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UAV-BASED MAGNETOMETRIC MODULE FOR DETECTING EXPLOSIVE OBJECTS

Abstract. The urgency of the problem of large-scale mining of the territory of Ukraine is considered. The existing methods of searching for explosive objects were considered. Based on the consideration, the magnetometric search was determined to be the most effective method. A block diagram of a sensor connected to a UAV was created. An equation for determining the location of explosive objects was presented.
Keywords: ***explosive devices, detection, magnetometers, UAVs***

INTRODUCTION

Explosive Ordnance Disposal systems are critical to security in many contexts. They help protect civilians from the dangers of unexploded objects (UXO), reduce the risk of terrorist attacks in public places and transport, and are essential for de-mining areas after military conflicts or disasters. The development of new technologies, such as robotics, drones and artificial intelligence, is improving these systems, making them more efficient and reliable, which ultimately increases security.

For Ukraine, this is of particular importance due to the lingering effects of conflicts and the occupation of certain regions, which have left a large number of explosive ordnance and mines. Clearing such areas is a complex and dangerous process, and advanced explosive ordnance detection systems can greatly facilitate this task, increasing efficiency and safety. The use of technologies such as drones and artificial intelligence can provide fast and accurate mine detection, reducing the risk to deminers and speeding up the recovery process [1].

Thus, the development and implementation of modern explosive ordnance detection systems is an important step towards restoring security and stability in Ukraine. This will allow for the safe return of territories to civilian use, ensure safe living conditions and contribute to the country's overall post-conflict recovery.

OVERVIEW OF EXISTING METHODS

There are several ways to search for explosive objects: using thermal imaging devices, visual methods, ground penetrating radar, magnetometers, radar and laser systems. Each of these methods has its advantages and disadvantages, and their use depends on specific conditions and tasks [2].

The most popular methods are thermal imaging, magnetometric and visual. The thermal imaging method allows detecting temperature changes that may be associated with explosive objects or their detonation. It is often used during night operations or in conditions of limited visibility [3]. The magnetometric method, based on the detection of magnetic anomalies, is effective for detecting metal explosive objects. The visual method involves the use of various cameras and optical devices for visual inspection of suspicious objects.

Ground Penetrating Radar, although an effective tool for finding explosive ordnance, is less commonly used due to its high cost and complexity. This method involves sending radio waves into the ground and analysing the reflected signal to detect objects.

Radar and laser explosive detection methods are relatively new and have not yet been widely used. Radar systems can detect objects at a great distance, while laser systems use light beams to detect objects or calculate the distance to them [4].

Thus, the choice of explosive ordnance detection method depends on the specific task, location and available budget. Popular methods such as thermal imagers, magnetometers and visual systems are more common, while ground penetrating radar, radar and laser methods have limited use due to high cost or technical difficulties.

MAGNETOMETRIC SEARCH FOR UXOS

Having reviewed all the methods of finding UXOs, we can conclude that each method has its own peculiarities and disadvantages. The most commonly used method is magnetometry. This method is notable for its efficiency, especially when searching for metal objects such as mines or ammunition. Magnetometers can detect even small changes in the magnetic field, which allows them to determine the exact location of underground or hidden objects [5].

Among magnetometers, there are optical, induction and resistive magnetometers, each of which has its own characteristics. Optical magnetometers use light and quantum effects, such as the Faraday effect, to measure magnetic fields. They are very sensitive and are used in astronomy, biological research, and even to detect explosives. Induction magnetometers work on the principle of electromagnetic induction. They measure changes in the magnetic field by inducing an electric current in coils. They are often used in geophysics and archaeology. Resistive magnetometers are based on the change in resistance of materials when exposed to a magnetic field. These devices can detect small changes in the magnetic field and are used in a variety of industries, including electronics and explosive detection.

Determining the position of an UXO is a critical process that requires precision and attention to detail. To locate an UXO, magnetometers detect magnetic anomalies that may indicate the presence of metal objects. This is done by scanning the area in a specific order, most often along a grid or scan lines. Once the data is collected, a map of magnetic anomalies is created, which is used to identify potential IED locations. A possible block diagram of the described system is shown in Figure 1.

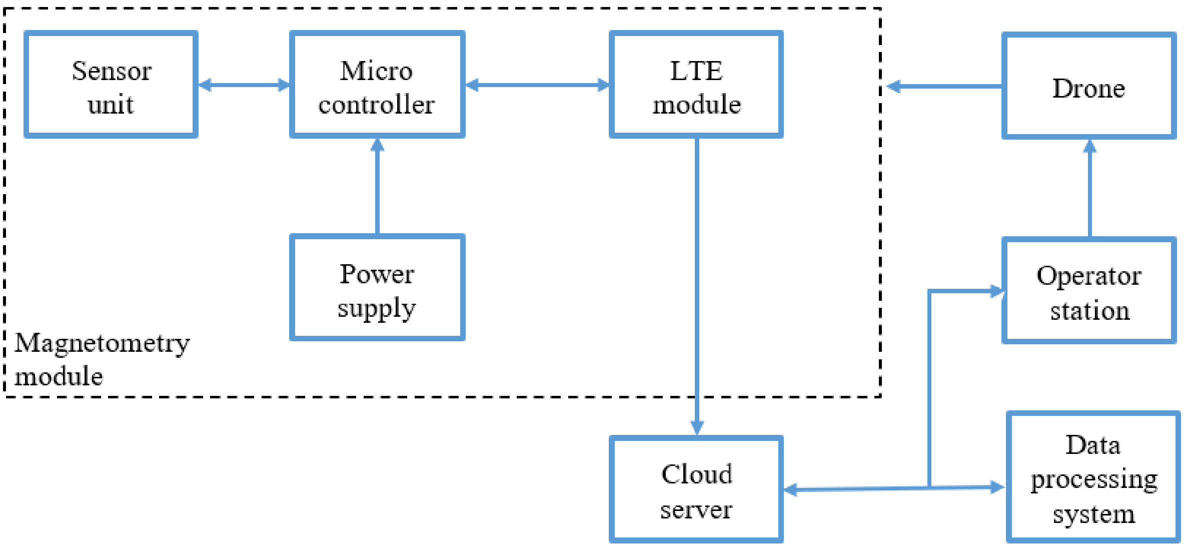

Figure 1. Block diagram of a magnetometer module on a drone

The magnetometric data can be analysed to determine the exact location, depth and orientation of the object. In addition, magnetometers can be easily placed on UAVs to speed up the procedure of scanning large areas [6].

Magnetometer module that connects to the drone. This module consists of a microcontroller that reads information from the sensors located in the sensor unit, all sensors and the microcontroller are powered by a power supply. Further, the information is transmitted via the LTE module to the cloud environment where it then enters the data processing system.

The following formula can be used to determine the position of the magnetic anomaly source relative to the magnetometer sensor, which will allow determining the exact location of the EMP:

$$\mathrm{r} = \mathrm{r} \cdot \mathrm{r}_0 = -\frac{3|\mathrm{B}|}{|\mathrm{G}|^2}\mathrm{G}, \quad (1)$$

where **r** is the bearing vector; r - is the magnitude of the bearing vector; r_0 - is a unit vector; G - magnetic induction gradient; $|\mathrm{G}|$ - is the magnitude of the magnetic induction gradient; $|\mathrm{B}|$ - Magnitude of magnetic induction. This method makes it possible to estimate the position of the magnetic anomaly created by the UXO and to build a map of the potential location of the UXO in the control area based on these data [7].

The minimum size and maximum depth of objects that can be detected by a magnetometer depend on its technical characteristics, design features and operating mode. The main limitations are related to the sensitivity of the detector, the strength of the magnetic field of objects, their size, shape and material.

The minimum size of an object that can be detected by a magnetometer depends on its sensitivity and noise filtering capabilities. For some measuring devices, this size can be very small, a few millimetres or less, while for others it can be larger.

The maximum depth of objects depends on the strength and range of the magnetic field generated by the magnetometer. This depth can vary from a few centimetres to several metres, depending on the type of device and its parameters.

Magnetometers used for explosive ordnance detection may have some limitations that affect their capabilities and effectiveness.

They may have limited sensitivity, which limits their ability to detect metal objects with low magnetic content or low magnetic permeability. Internal and external noise sources can affect the accuracy and reliability of the magnetometer's measurements, which can lead to false results or reduced sensitivity. Some magnetometers may have a limited depth of detection of metal objects, which can make it difficult to find large or deeply buried objects. In general, to use magnetometers effectively in explosive ordnance detection applications, these limitations must be taken into account and optimal measurement conditions must be maintained.

CONCLUSIONS

The magnetometric method is critical to the detection of explosive ordnance in a variety of contexts, as it allows the detection of ferromagnetic objects at great depths, with high resistance to electromagnetic interference. This makes it ideal for humanitarian demining and the search for buried mines and explosives. Due to their high selectivity, the magnetometers reduce the risk of false alarms, allowing for more efficient clearance of areas.

However, magnetometers can be less mobile and more difficult to use than active metal detectors, making them less suitable for field conditions or rapid inspections. Active metal detectors, on the other hand, are easier to use and quicker to respond, making them useful for surface inspections, such as in controlled environments such as airports or checkpoints.

Therefore, the choice of UXO detection method depends on the specific needs and context. Magnetometric methods are suitable for deep demining and situations with a high risk of electromagnetic interference, while active metal detectors are more effective for quick checks on the surface or in controlled environments. It is important to understand the advantages and limitations of each method to ensure maximum safety and efficiency when searching for explosive ordnance.

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