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DEVELOPMENT OF A SYSTEM FOR REMOTE DETECTION OF EXPLOSIVE DEVICES AND POLLUTION ON AGRICULTURAL LANDS

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One of the main principles of the precision farming system is to increase the accuracy of agrotechnical operations with the help of high-precision equipment and data collection technologies. Remote sensing uses satellite and aerospace means to obtain images and data about the state of plants, soil, and other agricultural parameters. This information is used to analyze and make decisions about the input of resources in specific areas of the fields.

In today's world, the problem of security on agricultural land is becoming increasingly important due to the spread of explosive devices and pollution. The development of an effective system for remote detection of these threats is becoming an urgent task today, which would ensure safety and stability in the work of agro-industrial enterprises, reducing the risk of negative consequences for civilians and the environment.

It is noted that remote sensing of the earth's surface in the context of the element of precision agriculture allows for maximization of the use of resources and ensures uniform and optimal cultivation of crops. This leads to an increase in the quality of products and a decrease in crop losses due to more efficient management of agrotechnical processes. Remote sensing of the soil surface can be one of the complementary methods in the search and detection of explosive devices, mines, shells, etc. It has been established that for these purposes it is possible to effectively use unmanned aerial vehicles for agricultural purposes from the companies XAG and DJI, which should be modularly equipped with optical-electronic means with a 30-fold optical magnification of surveillance objects, a multispectral camera, a thermal imager, a ground-penetrating radar (non-linear radar), which surveys areas of the earth to detect landmines by determining their position on a 3D map or orthophoto plan with high accuracy of ±2.5 cm and creating maps of minefields and a ground station, which provides manual and automatic drone operation modes with the ability to program the flight path based on GPS/RTK coordinates, is used for map creation and drone control.

A system of remote detection of explosive devices and pollution is proposed with the possibility of expanding the search for the nomenclature of dangerous objects by installing optical-electronic means, a thermal imager, radar, and artificial machine vision. It is noted that the developed method of mapping the territory of chemical pollution, which includes the control of an unmanned aircraft from a ground radio control station and the conduct of chemical (radiation) reconnaissance of the studied territory, is carried out in two stages. At the first stage, the flight of the unmanned aerial vehicle is performed at a fixed altitude, during which measurements are synchronously carried out: coordinates, heights relative to terrain surfaces, and radiation power values. At the second stage, the unmanned aerial vehicle performs sounding of elevations and depressions of the terrain, folds of the roofs of buildings, places of maxima, and danger limits. The developed system will increase the efficiency of remotely detecting the locations of explosive devices, improve the accuracy and reliability of mapping areas of ground radiation localization, and determine its intensity in areas of radiation pollution, as well as mark the boundaries of pollution on the ground. Additionally, digital marking of the location of explosive devices and mines, as well as marking the territory of radiation pollution on the ground, facilitates the quicker search for contaminated areas for decontamination and prevents unauthorized people from entering these territories.

Key words: *precision farming system, remote sensing of the earth, explosive devices, mines, pollution, unmanned aerial vehicle.*

Fig. 11. Ref. 19.

1. Problem formulation

Russia's full-scale invasion of Ukraine, starting in February 2022, significantly damaged the Ukrainian agricultural sector and led to multibillion-dollar losses. Not only the infrastructure and the economy but also the agricultural sector became the object of attacks by Russian forces. Attacks on fields and farms, occupied territories with agricultural resources, as well as attempts to block the export of grain put a heavy burden on Ukrainian farmers.

Not only the infrastructure and the economy but also the agricultural sector became the object of attacks by Russian forces, as a result of which large areas of territory are today contaminated with unexploded explosive devices and mines. All of them pose a threat to the military and the civilian population. Explosive objects are also found on land and agricultural fields, which makes it impossible to carry out mechanized work in a timely and qualitative manner. Therefore, the need to detect and neutralize unexploded ordnance, their remnants, or mines remains relevant today for all regions of Ukraine where active combat operations were and are being conducted. One of the effective ways (methods) of their search is remote.

One of the main principles of the precision agriculture system (PRA) is to increase the accuracy of agricultural operations with the help of high-precision equipment and data collection technologies. This allows efficient use of resources, reducing costs and negative impact on the environment. The purpose of STZ is to increase the yield, improve the quality of products, and reduce losses.

Remote sensing uses satellite and aerospace means to obtain images and data about the state of plants, soil, and other agricultural parameters. This information is used to analyze and make decisions about the input of resources in specific areas of the fields.

Drones provide highly advanced aerial photography, collecting detailed data on plant health, irrigation efficiency, and other parameters. They allow monitoring of even hard-to-reach or large areas, making them a useful tool for precision farming.

Remote sensing of the soil surface, as an element of STZ, is one of the complementary methods in the search and detection of explosive devices, mines, projectiles, etc. For this, one can use unmanned aerial vehicles (UAVs) of mass production, for example, for agricultural purposes, which can work with RTK-systems, such as XAG models V40, P100, P40, and DJI Agras T16, T20, or T30 models. Their main recognition is the spraying of crops with plant protection products.

The use of modern technical means in agriculture, in particular UAVs for technological operations, encourages the creation of new approaches and methods of their effective use, which is an urgent task not only for agriculture but also for military enterprises.

In today's world, the problem of security on agricultural land is becoming increasingly important due to the spread of explosive devices (EDs) and pollution. The development of an effective system for remote detection of these threats is becoming an urgent task today, which would ensure safety and stability in the work of agro-industrial enterprises, reducing the risk of negative consequences for civilians and the environment.

2. Analysis of recent research and publications

Today, the need to identify and dispose of unexploded ordnance, their remnants, or mines [1, 2] remains relevant for all regions of Ukraine, where active military operations were and are being conducted. Currently, there are quite a lot of methods and various systems designed to solve the problems of demining, both ground and above-ground means. These include manual demining, the use of metal detectors, trained dogs, unmanned aerial vehicles, robots, and specialized demining machines. The choice of methodology depends on the type and number of mines, the geography of mined areas, available resources, and technologies.

One of the most traditional methods of detecting and destroying explosive mines is manual demining (Fig. 1). This method involves the use of specialists who thoroughly inspect the area for the presence of mines. For this, they mainly use a metal detector, which has a wide range of applications. They are used in medicine to find metals in the human body, as well as for military purposes to assist in the detection of explosive devices (mines). However, there are many risks associated with threats to the lives of deminers. Practical experience shows that for every 5,000 defused mines there is one dead and two injured sappers [3]. In addition, when surveying large areas, such ground systems and technical means do not allow to achieve sufficient efficiency, since the process of surveying minefields takes a lot of time.

Machine demining is an effective method of detecting and destroying mines on large areas of land (Fig. 1). This method uses special machines that can detect and destroy mines [4, 5].

A well-known demining machine containing an armored self-propelled chassis, a means of communication, a means of firing, a place for personnel, and a towed demining device of pressure action. At the same time, a place for the personnel, and means of communication are placed inside the armored self-propelled chassis, the means of firing is placed on the armored self-propelled chassis, the towed demining device of pressure action is placed in front of the armored self-propelled chassis [5].

The disadvantages of the well-known demining machine are that demining is carried out only on a track passage by hitting the demining trailer with pressure action on explosive objects, low maneuverability due to the large mass of the demining trailer with pressure action, and after seven or ten detonations on explosive objects, the demining trailer is destroyed. Additionally, the machine has a low rate of explosive object search and low personnel security.

manual machine remote

Fig. 1. Demining methods

A known method of demining mine-explosive obstacles involves dispersing a demining charge in the form of a fuel-air cloud over the mined area by deploying a shell over the area, filling it with a fuel-air mixture by inflating the shell under the pressure of this mixture and initiating the detonation of the fuel-air cloud within the shell. The deployment of the shell over the mined area is carried out by unwinding and moving the coil with the shell over the mined area under the pressure of the fuel-air mixture stream [6].

The disadvantage of the known method is that the deployment of the coil on mine-explosive barriers is possible only if there are no obstacles in the direction of its movement. In addition, during the deployment of the coil under the influence of its weight, the mine may be triggered, which makes further demining impossible.

The use of robotics for demining is becoming more common as it reduces the risk to human life. Different types of robots can be used depending on specific conditions and needs.

There is a known method of remote demining, in which a single charge is transported to a minefield using a launcher [5].

The disadvantage of the known method is that it is impossible to ensure the arrangement of a passage in a minefield using a single charge. With repeated use of single charges, it takes a lot of time to arrange the necessary passage, as well as significant costs of explosives. In addition, it is impossible to ensure that single charges hit the minefield in a specific place, which significantly reduces the probability of destroying all mines in the passage being arranged.

A known method for assessing radiation levels in areas near radiation-hazardous facilities and after emergency releases is based on remote measurement from unmanned radiation and spectrometric measurements of its composition [7]. The data obtained are used to calculate partial concentrations of radionuclides on the ground surface within the radioactive cloud's footprint, taking into account the distance measured by the altimeter.

The disadvantage of this method is the lack of binding of dosimetric and spectroscopic measurements to the area, which makes it difficult to map and establish the border of the radiation-contaminated territory.

UAVs (drones) are becoming an increasingly important tool in the demining process. They can be used for different tasks, depending on their equipment and configuration, for example, they can be equipped with sensors to help detect mines and other explosive devices; can collect geographic data, and create high-quality maps of minefields, which helps demining teams in planning their actions; can be equipped with small explosive charges, which are used to destroy detected mines.

Today, for the detection of explosive devices and mines, a remote method is used, which is based on various physical phenomena (Fig. 1). With the development of the element base, it became possible to implement various approaches that were previously considered unlikely: a microprocessor system for the remote detection of metal objects "beating method" BFO (Beat Frequency Oscillator); type "reception - transmission" TR-IB (Transmitter Receiver - Induction Balance); of the "disruption of resonance" type OR

(Off Resonance); radio frequency systems for detecting metal objects RF (Radio Frequency) and pulse MK systems for remote detection of metal objects PI (Puls Induction) [8].

Therefore, we can confidently note that the disposal (destruction) of explosive objects on the territory of Ukraine is a priority measure. And to solve them, all possible, various demining systems should be used, in particular, the method of remote detection.

3. The purpose of the article

The purpose of the work is to develop a system for detecting explosive devices, mines, or pollution utilizing remote sensing by unmanned aerial vehicles of the earth's surface on agricultural land.

The tasks of the work were: to consider remote sensing of the earth's surface in the context of the element of precision agriculture; carry out an analysis of widely used explosive devices, mines, or pollution on agricultural land; to investigate the existing means and methods of detecting explosive devices and pollution; to develop a system for remote detection of explosive devices and pollution on agricultural land.

The research methodology was based on the application of methods of analysis and synthesis of information from official sources and scientific research, the method of materialistic dialectics of physical phenomena.

4. Results of the researches

The relevance of the study of remote sensing of the Earth (RS) in the context of precision agriculture has gained special importance in the conditions of global climate change and the growth of the world population. Precision agriculture includes systems that ensure optimal use of resources and increase yields.

Remote sensing allows for effective monitoring of the condition of soils and vegetation in real-time, which is critical in conditions of unpredictable changes in the distribution of precipitation, temperature fluctuations, and other natural factors. The use of remote monitoring makes it possible to reduce the need for plant protection products and manual labor during agricultural work, which leads to a reduction in the negative impact on the environment [9, 10].

In comparison with traditional methods, RS provides an opportunity to obtain data on a large area at the same time, which increases the efficiency and speed of monitoring (Fig. 2). In addition, it allows monitoring in hard-to-reach or large areas without the need for researchers to be physically present on site.

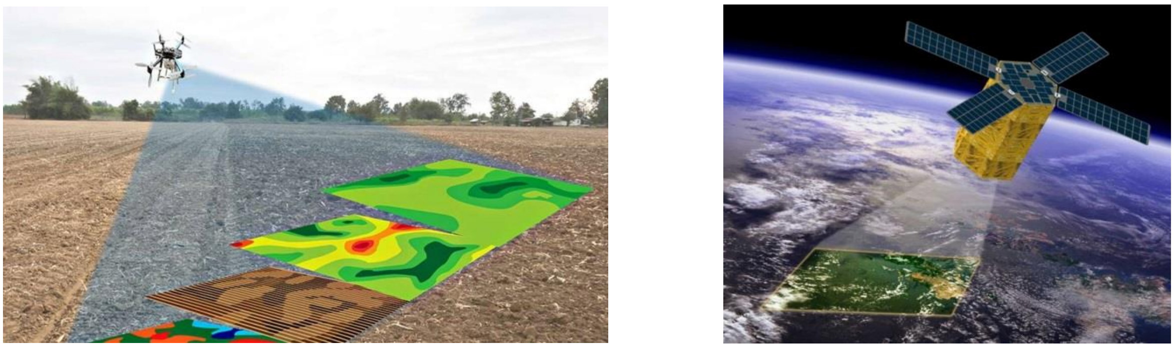

Fig. 2. Remote sensing of the Earth

Remote sensing of the Earth's surface is based on the use of electromagnetic waves of various lengths. Observations take place in the infrared, visible, and microwave ranges. Each range has unique properties that allow obtaining different aspects of information about the Earth's surface [9, 11].

Electromagnetic waves interact with various objects on the Earth's surface. For example, soil, plants, and water have different light absorption and reflection properties depending on their physical and chemical properties.

Each object has a unique spectral signature known as a "spectral signature". This signature is determined by the specific properties of the material and becomes the key to identifying objects in images obtained from satellites.

Therefore, remote sensing enables the use of spectral analysis to assess not only crops but also to detect explosive objects or contaminants. Different growth stages of plants and the presence of soil contaminants have their unique spectral characteristics, and changes in these characteristics can indicate stress, diseases, nutrient deficiencies, or the presence of explosive items. Changes in spectral indices can indicate the presence of pests or diseases in plants. RS allows detecting these changes at early stages, enabling farmers to take timely actions for control and treatment.

Detecting diseases and pests in their early stages allows farmers to respond promptly and take measures for treatment or control. This can significantly reduce crop losses and plant protection costs. In turn, the detection of explosive objects, mines, or pollution allows one to create an electronic map of their location and subsequently take measures for their disposal.

Currently, Ukraine is under martial law and hostilities are ongoing, the Russian occupiers are using a large number of various explosive devices on the territory of Ukraine. All of them pose a threat to the military and the civilian population. Today, a large area remains contaminated with remnants of explosive objects and mines. In addition, explosive objects are also found on agricultural land, which makes it impossible to carry out mechanized work in a timely and qualitative manner.

Particular attention should be paid to informing the population about dangerous objects and once again urging the civilian population not to approach mines and ammunition. In the case of discovering the location of an explosive device, it is forbidden to approach the object, move it, or take it in hands, discharge, throw, hit it, light a fire next to it, or throw an object at it, bring the object home, to the yard, or any other place of storage. It is necessary to notify the police and emergency services immediately.

Today, a colossal number of explosive devices and mines have accumulated in agricultural fields, especially in enemy-occupied territories and those close to the front line [12, 13, 14]. The military and state emergency service of Ukraine warns that it is forbidden to approach such objects thrown by the enemy. Among such devices, the following can be noted (Fig. 3):

POM-2 is a fragmentary anti-personnel mine of tension effect circular damage of remote demining, which has a metal body and 4 tension sensors that trigger its detonation upon contact;

03M-72 is similar to the previous one in terms of characteristics, which is a pop-out fragmentation anti-personnel mine of circular damage with a metal case and stretch sensors. It can be installed in a managed and unmanaged form;

PFM-1 and PFS-1S are high-explosive anti-personnel mines designed to detonate enemy personnel with an explosion. It has a green or brown plastic body and small dimensions, is triggered by pressing a weight of more than 5 kg, and has a self-liquidating mechanism;

MON-200 is a directional anti-personnel mine with a metal body and target sensors in the form of stretch marks. It differs from the MON-50 mine in its shape and larger dimensions;

PMN-2 is a high-explosive anti-personnel pressure mine, 12 cm in diameter, triggered by pressure from 5 kg. The plastic case of this mine is green or brown with a detonator in the form of a cross. They are installed in the soil or on its surface;

PTM-3 is a high-explosive anti-tank mine containing a metal case and an electromagnetic target sensor. Its operating radius is at least 3 meters;

TM-62 is an anti-tank mine that explodes when a car or other vehicle hits it.

Most of the considered mines (Fig. 3) are equipped with a special electronic unit responsible for processing signals from the seismic sensor and controlling the warhead. The electronics unit of the mine receives signals from the vibration of the ground under the mine and compares them with the signatures in the memory. If the vibrations are similar to those caused by human steps and also have a sufficient amplitude, which indicates an approach, the command is given to activate the warhead, which flies to a height of about 1-1.5 m and explodes.

POM-2 PFS-1S PMN-2 TM-62

Fig. 3. General appearance of anti-personnel and anti-tank mines

As a result of Russia's full-scale war against Ukraine, many thousands of square kilometers of Ukrainian land were mined, which will take many years to clear. Where the Russian troops advanced, the aggressors did not create minefields with specific designations and complete maps but simply mined the small areas they needed - dirt roads, forests, and arable land. Some of the unexploded mines and shells lie on arable land, which prevents sowing, mowing, and harvesting. The first stage on the way to the final goal of demining dangerous zones is their detection.

The risks and difficulties associated with manual demining, along with strict reliability requirements, make mine detection and clearance a time-consuming and expensive process. Also, clearing efforts are affected by climatic conditions or complex topography. To reduce the influence of the specified factors, an unmanned aerial vehicle (UAV, drone) can be used for remote search and detonation of explosive devices of EDs and mines.

One of the promising directions for the detection of EDs and mines, in addition to ground-piloted and unmanned field vehicles, can be the use of mass-produced UAVs, for example, for agricultural purposes, which can work with RTK systems, for example, the V40, P100, P40 models of the XAG company [8] (Fig. 4) and DJI models Agras T16, T20 or T30 [15, 16] (Fig. 5), which increases the accuracy of positioning up to 2 cm. Their main recognition is spraying crops with plant protection agents. At the same time, drones ensure the application of the necessary payload.

The use of UAVs in agriculture has a huge potential primarily due to their use and implementation in the tasks of precision agriculture.

Using UAVs in agriculture allows for solving tasks such as: creating electronic maps of fields (building a 3D model of fields); inventory of agricultural land; assessment of the scope of works and control of their execution; operational monitoring of crop conditions; evaluation of the similarity of crops; carrying out of ecological monitoring of agricultural lands; protection of agricultural lands; spraying crops with chemical preparations to combat pests and diseases; evaluation of the chemical composition of the soil, etc.

V40 P100 P40

Fig. 4. General view of XAG spraying drones

T16 T20 T30

Fig. 5. General view of DJI Agras spraying drones

It is not excluded that the use of UAVs for the remote detection of EDs and mines may come in handy, because, from the point of view of safety, methods of aerial reconnaissance using free-flying drones are certainly more effective.

The basis of the proposed method is the task of expanding the search for the nomenclature of dangerous objects, improving the effectiveness of remote detection (searching) of the locations of IEDs and mines, and increasing the reliability of the search process.

The technical task is solved due to the use of an agricultural UAV, which can be modularly equipped with optical-electronic means with a 30-fold optical magnification of observation objects, a multispectral camera, a thermal imager, a ground-penetrating radar (non-linear radar) (Fig. 6), which surveys areas of land with to detect land mines by determining their position on a 3D map or orthophoto plan with a high accuracy of ± 2.5 cm, creating minefield maps. To control and manage the drone, a ground station is used, enabling both manual and automatic drone operation modes, with programmable flight plans based on GPS/RTK coordinates.

Optical camera Multispectral camera Thermal imager Ground radar

Fig. 6. Possible options for using electronic means to detect GNP and min

The UAV flies along a pre-planned route (Fig. 7) in manual or automatic modes to detect UAVs and mines.

Fig. 7. An example of a UAV flight route when planning a terrain survey

Let's consider possible methods for detecting explosive devices and mines in agricultural fields.

Use of optical and electronic means. The method of detecting EDs and mines on agricultural land is carried out with the help of an agricultural UAV, which includes a video surveillance system, a communication unit with a flight control point, in which the received intelligence information is transmitted from the aircraft to the command post (Fig. 8) [17].

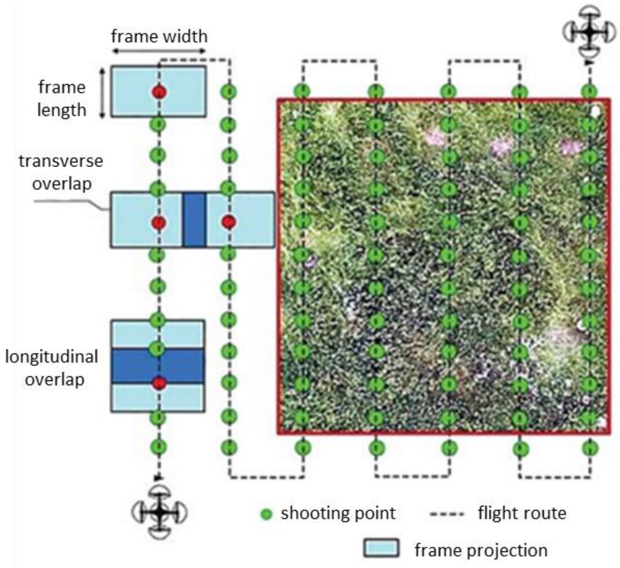

Fig. 8. Scheme of implementation of UAV field reconnaissance using opticalband electronic means [17]

At the first stage of aerial reconnaissance, the overall picture of anomalies and surface damage in areas likely to have mines is identified. This involves flying over the reconnaissance zone at a high altitude and, if necessary, conducting comparative frame-by-frame photography to capture the topographical layout of the area with potential mine placements. If topographical anomalies from the activity of mine-layers are detected, the second stage of reconnaissance is conducted-discrete frame-by-frame photography of these zones at a low altitude using the same or an additional UAV, such as a quadcopter equipped with high-resolution optoelectronic equipment and 30x zoom capabilities. Powerful software allows for the comparison of frames taken at different heights and angles, and following a set algorithm, it makes a final conclusion regarding the placement of mines and the creation of minefield maps with geodetic accuracy of ± 2.5 cm. An example of the cartographic capabilities of agricultural UAVs is shown in Figure 9. Powerful software allows for the comparison of frames taken at different heights and from different angles, and based on the established algorithm, makes a final conclusion about laying mines and creating maps of minefields with geodetic reference with an accuracy of ± 2.5 cm. An example of cartographic capabilities and agricultural UAV assignment is presented in Figure 9.

In the case of using special equipment in the form of a hyperspectral camera with multiple zooms and a magnetometer on a UAV, the ability to detect EDs and mines appears both on the surface of the earth and under the soil layer (metal objects). UAVs spend about 15 minutes surveying along the defined trajectory of one hectare of land, after which they leave the exact coordinates of suspicious metal objects. After the readings are taken, special software can be used to create maps with diagrams of the location of explosive objects and exact GPS coordinates in the survey area.

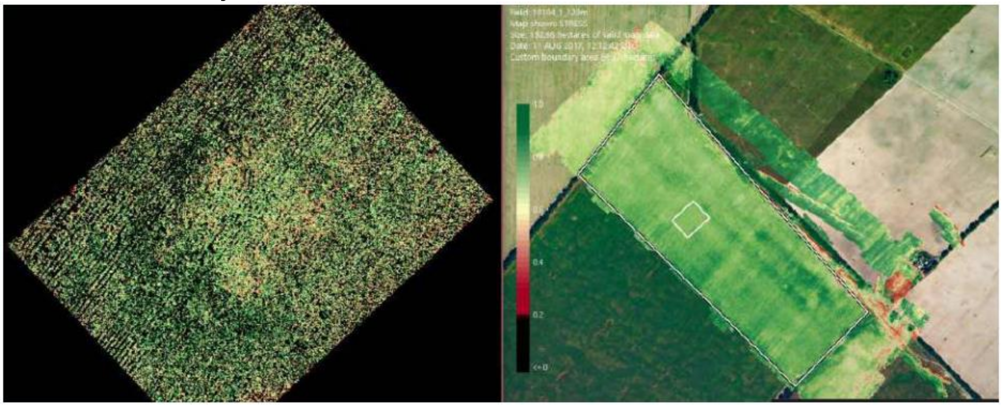

Fig. 9. An example of mapping capabilities and agricultural UAVs [18]

Using a thermal imager. It is known that a thermal imager is a device that allows you to visualize the temperature field when measuring temperature. It works mainly in the infrared part of the electromagnetic spectrum. During the day, under good weather conditions (when it is sunny), GNPs and mines located on the surface of the earth heat up much faster than the surrounding stones, and therefore infrared cameras can detect their location with high accuracy (Fig. 10). It is known [14] that in the first half of the day, mines in a plastic case are better detected, in the second - in a metal case. This property can be explained by the fact that during the daylight the mines, which are in the metal case, gradually heat up, and when in the evening, the temperature starts to decrease, it is more clearly distinguished from the thermal images. Some mines can be recognized from a great height, some - only from a height of several meters.

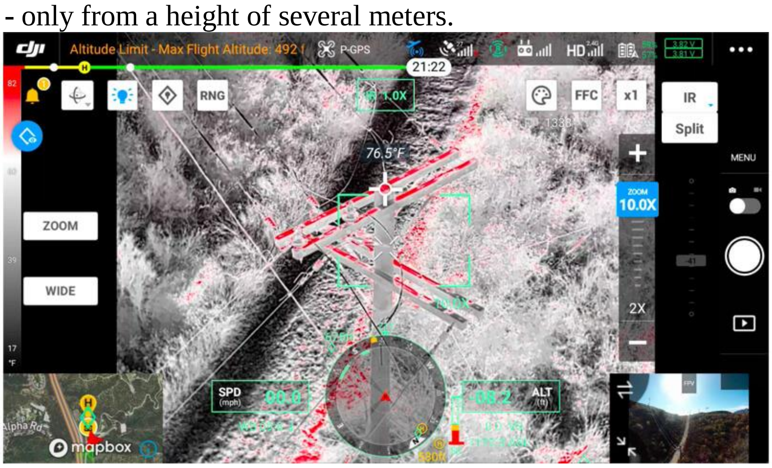

Fig. 10. Visualization of the area when using the DJI UAV thermal imaging camera

In the case of detection of such explosive devices and mines, the UAV software automatically stores their location data with high accuracy in combination with an automated topographical system and digital information processing.

The indicated method of detection of IEDs and mines can only be a component of a complex process because the given method can bring results only for a limited list of mines and under certain weather conditions and times of day.

Use of non-linear radar. The essence of the proposed method is that a non-linear radar (non-linear junction detector - Non-Linear Junction Detector, NLJD) is used for remote search and detection of EDs and mines. Its principle of operation is based on the irradiation of objects with short radio frequency pulses and the reception of echo signals at other frequencies (second and third harmonics). Echo signals at the frequencies of the second harmonic appear as a result of the spectral transformation of the probing signal on elements with a non-linear current-current characteristic. Semiconductor components contained in any radio-electronic device have this characteristic. Echo signals of the third harmonic appear from the contacts of metal parts. It provides detection of objects (regardless of whether they are on or off and the presence of power sources) that contain semiconductor products located on the surface of the ground, in the soil (snow), and radio-transparent building structures.

Thus, it is possible to detect the following elements: radio transceivers used as alarms, communication systems, and remote controls of various GNPs; electronic and electromechanical timers for GNP; acoustic, magnetic, and optoelectronic sensors installed on the GNP; television (video, photo) cameras. At the same time, the nonlinear radar can be used not only as a separate sensor but also in combination with a mine detector.

The practical implementation of the claimed method is reduced to the use of mass-produced drones, for example, for agricultural purposes, which can work with RTK systems, such as XAG V40 and DJI Agras T20 [15, 16], which increases the positioning accuracy to 2.5 cm. When detected the software automatically creates a map with the exact coordinates of their location using the non-linear GNP radar and mines. Agricultural UAVs ensure the application of the necessary payload. For joint work with existing hand-held devices for the search and detection of GNP and mines, the drone is equipped with a suitable mount. To increase the time spent in flight and the operation of sensors, the drone is equipped with an additional power supply battery. At the same time, standard multispectral cameras included in the agricultural drone can be used.

Using artificial machine vision. The laying of explosive objects, such as mines, shells, etc., is carefully masked, but it is almost impossible to hide the traces of the mining process - they are revealed by changes in the topography of the surface, and it will always differ from the topography of the area that was not touched by the miners. After all, the latter, as a rule, make markings, walk on the ground, remove the top layer of sod, dig a hole, remove soil, etc., and after laying this hole, bury it, return the sod and soil to its place and mask the dangerous place. It is difficult to make the consequences of all these operations of a team of miners invisible, especially if you look, for example, at agricultural fields from a height of several tens of meters.

It is also necessary to take into account the fact that after some time of explosive devices being in the soil after their installation, the chemicals contained in the anti-personnel mine begin to seep into the soil. From there, they get into the grass and onto the leaves, which changes their color. The drone helps to create a map of minefields based on such rather insignificant changes in the color of vegetation, which greatly simplifies the demining process for deminers. An unmanned minesweeper will be especially useful when looking for old, long-established mines, which are usually covered by a layer of soil, making it difficult to detect their locations.

Given the specified features of the surfaces of agricultural land, artificial intelligence can be used to help detect explosive devices, which, with traditional machine vision tools, will independently detect such objects with high probability and accuracy.

The considered method of detecting explosive objects based on anomalies in the topography of the earth's surface minimizes gaps and provides opportunities to significantly reduce search costs and possible human casualties when demining large areas and agricultural lands.

The basis of the development is the well-known method of mapping the territory of radiation pollution [19] with the possibility of expanding the search for the nomenclature of dangerous objects by installing optical-electronic means, a thermal imager, radar, and artificial machine vision. The task of development is to improve the method of remote detection of UAVs, mines, pollution, and radiation dose rate from UAVs by measuring pressure, humidity on the territory of the ground control station, and air temperature and UAV height relative to the earth's surface at each survey point [19].

The task is solved by using the method of mapping a chemically contaminated area [19], which includes controlling the UAV from a ground control station via radio communication and conducting chemical (radiation) reconnaissance of the surveyed area in two stages.

The essence of the improved detection system is explained by the block diagram of the equipment located on board the UAV (Fig. 11).

At the first stage, the UAV flies at a fixed altitude, during which the following measurements are made synchronously: the coordinates of the UAV using an on-board GPS receiver, the height of the UAV relative to the terrain with a laser altimeter, the power value of the ground-penetrating radar with a detector, the measurement results of which are adjusted depending on the measured heights relative to the surfaces area. At the second stage, the UAV flies at a variable altitude and determines the radiation power. Next, the ground control station receives the results of measurements and observations via radio communication from the UAV and generates, at the first stage, map information about the approximate distribution of hazards in the study area, which is refined at the second stage of research. According to the development of the system for the remote detection of GNP and pollution, at the preparatory stage, air pressure and humidity are measured, georadar readings are calibrated by the location of the UAV in the air at a fixed height relative to the reference source with the possibility of correcting the readings according to the reference, and air temperature is measured at the detector level. During the first stage, the following are carried out synchronously over the studied territory from the UAV: observations with a GPS receiver, air temperature measurements, aerial photography of the studied territory, and at the ground control station based on the results of the aerial photography, a digital terrain model and an orthophoto plan are generated, on which the distribution of the power of the chemical hazard in the research area is built, which is reduced to a height of 1 m above the surfaces and constant values of air temperature, pressure and humidity.

At the second stage, the UAV performs sounding of elevations and depressions of the terrain, folds of the roofs of buildings, places of maxima and danger limits, and on each vertical, the following is performed: hovering of the UAV; determination of planned coordinates by the GPS receiver, which is controlled by the difference in the readings of the laser altimeter; measurement of the level (radiation power) of chemical danger; air temperature measurement at the detector level. After the end of the mission, the readings of the detector are calibrated relative to the reference source and corrections are made to the measured values, and at the ground control station based on the data transmitted from the UAV on the orthophoto plane, a refined distribution on the research territory is constructed. To mark the borders, a marker module can be installed on board the UAV, and following commands from the ground control station, the markers are dropped along the border of the radiation contamination zone and the drop locations are displayed on the orthophoto plane.

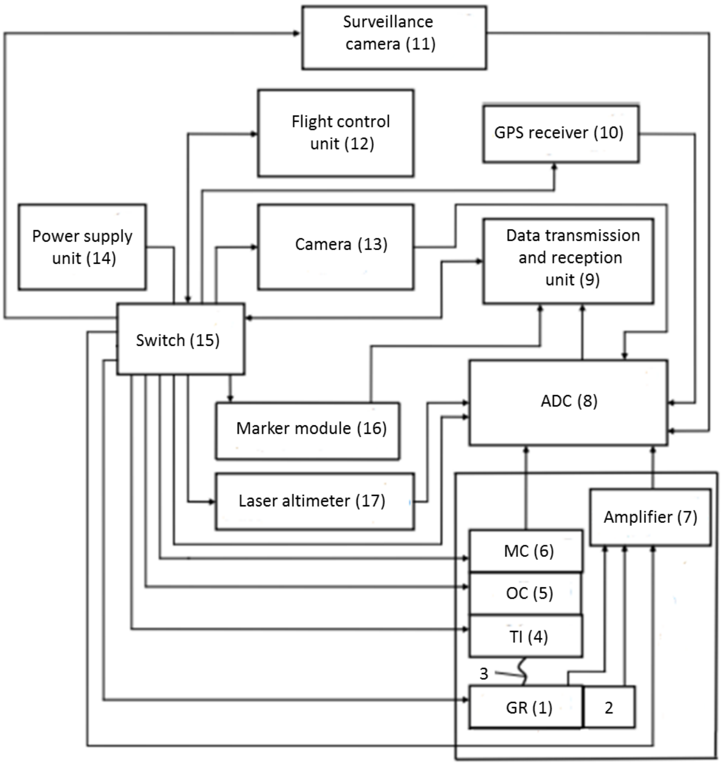

Fig. 11. Block diagram of the equipment located on board the UAV:

1 – ground-penetrating radar, 2 – thermocouple, 3 – cable from GR and thermocouple, 4 – thermal imager, 5 – optical camera, 6 – multispectral camera, 7 – two-channel amplifier, 8 – multi-channel analog-to-digital converter (ADC), 9 – data transmission and reception unit, 10 – GPS receiver, 11 – surveillance camera, 12 – flight control unit, 13 – camera, 14 – power supply unit, 15 – switch, 16 – marker module, 17 – laser altimeter

The technical result is an increase in the efficiency of remote detection of the locations of GNP, an increase in the accuracy and reliability of mapping the areas of localization of surface radiation and the determination of its intensity in places of radiation pollution, and the possibility of marking the limits of pollution on the ground. In addition, the digital marking of the location of mines and mines, as well as the marking of the area of radiation contamination on the ground, helps to find contaminated sites for decontamination more quickly and ensures that outsiders do not enter these areas.

Therefore, the developed system of remote detection of GNP and pollution has great potential for implementation in practical use in agriculture to ensure the safety and protection of resources.

5. Conclusions

1. In modern agriculture, there is an active transition to the use of the latest technologies, in particular precision farming systems. They make it possible to reduce the consumption of resources and increase the accuracy of applying fertilizers and pesticides, which leads to an increase in the yield and quality of the obtained products. The use of elements of precision agriculture, in particular remote sensing, allows for maximization of the use of resources and ensures uniform and optimal cultivation of crops. This leads to an increase in the quality of products and a decrease in crop losses due to more efficient management of agrotechnical processes.

2. Remote sensing allows for effective monitoring of the condition of soils and vegetation in real-time, which is critical in conditions of unpredictable changes in the distribution of precipitation, temperature fluctuations, and other natural factors. Remote sensing of the soil surface, as an element of the precision farming system, can be one of the complementary methods in the search and detection of explosive devices, mines, shells, etc. It has been established that agricultural UAVs from XAG and DJI can be effectively used for these purposes.

3. It has been established that for the effective detection of explosive devices and mines, agricultural UAVs can be used. These UAVs should be modularly equipped with optoelectronic devices with 30x optical zoom for observing objects, a multispectral camera, a thermal imager, and a ground-penetrating radar (non-linear radar). These devices survey the land to detect surface mines by determining their position on a 3D map or orthophotoplan with a high accuracy of ±2.5 cm and creating minefield maps. A ground control station, which provides both manual and automatic drone operation modes with the ability to program flight patterns based on GPS/RTK coordinates, is used for map formation and drone control and management.

4. A proposed system for the remote detection of explosive devices and contamination allows for an expanded search for dangerous objects through the installation of optoelectronic devices, a thermal imager, a radar, and artificial machine vision. The developed method for mapping chemically contaminated areas includes controlling the UAV from a ground control station via radio communication and conducting chemical (radiation) reconnaissance of the surveyed area in two stages. In the first stage, the UAV flies at a fixed altitude while synchronously measuring the UAV's coordinates, altitude relative to the terrain, and radiation power levels. In the second stage, the UAV surveys elevations and depressions in the terrain, folds in building roofs, areas of maximum radiation, and hazard boundaries. The developed system will increase the effectiveness of remote detection of explosive device locations, improve the accuracy and reliability of mapping areas of ground-level radiation localization, determine its intensity in radiation-contaminated areas, and enable the marking of contamination boundaries on the ground. Additionally, digital marking of the locations of explosive devices and mines, as well as marking areas of radiation contamination, will facilitate quicker identification of contaminated sites for decontamination and prevent unauthorized access to these areas.

Therefore, the use of the proposed system for detecting explosive devices and contamination in agricultural areas can significantly reduce the risk of explosions and contamination, which could cause serious harm to both people and the environment.

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РОЗРОБКА СИСТЕМИ ДИСТАНЦІЙНОГО ВИЯВЛЕННЯ ВИБУХОНЕБЕЗПЕЧНИХ ПРИСТРОЇВ ТА ЗАБРУДНЕНЬ НА СІЛЬСЬКОГОСПОДАРСЬКИХ УГІДДЯХ

Одним із основних принципів системи точного землеробства є збільшення точності виконання агротехнічних операцій за допомогою високоточного обладнання та технологій збору даних. Дистанційне зондування використовує супутникові та аерокосмічні засоби для отримання зображень та даних про стан рослин, ґрунту та інших агрокультурних параметрів. Ця інформація служить для аналізу та прийняття рішень щодо внесення ресурсів на конкретних ділянках полів.

У сучасному світі проблема безпеки на сільськогосподарських угіддях набуває все більшого значення у зв'язку з поширенням вибухонебезпечних пристроїв та забруднень. Розробка ефективної системи дистанційного виявлення цих загроз стає нагальним завданням сьогодення, яка б дозволила забезпечити безпеку та стабільність у роботі агропромислових підприємств, зниження ризику виникнення негативних наслідків для цивільних людей та навколишнього середовища.

Відмічено, що дистанційне зондування поверхні землі в контексті елемента точного землеробства дозволяє максимізувати використання ресурсів та забезпечує рівномірне та оптимальне вирощування культур. Це призводить до збільшення якості продукції та зниження втрат врожаю через ефективніше управління агротехнічними процесами. Дистанційне зондування поверхні ґрунту може бути одним із доповнюючих способів (методів) у пошуку та виявлення вибухонебезпечних пристроїв, мін, снарядів тощо. Встановлено, що для цих цілей ефективно можна використовувати безпілотні літальні апарати сільськогосподарського призначення компаній XAG та DJI, які доцільно модульно дообладнати оптико-електронними засобами з 30-кратним оптичним збільшенням об'єктів спостереження, мультиспектральною камерою, тепловізором, георадаром (нелінійний радар), що обстежує ділянки землі з метою виявлення наземних мін шляхом визначення їх положення на 3D-карті чи ортофотоплані з високою точністю ±2,5 см та створення карт мінних полів, для формування якої, а також для контролю та керування дроном, використовується наземна станція, що забезпечує ручний та автоматичний режими роботи дрона, з можливістю програмованої схеми польоту на основі координат GPS/RTK.

Запропонована система дистанційного виявлення вибухонебезпечних пристроїв та забруднень з можливістю розширення пошуку номенклатури небезпечних обєктів шляхом встановлення оптико-електронних засобів, тепловізора, радара та штучного машинного зору. Відзначено, що розроблений спосіб картографування території хімічного забруднення, що включає управління безпілотним апаратом з наземної станції керування по радіозв'язку та проведення хімічної (радіаційної) розвідки досліджуваної території виконується в два етапи. На першому етапі політ безпілотного літального апарата виконує на фіксованій висоті, під час якого синхронно проводять вимірювання: координат, висоти відносно поверхонь місцевості, значення потужності випромінювання. На другому етапі безпілотний літальний апарат виконує зондування підвищень та падин місцевості, складок дахів споруд, місць максимумів і межі небезпеки. Розроблена система дозволить підвищити ефективність дистанційного виявлення місць розташування вибухонебезпечних пристроїв, підвищити точність та достовірність картографування ділянок локалізації приземного випромінювання і визначення його інтенсивності в місцях радіаційного забруднення та можливість маркування меж забруднення на місцевості. Крім того, цифрове маркування розташування вибухонебезпечних пристроїів і мін, а також, маркування території радіаційного забруднення на місцевості сприяє більш швидкому пошуку місць забруднення для проведення дезактивації та убезпечує потрапляння сторонніх людей на ці території.

Ключові слова: *система точного землеробства, дистанційне зондування землі, вибухонебезпечні пристрої, міни,забруднення,безпілотний літальний апарат.*

Рис. 11. Літ. 19.

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