# **UAV Prototype for Geophysical Studies**

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Abstract—Unmanned aerial vehicles (UAVs) have become an important part of modern fieldwork. Constant innovations, expansion of the functionality of UAVs, and the reduction of their costs are creating new opportunities for drones to be used in geophysical research. The conditions prevalent in difficult terrain are no longer insurmountable. UAVs allow magnetic surveys to be carried out faster than portable magnetometers carried on foot and they also use much fewer resources than manned aviation. There is a need for UAVs designed to perform such tasks. The prototype created includes the equipment needed for programming and operating the vehicle for conducting geophysical research and storing the data obtained. It is tested under different conditions in order to define the optimal technical parameters of the UAV. Detailed technical descriptions of the prototype, the different stages of the experiment conducted, and operation procedures for controlling the prototype are described.

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## **INTRODUCTION**

Magnetic surveys, e.g., mineral prospecting, are usually carried out using mobile magnetometers These can be either portable devices, consisting of a magnetic field sensor, a global navigation satellite systems (GNSS) receiver with an antenna, a recording system (Laboratory of Quantum Magnetometry, Magnetometer..., 2020; GEM System, GEM GSMP..., 2020; GEM System, GEM GSM-19T..., 2020; Geometrics Company, G-858..., 2020), or special equipment kits to be placed on manned aircraft (airplanes and helicopters) (Mavrichev and Petrova, 2001; Babayants et al., 2006). Mobile magnetometers allow information about the magnetic field to be obtained with a very high spatial resolution; however, to achieve this objective, the device must be carried along all the profiles of interest, which can be difficult in difficult terrains, such as swamps and rocks. Filming from manned vehicles, on the other hand, is guite expensive and does not always provide a sufficiently high resolution. Magnetometers mounted on unmanned aerial vehicles (UAVs) make it possible to combine the advantages of the shooting speed and area coverage available to aircraft with the resolution comparable to ground-based methods.

Most UAVs are heavier than two types of aircraft: airplane and copter (vertical takeoff and landing). Airplane-type UAVs are also called fixed-wing UAVs. This type of apparatus is characterized by a high speed and greater autonomy of flight compared to helicopter-type apparatuses, which allows covering large areas. When a low speed (including hovering in place) and a low flight altitude is required, the copter-type, multirotor UAVs or helicopters are used. Their maneuverability allows research to be carried out at low altitudes, while positioning the equipment in the best way with respect to the studied object. The Federal Air Transport Agency in the regulatory documents (Decree of the Government..., 2019) distinguished UAVs (in the terms of the official documents they are unmanned aerial vehicles) weighing up to 250 g, up to 30 kg, and over 30 kg, regardless of the principle of takeoff and flight.

Similar classifications by mass are accepted in most countries in the world and are used mainly to regulate the registration of UAVs and flight rules. It should be noted that the geophysical surveys, as well as obtaining images in the visible range using UAVs, are often attributed to the commercial use of airspace and require special licensing (Decree of the Government ..., 2016; The Law of Russian Federation..., 2018) and operator certification (Federal..., 2016) or permissions for data release (The Law of Russian Federation..., 2018; Lantmäteriet..., 2018).

#### FEATURES OF UAV MAGNETIC SURVEYS

To perform magnetic surveys, we can use helicopters, multirotor devices (Parshin, 2016), or fixed-wing vehicles (Cherkasov et al., 2016). Although their operation principles differ quite significantly, from a technical point of view, they have a lot in common. All of



Fig. 1. The UAV prototype.

them are controlled by a flight computer with sensors for the flight parameters and one or more speed controllers for the electric motors. The flight computer is a computing device that controls the speed of the electric motors and the wing in accordance with the software, commands are received through the control channel and input data from sensors (accelerometer, gyroscope, airspeed sensor (Pitot tube), barometer, magnetic compass, GNSS receiver, acoustic rangefinder (sonar), light or laser rangefinders (lidars), etc.).

As with any magnetic survey, such measurements require minimized electromagnetic (EM) noise near the sensors or, at least, the possibility to eliminate this noise at the data processing stage (Macharet et al., 2016). The sources of EM interference in UAVs are primarily high-frequency MOS transistors of the electronic systems used for controlling the speed of rotation of electric motors (Tuck et al., 2018). Since the rotation speed of electric motors is constantly changing, even in the case of a fixed-wing UAV having only one electric motor, this interference cannot be excluded without knowing the motor's operational parameters at each moment of measurement.

Modern flight computers allow all flight parameters to be recorded; therefore, the necessary information for filtering can be extracted from these records. Other sources of EM interference are telemetry transmitters and the video signal from an FPV camera. A telemetry transmitter typically operates at frequencies ranging from 433 MHz to 1 GHz with a dynamic output power of up to 500 mW. Such modems usually operate in the discrete mode and the periods of radiation are distributed unevenly in time. The FPV camera transmitter can be either analog or digital, and usually operates at 1.2 GHz, 2.4 GHz, or 5.8 GHz. It produces constant radiation with power of up to 2000 mW (AKK Technology..., 2020; TBS Avionics..., 2020).

The effect of this interference can be reduced using antennas with a pronounced radio shadow, a sector with a low gain in the vertical direction, e.g., the common cloverleaf antenna (Smith, 1947), as there is no need to transmit directly upwards and downwards from the UAV. Other interference, e.g., from wires, batteries, flight computer electronics, and data acquisition systems, can be reduced by placing the MF sensor at some distance from the UAV on a suspension or a rod (Macharet et al., 2016).

### PROTOTYPE FOR AEROMAGNETIC SHOOTING

To prepare for UAV magnetic surveys, we have built a multirotor vehicle (Fig. 1) with the necessary research equipment installed.

The construction was based on a carbon-fiber lamellar X-shaped frame designed for four engines with the diagonal distance of 220 mm between the motors. The size of the frame determines its basic properties: weight, equipment placement capabilities, and the maximum diameter of the propellers. The lifting force is created by four five-inch three-bladed propellers with a pitch of 4.5 inches (no. 5045), driven by brushless motors with a rotor diameter of 22 mm and a rotor height of 5 mm (no. 2205) with the Kv number = 2500. Given that all the equipment is located in the plane of the motors, i.e., at the base of the frame, the maximum diameter of the propellers should be 6 inches.

The maximum efficiency is achieved by maximizing the rotor size (Achtelik et al., 2012), however, in this case, optimization is limited by the size of the



Fig. 2. Glider expansion with mounted data acquisition system.

equipment mounted in the center of the frame. Ready-made modules based on an 8-bit microcontroller manufactured by SiLABS and rated current of 40 A were used as the controllers of the motor's speed. Flight control was performed by the Fateme computer F405CTR by Matek Systems (Matek Systems..., 2020). The flight computer was based on the ARM processor and equipped with a barometer, a gyroscope, an accelerometer, and input/output ports for control by the operator, as well as for receiving performance information and data from the GNSS receiver. A flight computer could run special software, such as iNAV (Geoscan Company, 2020) or Betaflight (Betaflight..., 2020).

Futaba's FASST solution is used as the control system. This solution is based on the pseudorandom tuning of the operating frequency and provides good noise immunity. The FPV camera and an analog video transmitter operating at a frequency of 5.8 GHz enable remote piloting. In addition, a data collection system based on the RaspberriPiZero microcomputer (Raspberry ..., 2020) and the GNSS receiver DrotekDP0601 (Drotek DP0601..., 2020), built around the u-blox-ZED-F9P platform (U-Blox ..., 2020; U-blox Company, 2020) and capable of receiving up to 184 different GNSS signals and telemetry systems operating at a frequency of 433 MHz was mounted in a special extension of the airframe (Fig. 2) with the aid of additional textolite mounting plates.

A digital magnetometer, e.g., RM3100 from Drotek (Drotek Company, RM3100..., 2020), one of the miniature versions of the POS series magnetometers (Laboratory of Quantum Magnetometry, OEM..., 2020) or GEMGSMP-25U (GEM Systems, GEM GSMP..., 2020.) can be connected to the data acquisition system. The onboard power supply was a lithium-polymer 4-cell battery weighing 200 g with the total nominal output voltage of 14.8 V. The UAV circuit is shown in Fig. 3.

The techniques used in (Geoscan Company, 2020; Parshin, 2016) and most of the other solutions are designed for automatic data collection. This underlines the need for the preliminary planning of the UAV's route, which takes into account the features of the terrain. To accelerate this process (Geoscan Company, 2020), it uses other UAVs, which flying at a safe altitude, provide additional data on the shape of the terrain and its heights using photogrammetry. These data, together with the satellite digital terrain model, were used to build the magnetic survey route for the drone. Given the low altitude accuracy of GNSS, the autonomous flight is safe at the altitude of the order of several tens of meters above ground/water and over possible obstacles (trees, buildings, power lines, etc.).

Having the route planned, the operator loads it into the UAV's memory and gives the command to start moving. The UAV autopilot follows the route and after completing it returns to the launch site for landing. More accurate navigation can be achieved if the GNSS airborne receiver can take into account the correction data (Wanninger, 2019) received from the GNSS ground station via a two-way radio channel. These corrections are accurate up to centimeters on all three axes. The channels can transmit measurement data practically in real time but usually the measurement data are downloaded after the flight using a wired connection or by downloading the data from a memory card.



**Fig. 3.** UAV scheme: (1) frame; (2) motors with propellers; (3), speed controllers of motors; (4) flight computer; (5) control receiver; (6) remote-person-view camera; (7) video transmitter; (8) microcomputer; (9) GNSS receiver; (10) telemetry system; (11) battery; (12) payload.



**Fig. 4.** The scheme of work using UAVs and the following components: control equipment, a data acquisition and control station, a GNSS receiver, and a magnetometer. The stages of takeoff and landing, the start of the mission, the flight over the given points, the return are reflected.

#### AEROMAGNETIC SURVEY TECHNIQUE

In this paper, we propose a procedure that has a number of new features. One of them is the use of various techniques (*Springer Handbook...*, 2016) to obtain updated UAV coordinates at each moment of the work. A combination of these methods is possible due to the use of dual-frequency GNSS receivers onboard the UAV, the preservation of raw satellite measurements with a high frequency (10 Hz), and the use of data from a GNSS base station located directly in the survey area (Perederin et al., 2018). Another feature is the possibility of accurate manual piloting in areas with a difficult terrain and vegetation, where a safe altitude for autopilot will not allow obtaining reliable geomagnetic data.

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The implementation of the methodology (Fig. 4) for magnetic reconnaissance involves both UAVs with a magnetometer and control equipment, and a ground-based monitoring and data acquisition system (GNSS station and a stationary magnetometer). It requires at least one operator for the UAV and data acquisition systems. Before the start of exploration, the GNSS ground station, as part of the control and data acquisition systems, has to be turned on and record satellite measurements for at least 30 minutes. If an autonomous flight is assumed, the route is loaded into the UAV's memory. Then, using the interface of the monitoring system, the recording of the ground magnetometer is started and the onboard data acquisition system on the UAV is turned on.



**Fig. 5.** Photo of the prototype during testing of the data acquisition system and its docking with the GNSS receiver. A plate with a geodetic mark applied to it is fixed in the upper part to assess the displacement of the calculated coordinates and coordinates obtained by tachymetry station's survey.

The telemetry monitoring system receives and displays the status of the UAV and its systems, and also sends a stream of GNSS measurements from the ground station to onboard the UAV. In particular, information about the state of the GNSS receiver is transmitted—the number of satellites being tracked and the state of receiving a stream of GNSS measurements from the monitoring and data collection station. After the operator is convinced that all systems are working properly, an autonomous flight takes place at the predetermined reference points or a manual flight is performed. Upon completion of the work or the battery charge dropping below the set value, the device is returned to the takeoff and landing point.

## CONCLUSIONS

The technologies for the creation, control, and application of UAVs have developed sufficiently to be universally applied for collecting data for geophysics problems, as well as for geodesy tasks, tracking natural and technogenic phenomena, and monitoring civilian objects. To create your own UAV for specific tasks, you will need the correct selection of components freely distributed on the market and the presence of certain skills in assembling and debugging the device. Before we found a solution in the form of expanding the aft part of the airframe, several layouts of the data acquisition system and the GNSS module were tested.

In the future, the use of a frame specially designed and manufactured for the selected tasks should be considered. This allows obtaining an aircraft with the best indicators of stability and maintainability. Another aspect of the creation of UAVs, not touched upon in this paper, is the use of components with special temperature and vibration resistance. These, and many other technical aspects of the creation of UAVs are important for obtaining a new geophysical instrument. Nevertheless, the adequacy of the methodology and its compliance with the selected tools and, in fact, the choice of the tool, the payload, are also responsible for obtaining high-quality results.

The proposed prototype (Fig. 5) passed flight tests aimed at checking the operation of the systems and assessing the deviations of the obtained coordinates at the scientific expeditionary Ledovo Base of the Institute of Physics of the Earth, Russian Academy of Sciences. During the tests, the satellite measurements were recorded onboard the prototype simultaneously with the tachymeter survey. In order to do so, a special plate with a geodetic mark was mounted on the prototype. To estimate the deviations, it was supposed to analyze the UAV's coordinates obtained by various methods (PPP, DGNSS) and the UAV's coordinates obtained by the tachymeter survey. To obtain this data, a flight was performed with several short-term landings to complete the survey with a tachymeter. The results will be processed, analyzed, and published later this year (2020).

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