Methods of automated detection of anomalies and nonlinear transitions by autonomous unmanned aerial vehicles

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Abstract. The paper considers the possibility of automating the recognition of anomalies and nonlinear properties of objects in different environments by assembling the UAV payload in the form of a nonlinear locator with a minimum participation of the operator in the processes of probing influence. The process of selecting the main flight platform has a number of requirements that meet the required mission, and by its tactics and technical characteristics it is able to fully implement monitoring algorithms. The theoretical basis of the model construction is given and the main parameters for the standard operation of the model in terms of height, speed and required payload set are defined. The regression model of the interval of scanning of terrain areas depending on the speed of the device and the load of the main processor is compiled. The results of the calculations are summarized and reduced to the method of automated detection of anomalies and nonlinear transitions of objects detected as a result of terrain scanning missions. The main operating properties and optimal conditions of external technological impacts of the developed mathematical model are described.

1. Introduction
Currently, the modernization of unmanned aerial vehicles (UAVs), scientific and technological progress in the field of payloads placed on the main frame of the UAV is almost daily. Since the first UAV entered the world markets, the classification is based on two main directions:

- Airplane;
- Multi-rotor:
  - monocopters;
  - quadrocopters;
  - hexacopeters.

Not so long ago the developers introduced to the world a new class of UAVs - a convertible plane. The design of the device allows to place complex specialized developments on the main frame. Modern UAVs allow to solve the following tasks: in the field of geodesy and cartography, agriculture, to perform a complex of geological surveys, to carry out remote control [1] over the progress of construction of large objects, to monitor the transmission line length of 10 km and placed in remote areas, to deliver
goods. Police, firefighters, government services and other state and commercial organizations have been created and exist to perform their official duties. But not all UAVs meet the necessary requirements, with a significant limitation on speed, flight range, placement of additional high-tech load is provided by battery power. The problems of such a plan will be solved in the near future. Hybrid technologies combining all the advantages of the battery in combination with fuel will allow to place much more high-tech equipment, expanding the field potential of the UAV for various missions.

Development of more effective methods for detection of objects with nonlinear properties and anomalies, representing threats of information field security violation, capable of causing significant technical and economic damage to objects of various types and classes [2] is an actual topic for today. Scientific novelty of the developed method consists in the use of mathematical model of detection of objects possessing nonlinear properties and anomalies by means of UAV application based on information obtained in the course of flight mission. high-tech complex based on domestic AVS platform. In Russian studies, there are developments aimed at finding objects with nonlinear properties. Such solutions have a number of drawbacks, in particular, on the range of anomalous objects detection. For example, non-linear locators of the Lornet series have a detection range of 0.8 to 5 meters without the possibility to place them on the UAV frame as a payload and with the functions of remote monitoring of the objects under investigation (important in Covid-19/20/21 conditions).

2. Materials and methods
Most of the nonlinear location technologies are based on RF signals coming from a nonlinear locator (NL). When irradiating semiconductor connections, the reflected signal returns at harmonic frequencies [3] of different levels. The concept of placing the NL as a payload on the UAV is proposed. Application of an automated detection system will reduce the burden on the operator, to analyze the data directly on board rejecting false positives, and in cases of anomalies detection to transmit a signal to the operator on the ground control complex. In this case, the task of automating the process of detecting anomalies are reflected in the study of large areas of open terrain with the coverage of areas during a single flight mission of 10 km² and above. Including the work is aimed at improving information security in the certification of large objects of information, public safety in civilian applications [4, 5]. So UAV with the necessary payload included in the ground robotic detection complex by conducting preliminary engineering reconnaissance of terrain areas is able to identify anomalies.

A number of requirements must be made to the choice of the main platform of the unmanned aircraft system and the implementation of the developed algorithm according to the methodology of automated anomaly detection and nonlinear locating [6 - 8]:

- a multirotor drone-type system;
- function of the vehicle movement along a programmed route;
- vertical takeoff and landing of the vehicle;
- function of returning to the base in case of signal loss, low battery charge and other adverse effects of external nature;
- all-weather performance of the flight platform (rain, snow, wind);
- up to 10 km flight range without navigation system;
- flight time with search function activated - from 1 hour;
- low weight - dimensional characteristics;
- flight speed - 60 km/h
- take-off weight up to 20 kg
- alternative power sources for the payload.

The majority of the NL models produced in the world use algorithms of continuous emission of a narrowband signal. Existing radar based on the principles of pulse amplitude modulation signals can minimize the irrational use of battery current, which is critical when interfacing the radar with the UAV platform [5]. In this case, for the "detection effect" does not matter what type of frequency modulation
uses the NL, the main criteria are ease of handling, easy installation on the UAV frame, the presence of interfaces to the digital platform of the multirotor drone, the maximum use of the "fading effect". When selecting the NL, you should also pay attention to the possibility of selecting the frequencies of the probing signal (3.6 GHz; 2.4 GHz and 0.8 GHz), easy mounting/dismounting of antenna modules. Frequency of 800 MHz for scanning soil, wet environments and iron-concrete structures, 2.4 GHz is capable of identifying small objects and devices and is designed for surveying buildings and structures both inside and outside, 3.6 GHz frequency for detecting embedded devices with electronic components at a considerable distance from the NL and the exact location of their location. At the same time nonlinear locator should operate in a broadband frequency range, performing in automatic and manual modes search for a free working channel excluding frequency overlap in cases of application in urban environment. In the process of selecting the NL should be based on the transmitter power and the degree of sensitivity of the receiver. In this case, the presence of a highly sensitive receiver NL low power detection efficiency can be an order of magnitude higher than the same device with a more powerful transmitter [9]. The general requirements for the selection of a nonlinear locator will be as follows:

- amplitude-pulse modulation;
- the peak power UHF signal in the search mode of not more than 700 mW;
- the sensitivity of the receiver not less than -160 dB;
- availability of own batteries not less than 3.7 V;
- Resistance to man-made interference when used in an urban environment;
- confident detection of anomalies and small objects on the ground, including wet environments;
- sensing range up to 50 m.

3. Theoretical justification

The time interval at which the payload in the form of a UAV inspects the terrain for anomalies and nonlinear properties of objects detected by the sounding scanning from the UAV on the ground surface has a weighty influence on the degree of microprocessor loading, expressed as an exponential relationship from the number of flight tasks to the degree of processor loading [10] and the mission execution time.

In the present study, it is proposed to use a UAV having equipment in the form of a multirotor system and a payload consisting of: UAV, GPS module, 4K HD video camera for a more detailed inspection of the detected object, replaceable LED module to perform missions in the dark. When carrying out experimental flight missions, favorable weather conditions should be chosen, as well as a low level of man-made impacts. For more qualitative testing of the product should conduct a series of experiments on a specially equipped test site, which has signs of difficult, rugged terrain (figure 1).

![Figure 1. Parameters of anomaly detection during the probing action of UAVs with NL.](image)
The power of microwave signal emitted by the UHF must be within 700 mVT, with flying altitudes from 30 to 50 m, speed up to 60 km/h. The angle of the sounding influence of the UAV placed on the UAV will be about 110°, the height of observation is 50 m and the "visibility zone" will have the size of 101.94*71.4 m. In order to reduce the share of false messages on anomaly detection coming to the operator of the digital control complex it is necessary to determine the optimal scanning zone. If the initial parameters of distance from the ground surface of 50 m are observed, the optimal width of the scanning zone will be 90% of the total width of the probing impact, which will reduce the area to 91.7 m. In this case the optimal operation of all UAV systems will be ensured: optimal power consumption of the PL, transmitter operation within 630 mW of the peak values.

In cases of detecting anomalies at a flight altitude of 50 m, the UAV performs an automatic descent to 1.5 m, using the optical zoom of the video camera in order to inspect the detected object in detail and transmit the video stream to the operator's desk. To exclude the cases of "unreadable" detected objects, it is necessary to shoot from four different angles, which will correspond to the directions of the light sides. In particular, for achievement of the required quality and reliability of scanning of terrestrial surface areas included in the route of the mission, it is necessary to enter the coefficient of overlapping of scanning zones $f$ equal to 0.15. In this case, based on the data of the mathematical model, the capture of the airborne scanning zones will occur every 33.2 m. The average speed $v$ of movement of the UAV in the study will be 42 km/h, taking into account external influences on the device in the form of rain, snow and wind.

4. UAV sensing algorithm
To implement the algorithm for automated detection of anomalies and nonlinear transitions by an autonomous UAV, the following operations are required:

- Preparation for vertical takeoff: modular assembly of the vehicle at the place of the flight mission, deployment of a ground control station consisting of an operator panel, ground antenna unit, in cases when the vehicle is 10 km or more away, a signal amplification station for confident control, processing of telemetry information and video signal reception in cases of anomaly detection.
- Checking the degree of battery charge, connection to the UAV, testing communication channels with ground control complex by sending Start/Stop commands, checking inertial sensors for measuring angular velocity, barometric altimeter and rangefinder in cases of deviation to make calibration in the field, checking the satellite navigation system.
- Installation of payload in the form of NL with the performance of verification actions on the semiconductor connection, video camera with verification in the form of sending an image to the operator's desk.
- Determination of weather conditions and influence of external factors: ambient temperature from -300 to +450°C with relative air humidity 85% and atmospheric pressure up to 780 mm Hg. Preferably no precipitation in the form of snow and rain, wind moderate to 5 - 7 m/s.
- UAV launching from prepared launch pad, with low engine rpm until reaching operating altitude of 50 m.
- Loading previously defined route, movement of the UAV along the trajectory, taking into account the terrain of hard-to-reach rugged terrain.
- Activation of algorithm of automatic detection of anomalies and non-linear transitions, in cases of payload equipment failures transition to manual mode with adjustment of parameters or cancellation of commands and return of the vehicle to the launch point.
- Detection of anomalies or objects with non-linear transitions on the surface of the surveyed terrain: one of the eight channels of control and telemetry information exchange between UAV and ground complex receives "Alarm" signal, fixing the exact coordinates of the object with demasking features, detection time.
• Marking on the map of the detected object, reduction of the UAV to 1.5 m, in order to organize a photograph from 4 angles, in case of a stable communication channel with the ground complex, organization of the data stream video transmission.
• The UAV continues to follow the route, completes the flight task, returns to the starting point, and lands vertically in automatic mode.

The result of performing the methodology of automated detection of anomalies and non-linear transitions will allow remote monitoring minimizing human presence in an aggressive environment.

5. Conclusion
Application of the proposed methodology will maximize the use of UAV capabilities through mathematical data processing by a microprocessor located onboard the vehicle, without overloading the control channels with false detection data. The introduction of hardware-software developments will allow to significantly reduce the final cost of the vehicle, and the interchangeability of payload modules to perform missions of different purposes, or to work in symbiosis. The data obtained during the study can be used to verify and validate the conclusions made, to serve as the basis for other developments and approaches in the detection of anomalies and properties of objects with nonlinear transitions.

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