DESIGN OF AN UNMANNED HELICOPTER SYSTEM FOR COLLECTION AND PROCESSING OF GEOPHYSICAL INFORMATION

Anastas Madzharov
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
a.madzharov@ir.bas.bg

Stefan Hristozov
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
st.hristozov@ir.bas.bg

Neda Chehlarova
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
nedachehlarova@ir.bas.bg

Rumen Georgiev
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
r.georgiev@ir.bas.bg

Ivan Gaidarski
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
ivangaidarski@ir.bas.bg

Alexander Alexandrov
Unmanned Robotics Systems Laboratory
Institute of Robotics-Bulgarian Academy of Sciences
Sofia, Bulgaria
akalexandrov@ir.bas.bg

***Abstract*— The report summarizes the possibilities for making geophysical measurements using unmanned aircraft system. A justification is given for the need for these measurements and conclusions about their suitability.**

Keywords — UAV, Unmanned Aircraft System, Gravitation Measurement System

I. INTRODUCTION

There are two concepts for building a defense capability "Aerial surveillance and reconnaissance with UAV by the Armed Forces of the Republic of Bulgaria" [4, 5]. They contain the following main tasks:

- aerial reconnaissance over zones, areas and roads;
- aerial surveillance of certain areas of special interest;
- participation in target identification and target allocation;
- targeting of highly accurate guided ammunition;
- assessment of destruction results;
- digital mapping for combat application purposes;
- cadastral survey of regions and territories.

These tasks are impossible without achieving high accuracy in determining the location of the helicopter above the ground and the inclination of its fuselage. It is necessary to ensure that the accuracy is maintained throughout the flight and it is not affected by atmospheric conditions, nor it change according to the planned parameters.

The necessary and effective accuracy is achieved when we use an Unmanned Aerial System (UAS) to perform all the basic tasks described in both concepts [4, 5]. It is necessary to define the purpose and tactical-technical characteristics of each component of this system.

Concept [4] defines the following components of the unmanned aerial system:

- aircraft / helicopter;
- payload;
- management team/ground crew;
- control systems;
- data transmission lines;
- logistics segment.

This functional separation is not appropriate when describing the composition of the unmanned aerial complex and should be specified in more detail, according to the purpose of the system and the purpose of each technical component of it. The UAV complex consists following a concept [5]:

„There are already proposed options for acquiring UAVs and after analyzing the possible options for building the "Aerial surveillance and reconnaissance with unmanned aerial systems by the Armed Forces of the Republic of Bulgaria" capability, the following three options are proposed:

- A united UAVs with centralized subsystems for command, control, communication, processing and distribution of information to users, with unitary subsystems for logistics, training of personnel and the possibility of decentralized use of components.

- Decentralized UAVs with independent components of different categories UAV for the types of military forces and independent subsystems for logistics and personnel training. “

It is not clear in both concepts what exactly an unmanned complex should contain as a technical implementation.

II. GEOPHYSICAL RESEARCH SYSTEM AS A REMOTELY CONTROLLED FLIGHT SYSTEM

The theoretical possibility of aviation gravimetry [2] awaits the following questions. Are there enough accurate sensors to measure linear accelerations and angular

THIS WORK WAS SUPPORTED BY THE NSP DS PROGRAM, WHICH HAS RECEIVED FUNDING FROM THE MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF BULGARIA UNDER THE GRANT AGREEMENT NO. Д01-74/19.05.2022.

velocities? How to use mathematical models for inertial sensor errors in Gravity Measured System algorithms [1]? How to use second derivatives of the Gravitational potential in these algorithms? Are the Eötvös effect and the Fai anomaly in free air enough compensated for in flight [1, 3]? The answers to these questions continue to be sought. New technical devices appear, initially as laboratory samples and then as industrial products. They are developed, refined and tested for measurement accuracy. Scientific research begins with the creation of new methods for measuring linear accelerations and angular velocities, continues with the improvement of technical instruments, studying their errors in measuring the relative force of weight and the angular speed of the Earth's diurnal rotation. New methods and algorithms for complex processing from multiple sensors are being created. The development of science and technology is reflected in the continuous improvement of standardization documents [6÷9].

The required accuracy to be achieved is with a probable circular position error of no greater than 5 meters and a maximum angular stabilization error of up to 12 arcminutes. Such error values are possible only when using high-tech inertial sensors, sensors for the Earth's magnetic field, and the measurement the parameters of the Earth's atmosphere. Complexing with a Kalman filter of navigation systems operating on different physical principles has been in practice for a long time. This filter has the property of reducing the probable circular error of the navigation complex in determining a location below the error value for each navigation system taken separately. It can be adaptive to individual sensor errors by automatically returning to the statistically measured rms of the input sensors. A Kalman filter is a mathematical algorithm that processes measured values from the systems at points 1.1.4.2÷5 and 1.2.2.

A. Structure of a Remotely Controlled Flight System

1. Aircraft / helicopter.
1.1. On-board equipment.
1.1.1. Telecommunication control channel.
1.1.2. Telecommunication channel for data exchange with the Ground Control Station (GCS).
1.1.3. DGPS receiver.
1.1.4. Navigation complex.
1.1.4.1. Autopilot with actuators.
1.1.4.2. Inertial Navigation System (IMU) - one or several.
1.1.4.3. Magnetometric unit (magnetic compass) - one or several.
1.1.4.4. Aerometric unit with air pressure receiver - barometer, aerometer, thermometers.
1.1.4.5. GPS receiver - one or several.
1.1.5. FPV (First Person View) camera.
1.2. Additional systems, optionally located in the aircraft or in a suspended container (payload) - one or several.
1.2.1. Electro-optical monitoring system.
1.2.1.1. Daytime surveillance video camera.
1.2.1.2. Video camera for night surveillance.
1.2.1.3. Laser range finder.
1.2.1.4. Laser target designator.
1.2.1.5. Selector for moving targets - MTI (Moving Target Indicator) radar.
1.2.2. Correlational Extreme Navigation System.

2. Ground Control and Monitoring Station (GCS).
2.1. Aircraft control telecommunications channel.
2.2. Telecommunication channel for data exchange.
2.3. Ground DGPS station.
2.4. A telecommunications channel to centralized subsystems for command, control, communication, processing and distribution of information to authorized users.

B. Optimization aim: Weight, Overall Size, Accuracy vs. Cost

There is a desire to put as many on board an aircraft possible and operate on a different principle (or the same type, but from different manufacturers) navigation systems corresponding to the requirement for **the minimum flight weight of the equipment and the maximum duration of the flight**. In this incongruity, opportunities are sought to achieve optimal operational (combat) capabilities. It is resolved in the design stage of the aircraft, when there is a possibility of different equipment, according to the assigned flight task. This incongruity cannot be avoided even at the stage of purchasing a new product. To solve it, it is necessary to follow the following scheme.

First, the main operational (combat) tasks must be specified to individual flight tasks.

Second, for each type of flight assignment, an engineering-navigator calculation is carried out, i.e. the required fuel is calculated (as a weight quantity) and taking into account the profile of the flight path, at set speeds and altitudes.

The aircraft has a payload as a technical characteristic. It includes the fuel necessary for the flight, the useful equipment that is in the body of the apparatus and what can additionally be attached, according to the requirements of the specific flight task being performed.

Third, according to the operational requirements for each flight task, the weight of the necessary equipment is calculated, and it should not exceed the value for the payload minus the fuel weight. When purchasing equipment, the optimization of the payload in terms of price and technical capabilities is sought, so that the least amount of fuel is consumed and the aircraft remains in flight as long as possible.

III. PHASES OF BUILDING A GEOPHYSICAL RESEARCH SYSTEM AS A REMOTELY CONTROLLED FLIGHT SYSTEM

Geophysical research system as a remotely controlled flight system (fig. 1) is a remotely controlled aircraft with reconnaissance containers or specially equipped for the purpose with GPS receivers, magnetometers, inertial sensors, barometers and airspeed meters. Airplanes with a payload of up to 5 kg and a flight time of up to 30÷60 minutes or helicopters of this class are used. To increase the range and altitude of the flight, a control system with more than one ground station tied to the State Geodetic System is being deployed.

The ground station of the system controls unmanned vehicles in the air, collects and processes the measured information from the primary sensors of the systems from points 1.1.4.2÷4. The ground unit for control and monitoring consists of mobile and stationary telecommunications points tied to the state geodetic system. The ground station provides server services to users and communicates with other user information systems.

A **method** [1] has been proposed and a specific scheme of a technical system for aerogravity measurements at low altitude flight has been developed. It is called the Gravitation Measurement System (GMS). The method assumes the presence of a middle precision Attitude and Heading Reference System (AHRS), located in the centre of mass of the aircraft, two GPS receivers and a number of high precision accelerometers located symmetrically to the centre of mass (fig. 1). The method is based on a mathematical model for converting the measurements of the accelerometers into a single rigid body navigational frame. This method solves two main tasks. The first is navigational and is decided by the measurements of the GPS and the main AHRS. The navigation parameters of the flight are determined with high accuracy. They are then used in the second gravitational problem, which is to separate the inertial components in the measurements of the plurality of high-precision accelerometers from the gravity field measurements.

The article [2] looks at the possibilities for gravitational measurements by accelerometers located on an aircraft that flies at a speed in the range of 100 to 300 km/h and at an altitude of 100 to 500 m above the ground. The described technical system for this solution of the problem (GMS - Gravitation Measurement System) can also be used for gravitational measurements by Low Earth orbit (LEO) satellites.

Figure 1. demonstrates investigating the readings of accelerometers installed on a vehicle flying within the indicated range of altitudes and velocities by separating the inertial components and leaving only gravitational field measurements.

The aim presupposes a solution to an inverse problem in relation to the navigation one. The normal gravity field in the inertial navigation systems is separated from accelerometer readings by its mathematical model. Then the flying vehicle velocities and location are determined by integrating the inertial components. Overall, if we have accurate data about the flying vehicle velocities and location (e. g. when using GPS under a differential operating mode), then by applying a mathematical model we can separate the inertial components from the accelerometer readings thus leaving only gravity field measurements.

The technical system designed for solving the problem will be called **Gravitation Measurement System** (GMS).

A. The aim of the Geophysical Research System:

Performing geophysical surveys in flight to create and maintain up-to-date geophysical models for the airspace over the country's territory and adjacent water area for the purposes of high-precision air and sea navigation.

B. Tasks to be solved in the Geophysical Research System:

- Collection and processing of information about the magnetic, gravitational and radiation fields above the earth's surface with specially designed unmanned aerial vehicles.
- Linking collected information to digital data maps.
- Using the collected information for the purposes of high-precision navigation and real-time trajectory control of one or a group of aircrafts.

The Geophysical Research System operates in a limited area of operation up to 60 km from a ground station. It is necessary to experiment and study the speed and height range of the fields in which geophysical information adequate in accuracy is obtained for the compilation of digital models of the geophysical fields in height above the relief.

C. Problems and proposed solutions

The navigation systems of modern aircraft use previously prepared geophysical data for the area in which they will fly. They may collect and update such data. The magnetic maps for the territory of Bulgaria have not been updated for decades. Information about the magnetic field over the territory of Bulgaria has not been collected. This is possible only with aerial reconnaissance methods.

The variation of the gravitational and magnetic field above the relief or on the surface of the sea for the adjacent water area are data of importance for national security, it is not by chance that all countries hide the data for their territory.

Current measured radioactivity values at altitude should be compared with previously taken measurements to make an early warning decision. Air defense of critical infrastructure or military sites is carried out by aircraft: missiles and airplanes. They can be manned or unmanned, the latter being radio-controlled or autonomous robots. Regardless of all the possible classifications for aircraft and the controversial terminology for their name, they have an aerobatics and navigation complex, which for combat use is supplemented with an aiming unit and weapons management.

Inertial navigation has a forward and reverse math problem. Navigators and air traffic controllers solve a forward math problem. They use standardized models for the gravity, magnetic field and topography. The inverse mathematical problem is solved by geophysicists with the help of surveyors, cartographers and meteorologists. The result of their work is precisely the standardized mathematical models used in flight by navigational aviation systems. Without having such information, current for the day and for the defended territory, it is not possible to plan a highly precise application of an aircraft. **The reverse math problem is part of aerial reconnaissance over a certain area.**

- We offer a solution to the described problem by organizing and conducting scientific and applied research. As a result of it, a scientific and technological solution must be given for building a unified information system for geophysical monitoring of the airspace on the territory of the country.

- Ways to achieve this are research using unmanned aerial vehicles, modelling and simulation; integration of new and already built systems.

- It is planned to use data from the GPS observatory located above the village of Kokalyane and other information from the Military Geographical Service.

D. Workflow - Stages and Activities

- **Stage 1:** Study of the possibilities of using the existing information systems and the necessary set of measurement sensors.

  The stage ends with synthesizing a scheme for measuring and communication equipment of an air-based measuring complex. Equipment options for different types of aircraft are presented. The accuracy characteristics and measuring ranges of the sensors are defined. Experimental samples are purchased.

- **Stage 2:** A scheme of the Ground Unit for control, collection and processing of measurement information is synthesized.

  Selected communication standards and technical equipment for Ground Stations. Variants of the ground unit of the system with different territorial coverage and technical capabilities for processing the received flight information are being prepared. A commercial and marketing analysis of the proposed options is carried out. Trial samples have been purchased.

- **Stage 3:** Explore the feasibility of using an autonomous aerial platform.

  An experimental model of an aircraft is purchased or constructed. Building an own aircraft may prove to be infeasible.

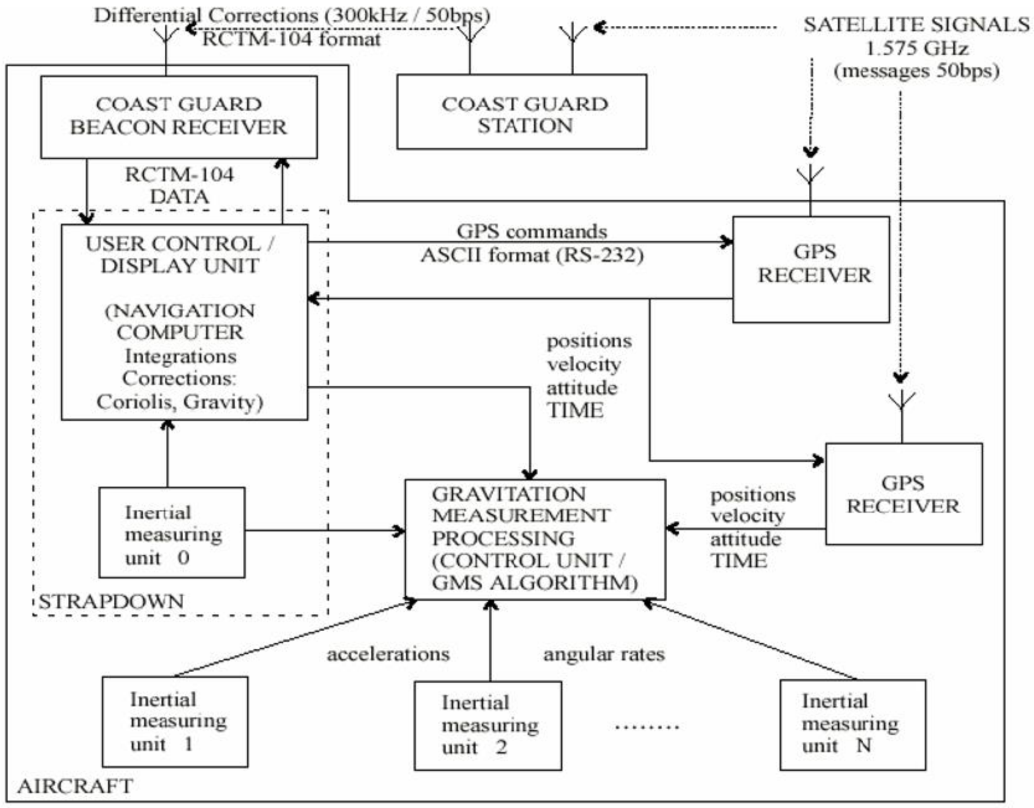

Figure 1. *Geophysical research system as a remotely controlled flight system or* ***Airborne Geophysical Survey System****.*

A single Node of Gravitation Measurement System (GMS), that is placed in the airframe or in an attached payload. (Manuscript document IAC-04-J.P.08.pdf, pp. 5133-5138) [2]

- **Stage 4:** Experimental studies.

  Experimental studies are carried out for a limited area up to 60 km from the take-off point of an autonomous aircraft. The data collected at different heights is examined and mathematical methods for their processing are proposed. The stage concludes with conclusions on the applicability and effectiveness of implementing an **Airborne Geophysical Survey System**.

IV. CONCLUSION

In order to fulfil the requirements laid down in the two concepts [4, 5], any purchased Remotely Controlled System can be equipped with the Geophysical Survey System. The moves for this should be carefully selected according to the cost and acquired abilities.

What is unique or what sets our solution apart from others is expertise in gravity and magnetic measurements with gyro-stabilized platforms on mobile objects in air and water. Our team at the Unmanned Robotic Systems Laboratory has specialists and researchers in magnetic sensors, UAV trajectory control systems, gyros and gyro-stabilized platforms, electronics, sensor networks and cyber security.

Technical Approach: The components of the proposed ecosystem will be developed in stages. The gravity measurement system (GMS) presents method [2] for ***in situ*** data processing and onboard or in-sensor analytics. The GMS solves two tasks, the navigation and the inverse navigation task. A GMS node will be placed in a buoy for environmental monitoring, magnetic sensing and recognition. So, the GMS algorithm is upgraded with 3D magnetometers.

General objective: Creation and maintenance of up-to-date geophysical models for the airspace over the territory of the country and adjacent water area for the purposes of high-precision air and sea navigation.

Specific objectives:

- Data collection and processing information about the magnetic, gravitational and radioactive field above sea level or the Earth's surface with specially designed unmanned aerial vehicles (UAV).

- Information data collection of the processing of the observations in complementary data link layers in the GIS and accordingly Big Data collecting in the National GPS Network of the Republic of Bulgaria.

- Using the collected information for the purposes of high-precision navigation and real-time trajectory control of one or a group of aircraft for critical infrastructure security and resilience and military points.

ACKNOWLEDGMENT

THIS WORK WAS SUPPORTED BY THE NSP DS PROGRAM, WHICH HAS RECEIVED FUNDING FROM THE MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF BULGARIA UNDER THE GRANT AGREEMENT NO. Д01-74/19.05.2022.

REFERENCES

[1] Madzharov A. N., Gyroscopes and inertial navigation systems. D. Metropolia, 2000, 422 pages. - ISBN 954-713-046-3.

[2] A.N. Madzharov, P.V. Panova, P.S. Getsov, Theoretical Research of Possibilities for Gravitation Measurements in Motion using the Inertial Navigation System, 55th International Astronautical Congress 2004 - Vancouver, Canada, IAC-04-J.P.08. (Scopus)

[3] Madzharov A. N., Biliderov S. S., The influence of the Free air anomaly over the stability of the vertical channel in Strapdown Inertial Navigation System, Proceedings of „First International Conference on Cartography & GIS", 25-28 January 2006, Borovets, Bulgaria, ISBN 10: 954-724-028-5 & ISBN 13: 978-954-724-028-5.

[4] Концепция за въздушно наблюдение и разузнаване с безпилотни летателни системи от Въоръжените сили на Република България, утвърдена със заповед на министъра на отбраната на Република България №ОХ-392/06.06.2012г.

[5] Концепция за изграждане на отбранителна способност „Въздушно наблюдение и разузнаване с безпилотни летателни системи от Въоръжените сили на Република България", утвърдена със заповед на министъра на отбраната на Република България, №РД-89-1/30.01.2014г.

[6] ASTM D 6429-99(2011)e1 : Standard Guide for Selecting Surface Geophysical Methods

[7] ASTM D 6430-99(2010) : Standard Guide for Using the Gravity Method for Subsurface Investigation

[8] ГОСТ Р 52334 2005 - Гравиразведка. Термины и определения. /Gravity prospection. Terms and definitions./

[9] ГОСТ 24284-80 - Гравиразведка и магниторазведка. Термины и определения. /Gravimetric and magnetic exploration. Terms and definitions./