X-Y-Z in numerical voltage values. The 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 30 Hz. This data must be converted to degrees and the measurement range must be set from 0 to 360 degrees. To do this, the previously written program code is added to the conversion function and setting the measurement range.

The relationship between normalized Mx1, My1, and Mz1 and raw measurements of the Mx, My, and Mz magnetic sensor can be expressed as [2]:

$$\begin{bmatrix} M_{x1} \\ M_{y1} \\ M_{z1} \end{bmatrix} = \left[M_{-m}\right]_{3\times3} \begin{bmatrix} \frac{1}{M_{-SC_x}} & 0 & 0 \\ 0 & \frac{1}{M_{-SC_x}} & 0 \\ 0 & \frac{1}{M_{-SC_x}} & 0 \end{bmatrix} \times \left[M_{-si}\right]_{3\times3} \begin{bmatrix} M_x - M_{-OS_x} \\ M_y - M_{-OS_y} \\ M_z - M_{-OS_z} \end{bmatrix} = \tag{5}$$

$$= \begin{bmatrix} MR_{11} & MR_{12} & MR_{13} \\ MR_{21} & MR_{22} & MR_{23} \\ MR_{31} & MR_{32} & MR_{33} \end{bmatrix} \times \begin{bmatrix} M_x - MR_{10} \\ M_y - MR_{20} \\ M_z - MR_{30} \end{bmatrix}$$

where [M_m] is the 3x3 displacement matrix between the magnetic sensor reading axes and the device housing axes; M_SCi (i = x, y, z) is the scale factor, and M_OSi is the displacement caused by hard distortion; [M_si] is the 3x3 matrix caused by soft iron distortion.

To display the converted data from the magnetometer sensor on the monitor screen, a program is compiled in the MatLab software environment.

The purpose of magnetic sensor calibration is to determine the parameters from MR10 to MR33 so that any given raw measurements at arbitrary positions can produce normalized values.

Next, the data obtained from the magnetometer is visualized. To do this, the magnetometer must be rotated around the z axis, and the program will record the sensor readings.

CONCLUSION

Laboratory and field tests of the compass and other on-Board instruments are carried out when an experimental model of an atmospheric satellite in the form of a UAV is made. Since the location of onboard sensors, electrical and electronic devices in the aircraft body relative to each other (wings, tail, fuselage) is very important, since they can significantly affect each other and thus create measurement errors.

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