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SYSTEM FOR DETECTION AND IDENTIFICATION OF POTENTIALLY EXPLOSIVE OBJECTS IN OPEN AREA

The **subject** of this research is the methods, means and systems for detecting potentially dangerous military objects in open terrain. The **purpose** of the study is to develop a system for the detection and identification of potentially explosive military objects using an unmanned aerial vehicle (drone), which includes a system for detecting an explosive object using a metal detector with the technology of adjusting the flight height and the detection method using a thermal imager. To achieve the goal, the following **tasks** were solved: a review and analysis of modern methods and systems for the detection and identification of potentially explosive military objects was carried out, the classification of identifiable explosive objects was determined, system components were selected, a structural diagram and an algorithm of the software control tool were developed system of identification of potentially explosive objects in an open area, a software tool for detection and identification of potentially explosive objects in an open area was created. The following **methods** are used in the work: the mathematical method of constructing cartographic grids, the method of recording infrared radiation, the method of eddy currents, methods and means of data collection and processing. The following **results** were obtained: the components of the system were selected, the structure, diagram and algorithm of the software tool for the identification of potentially explosive objects in the open area were developed, and the corresponding software was created. **Conclusions:** the application of the proposed system makes it possible to increase the accuracy of finding or the absence of a potentially explosive object in a certain area due to the use of two methods of detecting potentially explosive objects at once, and provides the opportunity to identify a sufficiently wide range of objects. The developed system is safe, as it is controlled by an operator who is at a safe distance, allows you to get special maps with terrain markings with information about the possible presence of potentially explosive objects in certain areas of the terrain and, in general, maps of metal detector and thermal imager signals.

Keywords: explosive object; mine; detection and identification system; drone; thermal imager; metal detector.

Introduction

Today, in the difficult conditions of martial law for Ukraine, it is important to preserve the lives and health of citizens who are returning to the territories that were under temporary occupation. Explosive military facilities pose a great threat. According to the spokesperson of the Ministry of Internal Affairs of Ukraine Alyona Matveeva the most common cases of injury and death of civilians from explosive objects are explosions of automobile and agricultural transport on anti-tank mines; on unpaved roads and fields, also explosions in forest belts and green zone on anti-personnel mines; and – explosions as a result of careless handling of ammunition found in areas of military operations by citizens. The problem also arises where farmland is cultivated – often agricultural machinery collides with mines, resulting in various emergency events.

In today's realities, the population of Ukraine is increasingly faced with the need for careful compliance with certain safety rules for many objects: industrial facilities, pyrotechnics, household chemicals, energy, etc. At first glance, simple things can become very dangerous to life and health. Such things include potentially explosive objects.

Most objects do not need special knowledge for identification because they have special stickers, inscriptions and markings that identify the object as explosive. However, there are explosive objects that do not have special markings and can be intentionally concealed to cause greater harm to the life and health of the person who finds them. These are military explosive objects. Therefore, the problem of detecting and identifying potentially explosive objects in open areas, especially where the most fierce hostilities took place, is an urgent task.

Open areas outside cities pose a great danger. For example, many explosive objects can be hidden in fields and plains: unexploded mines, shells, abandoned ammunition, etc.

In order to identify and neutralize such objects, mankind creates more efficient and safer automated systems.

Analysis of recent research and publications.

Demining involves a comprehensive approach to the entire area where combat operations have taken place and includes a survey of the entire area, identifying areas of concern, identifying areas with mines and explosive remnants, and clearing them. After humanitarian demining, the terrain becomes fully suitable for civilian use.

In the scientific literature, considerable attention has been paid to the training of demining specialists [1], the technology of mine clearance [2, 3]. The problems of humanitarian demining in their works covered Bevz A.M., Tolkunov I.O. [4], Govduk A.V., and Polotay O.I. [5]. The issue of mine safety training of the population in the scientific literature is still unexplored.

Taking into account the rapid development of robotics in the sphere of the considered activity, mine clearance works have gained popularity [6 - 8]. There is a robot for observation and work on explosive objects (EO) tEODor and a series of robots Telemax. TEODor. It is considered a large demolition robot for police and military purposes. Its approximate cost is $750,000. It can be used universally as a basic tool for tasking, threat prevention, firefighting or industrial applications. Its strong arm and extremely high reliability make it the No. 1 choice for the most dangerous and difficult tasks around the world [9 - 13]. The Telemax series of robots includesTelemax

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4x4, Pro, Hybrid, Plus, Recce. Works from telemax series have different types of chassis and manipulators; they are specialized for individual tasks and can be used universally.All (except telemax RECCE) have a manipulator with Point Center Control tool for gripping objects with tongues, a tool magazine with automatic tool change and countless pre-programmed motion sequences. A wide range of accessories suitable for all telemax robots allows adaptation to a wide range of applications and specific tasks. Telemax 4x4: the wheeled version with a wide wheelbase and 4x4 drive for fast tasks on difficult terrain or loose ground. Telemax HYBRID, PRO and PLUS are similar models, characterized by the combination of the arm and different size of the "body" of the robot. Telemax RECCE is a compact and powerful reconnaissance system without a robot arm, which provides detailed information about the location of the necessary objects, especially when combined with a module creating 3D maps of the area. The most popular of the Telemax series of robots in "demining work" is Telemax PRO. Unlike the tEODor robot, Telemax: is equipped with a seven-axis manipulator, which is more maneuverable, allowing it to perform more delicate work, but with a smaller payload (up to 20 kg). A. Yakovlev and A. Parfilo note that to detect and neutralize explosive objects it is advisable to use robotic complexes such as "CALIBER MK4 Large EOD" from "ICOR Technology Inc." or 510 PackBot or even 710 Kobra from Endeavor Robotics. With their help, the operator can from a safe distance not only photograph the object and record video, but also remove traces of biological origin, which could belong to the person equipping and/or installing the EO [14].

Research material and results.

Explosive military objects that can threaten the lives of citizens returning to temporarily occupied territories can be divided into two types: mines and unexploded high-explosive shells.

Mines began to be used centuries ago and were surface or underground devices made of wood, explosives and triggers. To date, mines have been modernized simultaneously with other weapons and have a wide variety of materials, shapes, active ingredients, methods of use, etc. (fig. 1). According to the results of the study of open sources, modern mines can be divided into several types according to different categories:

- by tactical purpose: anti-tank, anti-personnel, anti-vehicle (road), anti-submarine, trap mines;
- by damage effect: blast wave, cumulative, fragmentation, shrapnel, thermal and others;
- by the principle of operation: controlled and automatic;
- by method of actuation: push, pull (tension), sentry and combined action;
- by the time of action: instantaneous action mines and delayed action mines;
- by body material: metal, plastic, wood, paper, glass and without body (of stamped explosives);
- by mounting level: suspended (mounted) above human height (above tank turrets, vehicle cabins); at ground level (human silhouette, vehicles, armored vehicles); buried in the ground (embedded in buildings or technical installations); mounted at the bottom of bodies of water or underwater part of a shore; floating in water
- by type of active substance;

Unexploded landmines can include projectiles that have been fired but have not detonated or ruptured for any reason. They are most often found up to 1 m deep near the ground or on the surface of the ground. They are dangerous because they can detonate and explode at any moment.

Fig.1. Types of mines and shells and their brief description

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Special teams consisting of sappers of the Armed Forces of Ukraine and pyrotechnicians of the State Emergency Service carry out mine clearance work. The process of searching for potentially explosive objects differs for some types of objects.

For different methods of searching for unexploded ordnance, only two factors matter: the material of the ordnance and the active substance.

With mines, the situation is different: based on the types into which mines are divided, we can conclude that not all of these criteria are worth considering more carefully. It is therefore possible to distinguish the main criteria by which the search will be made:

1. By mode of actuation, by the material of the body;
2. By level of installation;
3. By type of active ingredient.

In 1881. Alexander Graham Bell invented the metal detector [15], which is now used for more thorough decontamination of large areas. It is possible to detect metal products in the ground by electrical conductivity. The detector works according to the following principle: a coil generates electromagnetic waves of a certain frequency, reflected from the sought target. The electronic unit processes the reflected wave and signals the detection of a metal object. Not all metals have the same electrical conductivity. This parameter allows you to understand what material the object is made of, even before digging. Most often, but not always when it comes to mines, there are mines of the same type in the same field. Therefore, when you manage to find one, you can find others by similar indicators. The advantages of the method include the accuracy and care for the area, but a significant disadvantage is the direct involvement in the search for the object and a very high cost of error for the health and the sapper, because some mines can react to changes in the magnetic field.

In the present, people have involved animals in the search for potentially explosive objects: dogs and rats. For the animal, it all looks like a game, but for sappers-cynologists it is a safer and faster method than using metal detectors. The disadvantages include the following: the quality and speed of detecting objects depends on the animal's mood, its relationship with the cyno-sapper and the ability to resist distractions.

Some experts argue that there are still no flawless solutions using automation, in particular drones to search for explosive objects. Technology is not yet able to say with absolute certainty that it has found a mine or a shell, but solutions already in the making make the detection process much easier and make it as safe as possible for both the sapper operator and the average person. The autonomy of drones and robots makes it possible to conduct search operations on the ground, with operators and sappers at a safe distance watching the process with the help of control devices.

Drones and search robots include those that have special devices with which a software tool or operator can determine the location of the explosive object with a certain accuracy. Such devices include thermal imager, metal detector and GPR [16, 17]. The advantages of such robotic systems include almost complete safety of the operator. To disadvantages - speed and accuracy of search, as almost always the results of search of drones and robots require verification by the operator-sapper, because they can react to almost any similar object, which is not explosive.

Modernity offers a great variety of solutions using robots and drones. Now they are not so effective as to completely replace humans, but they are already useful enough to be used in humanitarian missions.

Drones with thermal imagers are used to detect mines that are almost entirely made of plastic. Such systems take advantage of plastic's ability to heat up or mature more slowly than the environment, such as sand. Even if they are covered by soil, the difference in temperature will cause the rock above the object to be noticeably cooler or warmer than the rock around it. The difference stands out best in the morning and evening. Such objects are very difficult to detect with a metal detector, although they have elements of metal in their structure, but they can easily be confused with trash, bullets, shrapnel and other small elements of metal. At the same time, there is a significant disadvantage of using only a thermal imager: If the object is under the ground or other heated longer or at the same speed as the object to be found, this method of search does not make any sense, because on the thermal imager screen the difference will not be noticeable. The time of day also plays an important role, because during the day and at night this method almost does not give the necessary results.

Another example is the use of drones and robots with a metal detector to search for explosive objects. Sometimes GPR is added to such systems, which is not advisable to use in conditions where it is not known exactly what objects are to be found. In general, flying drones and works riding on a tracked platform are used. Works relatively not expensive, fast and accurate, but if you need to find explosive objects in areas with difficult terrain, in which the positioning of the robot will not be accurate enough, it is advisable to use flying drones.

For more efficient and safe operation, it is advisable to develop a system using a drone that includes a detection system with a metal detector with flight altitude adjustment technology and a detection method using a thermal imager. To control the proposed system of detection of potentially explosive objects requires the development of a software tool.

Research results and their discussion.

The proposed system for detecting and identifying potentially explosive objects in open terrain consists of the following components:

1. Drone with accelerometer and gyroscope.
2. A metal detector for the drone.
3. A digital thermal imaging camera for the drone.
4. A regular resolution camera.
5. Smartphone to control the system.

The structural diagram of the system for detection and identification of potentially explosive objects in an open area is shown in figure 2.

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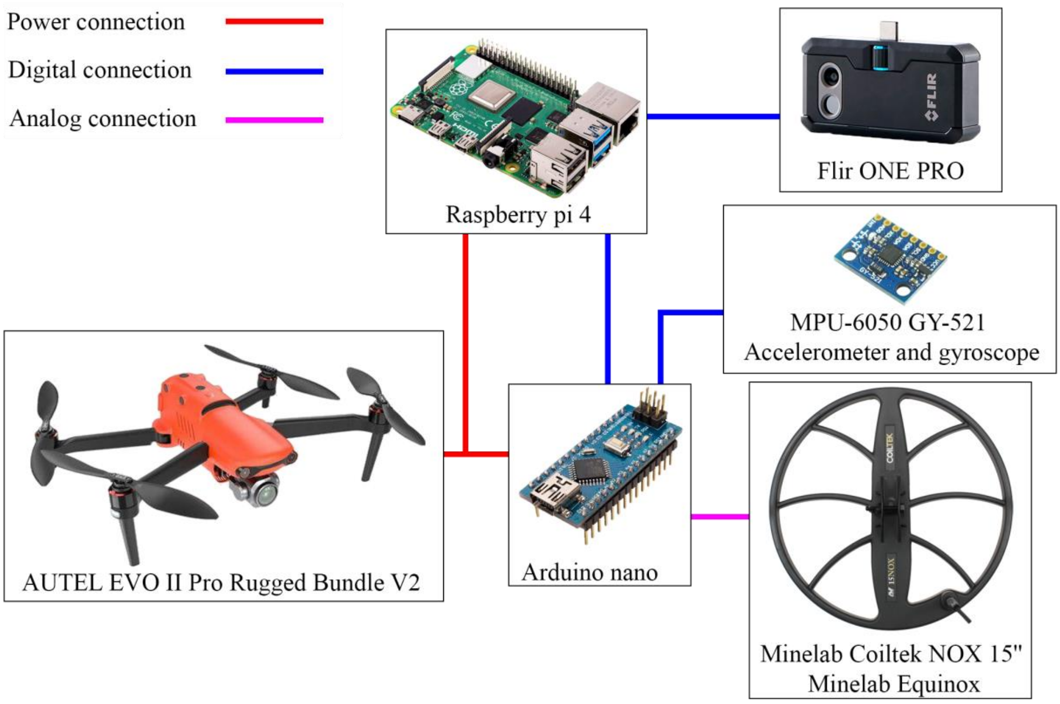

Fig. 2. Structural scheme of the detection and identification of potentially explosive objects in open areas

The proposed system consists of a computing device, sensors and a platform through which the system moves. The platform chosen is the AUTEL EVO II Pro Rugged Bundle V2 drone, which is reliable in terms of stabilization and ability to lift the entire system with a small margin. The selected drone platform has the ability to lift up to three kilograms of cargo and a flight time margin of up to 40 minutes. A metal detector and a thermal imager are needed to detect explosive objects. As a metal detector is used depth coil MinelabCoiltek NOX 15" Minelab Equinox, which weighs 890 grams. For thermal imaging was selected Flir one PRO, because it has a low weight, connection via Type C and a built-in camera used for the operation of the system. A computing device in the form of a Raspberry pi 4 mobile computer was chosen. The Raspberry Pi 4 computer is lightweight and has various digital interfaces, which are used to process data from the sensors and transfer it to the operator. The Raspberry Pi 4 has only digital ports, so the system comes with Arduino Nano, which has enough processing power to process signals from the coil of the metal detector. The gyroscope and accelerometer are built into the MPU-6050 GY-521 modules, used to calculate the movement and connected to the Arduino Nano board. The power of the system is connected to the power system of the drone itself or can be a separate element in the form of three lithium-ion batteries. First of all, the power is supplied to the Arduino Nano and Raspberry pi boards. Power for the thermal imager and camera is supplied from the Raspberry pi, power for the coil and the twin gyroscope and accelerometer module is supplied from the arduino nano.

A software tool was developed to control the proposed potentially explosive object identification system, the algorithm of which is shown in fig. 3.

To start working, it is necessary to select the mode of action of the thermal imager, depending on the time and weather conditions. During the flight, the software tool analyzes the output signals from the thermal imager, the data collector and sensors (gyroscope and accelerometer). After each interrogation, according to a certain algorithm, the map data is restored in certain areas where the scanning is performed.

The electrical conductivity of the area is different from the electrical conductivity of the ground.

Once the map is complete, the analysis of the map begins. During the analysis, according to the data received from the metal detector and thermal imager, areas with a higher probability of the presence of a potentially explosive object are determined. As a result of the work, the operator receives a map of the area with detected areas, signal maps of the metal detector and thermal camera.

Conclusions

Thus, the proposed system of identification of potentially explosive objects in the open terrain due to the premature use of metal detector with the technology of correcting the flight altitude and the method of detection using thermal imager allowed with high accuracy to identify a wide range of objects, also the system is safe for the operator.

Safety is understood to mean that the operator, who is at a safe distance, controls the drone. At the end of the terrain check, the operator receives a map containing terrain marks with information about the possible presence of potentially explosive objects in certain areas of the terrain and in general, the signal maps of the metal detector and thermal camera.

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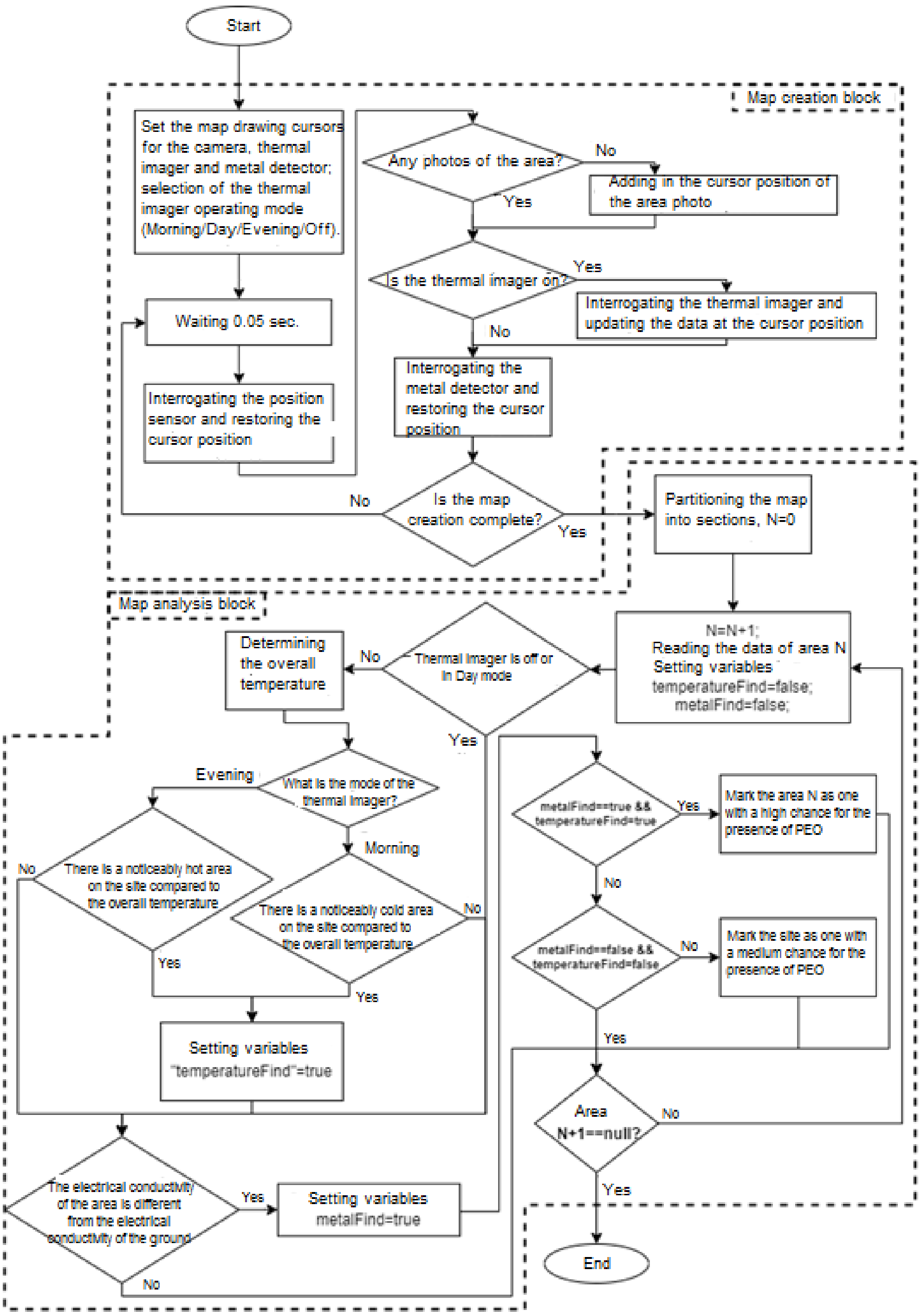

Fig. 3. Algorithm of the software control system of identification of potentially explosive objects in open areas

Accuracy – the idea of finding or not finding a potentially explosive object in a certain area consists of the result of the two most common methods of detecting potentially explosive objects at once.

Wide range of objects, determined by the fact that the system can detect all objects that can be detected separately by thermal imager and metal detector.

The disadvantages of the system is the speed and reduced accuracy or inability to explore the area at a certain time of day or weather conditions.

Speed is a disadvantage because due to the increased accuracy and the use of two methods at the same time, it takes time to complete a full route.

Reduced accuracy or inability to survey an area at certain times of day or weather conditions is due to the use of a thermal imager, less effective in certain times of day and territorial conditions. In addition, using a drone under certain weather conditions can decrease accuracy, but this is corrected by using more advanced drone stabilization systems and design solutions.

Further research to improve the system could add an automatic drone control system, such as a control system using a dedicated coordinator station, which would allow positioning and control of the drone with centimeter accuracy.

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СИСТЕМА ВИЯВЛЕННЯ ТА ІДЕНТИФІКАЦІЇ ПОТЕНЦІЙНО ВИБУХОНЕБЕЗПЕЧНИХ ОБ'ЄКТІВ НА ВІДКРИТІЙ МІСЦЕВОСТІ

Предметом даного дослідження є методи, засоби та системи виявлення потенційно небезпечних об’єктів воєнного призначення на відкритій місцевості. **Метою** дослідження є розроблення системи виявлення та ідентифікації потенційно вибухонебезпечних об’єктів воєнного призначення з використанням безпілотного літаючого апарату (дрону), який налічує в своєму складі систему виявлення вибухонебезпечного предмету за допомогою металодетектора з технологією корегуванням висоти польоту та методу виявлення за допомогою тепловізора. Для досягнення мети вирішені такі **завдання:** проведено огляд та аналіз сучасних методів засобів та систем виявлення та ідентифікації потенційно вибухонебезпечних об’єктів воєнного призначення, визначено класифікацію вибухонебезпечних об’єктів, що ідентифікуються, обрано компоненти системи, розроблено структурну схему та алгоритм роботи програмного засобу управління системою ідентифікації потенційно вибухонебезпечних об’єктів на відкритій місцевості, створено програмний засіб виявлення та ідентифікації потенційно вибухонебезпечних об’єктів на відкритій місцевості. В роботі використовуються наступні **методи:** математичний метод побудови картографічних сіток, метод реєстрації інфрачервоного випромінювання, метод вихрових струмів, методи та засоби збору та обробки даних. Отримано наступні **результати:** обрано компоненти системи, розроблено структуру схему та алгоритм роботи програмного засобу управління системою ідентифікації потенційно вибухонебезпечних об’єктів на відкритій місцевості, створено відповідне програмне забезпечення. **Висновки:** застосування запропонованої системи дозволяє підвищити точність знаходження або відсутність потенційно вибухонебезпечного об’єкту у певній ділянці за рахунок використання одразу двох методів виявлення потенційно вибухонебезпечних об’єктів, надає можливість ідентифікувати достатньо широкий спектр об’єктів. Система, що розроблена є безпечною, оскільки керується оператором, який знаходиться на безпечній відстані, дозволяє отримати спеціальні мапи з позначками місцевості з інформацією про можливу наявність потенційно вибухонебезпечних об’єктів на певних ділянках місцевості та загалом мапи сигналів металошукача та тепловізора.

Ключові слова: вибухонебезпечний об'єкт; міна; система виявлення та ідентифікації; дрон; тепловізор; металодетектор.

СИСТЕМА ВЫЯВЛЕНИЯ И ИДЕНТИФИКАЦИИ ПОТЕНЦИАЛЬНО ВЗРЫВООПАСНЫХ ОБЪЕКТОВ НА ОТКРЫТОЙ МЕСТНОСТИ

Предметом данного исследования являются методы, средства и системы выявления потенциально опасных объектов военного назначения на открытой местности. **Целью** исследования является разработка системы выявления и идентификации потенциально взрывоопасных объектов военного назначения с использованием беспилотного летающего аппарата (дрона), который содержит в своем составе систему обнаружения взрывоопасного предмета с помощью металлодетектора с технологией коррекции высоты полета и метода обнаружения с помощью тепловизора. Для достижения цели решены следующие **задачи**: проведен обзор и анализ современных методов, средств, систем выявления и идентификации потенциально взрывоопасных объектов военного назначения, определена классификация идентифицируемых взрывоопасных объектов, выбраны компоненты системы, разработана структурная схема и алгоритм работы программного средства управления системой идентификации потенциально взрывоопасных объектов на открытой местности, создано программное средство выявления и идентификации потенциально взрывоопасных объектов на открытой местности. В работе используются следующие **методы**: математический метод построения картографических сетей, метод регистрации инфракрасного излучения, метод вихревых токов, методы и средства сбора и обработки данных. Получены следующие **результаты:** выбраны компоненты системы, разработана структура схемы и алгоритм работы программного средства управления на открытой местности, создано соответствующее программное обеспечение. **Выводы**: применение предлагаемой системы позволяет повысить точность нахождения или отсутствие потенциально взрывоопасного объекта на определенном участке за счет использования сразу двух методов обнаружения потенциально взрывоопасных объектов, дает возможность идентифицировать достаточно широкий спектр объектов. Разработанная система является безопасной, поскольку управляется оператором, который находится на безопасном расстоянии, позволяет получить специальные карты с пометками местности и информацией о возможном наличии потенциально взрывоопасных объектов на определенных участках местности и в целом карты сигналов металлоискателя и тепловизора.

Ключевые слова: взрывоопасный объект; мина; система выявления и идентификации; дрон; тепловизор; металлодетектор.

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