

Field testing of a high-precision quadcopter VLF measurement technology

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SUMMARY

VLF fields are successfully used in geological mapping in ground and aerial versions with combined surveying using helicopters and airplanes. We have developed a technology for conducting VLF surveys using small UAVs. A prototype of measuring system with total weight of just about ~2kg was developed. The proposed methodology was tested at the Aleksandrovka geophysical test site of Moscow State University. At the first stage, repeated profile measurements were performed, which showed high accuracy and good repeatability. At the second stage, a small areal survey was carried out. The results obtained during the test flights are consistent with ground-based measurements made by land electrical prospecting methods.

Keywords: VLF, drone measurements

INTRODUCTION

The fields of very low frequency (VLF) radio stations have been used for geological exploration purposes for quite a long time. For instance, in the USSR the development of radio wave geophysical methods began back in 1946 and by Prof. Anatoly Tarhov and colleagues (Tarhov 1961). During the second half of the XX century, the method was actively developed in both ground and air modifications.

For now, airborne VLF data are routinely collected by national agencies and commercial companies all over the world, together with other passive geophysical measurements of the static magnetic field and radiometric data. VLF data contain a lot of useful quantitative and qualitative information about the electrical conductivity distribution in the upper few hundred meters (Pedersen & Oskooi 2004).

Due to rapid development of the unmanned aerial vehicle (UAV) technologies in the last decades, the use of this new technical base and development of an appropriate VLF modification becomes relevant.

The UAV usage leads to a number of features when developing survey techniques. Firstly, it is important that the measuring equipment should be lightweight. Also, the equipment should be simple and reliable. Next, because The UAV operator stays at the same place during the flight, which is not very far from the

measurement area, it becomes easy to install and use a remote base to record EM field variations and suppress uncorrelated noise during data processing. Finally, during the flight it is not always possible to accurately determine sensor orientation (roll, pitch and yaw), so it becomes desirable to measure some invariant quantities that would not depend on the orientation of the sensors.

Based on these concerns, we have developed a quadcopter VLF survey technique described below.

Quadcopter VLF technique

Standard airborne VLF surveying usually employs the total magnetic field calculated from the three orthogonal components generated by a given VLF radio transmitter, suitably oriented with respect to the dominant geological strike in the area.

The total field may vary due to variations in position of the reflecting ionosphere boundary (Vallee et al. 1992). In the case of quadcopter surveying, we are usually interested in detailed mapping over a small area, and finding conductivity anomalies that are small in amplitude and size. In this situation the source signal variations could not be neglected. To register them, we use a ground base station at the take-off point, which is continuously recording the full vector of the alternating magnetic field T^{base} at VLF radio frequencies (from 10 kHz to 30 kHz).

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A similar set of equipment, capable of recording the total magnetic field T^{UAV} in the frequency range from 10 kHz to 30 kHz, is installed on a UAV.

At the data processing stage, the following simple and dimensionless ratio is calculated:

$$K = \frac{T^{UAV}}{T^{base}}$$

To achieve maximum accuracy of the field data the sensors are calibrated before and after each flight.

Equipment

To carry out the field measurements we used a modified lightweight version of the broadband MT receiver NORD (Epishkin et al. 2022). The number of channels in the station was reduced from 10 (5 with 24-bit ADCs and 5 with 32-bit ADCs) to just 3, and the rugged casing replaced by a lightweight one. Due to this, the weight of the receiver was reduced from 2 kg to **1.1 kg**. Signal registration is carried out in the broadband mode continuously at a sampling frequency of **78 125 Hz**, which makes possible to perform advanced processing of the received data and pick radio stations that create strong and stable signals.

During the experiments, several three-component sensors were successively developed for surveying in different frequency ranges. Figure 1 shows the first prototype of the magnetic sensor. This sensor was created both for measuring lightning fields and the fields of radio stations. It allowed measurements of natural and VLF radio signals in the frequency range from ~1 kHz to ~30 kHz. The dimensions of the sensor are 45 x 45 x 45 cm, weight – 2.2 kg.

Figure 2 shows the second prototype of the three-component magnetic field sensor, which has a small size (**15 x 15 x 15 cm**) and reduced weight (300 g), and allows independent recording of 3 components of the magnetic field in the frequency range from **~10 to ~30 kHz**. When using the second lightweight version of the sensor, the weight of the entire receiving system is just about **~2 kg**, which makes it possible to mount it on a small quadcopter.

Field tests

The technology was tested at the MSU geophysical test site in Aleksandrovka (Aleksanova et al., 2018), Kaluga region, Russia. Many geophysical methods are regularly tested at this area, and a large number of surveying results are available for comparison.



Figure 1. Cubic sensor prototype with dimensions of 45 x 45 x 45 (cm) for 3-component magnetic field measurements at frequencies from ~1 to ~30 kHz.

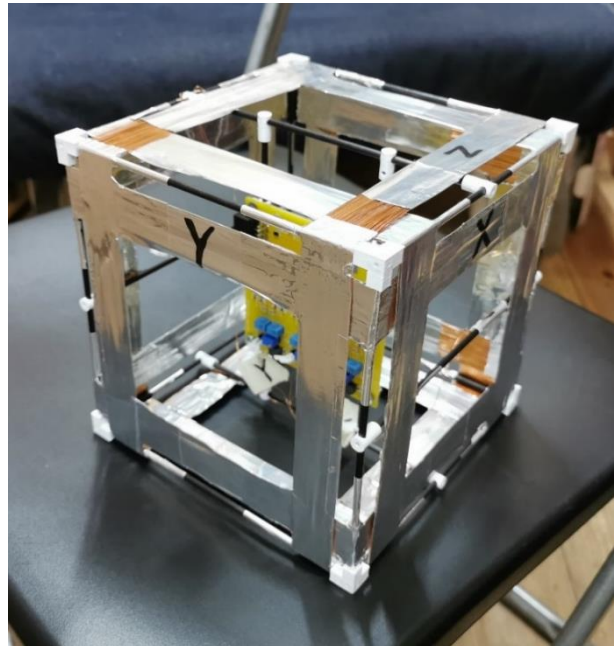


Figure 2. Cubic sensor prototype with dimensions of 15 x 15 x 15 (cm) for 3-component magnetic field measurements at frequencies from ~10 to ~30 kHz.

As a first experiment, a repeated flight was carried out in the forward and reverse directions along the same route with the length of about ~3 km. The measurements were carried out at a speed of 5 m/s. It was possible to identify areas of increased and decreased conductivity (Figure 3). Repeated flights showed high accuracy and good repeatability (see Figure 4).

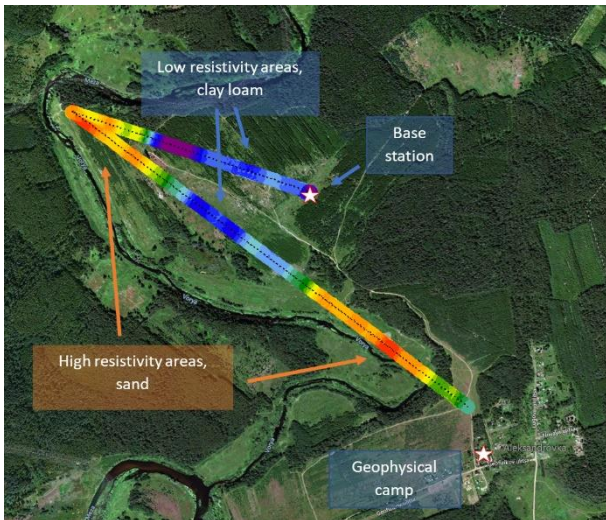


Figure 3. The first test flight and acquired data.

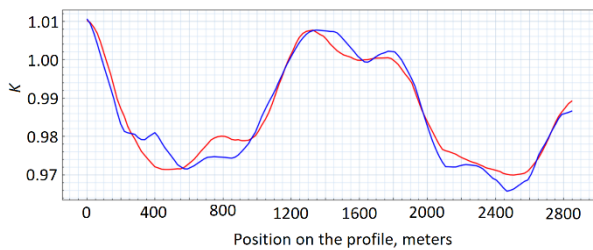


Figure 4. Comparison of repeated measurements along the 1st test profile at 16 kHz. Red curve – forward flight, blue curve – backward flight

The second experiment flight was performed at an altitude of 48 m over the rectangular area of 1000 m by 400 m (Figure 5). The spacing between profiles was 45 m.

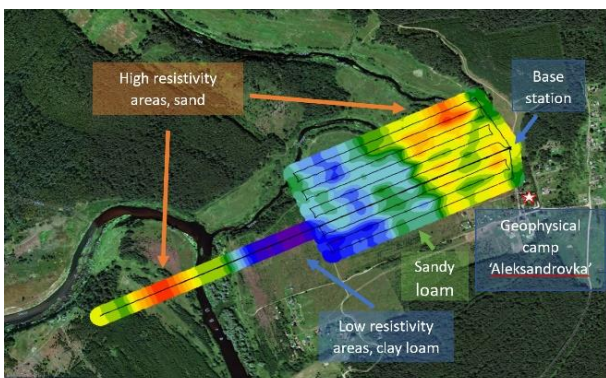


Figure 5. The second test flight and acquired data

In addition to the areal measurement, during the same test, a repeated flight was made in the forward and reverse directions along a survey line of about ~2 km long. The results of these repeated flights are shown in Figure 6.

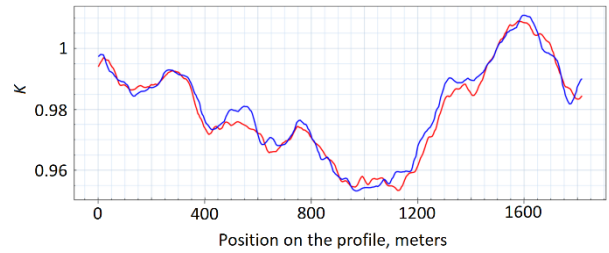


Figure 6. Comparison of repeated measurements along the 2nd test profile at 16 kHz. Red curve – forward flight, blue curve – backward flight

In the area of experimental work, ground-based electrical surveying was previously carried out using various EM methods. The figures below show the results of comparing the obtained VLF data with the results of regular shallow DC resistivity profiling.

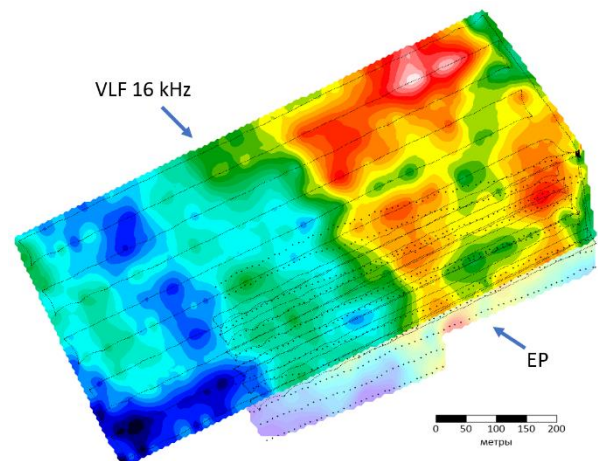


Figure 7. Comparison of the quadcopter VLF data (foreground layer) with the DC resistivity electrical data (background layer)

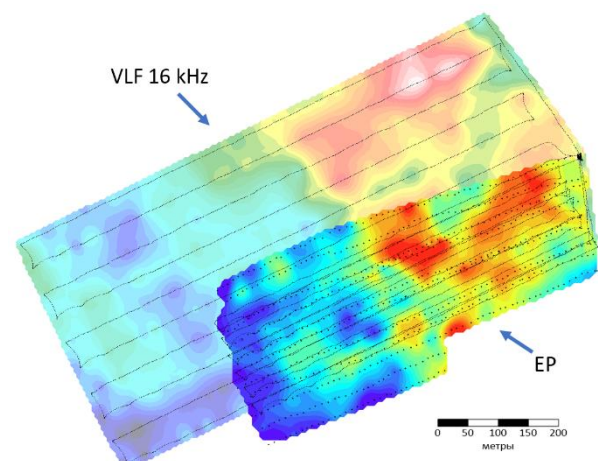


Figure 8. Comparison of the quadcopter VLF data (background layer) with the DC resistivity electrical data (foreground layer)

Conclusion

In this paper we show the results of our first steps in creating VLF mapping technology using lightweight quadcopters.

We have managed to create a compact measuring complex (receiver, GPS positioning system, three-component magnetic sensor, connecting cables and suspension) weighting just about 2 kg, which allows to mount all equipment on a small UAV.

The accuracy of the obtained field data is very high, which is confirmed by repeated measurements and good correlation with ground-based DC resistivity data. During the test flights, it was possible to detect anomalies of about 0.5% of the total signal level. To achieve this result, we performed sensor calibration at the beginning and end of each flight.

At the moment interpretation of the quadcopter VLF anomalies is only qualitative. The obvious next step we would like to take is to perform some inversion over a set of all available frequencies and get some quantitative resistivity estimations.

References

- Aleksanova E, Kulikov V, Shustov N, Yakovlev A, (2018) Aleksandrovka geophysical field camp: a place for probing new EM technologies. 24th EM Induction Workshop, Helsingor, Denmark
- Epishkin D, Zorin N, Yakovlev D, Yakovlev A, (2022) Magnetotelluric system NORD. 25th EM Induction Workshop, Cesme, Turkey
- Pedersen LB and Oskooi B (2004) Airborne VLF measurements and variations of ground conductivity: a tutorial, *Surveys in Geophysics* 25: 151–181
- Tarhov AG (1961) Fundamentals of geophysical prospecting using the radiokip method [in Russian], Moscow, Gosgeoltekhizdat
- Vallee MA, Chouteau M and Palacky GJ (1992) Variations of the VLF-EM primary field: Analysis of airborne survey data, *New Brunswick, Canada, Geophysics* 57, 181– 186