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Mykhailo POPOV[1], Sergey STANKEVICH[1], Sergey MOSOV[2], Stanislav DUGIN[1], Stanislav GOLUBOV[1], Artem ANDREIEV[1], Artur LYSENKO[1], Ievgen SAPRYKIN[1]

[1] Scientific Centre for Aerospace Research of the Earth, the NAS of Ukraine, Kyiv, Ukraine
[2] Institute of Public Administration and Research in Civil Protection, Kyiv, Ukraine

CONCEPT OF A GEOINFORMATION PLATFORM FOR LANDMINES AND OTHER EXPLOSIVE OBJECTS DETECTION AND MAPPING WITH UAV

*The **subject of** this article is the concept of a geoinformation platform for landmine detection. Modern warfare and its increasing scale have become a relevant topic today. Undetected explosives threaten business (agriculture, logistics, etc.) and human lives. The problem becomes more acute with the rapid extension of minefield areas, which requires significant time and resources and carries high risks. Remote sensing leverages landmine detection possibilities, providing useful information about landmine displacement with no additional risk during data collection over a large area. This study **aims** to present a combined approach for revealing hidden landmines using UAVs equipped with different sensor types. The **tasks** to be solved are to define the overall structure and components of the geoinformation platform, choose the technological solutions for each of them, and implement the system prototype that makes it possible to extend its configuration in the future. The **methods** used are remote sensing, automated object detection, and centralized data processing in a geographic information system (GIS). Multispectral imagery and magnetometric remote measurements create the background information required to detect landmines and other explosive objects. The **results** of this study provide a general framework, i.e., a geoinformation platform for landmine detection and mapping. The tasks include UAV-based remote data gathering, UAV mission planning and flight control, data processing and mapping via general GIS, and updating new landmine signatures in the corresponding database. The landmine detection process uses information from the landmine signature database to verify suspicious objects. The results are presented in the form of a probabilistic map, which supports the decision-making process **of** demining. **Conclusion**. The proposed approach significantly decreases the time required for landmine detection and mitigates demining risks, which is crucial for dealing with the consequences of war. At present, the concept is being developed in the form of a geoinformation platform research prototype involving an open-source Quantum GIS (QGIS) software system and Python programming language, which is used to create plug-ins for QGIS. The entire landmine remote detection process can be fully automated. Future studies will involve extensive experimental testing and may involve convolutional neural networks (CNN) as a detection mechanism.*

***Keywords**: geoinformation platform; landmine detection and mapping; copter-type UAV; sensor fusion; probabilistic model.*

1. Introduction

The world community has made significant efforts to eliminate the threat posed by post-war landmines and other explosives. Therefore, demining is important for advancing the Sustainable Development Goals (SDGs) by eliminating explosive hazards and allowing communities to recover and grow (https://www.undp.org/publications/mine-action-and-sustainable-development-goals). There are several examples: alleviating poverty (SDG 1), combating food insecurity (SDG 2), supporting quality education (SDG 4), and providing clean water and energy (SDG 6), etc.

One of the necessary components of demining is the detection of landmines and other explosive objects. To ensure safety for humans, it is customary to use remote detection methods and tools, i.e., Unmanned Aerial Vehicle (UAV). For this reason, we developed a geoinformation platform for the detection and mapping of landmines and other explosive objects using UAV.

1.1. Motivation for the research

At present, the problem of humanitarian demining is acute worldwide [1], but in Ukraine, it has taken on a truly frightening scale. Traditional methods for landmine detection are dangerous and too slow for a large area [2]. In Ukraine, the area that requires humanitarian demining reaches 174 thousand km² [3]. Agricultural land is particularly affected by minelaying and explosive contamination [4]. On the other hand, currently actively developing methods for remote detection and mapping of landmines and other explosive objects, including UAV-based methods, remain insufficiently reliable [5]. Unfortunately, it must be recognized that no universal method for landmine detection using UAVs would provide acceptable reliability [6]. The solution lies in integrating the outputs of multispectral, thermal infrared, magnetometric, and radar mapping [7, 8]. Moreover, this is one of the key functionalities of the proposed geoinformation platform.

1.2. State-of-the-art

There are several approaches to the detection of landmines and other explosive objects using UAVs [9]. A variety of sensors, such as induction metal detectors, magnetometers, infrared and visible band cameras, hyperspectral cameras, etc., are used for this purpose [10]. Most research has focused on developing new methods or improving existing ones, as well as on sensor design [11, 12]. Sometimes, only the partial fusion of two sensors is considered [13]. The simultaneous use of optical sensors and passive magnetometers is considered exceptionally promising now [14]. Many studies have applied neural networks from a well-known architecture to landmine detection [15, 16]. In Ukraine, the problem of landmine detection is highly acute, so the development of relevant technologies is actively performed in many directions: specialized UAVs for landmine mapping are being produced, the optimal compositions of onboard sensor kits are being evaluated, efficient machine learning and computational intelligence methods for landmine detection are being elaborated, and attempts to combine all these developments using geographic information systems (GIS) are being made [17].

Thus, two general approaches can be highlighted: the involvement of new types of sensors, such as thermal cameras, multispectral cameras, and ground penetrating radars, etc., and the implementation of new data processing methods, such as deep learning. Sometimes a combination of both is used when a new data processing method is applied to data from a new sensor.

In turn, geoinformation platforms for demining tasks are used, as a rule, in the form of a simple cartographic service that combines data on the location and specifications of identified landmines [18]. At the same time, direct landmine detection is usually performed outside geoinformation platforms. Even if any quantitative estimates are made, this is most likely to be a generalized minelaying risk for a wide area [19]. We must state that, despite the rapid development of both landmine detection methods and geoinformation systems, the potential of the latter is not sufficiently involved in landmine detection, so the described concept of the platform can contribute to further development of both.

1.3. Objective and Approach

This study aims to develop the concept of a geoinformation platform as an integrated environment with a cut-through workflow for the detection of landmines and other explosive objects, including mission planning; UAV imagery acquisition, calibration and visualization; and locating and mapping. In addition, this concept ensures deminers' safety due to the strictly remote operation of the workflow.

This paper has the following structure. In section 2, the general concept of platform architecture is considered. In section 3, the implementation of the existing system elements is described. Then, a conclusion is made, including the direction of future research. Finally, brief information about the project is provided, and the contributions of the authors are briefly described.

2. Geoinformation platform general architecture

The main idea of our study is to expand the functionality of general GIS by introducing and interfacing additional modules and forming an extended geoinformation platform for comprehensive information support for demining in this way. The proposed architecture of the geoinformation platform is illustrated in Fig. 1.

The core of the proposed platform is a general GIS. The system includes a geodatabase with topographic and thematic maps of the operational area, accumulated satellite and airborne imagery, and other necessary materials. The system should also have a special database with signatures and other characteristics of landmines, which will be used in the process of UAV mission planning and landmine detection. In addition to its primary function, this special database can serve as a reference subsystem for operator support.

The interaction between the geoinformation platform and the UAV is carried out through the mission planning subsystem and the connector with the UAV's ground control station. Usually, several different types of UAVs equipped with electro-optic and infrared (EO/IR) cameras, a magnetometer, a ground penetrating radar (GPR), and other possible sensors should be involved in a mission over a minefield.

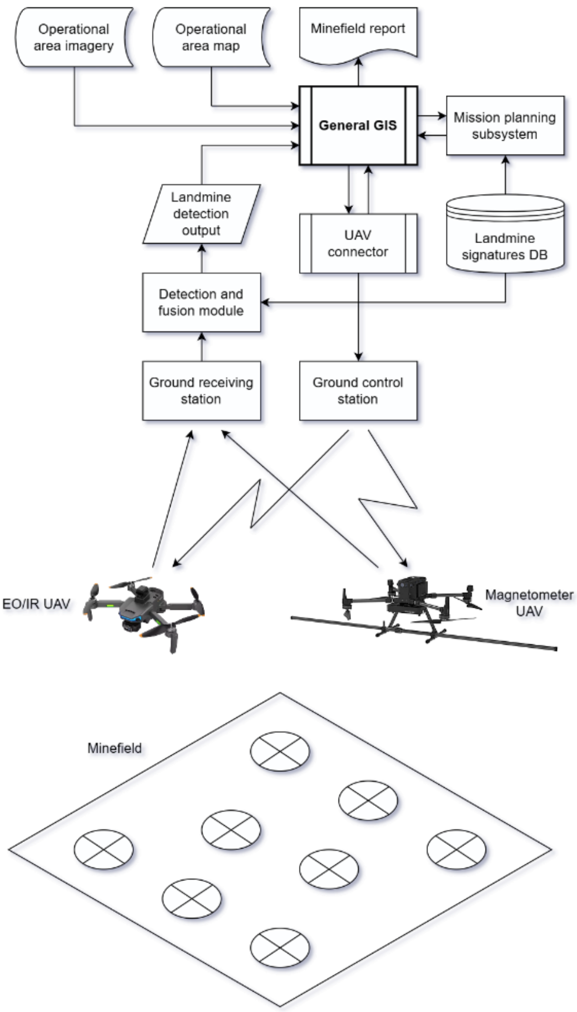

Fig. 1. Architecture of a geoinformation platform for the detection of landmines and other explosive objects and mapping with UAVs

Optical images, magnetometric data, radargrams, etc., acquired by the UAV's ground receiving station are processed by the detection and fusion software module, the output of which contains the results of the detection of landmines and other explosive objects. A probabilistic map of the detected landmines was chosen as a unified format for arranging the results, which is sensor-independent, exceptionally convenient, and relies on widely used probabilistic models [20]. The probabilistic model provides a conform interface for data fusion and allows easy algorithmization and unification of the analysis and decision-making procedures. The landmine detection probabilistic maps are assimilated by general GIS and used to draw a minefield report.

We hope that due to the correct integration of data of different physical natures, an increase in the detection probability of landmines and other explosive objects will be achieved [21]. An integrated geoinformation platform will ensure the simplicity, convenience, flexibility, and performance of the UAV fleet under its management. In addition, with the help of such a platform, the necessary statistics and analytics on humanitarian demining and territory safety can be easily extracted [22].

3. Results

Currently, the Scientific Centre for Aerospace Research of the Earth (CASRE) is developing a research prototype of a geoinformation platform for the detection of landmines and other explosive objects using UAVs. The open-source Quantum GIS (QGIS) software system was chosen as the general GIS [23, 24]. The choice of QGIS is based on its rich set of features combined with extensibility by Python-based plug-ins that allow the integration of scientific calculations, particularly machine, and deep learning methods, directly into GIS software with a user-friendly interface. The following components have been implemented: 1) mission planning subsystem; 2) module for multispectral and thermal imagery calibration, landmine detection, and fusion; and 3) module for landmine detection in RGB imagery using a convolutional neural network (CNN).

The first consideration is the mission planning subsystem. For short experimental flights, we relied on the manufacturer's software. However, for real-life cases, we need the possibility of preliminary estimation of the resources for explored areas under specific weather and UAV models. Thus, the mission planning subsystem (Fig. 2) based on the modified QGIS Flight Planner plug-in [25] was enriched by the possibility of considering weather conditions [26].

The second component is the multispectral and thermal imagery processing module (Fig. 3), which was programmed in the Python environment. It provides functions such as radiometric calibration, landmine detection, and fusion. The calibration is only applicable to multispectral imagery. This method converts the pixel values from raw to surface reflectance. The landmine detection function was developed for both multispectral and thermal imagery. For each data type, we apply the anomaly detection approach. This implies searching for anomalies (i.e., landmines) in the background. The input requires a training sample of the background (i.e., the pixels which do not belong to the landmines). The fusion function is applied to obtain a joint probability map based on both imagery sources: thermal and multispectral [21].

Furthermore, the last component was the YOLOv8 architecture CNN [27], which was trained on the images acquired in the special military test area. It has also been applied to landmine detection in RGB imagery [28] using the Deepness plug-in [29], which makes direct detection on orthoimages possible (Fig. 4).

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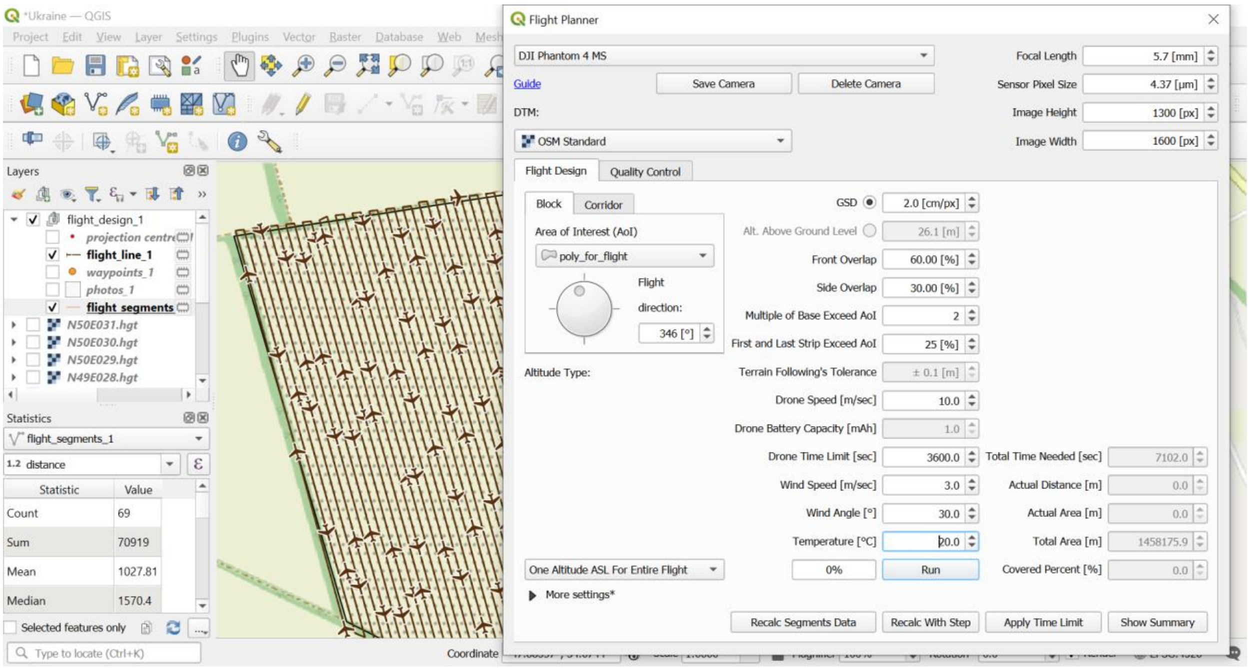

Fig. 2. Graphical interface of the UAV mission planning subsystem

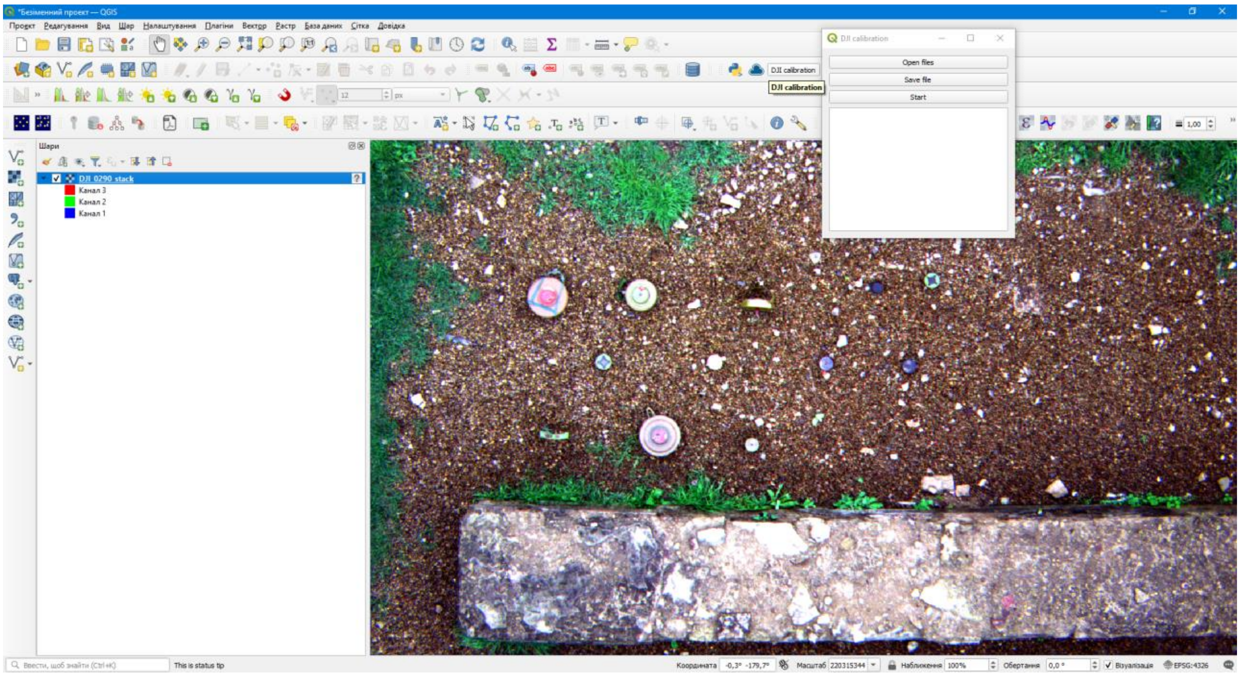

Fig. 3. Graphical interface of optical image calibration/detection/fusion module

The platform interacts with the DJI Phantom 3 Pro, DJI Phantom 4 MS, and DJI Matrice 300 RTK light quadcopters, equipped with full-color, multispectral, infrared thermal cameras and a passive magnetometer (Fig. 5).

In the future, the number of supported UAV' types and their onboard optical and non-imaging sensors will expand.

4. Discussion

There is some ambiguity in the description of the geoinformation platform, which is related to both detection probability and coordinate accuracy. Here are some considerations.

Suppose we use a probabilistic approach to object detection while integrating deep learning methods like YOLO. In this case, we must represent a mathematical

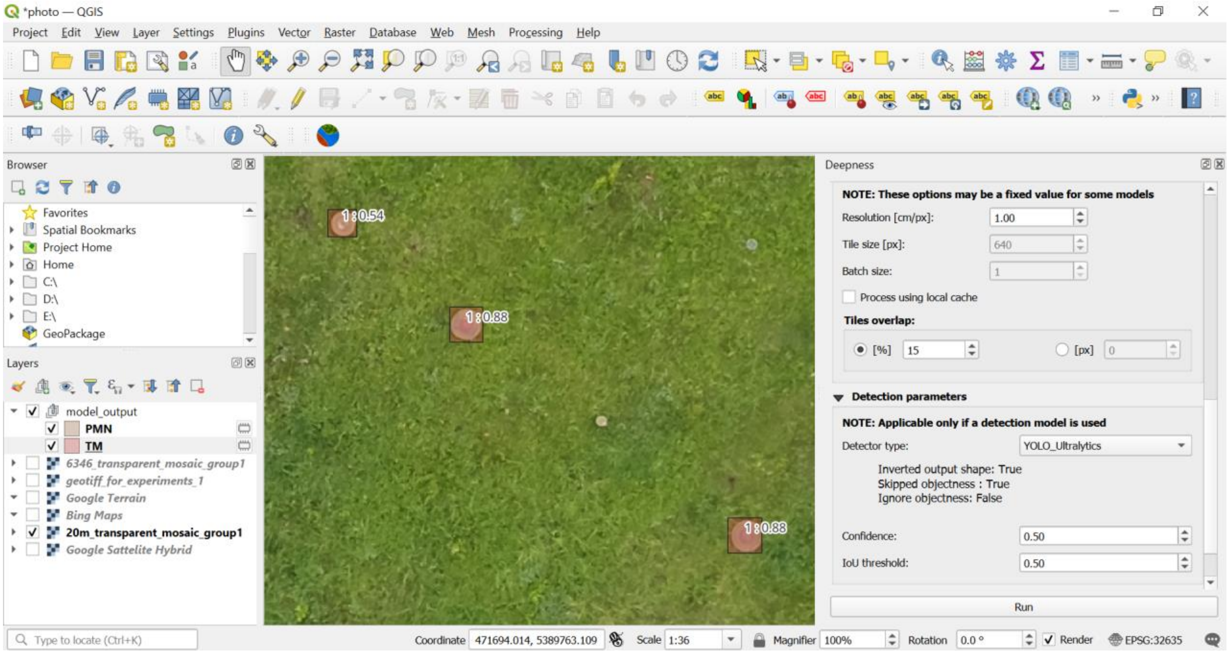

Fig. 4. Landmine detection in orthoimage by YOLOv8 under QGIS

a

b

Fig. 5. The currently operating quadcopters with the geoinformation platform prototype:
a – Phantom 4 Multispectral, b – Matrice 300 RTK equipped with a magnetometer

basis for the fusion of *confidence* in the neural network returns and probability returned by pixelwise methods. Intuitively, both share the same statistical nature. However, it is not obvious, and a theoretical basis is required to prove it. In addition, neural network detectors usually deal with bounding boxes that assume equal confidence for any pixel inside the box, even those that do not contain objects. It should also be considered. Implementing *segmentation* rather than *detection* makes it possible to overcome this ambiguity; however, segmentation is computationally heavier and undesirable for large data processing.

The system prototype was tested on a limited area, which was represented as an orthoimage. It is necessary to perform tests on the amount of data similar to real-life tasks. The accuracy of the coordinates obtained by detecting the large-scale orthoimage must also be carefully checked. An approach that performs detection directly on UAV photos captured at known coordinates can be more optimal. There is clear redundancy in this approach when, initially, the orthoimage is assembled from fragments after the algorithm splits the image to perform fragment detection. Finally, the detection results are assembled again to obtain a map of detections. The geographic coordinates of the detected objects in GIS can be calculated in different ways, and the most accurate coordinates must be selected.

It is impossible to discuss landmine detection technology without considering safety considerations. It may seem that as far as remote sensing technology is implemented, the desired level of safety will be reached by default. However, considering real-life scenarios, we must state that safety depends directly on planning quality. During the demining mission, only strict adherence to the plan can ensure maximal safety. Therefore, exploring a large area under specific weather conditions, we must ensure that all the conditions are considered, and the mission will proceed according to the plan. The less improvisation is needed, the more safety is provided. Accurate mission planning at such a scale cannot be performed without appropriate geoinformation tools.

Also, it is worth mentioning that landmine detection by combining different sensors mounted on UAVs has inherent physical limitations. First, the defined area cannot always be explored by certain types of sensors. A former battlefield can contain much contamination from metallic war remnants, making reliable magnetic detection impossible. In addition, vegetation can avoid UAV flights at the altitudes needed for certain sensors. Weather can preclude thermal detection. However, the rapid development of ground-based robotic platforms can bring new possibilities, as well as produce spatial data that can be integrated into the detection process. However, we must admit that remote sensing cannot completely replace manual landmine detection.

It can be reasonably noted that authors don't provide any reliability metrics in comparison with existing methods; however, the reason is that currently, the comparison with known solutions using reliable metrics is problematic because groups of researchers usually don't share their datasets, as well as data representation formats. It is, however, possible to create a universal dataset for optical detection method comparison, as well as to provide a benchmark methodology, as it has already been done for some other computer vision tasks, but currently authors are not aware of such a dataset or methodology. The situation is even worth for the methods that use the fusion of results from different sensors because the data of the same area from several different sensors are almost never available to a wide audience, as well as data formats for non-optical sensor data suitable for landmine detection are not standardized. Reliable methods for landmine-detection performance evaluation are a subject of ongoing research.

5. Conclusions

The proposed geoinformation platform for landmine and other explosive object detection and mapping with UAVs is assembled from standard, well-proven software / partially hardware modules and is therefore easy to implement. The platform contains all the necessary components to detect, output fusion, and map landmines and other explosive objects in commonly accepted data presentation formats.

Preliminary quantitative estimates demonstrate that the landmine detection technology embodied in the proposed platform is reasonably reliable although experimental testing is ongoing. The theoretical calculations show that the entire system has relatively high time productivity, at least sufficient for humanitarian demining.

Future research should focus on the attachment of additional, primarily hardware-dependent modules, such as calibration and stitching of optical images, accurate cross-reference between optical imagery and parametric trace surveys, and UAV navigation optimization when detecting various landmines. It is also essential to improve the versatility of the elaborated geoinformation platform by expanding the range of compatible UAVs and replenishing the landmine signature database, including the magnetometric and radar databases.

Contributions of authors: global supervision, conceptualization, funding acquisition – **Mykhailo Popov**; conceptualization, methodology development, scientific supervision – **Sergey Stankevich**; military

expertise, methodology development – **Sergey Mosov**; technical UAV and sensors supervision, data acquisition – **Stanislav Dugin**; data acquisition, data pre-processing and analysis, visualization – **Stanislav Golubov**; data analysis, datasets creation, algorithms development (statistics, machine learning), GIS integration, programming, visualization – **Artem Andreiev**; data analysis, datasets creation, algorithms development (statistics, machine learning), GIS integration, programming, visualization – **Artur Lysenko**; GIS UAV mission planning customization, datasets creation, deep learning and GIS integration, programming, visualization, review and editing – **Ievgen Saprykin**.

Project information: current research is performed within the R&D project mentioned in the acknowledgment, which is part of the broader program of NAS of Ukraine aimed at increasing Ukraine's defense capability. The objective of this project is to provide a reliable landmine detection method using UAV data. It has currently resulted in the prototype of a hardware and software complex that includes a number of commercial drones accompanied by a set of statistical and machine learning methods, both developed in CASRE and borrowed from open-source libraries, a rich data library including RGB, multispectral, thermal, and magnetometric data. The data acquisition and verification of the methods are performed in cooperation with the military authorities. The geoinformation platform that this paper is dedicated to is an important part of the project that connects all the related spatial data and streamlines the overall workflow. This paper describes the current progress of the platform development. The direction of future research is described in the conclusion.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data Availability

The data can be made available upon reasonable request to the project customer.

Use of Artificial Intelligence

As described in the research methodology section, the authors used artificial intelligence technologies within acceptable limits to provide verified data.

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All the authors have read and agreed to the publication of the final version of this manuscript.

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КОНЦЕПЦІЯ ГЕОІНФОРМАЦІЙНОЇ ПЛАТФОРМИ ДЛЯ ВИЯВЛЕННЯ І КАРТУВАННЯ МІН ТА ІНШИХ ВИБУХОНЕБЕЗПЕЧНИХ ОБ'ЄКТІВ З ВИКОРИСТАННЯМ БПЛА

М. О. Попов, С. А. Станкевич, С. П. Мосов, С. С. Дугін, С. І. Голубов, А. А. Андреєв, А. Р. Лисенко, Є. Ю. Саприкін

Предметом статті є презентація концепції геоінформаційної платформи виявлення мін. Сучасне ведення війни та її зростаючі масштаби зробили розмінування актуальною темою сьогодення. Невиявлені вибухові пристрої загрожують як бізнесу (сільському господарству, логістиці тощо), так і людським життям. Проблема загострюється при стрімкому збільшенні площі мінних полів, що вимагає значних витрат часу, ресурсів і високих ризиків для її вирішення. Дистанційне зондування використовує можливості виявлення мін, надаючи корисну інформацію про розташування мін без додаткового ризику під час процесу збору даних на великій території. **Метою** є представити комбінований підхід до виявлення прихованих мін за допомогою БПЛА, обладнаних різними типами датчиків. **Завдання, які вирішуються**: визначити загальну структуру та компоненти геоінформаційної платформи, підібрати технологічні рішення для кожного з них та реалізувати прототип системи, що дозволить розширити її конфігурацію в майбутньому. **Методи**, що використовуються - дистанційне зондування, автоматизоване виявлення об'єктів, централізована обробка даних у геоінформаційній системі (ГІС). Мультиспектральне зображення, що доповнюється даними магнітометричного дистанційного вимірювання, створює фонову інформацію, необхідну для виявлення наземних мін та інших вибухонебезпечних предметів. Як **результат** цього дослідження представлено загальну структуру, тобто геоінформаційну платформу для виявлення мін і картографування. Вона складається з дистанційного збору даних з допомогою БПЛА, планування місії БПЛА та управління польотом, обробки даних і картографування через загальну ГІС та оновлення нових сигнатур наземних мін у відповідній базі даних. Процес виявлення мін передбачає використання інформації з бази даних сигнатур мін для перевірки підозрілого об'єкта. Результат представлений у вигляді імовірнісної карти, яка повинна підтримувати процес прийняття рішень при розмінуванні. **Висновки.** Даний підхід значно скорочує час, необхідний для виявлення протипіхотних мін, а також знижує ризики розмінування, що вкрай важливо для подолання наслідків війни. Наразі дана концепція розробляється у вигляді дослідницького прототипу геоінформаційної платформи із залученням відкритого програмного комплексу Quantum GIS (QGIS) та мови програмування Python, яка використовується для створення плагінів для QGIS. У перспективі весь процес дистанційного виявлення мін може бути повністю автоматизований. Майбутні дослідження будуть спрямовані на широке експериментальне тестування та можуть включати згорткові нейронні мережі як механізм виявлення.

Ключові слова: геоінформаційна платформа; виявлення і картографування мін; БПЛА коптерного типу; поєднання сенсорів; імовірнісна модель.

Попов Михайло Олексійович – д-р техн. наук, проф., чл.-кор. НАН України, директор, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Станкевич Сергій Арсенійович – д-р техн. наук, проф., зав. від. геопросторового моделювання в аерокосмічних дослідженнях, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

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Мосов Сергій Петрович – д-р військ. наук, проф., проф. каф. авіації та авіаційного пошуку і рятування, Інститут державного управління та наукових досліджень з цивільного захисту, Київ, Україна.

Дугін Станіслав Сергійович – канд. геолог. наук, зав. лаб. технічних засобів дистанційного зондування Землі при відділі геоінформаційних технологій у дистанційному зондуванні Землі, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Голубов Станіслав Іванович – д-р філос., мол. наук. співроб. лаб. технічних засобів дистанційного зондування Землі при від. геоінформаційних технологій у дистанційному зондуванні Землі, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Андрєєв Артем Андрійович – д-р філос., мол. наук. співроб. від. геоінформаційних технологій у дистанційному зондуванні Землі, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Лисенко Артур Ростиславович – д-р філос., мол. наук. співроб. лаб. методів обробки даних дистанційного зондування при від. геопросторового моделювання в аерокосмічних дослідженнях, ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Саприкін Євген Юрійович – асп., ДУ «Науковий центр аерокосмічних досліджень Землі Інституту геологічних наук Національної академії наук України», Київ, Україна.

Mykhailo Popov – Doctor of Technical Sciences, Professor, Corresponding Member of the National Academy of Sciences of Ukraine, Director of Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine, Kyiv, Ukraine,
e-mail: mpopov@casre.kiev.ua, ORCID: 0000-0003-1738-8227, Scopus Author ID: 55781766400.

Sergey Stankevich – Doctor of Technical Sciences, Professor, Head of the Department, Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine, Kyiv, Ukraine,
e-mail: st@casre.kiev.ua, ORCID: 0000-0002-0889-5764, Scopus Author ID: 16176794100.

Sergey Mosov – Doctor of Military Sciences, Professor, Institute of Public Administration and Research in Civil Protection, Kyiv, Ukraine,
e-mail: gurman63@ukr.net, ORCID: 0000-0003-0833-3187, Scopus Author ID: 57283139400.

Stanislav Dugin – Candidate of Geological Sciences, Head of the Laboratory, Scientific Centre for Aerospace Research of the Earth, Kyiv, Ukraine,
e-mail: sdugin@casre.kiev.ua, ORCID: 0000-0002-2960-3783, Scopus Author ID: 57219448805.

Stanislav Golubov – PhD, Junior Researcher, Scientific Centre for Aerospace Research of the Earth, Kyiv, Ukraine,
e-mail: asdfieldspec3@gmail.com, ORCID: 0000-0003-3711-598X, Scopus Author ID: 57219614213.

Artem Andreiev – PhD, Junior Researcher, Scientific Centre for Aerospace Research of the Earth, Kyiv, Ukraine,
e-mail: artem.a.andreev@gmail.com, ORCID: 0000-0002-6485-449X, Scopus Author ID: 57203280237.

Artur Lysenko – PhD, Junior Researcher, Scientific Centre for Aerospace Research of the Earth, Kyiv, Ukraine,
e-mail: artur.r.lysenko@gmail.com, ORCID: 0000-0003-2923-8648, Scopus Author ID: 57212528164.

Ievgen Saprykin – PhD Student, Scientific Centre for Aerospace Research of the Earth, Kyiv, Ukraine,
e-mail: ye.sapr@gmail.com, ORCID: 0009-0004-2347-3756, Scopus Author ID: 58775079300.