This is the template for the 1 page proposal (500-600 words) that presents a solution (new usage or suggest improvements on a new technology).

If your proposal is selected for the second stage of the Challenge, you will be asked to expand the description to 10 pages (5000-6000 words) which should be a development of the previously submitted proposal.

IMPORTANT: Students are strongly encouraged to team up in pairs, finding a partner in a different university or country. Teams will get an additional point in the final score.

A fresh view is valued. Please, defend your proposal by including not only technological, but also socio-economic, political, ethical and/or environmental aspects.

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Subject/title: The concept of ultrasonic mine detection

1. Introduction

The years 2022 and 2023 have brought immediate changes to the international arena, particularly in the context of Russia's full-scale invasion of Ukraine. The hostilities have resulted in significant areas being mined by both sides of the conflict, posing a serious threat to the civilian population and hampering the reconstruction of infrastructure and access to basic services [1]. According to many humanitarian organizations, including the UN and the International Committee of the Red Cross (ICRC), landmines in Ukraine represent one of the greatest humanitarian challenges in the world today [2].

Landmines are a consequence not only of the conflict in Ukraine but also of more than 60 other conflicts around the world. Their use causes socio-economic paralysis, including blocked roads and railways, uncultivated farmland, and lack of access to public services. Traditional mine detection methods based on metal detectors, manual land searches, or sniffer dogs often prove inadequate, especially for mines made of non-metallic materials. In addition, these methods pose significant risks to the operators involved in the demining process [3], [4].

In response to these challenges, modern technologies such as ultrasonic mine detection methods based on acoustic resectoscopes and drones using infrared vision are attracting increasing attention. The use of advanced ultrasonic equipment allows the detection of not only metallic but also non-metallic components and integration with drones enables safe and efficient fieldwork. This paper discusses the detailed design of this concept, its technical solutions, potential risks, and expected socio-economic and humanitarian impacts.

2. System description and purpose

The creation of an automated explosive detection system, based on pre-collected and processed ultrasonic data, can significantly improve the work of mine sweepers. In the presented solution, the interaction of unmanned platforms (drones), ultrasonic sensors, and artificial intelligence algorithms is crucial. The system starts with initiation, where basic mission parameters are selected and information on the location of the potential threat is gathered. This is followed by optimization of the drone's flight path to ensure maximum area coverage and efficient use of available resources.

Once the unmanned platform arrives at the designated area, sensors are deployed in the field where the transmission and reception of ultrasonic waves begin. The data recorded by the sensors is sent to a processing module where artificial intelligence algorithms analyze the characteristics of the reflected signals to identify and locate potential explosive charges. At the end of the measurement cycle, the drones retrieve the sensors and return to the starting point for reuse.

The system then generates an operational report documenting all identified threats and the estimated probability of false alarms. In parallel, an assessment of sensor wear or damage is carried out, enabling the system to maintain high detection performance and reduce the risk of failure. Finally, the process is completed by shutting down the system and summarizing the results - this allows the database to be further expanded, enabling continuous improvement of the decision-making algorithms and increasing the efficiency of operations in subsequent deployments. A diagram of the concept under discussion is shown below (Figure 1).

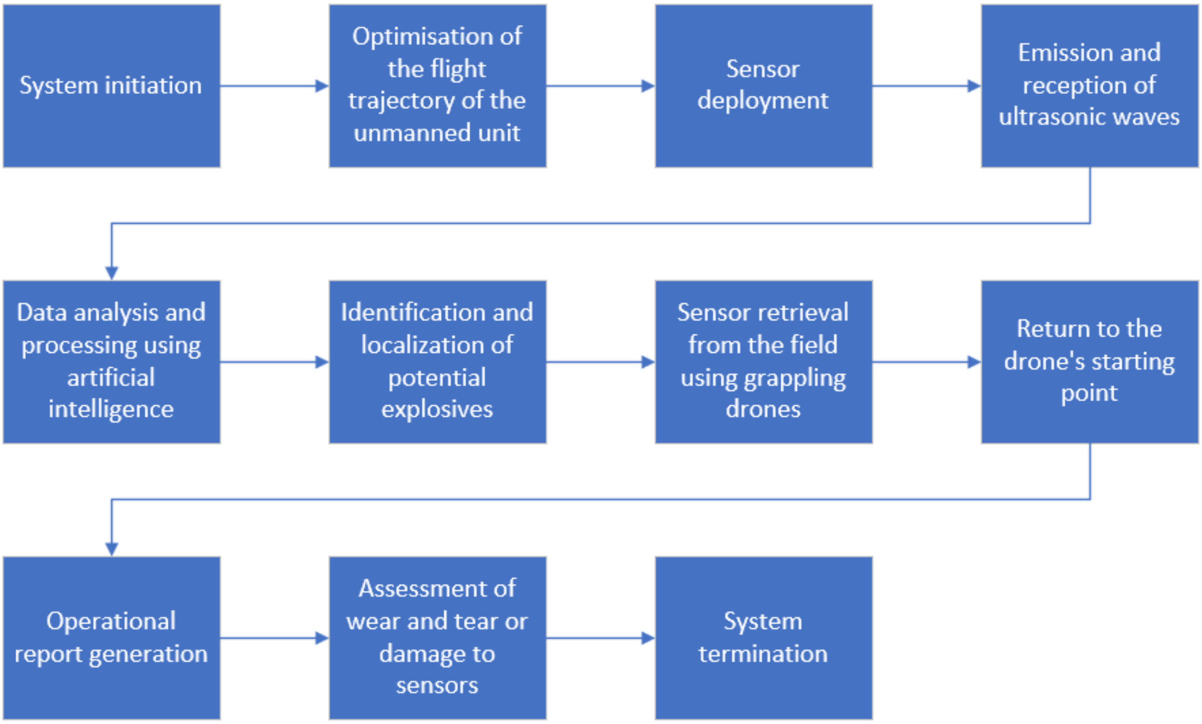

Figure 1. System operation diagram

3. Detection of underground objects using ultrasonic waves

The use of ultrasonic waves to detect underground objects is based on the phenomenon of reflection and scattering of acoustic waves at boundaries between media of different densities or material properties [5]. In practice, the wave is generated by a transmitter placed in the sensor, then propagates deep into the ground and is reflected at contact with an object whose acoustic impedance differs from the surrounding ground [6]. The registration of the reflected signal by the receiver in the sensor makes it possible to determine the distance to the detected object, which is obtained by measuring the transit time of the wave between the moment of emission and the detection of the echo [7]. The frequency of the emitted ultrasound is important as it affects the resolution of the measurement and the depth of penetration - higher frequencies provide a more accurate measurement but are more attenuated, limiting the maximum detection range [8].

Depending on the type of soil, its moisture content, and its structure, the transmission conditions for ultrasonic waves can vary considerably. Studies show that in soils with higher water content, where there is greater attenuation, it is advisable to use frequencies at the lower end of the ultrasonic band to minimize signal energy loss and improve the signal-to-noise ratio [7]. At the same time, in loose soils dominated by particles with weaker intergranular bonds, ultrasound can penetrate to greater depths, facilitating the detection of objects a few or even several centimeters below the surface [6]. A key factor in this is the accurate calibration of the sensors, as any variation in acoustic parameters such as operating frequency or pulse characteristics will introduce uncertainty into the distance determination [9].

The accuracy of the distance measurement depends not only on the travel time of the wave itself but also on the intensity of the reflection and the shape of the returning signal. When a wave is reflected from multiple layers of different impedance (e.g. a bed of gravel or stones), artifacts can occur that make it difficult to distinguish echoes that are solely from the target. One solution to minimize the risk of misinterpretation is to use correlation techniques and filters tailored to the expected shape of the reflected pulse. In this way, the reliability of the measurement can be increased and the information about the object's position can be more effectively separated from noise or unwanted reflections [10].

In the context of (accurate) targeting, the ultrasonic detection range is critical and depends largely on the signal strength and stability of the sensor operation. Sensors with built-in microcomputers are able to pre-process the received signal and correct errors due to uneven wave propagation in heterogeneously structured ground. This enables more efficient targeting of objects while reducing false alarms.
Field trials of Ground Penetrating Radar (GPR) have shown that, with the right choice of operating frequency and transmitter power, it is possible to effectively detect objects similar in size to typical landmines at a depth of a few centimeters or even several centimeters [11].

4. Ultrasonic object detection

After the initial detection of an anomaly in the ground and the determination of its approximate location, the system begins the recognition phase of the detected object. The analysis of ultrasonic waves, which are reflected and scattered depending on the properties of the material, plays a key role in this process [12]. The data recorded by the sensors are transmitted to the processing unit where they are pre-processed to eliminate background noise. Algorithms are then used to determine the parameters relevant to object identification, such as amplitude, phase, or wave propagation time [13].

The use of ultrasonic waves to categorize measurement results provides an effective method for analyzing and reconstructing details hidden in deeper soil layers. In situations where models describing the relationship between soil type, moisture content, and signal propagation are inaccurate, the use of a multi-sensor combination approach can significantly improve the overall procedure [14]. Studies show that even small differences in the acoustic impedance of objects (e.g. the difference between plastic and metal) affect the nature of the ultrasonic echo [12]. This makes it possible to pre-differentiate between non-metallic and metallic mines and to separate natural objects (roots, stones) from potentially dangerous ones.

Signal filtering and segmentation techniques also play an important role in the detection process, allowing the precise extraction of features of selected objects. The input data, which contains a number of distortions related to the heterogeneity of the ground and the presence of different rock fractions, is processed in such a way as to maximize the differences between material with an organic structure and plastic or metal [14]. In practice, this reduces the number of false alarms and speeds up the process of verifying suspicious points in the field.

5. Ability to map the site using sensors and an appropriate algorithm

Once an object has been detected and its material characteristics initially identified, the system moves on to the next stage, which is to map the spatial location of the find in the operational area. To do this, the computational algorithms use measurement data from multiple distributed sensors to more accurately determine the position of a potentially hazardous object. A key element of this process is the analysis of the differences in the time of arrival of the ultrasonic waves (time-of-flight), which allows the distance between the object and each of the deployed sensors to be estimated. A schematic of the object mapping process is shown in Figure 2.

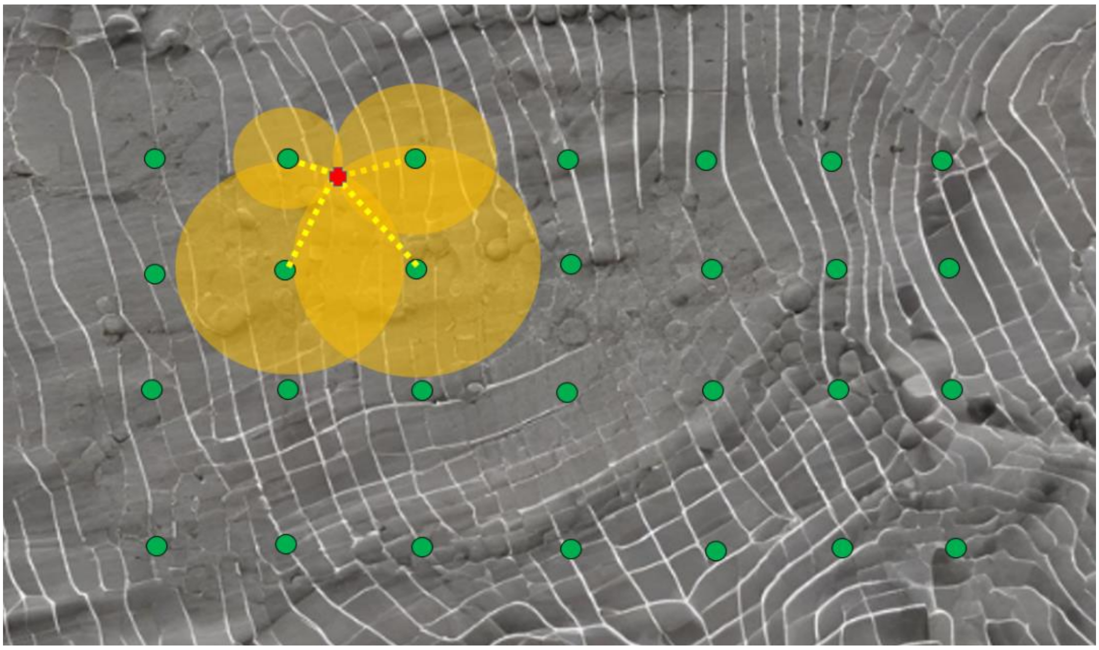

Figure 2. Site mapping (in-house development)

Legend:
Green circles - deployed sensors transmitting and receiving ultrasonic waves
Yellow circles - visualization of the estimated distance of the object from the sensor
Yellow line - Designated nodes of the computational network, corresponding to the locations of object detection by the various sensors
Red crosses - Identified potential explosives

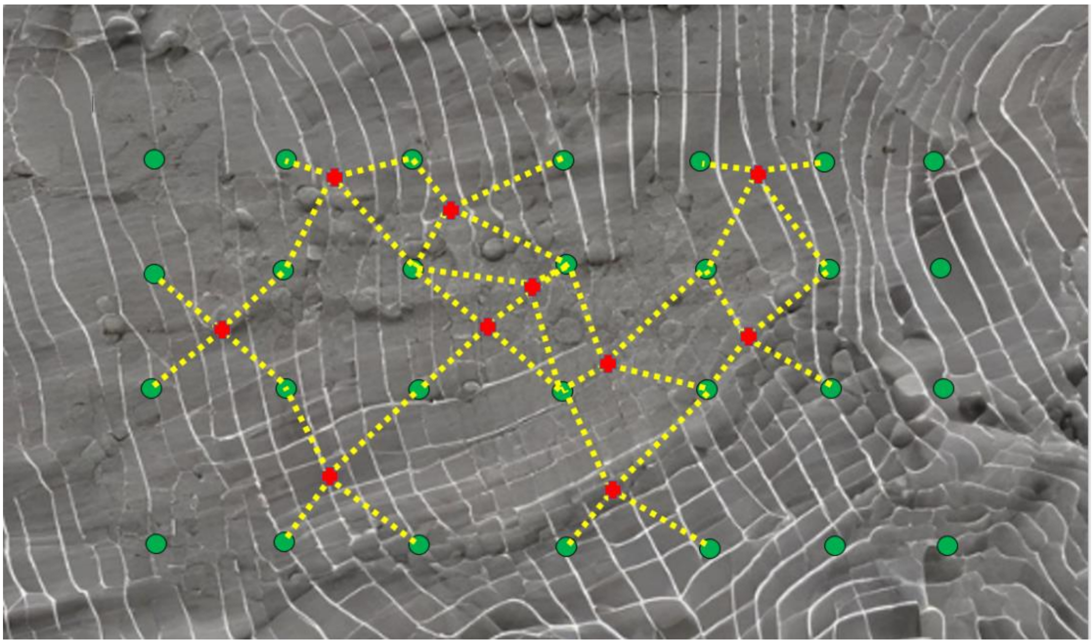

Figure 3. Site mapping with multiple sensors (own work)

In situations where the ground is characterized by uneven texture or increased moisture content, the use of a multi-point sensor system makes it possible to compensate for local disturbances in the speed of wave propagation [9]. This provides the system and the operator with a more consistent picture of the terrain, even in the presence of disturbances such as layers of different densities or stone fractions in the ground. At the same time, the data from each sensor is pre-filtered and synchronized in time, reducing the risk of misinterpretation of measurements due to uneven sensitivity distribution in the terrain.

The information processed in this way is sent to the artificial intelligence module, which uses pre-trained models to check that the recorded signal matches the patterns stored in the database. As a result, each detected object is assigned geographic coordinates and an initial classification label, such as 'high probability metallic object' or 'suspected non-metallic mine'. The mapping of the results is presented in an interactive form, allowing an immediate assessment of the situation and the planning of further actions in the field, especially with regard to the safety of the sapper service.

Such a solution makes it possible to quickly check the level of threat in a given area and to manage resources more efficiently by focusing on the most vulnerable sectors. An additional benefit is the ability to integrate the results with geodetic systems, making it easier to archive the data and process it in the context of planned military or humanitarian operations. This is particularly important in the case of demining large areas under changing environmental conditions, where the coordination of operations requires a clear understanding of the distribution of potential hazards and control of the precision of subsequent operations.

6. Deployment of sensors in the field and recovery after diagnosis

The initial terrain analysis is followed by the deployment of ultrasound sensors, using the DJi Flycart-30 drones as the transport element. The use of an appropriately designed platform allows the sensors to be dropped at precise points, resulting in optimum ground coverage and maximizing the probability of mine detection. The choice of drop height depends on the type of ground and the estimated level of contamination.

In practice, the distribution of the sensors in the field is sometimes modified in response to initial measurement results. If the artificial intelligence algorithm indicates a higher probability of mines in a particular part of the area, more sensors can be deployed more densely to provide a more accurate picture of the potential threat. In situations where there is insufficient certainty, it is possible to deploy individual sensors closer to the indicated anomaly points, allowing faster verification of suspicious zones and reducing the number of simultaneously active devices in the area.

Once the field diagnosis is complete, the grappling drones proceed to retrieve the sensors, following navigational guidance generated by the flight management system. Each sensor transmits pre-recorded data, making it possible to check for wear and tear or mechanical damage caused by contact with the ground. The final stage is the return to the launch site to hand over the sensors for further analysis and to complete the database with the measurement results. This logistical structure of the operation ensures the continuity of the system's work and allows the next mission to be launched quickly in another sector, which has a significant impact on the efficiency of the entire demining process.

7. Threats and opportunities for improvement

The operation of ultrasonic sensors can present a number of challenges, both due to field conditions and the operating characteristics of the equipment itself. One of the most common hazards is damage to the sensors when they come into rapid contact with the ground during a drop. Depending on the type of ground (rocky or highly compacted) and the height of the drop, electronic components and housings are exposed to vibrations or shocks that can exceed the maximum strength of the structure. Inadequate embedding of the sensor in the ground can lead to measurement errors due to a lack of stable ground contact and local variations in acoustic wave propagation.

Another significant area of risk is sensor recalibration due to mechanical overload or changes in temperature and humidity. In extreme cases, this can lead to a significant reduction in detection accuracy, especially if the environmental conditions differ from those in which the sensors were tested in the laboratory. In addition, prolonged use in the field requires constant monitoring of the battery status and possible replacement of the power supply in the sensors. Failure to adequately monitor power levels can lead to unplanned interruptions in data logging or hang-ups in the processing system.

Several strategies are used to improve the system and minimize the above risks. Firstly, special protective coatings and damping are introduced in the sensor housing to reduce the risk of mechanical damage. Secondly, regular mission control tests, consisting of short calibration pulses, are implemented to verify the accuracy of the measurements and quickly detect anomalies. Thirdly, real-time monitoring of battery status allows power regeneration to be scheduled and reduces the risk of sudden sensor shutdown at a critical detection moment. As a result, the system not only gains in operational stability but also increases its effectiveness in difficult field conditions, resulting in a higher level of safety and reliability of the demining operations carried out.

8. Conclusions

The use of ultrasonic sensors, supported by unmanned platforms and artificial intelligence algorithms, is a promising approach to speeding up and improving demining operations. Analyses to date indicate that the accurate detection and recognition of materials not only reduces false alarms but also increases operator safety by eliminating the need to enter high-risk areas. A key advantage of the system is its ability to provide fast, real-time data and reduce costs by reusing the same sensors.

One of the key challenges remains the variation in field conditions - soil with different moisture content and composition can affect wave attenuation and make the interpretation of reflections difficult. The solution is to continually improve the database, expand the range of sensor frequencies, or introduce dynamic-matched filtering algorithms. In addition, integration with other detection methods, such as GPR or systems based on electromagnetic field analysis, can further improve the accuracy of object identification and minimize time loss.

As the project develops, it is envisaged that even more autonomous missions could be developed, with drones planning their own routes based on current measurement results, without the need for constant operator supervision. As a result, further development of this idea offers significant potential for improving humanitarian demining operations, as well as contributing to increased safety and reduced costs of field operations.

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