Development of a combined navigation and measurement system for manned airborne geophysical measurements

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Abstract. The article is devoted to the idea of combining navigation and measurement software to provide a higher level of efficiency and quality of aerial electromagnetic survey. Complex geophysical measurement systems of “Impulse-Aero” series are overviewed. Current survey technology with the above-mentioned systems includes human-based control of the measurements with a geophysicist on-board. The technology also includes the navigational support by the geophysicist or an additional navigation specialist. The concept of automatic combined complex for navigational and measurement monitoring is proposed in the article. The main goal of the system under analysis is to automatically estimate the quality of received data and to give necessary recommendations on the screen of the navigation unit. As the result of the survey, some tasks during the flight can be solved by pilots without any additional staff. This approach is supposed to increase flight safety, reduce costs and raise the efficiency of the survey in general.

1. Introduction
Airborne geophysical measurements, in particular electromagnetic exploration by the electrical transient method in combination with magnetic measurements and spectrometry are effectively used for engineering-geophysical and engineering-geological surveys [1–5].

Most commonly, complex geophysical measurement systems such as electrical exploration, receiving and generating structures (platforms) are used to perform such surveys. Such measuring systems are widely used abroad, in particular by the following companies: Furgo N. V., Geotech, U.S. Geological Survey, and others [4, 5]. An example of home-grown developments in this area can be helicopter electromagnetic complexes with remote platforms of “Impulse-Aero” series (Sibgeotech, Aerogeophysical Surveys) [2, 3].

The survey equipment of such complexes is partially located on board the carrier, but the electromagnetic (EM) measuring systems are carried overboard on an EM platform connected with a cable. For example, for measuring systems of the Impulse series, the cable length is 30-50 m. Typical EM platform diameter is about 15-25 m and the weight can reach 450-750 kg. The gamma-ray spectrometer used can also weigh about 200 kg. The survey using the above-mentioned complex is performed with the terrain-flowing at a speed of 80-130 km/h. (Figure 1).
Despite the general trend in aerogeophysics, aerial photography, and other industries to replace manned aircraft systems with unmanned ones (primarily in magnetic exploration [6-10]), complex multi-method airborne electromagnetic (AEM) survey is performed by manned carriers. This is due to several factors: mass-dimensional characteristics of measuring equipment, complexity of piloting due to the presence of remote objects and structures, low altitude surveys (3050 m above the surface).

As a result, while performing such surveys it is important to pay special attention to the safe control of the aircraft, to provide pilots and crew with the necessary navigational and informational data, and to monitor the quality of measured information in order to avoid errors and re-taking measurements.

This is done using standard navigation equipment together with non-standard aviation receivers of global navigation satellite systems (GNSS) and special software-hardware survey complexes for aggregation and monitoring of geophysical sensors measurements. All of the above-mentioned systems require the presence of an operator-geophysicist alongside with a non-staff navigator. However, the latter may not be present if specialized navigation systems are used and a pre-flight pilot training is performed.

![Electromagnetic complex example](image)

**Fig. 1. Electromagnetic complex example**

### 2. Material and method

Navigational support is regulated by the instructions for each type of survey [11, 12], it is described in the manuals [13, 14], and is specified in the technical enquiry, compiling which the specified sources should be taken into account. The main tasks of navigational support are to maintain survey routes with the control of deviations within the specified tolerance. The survey speed, altitude above the surface, and other navigation parameters are also to be controlled [15]. In case of significant deviations of navigation values from the permissible limits, a decision is made to re-survey the current route.

This is done using airborne GNSS receivers (for example, CCNS [16]), altimeters, and standard aircraft equipment. There are also various specialized navigation systems [17, 18]. A navigation system based on the RouteNav program [19, 20] was developed by the authors for the needs of aerogeophysics (Figure 2).
One of the advantages of the program presented is a simple user interface that is as close as possible to modern car and pedestrian navigators (and smartphone navigation applications). This requires minimal training from pilots. Complex geophysical survey requires aggregation and monitoring of data from various geophysical sensors, their analysis in real time. Thus, if there are any system failures, a decision to re-pass the current route or stop the survey is to be made.

An example of such a program is the software package QAeroRecorder, developed by Aerogeophysical Surveys company (Figure 3).
QAeroRecorder program has the following main functions:

- displaying diagnostic information about the status of connected equipment;
- recording of geophysical information to an external storage medium, displaying the recording status;
- logical division of the information on the routes in the process of surveying;
- labelling events while surveying;
- visualization of measured EM field signals, magnetic field strength along the current route, graphs of gamma-ray energy and derived numerical characteristics, and the state of equipment in use;
- profiling the electromagnetic field along the route;
- visualization of the current altitude and an alarm warning about exceeding the maximum and minimum possible “ground-platform” distance.

The program interface is designed to interact with a specialist who, based on the information received, makes a decision about the future flight strategy. It is important to note that in some situations this problem can be solved automatically.

3. The concept of a combined navigation and survey system.

The combined system should provide the pilot with information about the current position of the aircraft relative to the survey routes and give recommendations for further flight strategy in the form of warnings (in the case of navigational and measured values reaching critical points). It also provides the pilot with instructions (repeated flight or abort of the flight due to serious failures).

Table 1 shows the current criteria for decision-making by the navigation and measurement system on the flight strategy based on the analysis of the measured navigation and geophysical parameters.

| Criterion | Condition | Characteristics/ action |
|-----------|-----------|------------------------|
| Sideways deviation from the current route | Exceeding the specified limit by half | Warning |
| Flight altitude | Exceeding the specified limit | Defect (re-recording) |
| Ground speed | Exceeding the specified limit | Warning |
| Correct operation of geophysical equipment | Absence of signals from at least one device | Defect (re-recording or abort of the mission) |
| Signal compliance with protocol and data format | Disruption of the data stream to at least one device | Defect (re-recording or abort of the mission) |
| Data continuity | Missing data (failures of measuring equipment) | Defect (re-recording) |
| Quality of geophysical information | Data meets certain criteria | Warning or defect (depending on the criteria) |

The combined navigation and measurement system can be implemented on the basis of QAeroRecorder and RouteNav (Figure 4).

The concept is to create a unifying sub-program based on the graphic interface RouteNav, which outputs recommendations from QAeroRecorder. Also, data exchange between the specified modules is to be established.

This approach will allow the pilot to conduct the survey independently based on the recommendations of the combined program.
4. Conclusion
The proposed combined navigation and measurement system significantly increases flight automation. It also provides the pilot with the most convenient interface for monitoring navigation and measurement information, which will make it possible to take pictures independently. The absence of non-staff crew members on board a helicopter will increase flight safety, reduce costs, and free up to more than 100 kg of payload. This can be used for transporting additional fuel to increase the duration of a single departure.

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