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INFLUENCE OF MAGNETIC FIELD CREATED BY UAV MOTORS ON ACCURACY OF FLIGHT CONTROL

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Abstract—*The article deals with the problem of researching the influence of the magnetic field caused by unmanned aerial vehicle navigation equipment. The possibilities of using magnetometric information in modern aviation are analyzed. The process of integrating inertial sensors and magnetometric devices for determining moving vehicle orientation is shown. The tested unmanned aerial vehicle, and attitude and heading reference system, which is used for magnetic heading determination, are described. Features of the experimental test and sequence of its stages are represented. The results of the experiment are given in a graphical way. The analysis of the obtained results is represented.*

Index Terms—Control signals; experimental test; integration; magnetic heading; orientation; unmanned aerial vehicle.

I. INTRODUCTION AND PROBLEM STATEMENT

Nowadays unmanned aerial vehicles (UAVs) are developed and operated in many countries. The modern approach to navigation measurements on UAVs is the integration of inertial sensors, magnetometers, and other sensors [1]. The modern inertial sensors based on micro-electromechanical systems and miniature magnetometers allow us to design the compact navigation system, which provides determining coordinates of UAV location and heading. As a rule, three-axis MEMS rate gyroscopes, MEMS accelerometers, and magnetometers are used in modern unmanned aviation [2]. Using magnetometers provides wide possibilities for unmanned aviation. It provides determining heading, improvement of navigation measurements by means of integration. At the same time magnetometer readings can be distorted by magnetic fields caused by the operation of UAV motors [3].

The theory of airborne magnetometer measurements is constantly developed. Creating new information-computer technologies, digital computing aids, the high-sensitive and high-precision magnetometers leads to solving navigation and orientation problems on a higher level [4].

The use of properties of the terrestrial magnetic field in navigation systems allows determining the heading, the speed, the location coordinates, and the spatial orientation of a moving object [5]. The information on the terrestrial magnetic field is also used during braking, manoeuvres, and determination of the orientation of a spacecraft. Operation of the navigation systems using information about the terrestrial magnetic field becomes complicated due to a high level of noise owing to the presence of the magnetic field sources at the moving object itself and owing to the random fluctuations and magnetic storms that influence parameters of the terrestrial magnetic field. For effective elimination of this noise, it is necessary to compensate for the external magnetic disturbances and to filter the random noise.

The idea of integrating navigation and orientation aids is known many years. The way of integrating inertial and geomagnetic aids is one of the most perspective directions for solving navigation problems [6].

The comparative analysis of information properties of geophysical fields shows that the terrestrial magnetic field is more informative in comparison with gravity field, Earth rotation field, and other geophysical fields. At the same time, the geomagnetic field is more sensitive to the influence of various disturbances [7]. The block-diagram of the device for determining orientation using magnetometers is represented in Fig. 1 [8], [9]. The geomagnetic model of the Earth was determined on the basis of long-term measurements of parameters of the terrestrial magnetic field and their statistical processing. The terrestrial magnetic field, as well as any other magnetic field, is characterized by its strength. The strength vector of the terrestrial magnetic-field consists of such components [10]

$$T = T_D + T_C + T_A + dT_V , \quad (1)$$

where T_D is the vector of strength of the dipole field caused by the uniform magnetization of the terrestrial globe; T_C is the vector of strength of the continental field conditioned by magnetic properties of the heterogeneous inner layers of the Earth; T_A is the vector of strength of the anomalous field caused by magnetization of rocks of the Earth's crust; δT_V is the vector of strength of the field of the geomagnetic variations conditioned by magnetic field sources external relative to the Earth.

The intensity and spatial distribution of the anomalous field are defined by the magnetic properties of the Earth's crust, depth of location of the magnetized layers, and the geological structure of the Earth's crust.

So, for the moving object, the anomalous field has a random spatial distribution and may be described by a random stationary function dependent on the geographical location.

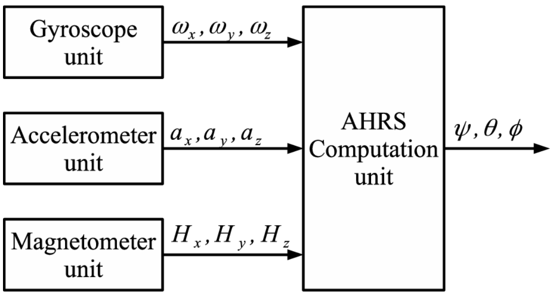

Fig. 1. The block-diagram of attitude and heading reference system

It should be noted that readings of the magnetometers can be distorted by the electromagnetic field caused by the equipment of UAV. Electric motors are exactly devices able to distort navigation information measured by magnetometers. The magnetic field sensed by magnetometers at UAV can be described by the formula

$$T_S = T + T_E, \tag{2}$$

where T_E is the magnetic field caused by the influence of UAV motors, namely, DC electric motors.

Projections of the vector H on the body-axis reference frame correspond to readings of magnetometers with sensitivity axes oriented relative to the ahead mentioned reference frame. Correlations between magnetometer readings and projections of the vector of terrestrial magnetic field strength (1) on the axes of the geographical reference frame can be determined in the following way [8], [9]

$$\begin{aligned} H_{Sx} &= H_{Sg}\sin\psi_m\cos\gamma - H_{Szg}\cos\vartheta\sin\gamma \\ &\quad + H_{Sg}\cos\psi_m\sin\vartheta\sin\gamma, \\ H_{Sy} &= H_{Sg}\cos\psi_m\cos\vartheta + H_{Szg}\sin\vartheta, \\ H_{Sz} &= H_{Sg}\sin\psi_m\sin\gamma + H_{Szg}\cos\vartheta\cos\gamma \\ &\quad - H_{Sg}\cos\psi_m\, sin\,\vartheta\cos\gamma, \end{aligned} \tag{3}$$

The expression (3) takes into consideration (2). Based on (3), the magnetic heading is determined

$$\sin\psi_m = \frac{(H_{Sx}\cos\gamma + H_{Sz}\sin\gamma)}{H_{Sg}}. \tag{4}$$

Transformation of the magnetic heading in the geographical heading can be carried out based on information about the magnetic inclination [9]

$$\psi = \psi_m + d = \operatorname{arctg}\frac{H_{Sx}}{H_{Sy}} + d, \tag{5}$$

where d is an angle of the magnetic inclination.

Analysis of expressions (4), (5) shows the influence of the accuracy of magnetometer readings on the quality of navigation. It should be noted that the influence of magnetometer information accuracy on navigation information accuracy is not studied enough yet. An experimental test of the influence of magnetic information distortions on the accuracy of a magnetic survey by means of UAV is described in [11]. The source of magnetic distortions is believed to be the electro-magnetic field of DC electric motors.

The novelty of the proposed approach in this paper is that influence of magnetic distortions on determining the magnetic declination is studied. Moreover, the features of experimental tests differ significantly. In the proposed experiment, the measurement of magnetic declination is carried out by the high-precision attitude and heading reference system, which is mounted on UAV. Unmanned aerial vehicle was fixed at the definite altitude, and influence of the distorted magnetic declination on control signals of UAV is studied. (To exclude motion of UAV, the power of DC electrical motor is forcibly diminished). Theoretically, the possibility of determining the influence of the electrical motor magnetic field on control signals is based on the Biot–Savart law [11]

$$B_i = \frac{\mu_0}{4\pi}\int_c \frac{I_i dl \times r_i'}{|r_i'|^3},$$

where μ_0 is the magnetic constant; I is a current; dl is the vector along with the path c which magnitude is equivalent to the length of the differential element of the wire in the direction of the conventional current; $r' = r - l$ is the full displacement vector from the wire element *dl* at the point *l* to the point at which the magnetic field is being computed (*r*).

The problem statement can be formulated in the following way. It is necessary to study the influence of the electromagnetic field caused by UAV motors on the accuracy of magnetometer measurements in an experimental way.

The proposed research can be especially important for Arctic districts. These districts are characterized by the great value of the magnetic declination, sharp changes, presence of magnetic anomalies, and storms. This is caused by the proximity to the North Pole.

Arctic districts differ from other terrestrial districts by the distribution of the terrestrial magnetic field. Non-stable readings of magnetometric devices are caused by a small value of the horizontal component of the terrestrial magnetic field [12].

The stored statistics, which can be obtained during similar experimental tests, will be useful for UAV navigation.

II. Description of Tested Device

The studied UAV represents a Tarot X6 hexacopter Build Kit [13]. The tested UAV has some basic specifications including a motor to motor spacing 960 mm, propeller standard 18", arm's length 392mm, arms weight 113 g, mainframe diameter 28 mm, ground clearance 328 mm, hovering time 15 to 17 min. The hexacopter includes motorized Landing Gear. Flip a switch on the RC controller and the landing gears will retract or deploy in mid-air. After the flight, it is necessary simply to flip the locks on each arm and pack it up. The appearance of this unmanned aerial vehicle is represented in Fig. 2. It includes such basic components as the frame, motor, and controller. The Tarot X6 airframe is assigned for carrying heavy 3-axis gimbals and cameras. The airframe has very useful features such as an integrated PCB board, which provides easy cabling. Foldable arms are convenient for fast transporting without any additional equipment. The motorized gear provides turns of the camera on 360 degrees [13]. The advantages of the airframe are also the low center of gravity of the mounted battery that provides the better stability of the flight. Dampers minimize the vibration of propellers.

Motor Tarot 5008 is very powerful. The motor is designed by brushless technology. Driving brushless motor is implemented by an electronic speed controller.

Magnets used in brushless motors are graded according to their magnetic field strength. The higher the number, the stronger the magnetic field. A stronger magnetic field is theoretically capable of generating power more efficiently, providing more torque and a faster motor response time.

Fig. 2 The hexacopter

At the same time, the magnetic field created by the motors can influence on navigation measurements implemented by magnetometers. Of course, this leads to distortion of control actions providing UAV flight.

III. Description of Measuring Device

Measurement of magnetometric information is implemented by attitude and heading reference system (AHRS).

The measuring unit is a solid-state sensor, which implements angular rate, linear acceleration, and magnetic field measurements. Such instrumentation allows the creating of electronically stabilized strap-down attitude and heading reference system [14].

From the point of view of traditional gyroscopic devices, the above-mentioned attitude and heading reference system carries out functions of the directional gyroscope. A strap-down attitude and heading reference system consists of three sensors providing measurements of roll, pitch, and heading. The AHRS is shown in Fig. 3.

Fig. 3. Attitude and heading reference system

IV. EXPERIMENTAL RESEARCH

It should be noted that dynamic interference on the UAV board is determined basically by the influence of DC electric motors. As is mentioned in [15], the dependence of the magnetic noise signal of a DC motor on low to high speed is approximately linear. In other words, the magnetic field changes approximately linearly.

If the motor speed is a constant value, the generated magnetic field is also a fixed value. There is a one-to-one correspondence between the current intensity flowing through the motor and the motor speed. There is also a one-to-one correspondence between the current intensity and the generated magnetic field interference. That is, the magnetic field noise is proportional to the equivalent current strength of the motor [15]. This feature allows us to carry out appropriate measurements. The illustration of the experimental research is shown in Fig. 4. The experiment results are shown in Fig. 5.

It should be noted that the modern UAVs, as a rule, use the brushless electric motors. Rotation of the rotor is carried out by changing the direction of the magnetic field in rotor windings in definite ordering.

In this case, the constant magnets interact with the rotor magnetic fields and drive the moving stator. By itself, the magnetic field is not completely closed inside the motor and is partially radiated into the external environment due to the imperfect design [13]. For the achievement of accurate measurement of the magnetometer readings, it is necessary to provide the rigid fixation of the measuring instrument.

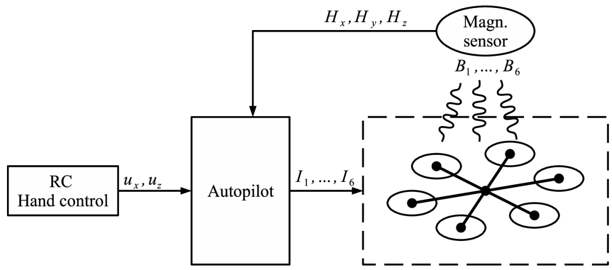

Fig. 4. The illustration of the experimental research

In other words, AHRS is rigidly mounted on the case of UAV. It should be noted that the hexacopter has been mounted in the smooth area. It stayed immovable during the experiment.

The experiment includes the following stages. (The numbers of stages correspond to numbers given in Fig. 5.)

1. At the initial stage, the power part of the hexacopter was not switched to the power supply. This allowed us to determine initial readings of the magnetic heading.

2. To determine the influence of the presence of currents in the power part on readings of the magnetometers, electric motors have been functioned on 30% of the power. This limitation is necessary for elimination hexacopter take off and providing its immovability.

3-11. To determine the influence of changing a level of control signals in power channels, we used a combination of commands of the maximum level assigned for lateral and longitudinal displacements of the hexacopter.

12. Checking residual deviation of magnetometer readings was carried out in conditions of absence of control commands.

13. Checking residual deviation of magnetometer readings was carried out in conditions of absence of power supply of the power part.

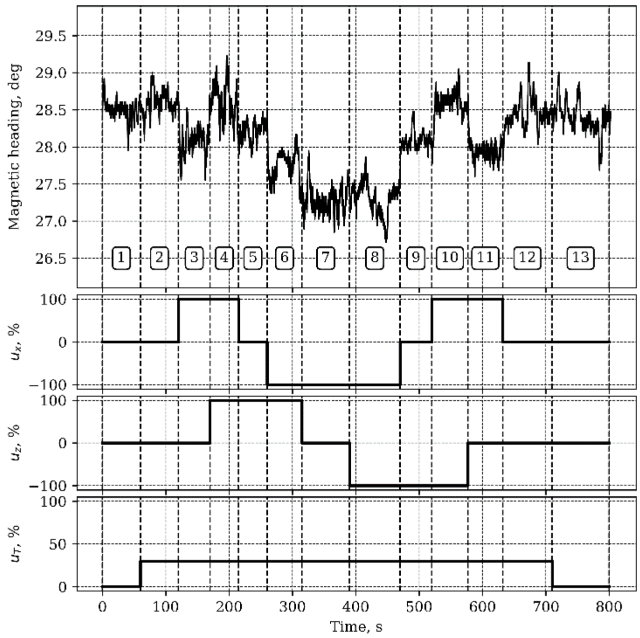

Fig.5. Experiment results: *Ux* is a signal of the longitudinal control; *Uz* is a signal of the lateral control; *Ut* is a signal of motor trust

Analysis of experiment results allows making the following conclusions. The clear deviation of magnetic compass readings on currents of hexacopter power plant takes place. In the future, the proposed approach can be developed in the part of using high-precision inertial sensors [15].

V. CONCLUSIONS

Presence of such a deviation is typical for aircraft with the electrical drive. It is known that the above-mentioned deviation depends on a level of control signals. Therefore, it is possible to use the possibility introducing the additional correction of magnetic compass readings. Such an approach can be used for aircraft with electrical drive and integrated aviation system. It should be noted that possibilities of the geomagnetic navigation are not fully studied yet. Improvement of determining orientation parameters can be achieved by using stabilized platforms for mounting inertial sensors [16]. Moreover, the possibilities of geomagnetic navigation can be used for autonomous determination of orientation parameters [6].

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Ю. М. Безковорайний, О. А. Сущенко, О. М. Мелащенко. Вплив магнітного поля, що створюється електродвигунами БПЛА, на точність керування польотом

У статті досліджується вплив зовнішніх магнітних полів на навігаційне обладнання безпілотного літального апарату. Проаналізовано можливості використання магнітометричної інформації у сучасній авіації. Показано процес інтеграції інерціальних та магнітометричних датчиків для визначення орієнтації рухомих об'єктів. Досліджено вплив бортових джерел змінного магнітного поля на точність визначення орієнтації безпілотного літального апарату.

Ключові слова: сигнал керування; експериментальне дослідження; інтеграція; магнітний курс; орієнтація; безпілотний літальний апарат.

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Ю. М. Безковорайний, О. А. Сущенко, О. М. Мелащенко. Влияние магнитного поля, создаваемого электромоторами БПЛА, на точность управления полетом

В статье исследуется проблема исследования влияния внешних магнитных полей на навигационное оборудование беспилотного летательного аппарата. Проанализированы возможности применения магнитометрической информации в современной авиации. Показан процесс интеграции инерциальных и магнитометрических датчиков для определения ориентации подвижных объектов. Исследовано влияние бортовых источников переменного электромагнитного поля на точность определения ориентации беспилотного летательного аппарата.

Ключевые слова: сигнал управления; экспериментальная проверка; интеграция; магнитный курс; ориентация; беспилотный летательный аппарат.

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