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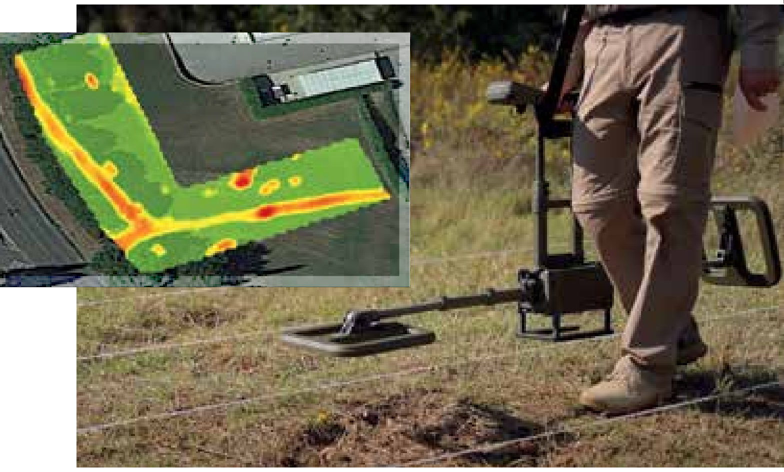

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# R&D AND INNOVATIVE SOLUTIONS WITHIN MINE ACTION

# Hyperspectral Sensor Management for UAS in Tactical Reconnaissance Missions:

## Performance Analysis of Environmentally Aware Anomaly Detection Architectures for UXO Detection

**by** *Linda Eckel[1], Tobias Hupel[2], Peter Stütz[3]*

## Introduction

The importance of small unmanned aerial systems (UAS) in tactical reconnaissance missions has increased significantly [1], [2]. Technical advances in UAV and sensor technologies allow UAS to be equipped with higher payloads while reducing the weight of on-board capabilities and sensors, enabling longer operational times with more complex payload technologies [3]. This capability allows large areas to be scanned more quickly and accurately, which is a key factor in tactical reconnaissance missions and has led to a significant research interest in this area [1], [2], [4], [5], [6], [7], [8]. The increasing development in payload technologies such as sensors and on-board capabilities further enables the use of new sensor types. Due to limited capabilities, sensors of low complexity, such as EO cameras, have been used to date, where incoming data can be easily interpreted and analyzed by the sensor operators themselves, who are often also the drone operators [9], [10], [11]. However, EO cameras are less suitable for detecting visibly obscured objects such as camouflage and unexploded ordnance (UXO), which are typical of reconnaissance scenarios [12], [13], [14], [15]. Therefore, sensors that provide information beyond the visible spectrum, such as hyperspectral sensors, are of great interest in research.

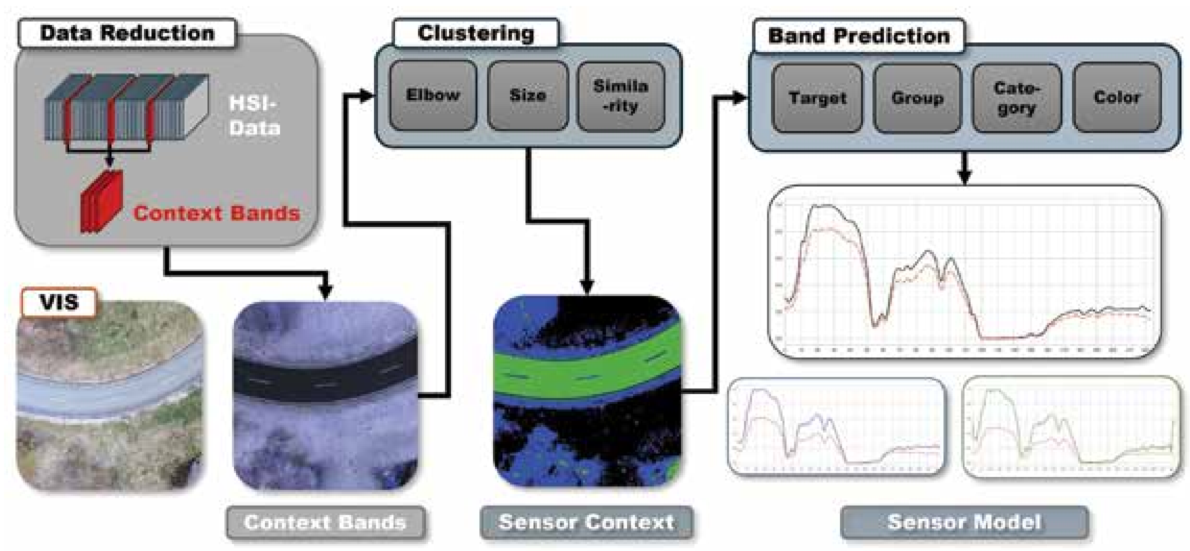


**Figure 1.** Concept of hyperspectral sensor management [16].

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## Hyperspectral Sensor Management

Hyperspectral sensors provide hundreds of spectral bands, such as the Specim AFX10 or Specim AFX17. Each may contain crucial information for detecting camouflage materials or unexploded ordnance. However, considering all at the same time may exceed the capabilities of sensor operators in tactical reconnaissance missions.

To address this problem, hyperspectral sensor management determines the most informative or valuable spectral bands with respect to the current environmental context. This is achieved by a sensor model based on machine learning that maps current environmental conditions to the performance of each spectral band of a hyperspectral sensor and was presented in [16]. With this information, the spectral bands with the highest performance predictions can be selected while the others can be discarded. This tremendously reduces the amount of information that needs to be processed and ensures the availability of the most crucial information at the same time.

The concept of hyperspectral sensor management is presented in Figure 1. First, three spectral bands are selected from the hyperspectral data cube and serve as context bands. These bands are then processed through a special clustering process based on the k-means algorithm and other implemented checks such as similarity, which assigns each pixel to a single cluster representing an environmental area. The clustering result can be interpreted as the sensor's context or the environmental context, as it reveals the most dominant environments and materials present in the context bands. Using the mean pixel value of each cluster, a machine learning model predicts the spectral difference of different camouflage materials and UXO for each spectral band and environment present in the scene. As a result, the spectral bands in which the difference and anomaly are greatest can be easily identified and selected for further anomaly detection.

## Datasets for Training and Testing

Naturally, the hyperspectral sensor management approach requires data to train the sensor model. In addition, this data needs to be as versatile and diverse as possible to ensure robust prediction even for unknown data. Therefore, targeted data collection campaigns were conducted that spanned multiple years, seasons and sites. Furthermore, numerous different camouflaged targets and UXO were considered and captured with a sophisticated hyperspectral UAS. As a result, hundreds of samples could be obtained and were split into dedicated training and testing datasets. The conducted results in [16] has shown that approach of hyperspectral sensor management enables the determination of the bands with the highest spectral difference with high accuracy for also unknown targets as well as unknown mission areas.

Figure 2 shows multiple samples of the resulting datasets. Each sample consists of a hyperspectral data cube and a label mask that identifies each target in the scene. For better clarity, a false color image based on three bands is shown to represent the hyperspectral data cube. As can be observed, some targets are very difficult to detect, especially those lying in the shadows. In addition, the small targets, which are UXO, manifest in very small dark spots in the hyperspectral data.

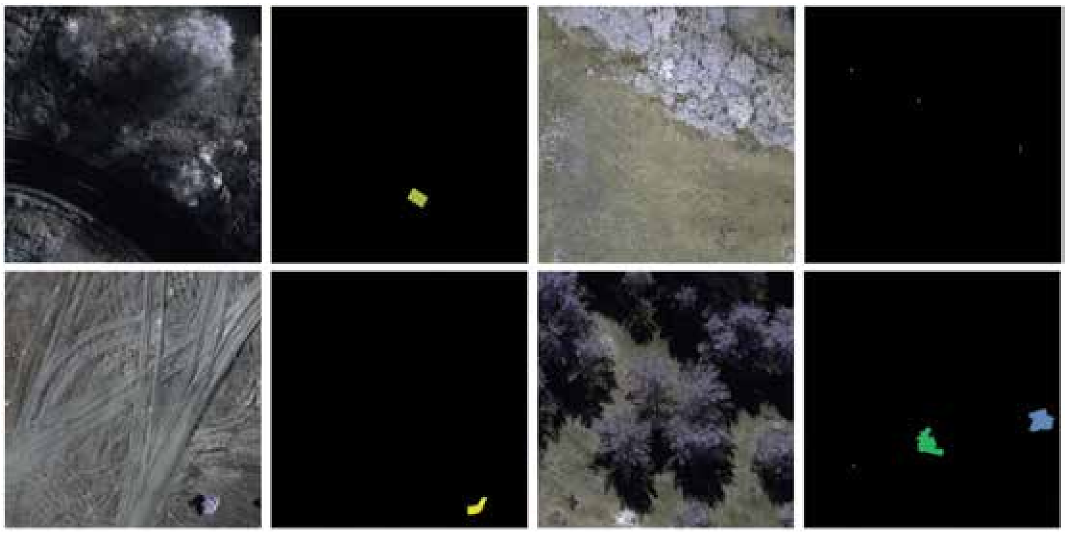

**Figure 2.** Multiple samples of the collected hyperspectral data, showing the difficulties to detect camouflage as well as UXO [17].

## Architectures of Environmentally Aware Anomaly Detection for UXO Detection

Since hyperspectral sensor management allows the selection of the spectral bands in which UXO differentiate the most from their surroundings, these bands make them also appear most anomalous. Therefore, anomaly detection benefits greatly in terms of detection rates and runtime by processing only those bands instead of the entire hyperspectral data cube. Furthermore, as there are countless methods for anomaly detection, each working on different detection mechanisms, selecting an appropriate algorithm with respect to the environmental context increases the precision of UXO detections as shown in [17]. UXO detection based on hyperspectral data can therefore also benefit from perception management, which determines the most powerful detection algorithm in relation to the actual sensor context.

Consequently, the combination of hyperspectral sensor management and perception management results not only in high UXO detection rates, but also in reduced processing runtimes, which is an essential requirement on resource limited UAS. With the spectral bands and anomaly detection algorithms selected based on environmental conditions, the entire UXO detection workflow depends on environmental conditions, as well.

The benefits of the environmentally aware anomaly detection approach using an extensive test dataset for UXO detection are shown in Figure 3. The tests were conducted with a local Reed-Xiaoli detector and varying detector parameters. In the left diagram, the detection rates in terms of F-Score and target hits of using the best average anomaly detection algorithm (unmanaged) are compared to the best dynamically selected anomaly detection algorithm (managed).

Note that this is a comparison of detection algorithm management, where the spectral bands are dynamically selected for both settings, whether the anomaly detectors are managed or unmanaged. As can be seen, dynamic selection practically quintuples the F-Score performance, demonstrating the effectiveness of the perception management.

The diagram on the right shows the comparison between a full managed sensor and perception management and a partially managed perception management with a static, statistically computed band selection. Here, the question is whether a targeted detector selection can compensate for a more disadvantageous, static band selection by their varying detection methodologies and make sensor management obsolete. As can be observed, the F-Score is more than twice as high and the number of successfully detected targets has increased by over 15%. This shows that the perception management approach is further enhanced by the preceding sensor management, which in turn demonstrates the effectiveness of environmentally aware anomaly detection for UXO detection.

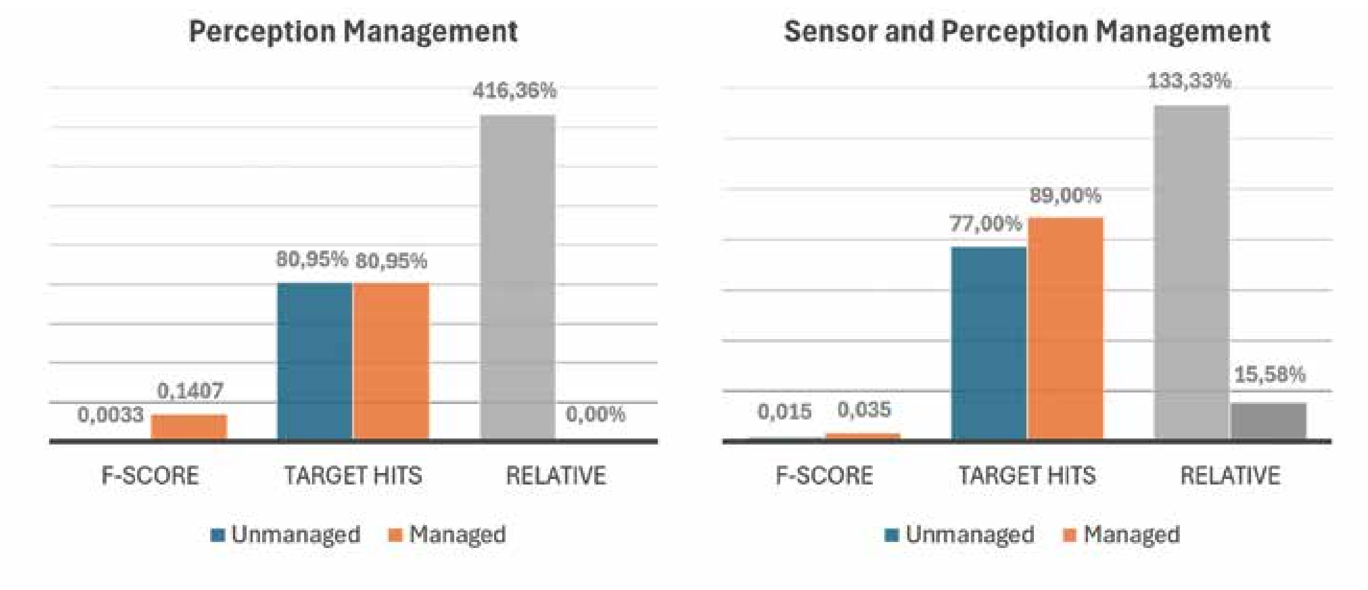


**Figure 3.** Comparison of UXO detection results based on F-Score and target hits. The left diagram shows the benefits of perception management alone, while the right diagram shows the benefits of combining sensor management with perception management.

## Acknowledgements

This research was funded by the Federal Office of Bundeswehr Equipment, Information Technology, and In-Service Support (BAAINBw) and dtec.bw – Digitalization and Technology Research Center of the Bundeswehr. dtec.bw is funded by the European Union – NextGenerationEU.

## References

[1] L. Bojor and L. Grigore, "Implementing Small Commercial Drones in Land Forces Operations: Considerations for Optimizing ISR (Intelligence, Surveillance, and Reconnaissance)," *Int. Conf. Knowl.-BASED Organ.*, vol. 30, no. 1, pp. 25–35, Jun. 2024, doi: 10.2478/kbo-2024-0004.

[2] L. Criollo, C. Mena-Arciniega, and S. Xing, "Classification, military applications, and opportunities of unmanned aerial vehicles," *Aviation*, vol. 28, no. 2, pp. 115–127, Aug. 2024, doi: 10.3846/aviation.2024.21672.

[3] B. Lu, P. Dao, J. Liu, Y. He, and J. Shang, "Recent Advances of Hyperspectral Imaging Technology and Applications in Agriculture," *Remote Sens.*, vol. 12, no. 16, p. 2659, 2020, doi: 10.3390/rs12162659.

[4] J. Cai, L. Meng, H. Liu, J. Chen, and Q. Xing, "Estimating Chemical Oxygen Demand in estuarine urban rivers using unmanned aerial vehicle hyperspectral images," *Ecol. Indic.*, vol. 139, p. 108936, 2022, doi: 10.1016/j.ecolind.2022.108936.

[5] W. Zhu *et al.*, "Estimating leaf chlorophyll content of crops via optimal unmanned aerial vehicle hyperspectral data at multi-scales," *Comput. Electron. Agric.*, vol. 178, p. 105786, 2020, doi: 10.1016/j.compag.2020.105786.

[6] M. M. Marques, *STANAG 4586—standard interfaces of UAV control system (UCS) for NATO UAV interoperability*. North Atlantic Treaty Organization, 2012.

[7] L. Liu, Y. Dong, W. Huang, X. Du, and H. Ma, "Monitoring Wheat Fusarium Head Blight Using Unmanned Aerial Vehicle Hyperspectral Imagery," *Remote Sens.*, vol. 12, no. 22, p. 3811, 2020, doi: 10.3390/rs12223811.

[8] T. Hupel and P. Stütz, "Adopting Hyperspectral Anomaly Detection for Near Real-Time Camouflage Detection in Multispectral Imagery," *Remote Sens.*, vol. 14, no. 15, p. 3755, 2022, doi: 10.3390/rs14153755.

[9] Y. Ren, H. Wang, D. Liu, W. Sang, and G. Cheng, "Robust seamless GEO scanning control strategy for airborne electro-optical/infrared reconnaissance systems," *Signal Image Video Process.*, vol. 18, no. 11, pp. 7611–7620, Nov. 2024, doi: 10.1007/s11760-024-03414-8.

[10] *IEEE Fourth International Conference on Big Data Computing Service and Applications: Proceedings : 26-29 March 2018, Bamberg, Germany*. Los Alamitos, California: IEEE Computer Society, Conference Publishing Services, 2018.

[11] J. Peksa and D. Mamchur, "A Review on the State of the Art in Copter Drones and Flight Control Systems," *Sensors*, vol. 24, no. 11, p. 3349, May 2024, doi: 10.3390/s24113349.

[12] P. S. Thenkabail and J. G. Lyon, *Hyperspectral remote sensing of vegetation*. Boca Raton, Fla.: CRC Press, 2012.

[13] N. M. Nasrabadi, "Hyperspectral Target Detection : An Overview of Current and Future Challenges," *IEEE Signal Process. Mag.*, vol. 31, no. 1, pp. 34–44, Jan. 2014, doi: 10.1109/MSP.2013.2278992.

[14] D. Manolakis and G. Shaw, "Detection algorithms for hyperspectral imaging applications," *IEEE Signal Process. Mag.*, vol. 19, no. 1, pp. 29–43, 2002, doi: 10.1109/79.974724.

[15] G. Camps-Valls, D. Tuia, L. Bruzzone, and J. A. Benediktsson, "Advances in Hyperspectral Image Classification: Earth Monitoring with Statistical Learning Methods," *IEEE Signal Process. Mag.*, vol. 31, no. 1, pp. 45–54, 2014, doi: 10.1109/msp.2013.2279179.

[16] L. Eckel, "Hyperspectral Sensor Management for UAS: Sensor Context Based Band Selection for Anomaly Detection," presented at the Aerospace Conference, Mar. 2024.

[17] L. Eckel and P. Stütz, "Hyperspectral Sensor Management for UAS: Performance Analysis of Context-Based System Architectures for Camouflage and UXO Anomaly Detection Workflows." Accessed: Feb. 18, 2025. [Online]. Available: https://www.mdpi.com/2504-446X/8/10/529

# TaMaCare:
## Integrating multi-spectral and SLAM for mine and environment mapping

*by Darius Couchard[1], Charles Hamesse[1] and Rob Haelterman[1]*

## Abstract
This paper outlines the objectives of the Belgian Defence research project « Tactical Environment Mapping for Battlefield Casualty Care » (TaMaCare), which focuses on integrating multi-spectral imaging (MSI) data with a simultaneous localization and mapping (SLAM) system to create a digital twin of the battlefield that contains precise information for first responders about potential threats (UXO, landmines, ...). HSI captures detailed spectral signatures across the electromagnetic spectrum, making it invaluable for mine detection by distinguishing various materials. Surface mines can employ camouflage to evade detection by RGB imaging systems, but developing camouflage that effectively covers broad portions of the electromagnetic spectrum is significantly more challenging. The rich data from HSI sensors therefore facilitate robust anomaly detection. However, the limitations of HSI sensors make the technology impractical for dynamic and unpredictable scenarios. Therefore, multi-spectral (MSI) sensors will be carefully selected based on HSI measurement campaigns which will study the spectral signature of threats. Data from the measuring campaigns will be published. SLAM technology enables systems to map unknown environments while determining their location, either through LiDAR or cameras and functioning independently of external networks. This capability is crucial in GPS-denied or jammed environments, as assumed by the project. By combining SLAM with MSI, a digital twin of an environment can be created, precisely identifying threat locations. The project will include regular validation experiments in Belgian Defense camps. Although the primary focus is on post-disaster scenarios, the technological advancements from this project are directly applicable to humanitarian demining, particularly in the acquisitions of datasets and in the advancements of mine detection through HSI.

## Introduction
Traditional methods of casualty care in military and emergency response scenarios have long been constrained by significant limitations in information availability and situational awareness. These challenges include a lack of a comprehensive picture of the battlefield, which hinders the ability to effectively locate and prioritize casualties.

Additionally, the limited capacity to minimize exposure to ongoing threats further complicates the process of providing timely and safe medical intervention. These challenges equally translate into humanitarian demining operations, where the environment is often unfamiliar. In such scenarios, deploying an unmanned system for initial reconnaissance would be desirable.

To address these critical issues, TaMaCare proposes the development of a real-time digital twin of the environment. This innovative system will integrate location data for both casualties and threats using a passive, portable, and wearable system that weighs less than 3 kilograms. This advancement will not only improve the efficiency of casualty care but also contribute to the overall safety and success of missions by providing a more accurate and up-to-date representation of the operational environment.

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## SLAM

To create a digital twin of the environment, the embedded system will utilize Simultaneous Localization and Mapping (SLAM) [1]. This technology enables the construction of a map of an unknown environment while concurrently determining the system's location within it (Figure 1).

**Figure 1.**
Digital Reconstruction of an environment with SLAM.
The represented image is rendered from a point cloud obtained through a LiDAR sensor.

SLAM operates by integrating data from various sensors, with LiDAR being particularly due to its precise range estimation [2]. However, given the modern battlefield's requirements for stealth sensors and technologies, the project aims to transition to a passive sensor system, specifically Visual-SLAM [3]. While Visual-SLAM in dynamic scenes with degraded visual conditions remains a challenge, this shift to passive sensors is crucial to avoid emitting detectable signals.

## Hyperspectral and Multispectral Imaging

Hyperspectral Imaging (HSI) is a technique that captures information across the electromagnetic spectrum, providing detailed spectral signature for each pixel in an image [4]. Unlike conventional imaging methods that capture light in one or few broad bands, HSI divides a portion of the spectrum into many narrow bands (Figure 2). This enables HSI to capture a detailed spectral signature of observed materials, enhancing the detection of camouflaged objects [5]. Landmines and UXOs, which often appear as spectral anomalies in a scene, can thus be detected more effectively than with traditional imaging techniques [6].

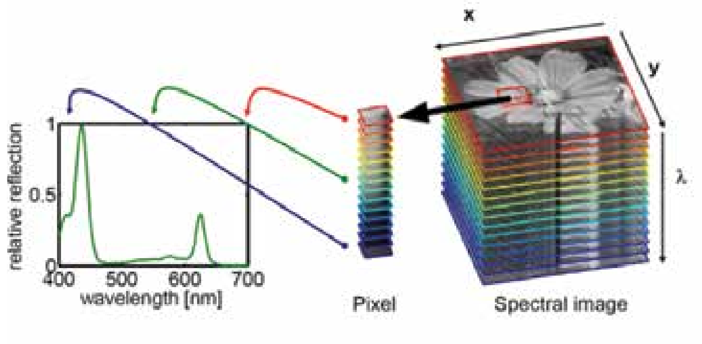


**Figure 2.** Hyperspectral Image represented as a cube.
The third dimension offers a detailed spectral signature for each pixel of the image.

HSI has demonstrated strong potential for detecting ground-laid and partially buried mines, particularly within the Visual/Near-Infrared (VNIR) and the Short-Wave Infrared (SWIR) spectra [7]. Long-Wave Infrared (LWIR) sensors can detect thermal anomalies in the ground, allowing for the detection of buried mines [8][9].

HSI provides comprehensive spectral data but is often constrained by spatial resolution, size, and cost, making it impractical for our embedded system. Instead, we will utilize panchromatic and multispectral sensors (MSI) for threat detection.

Unlike HSI, which captures numerous narrow spectral bands, MSI focuses on fewer, broader bands (typically 10-20). Although MSI offers less detailed spectral information, it provides superior spatial resolution and is more compact and cost-effective, making it better suited for practical applications.

Measurement campaigns using high-resolution HSI sensors will be organized to capture precise spectral signatures of threats. Studying these signatures will enable us to carefully select our embedded MSI sensor suite, enhancing the detection of landmines and UXOs.

## System Description

In this section we describe the hardware components of the system.

### Sensor Setup

The initial SLAM setup will be based on a *Livox MID-360* LiDAR [10]. The rotating mirror of the sensor provides a large horizontal FOV of 360° and vertical FOV of 59°, enabling efficient and broad environmental mapping. This sensor provides a precision of 2-3 cm, depending on the range, and can detect objects staring from a distance of 10 cm.

The final SLAM setup (Figure 3) will use the *Core Search Development Kit* sensor suite from *Sevensense Robotics* [11]. This device includes five global shutter cameras with a FOV of 165.4° (D) 126°(H) 92.4° (V) using a *Sony IMX-273* panchromatic visible sensor of 1.6 megapixels (MP) [12].

In addition to the LiDAR or optical sensors, the SLAM system will incorporate an Inertial Measurement Unit (IMU) consisting of an Accelerometer, Gyroscope and a Magnetometer. Such measurements can be integrated with LiDAR or optical data to increase the performance of the localization system [13].

For threat detection, the initial setup will include *Alvium 1800 U-240* and *U-130 VSWIR* cameras from *Allied Vision*—a 2.4 MP RGB camera for the visible spectrum and a 1.3 MP panchromatic camera for the visible and SWIR spectrum, respectively [14] [15]. For the LWIR spectrum, the *Boson 640* panchromatic 0.32 MP camera from *Teledyne Flir* will be used [16]. Those sensors weigh less than 100 grams and consume less than 5W each. Following the HSI study of threat spectral signatures, multispectral cameras focusing on relevant wavelengths will be added to the embedded system.

The *HySpex Mjolnir S-620* [17] sensor will be employed for HSI analysis in measurement campaigns, as it captures images in the SWIR spectrum with large spatial and spectral resolutions. At the time of writing, we are in the process of purchasing a pushbroom VNIR sensor.

### Computing unit

In addition to the sensor suite, the embedded system will be connected to an NVIDIA Jetson Orin computer [18]. This platform is ideal for embedded systems requiring intensive computation while maintaining energy efficiency. With an integrated modern GPU, this system can run state-of-the-art models for sensor fusion and real-time anomaly or target detection.

**Figure 3.** Sample 3D mapping rig. Including LiDAR and Visual SLAM.

## Objectives

The project will include regular validation experiments in Belgian military camps, joining various MASCAL exercises and using our own collection of landmines.

For threat detection, the system is expected to attain an F1-score of at least 80% under both day and night conditions. HSI Measurement campaigns will help us select multispectral sensors to target the most appropriate bands for the detection of threats by analysis the spectral signatures of composing materials.

## Conclusion

The TaMaCare project aims to develop a digital twin of the battlefield and detect potential threats such as landmines and UXOs. By utilizing advanced Visual-SLAM and MSI technologies, the system seeks to achieve state-of-the-art performance as a passive, non-emitting system.

This paper outlined the project's objectives, introduced the SLAM, HSI and MSI domains, and detailed hardware configurations and intermediate research, including the study of threat spectral signatures.

## Acknowledgements

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## References

[1] U. Frese, R. Wagner and T. Röfer, "A SLAM overview from a User's Perspective," *Künstliche Intelligenz*, 2010.

[2] B. Yang, T. Minh, T. Pham and J. Yang, "Evaluating and Improving the Robustness of LiDAR-based Localization and Mapping," *ArXiV*, 2024.

[3] C. Yan, D. Qu, D. Xu, B. Zhao, Z. Wang, D. Wang and X. Li, "GS-SLAM: Dense Visual SLAM with 3D Gaussian Splatting," in *CVPR*, 2024.

[4] D. Manolakis, R. Lockwood and T. Cooley, Hyperspectral Imaging Remote Sensing, 2016.

[5] T. Hupel and P. Stütz, "Adopting Hyperspectral Anomaly Detection for Near Real-Time Camouflage Detection in Multispectral Imagery," *Remote Sensing*, 2022.

[6] M. Khodor, I. Makki, R. Younes, T. Bianchi, J. Khoder, C. Francis and M. Zucchetti, "Landmine detection in hyperspectral images based on pixel intensity," *Remote Sensing Applications: Society and Environment*, 2021.

[7] I. Makki, R. Younes, C. Francis, T. Bianchi and M. Zucchetti, "A survey of landmine detection using hyperspectral imaging," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 124, 2017.

[8] Deans, Gerhard and Carter, "Analysis of a thermal imaging method for landmine detection, using infrared heating of the sand surface," *Infrared Physics & Technology*, vol. 48, 2006.

[9] R. Haleterman, "Stand-off landmine detection using (hyperspectral) infrared imaging," in *Mine Action Symposium*, 2024.

[10] Livox, "Livox Mid-360," [Online]. Available: https://www.livoxtech.com/mid-360.

[11] Sevensense, "Core Search Manual," [Online]. Available: https://github.com/sevensense-robotics/core_research_manual.

[12] Phase 1 vision, "Sony IMX273 3.4µm x 3.4µm sensor," [Online]. Available: https://www.phase1vision.com/sensors/sony-sensors/pregius/imx273.

[13] Mostofi, Elhabib and El-Sheimy, "Indoor localization and mapping using camera and inertial measurement unit (IMU)," in *IEEE Symposium on Position Location and Navigation (PLANS)*, 2014.

[14] Allied Vision, "Alvium 1800 U-240," [Online]. Available: https://www.alliedvision.com/en/products/alvium-configurator/alvium-1800-u/240/.

[15] Allied Vision, "Alvium 1800 U-130 VSWIR," [Online]. Available: https://www.alliedvision.com/en/products/alvium-configurator/alvium-1800-u/130-vswir/.

[16] Teledyne Flir, "Boson - Uncooled Longwave Infrared (LWIR) OEM Therman Camera Module," [Online]. Available: https://www.flir.com/products/boson/?vertical=lwir&segment=oem.

[17] Norsk Elektro Optikk, "HySpex Mjolnir S-620," HySpex, [Online]. Available: https://www.hyspex.com/hyspex-products/hyspex-mjolnir/hyspex-mjolnir-s-620/.

[18] Nvidia, "Jetson AGX Orin," [Online]. Available: https://www.nvidia.com/fr-fr/autonomous-machines/embedded-systems/jetson-orin/.

# Beyond the Visible – Multispectral & TIR sUAS Minefield Mapping

## Lessons Learned from the Successful Deployment of MS & TIR Imaging Over Live Minefields

**by** *John Fardoulis[1], Xavier Depreytere[2]*

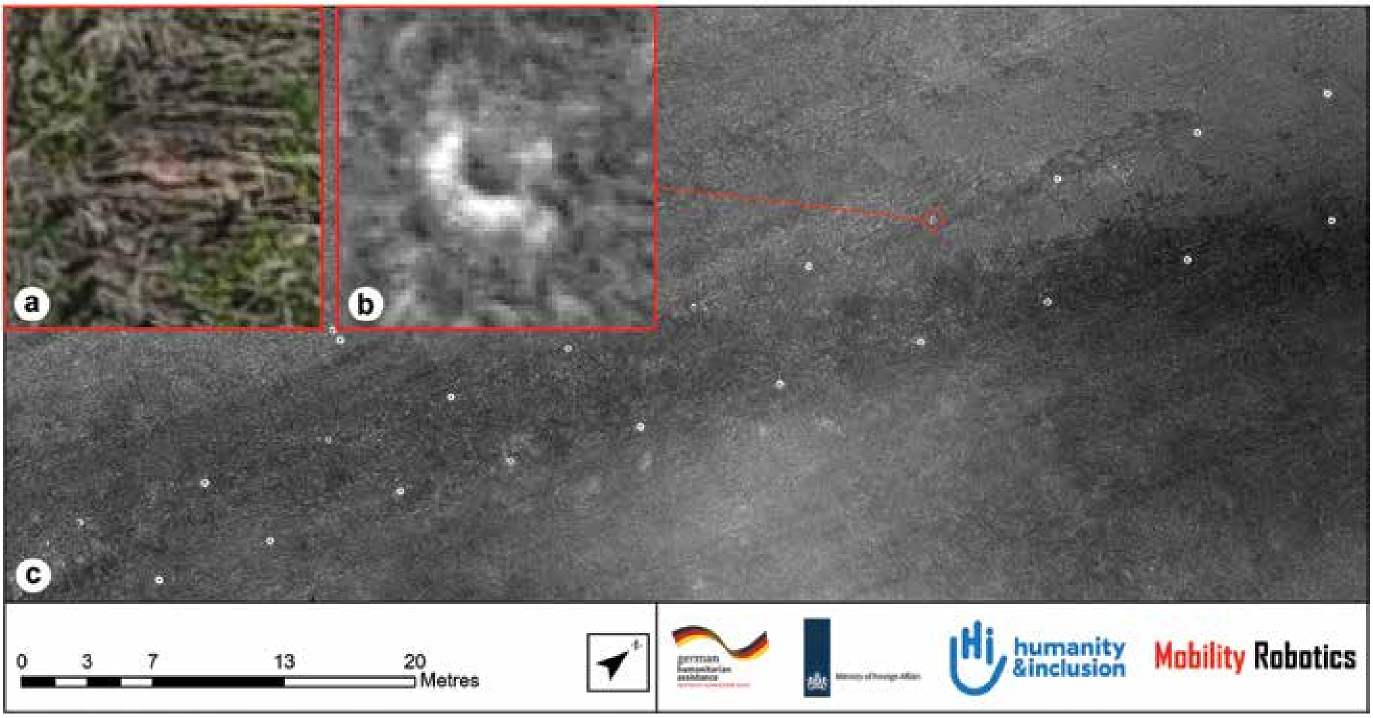


**Figure 1.** Above are parts of a sUAS minefield map created in May 2023 from an altitude of 25m at a live site in Ukraine (c). This shows how MS imaging can help better visualise plastic TM-62 P3 AV landmines in an environment of wild grass and weeds. Zooming in to an individual TM-62 P3 AV landmine in the map, (b) shows how the technique can help to visualise landmines that are obscured by such vegetation, making the target seem more obvious than imagery of the same device captured with a standard RGB camera (a). The technique also has camouflage-reduction properties: note how the influence of the vegetated background is reduced when visualising the twenty-three AV landmines in (c).

This paper presents key lessons learned from the use of small uncrewed aircraft systems (sUAS) for minefield imaging with multispectral (MS) sensors in the visible to near infrared (NIR) light bands, and thermal infrared (TIR) sensors.

The ethos was to conduct brief baseline trials in controlled environments, and then deploy in the real world during operational deployment with humanitarian mine action (HMA) teams at live minefields.

MS imaging was employed in Ukraine to locate surface and partially buried metal and plastic anti-tank/anti-vehicle (AT/AV) landmines which were obscured by long grass and weeds, beyond the clear visibility of a standard (RGB) camera.

TIR technology was utilised in the Sahara Desert in Chad to locate buried plastic anti-personnel (AP) and AV landmines[1].

Work took place as part of the Odyssey 2025 project, led by Handicap International/Humanity & Inclusion (HI), with Mobility Robotics responsible for research and development and conducting sensor trials. The project has been made possible by the German Federal Foreign Office (GFFO) and the Ministry of Foreign Affairs of The Netherlands (BUZA) as donors.

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## Materials and Methods

Two different use cases are presented:

(1) Using MS imaging to reduce the camouflage effect of surface landmines obscured by grass and weeds in vegetated environments, providing better visualisation than a regular RGB camera (Figure 1(a) vs (b), and Figure 4).

(2) Using TIR to locate buried landmines in the desert.

There are multiple segments in the infrared (IR) light range (Figure 2). This indicates that MS and TIR sensors operate differently.

Various sUAS have been deployed over the last five years. Currently, the DJI Mavic 3 Enterprise Multispectral (M3M)[2] is used for MS imaging/mapping, while the DJI Mavic 3 Enterprise Thermal (M3T)[2] is utilised for TIR work.

Pix4D Mapper[3] and DJI Terra[4] were used for stitching imagery and data processing, with ArcGIS Pro[5] used for mapping, analysis, post-processing, visualisation, and planning. An Ocean Optics USB2000 handheld spectrometer[6] was used for creating a spectral reflectance reference library.

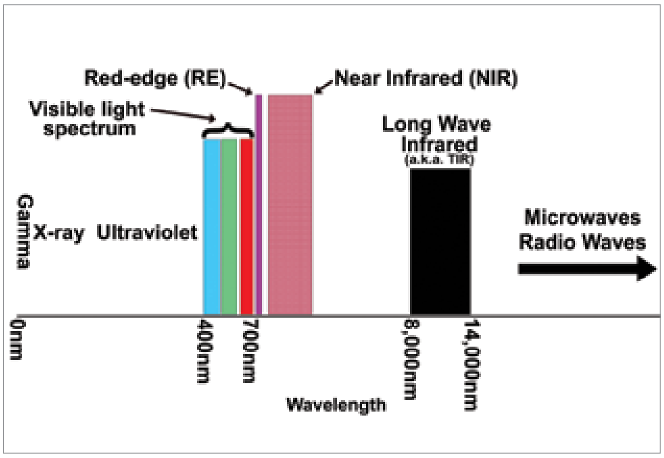


**Figure 2.** Above is a simplified diagram showing physics/remote-sensing concepts where visible and infrared wavelengths appear along the electromagnetic spectrum (using a modified log scale). We are referring to the visible light spectrum (just over 400nm to just under 700nm) to NIR sector when referring to MS imaging/mapping in this article.

TIR is different, with such sUAS sensors capturing temperature, in the 8,000nm to 14,000nm range.

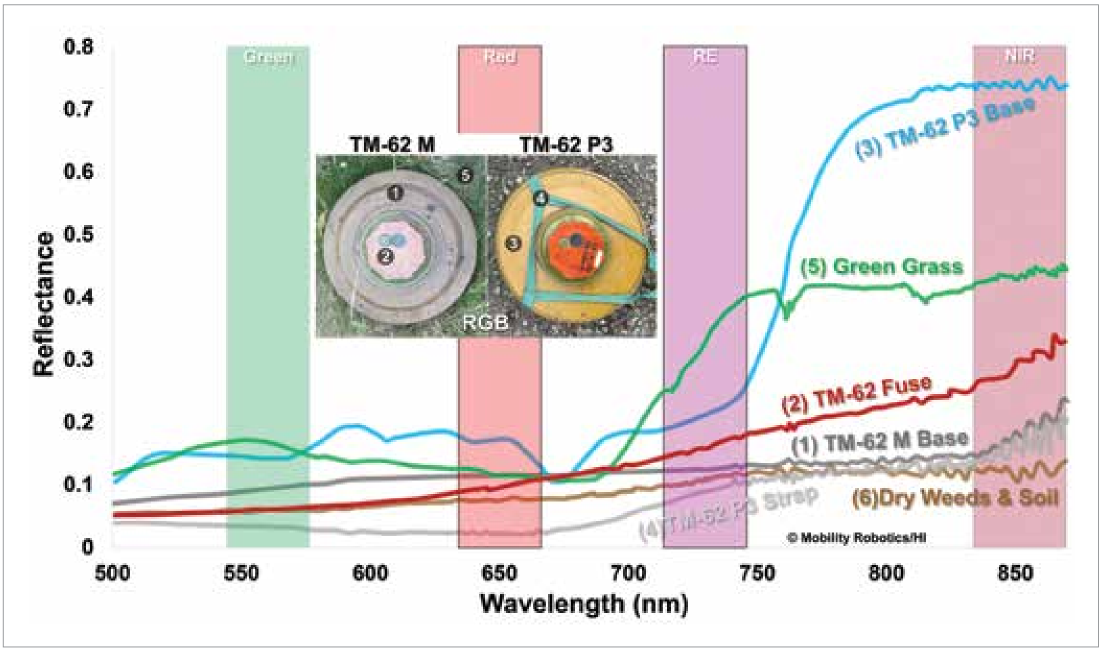


**Figure 3.** Above are spectral reflectance curves for metal TM-62 M and plastic TM-62 P3 AV landmines from our library. These help to explain the how each component has a different spectral reflectance signature for insight into how to post-process MS imagery from the DJI M3M. Shaded background columns have been included to show the bands at which the DJI M3M's four MS cameras capture calibrated imagery.

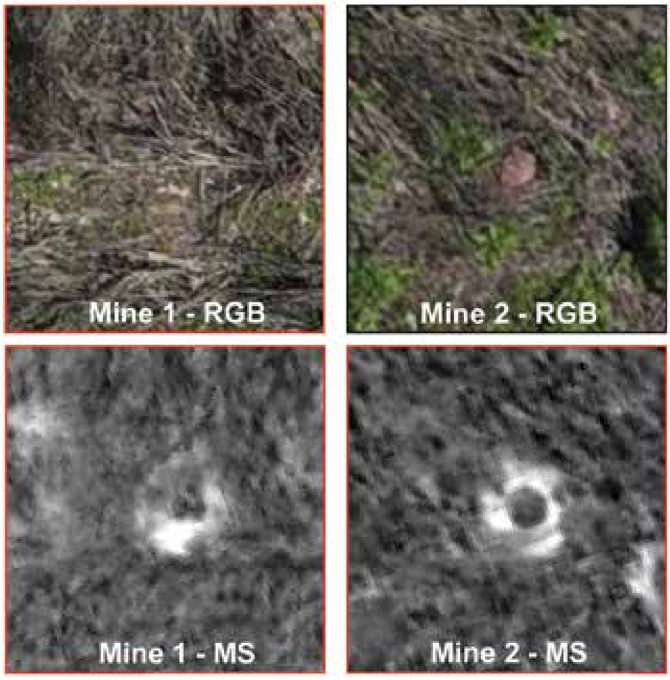


**Figure 4.** Above are two TM-62 P3 AV devices which are covered by grass/weeds at a live minefield in Ukraine. The top row shows the two landmines from a map layer created from a standard RGB camera, with the same landmines shown below in the post-processed MS map layer. You can see how the MS visualisation is more obvious in this scenario.

## Lessons Learned - MS Mapping/Imaging

MS imaging helped reduce the camouflage effect of, and concealment by thin vegetation in two ways. First, it improved visibility of individual landmines that were partially covered by thin vegetation, making them easier to locate compared to a regular RGB camera (Figure 1 (a)). Second, it reduced the visual prominence of the surrounding vegetation, making the targets stand out more clearly against the background (Figure 1 (c), Figure 4).

Visualisation was strongest in cases when landmines and vegetation had the greatest differences in their spectral reflectance curves in the NIR band, and to some extent the RE band. This was the case with the plastic body of the TM-62 P3 AV landmine, which had a significantly higher level of spectral reflectance in the NIR band than did green grass/weeds and dry grass/weeds (Figure 3 (3) vs (5) or (6)).

Landmine spectral fingerprints can vary by model. e.g., a TM-62 M body compared to that from a TM-62 P3 (Figure 3 (1) vs (3)). It was also found that spectral reflectance curves for green plastic landmines varied by model in the NIR, and some in RE bands. Hence, different post-processing vegetation indices or algorithms may be required by landmine model or material type.

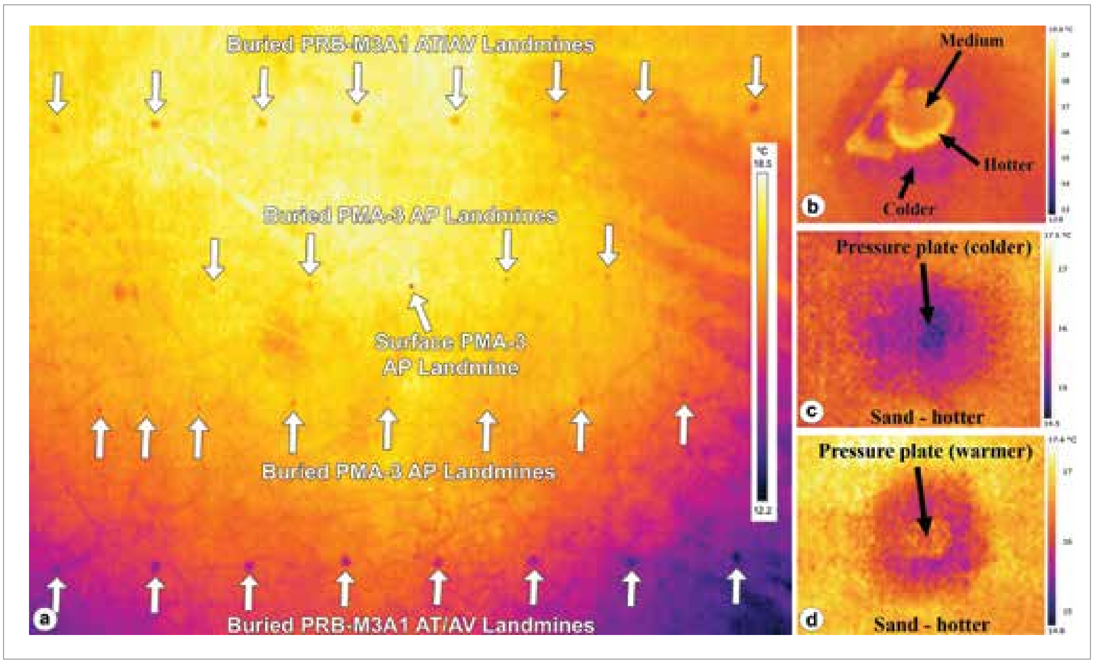


**Figure 5.** Above are examples of real world TIR signatures from live minefields which taught us how to interpret TIR data. Twenty-eight buried landmines are shown in (a) above. There are two rows of PRB-M3A1 AV landmines, and two rows of PMA-3 AP landmines. Each signature provides an idea regarding the landmine type and if it is buried at a shallow or medium depth. For example, the PRB-M3A1 pressure plate heated up at night when interfacing with the air – so it was warmer when buried close to the surface but cooler if deeper. (b) shows a pressure plate that is above the surface, but the device body is partly buried. (c) shows a live PRB-M3A1 that is deeper because the pressure plate is colder than the body. (d) shows a live PRB-M3A1 that is shallower because the pressure plate is warmer than the body.

## Lessons Learned - TIR Mapping/Imaging

TIR data was collected from over two-thousand-five-hundred in-situ landmines at live sites, providing experience in analysing data for various landmine models found in Chad (Figure 4).

Collecting real world data from so many targets provided valuable insight because all the variables were in place. This included 30-year-old weathered production landmines with the correct casings and explosive fills. Other factors were the correct particle characteristics for that type of sandy ground, burial depth, local weather, condensation or moisture, erosion effects and water transport in the environment. Additional variables included temperature, sunlight, cloud cover, wind, and the diurnal cycle.

A key lesson learned from the real world was that TIR imaging was sensitive to environmental and weather variables, and worked best at night.

The diurnal cycle influenced the results, with optimal times to operate being in the hours just before sunrise and just after sunset (Figure 6 (b) and (e)).

The wind also affected TIR sensor data, with anomalies from buried landmines appearing weak or indistinguishable when experiencing windspeeds greater than a light breeze.

The impact of depth is an important consideration, which would depend on many of the complex variables such as: landmine construction - materials, size, wall thickness, and explosive fills , the environment, ground characteristics, and weather.

We found that it was possible to locate PRB-M3A1 AV and PMA-3 landmines up to a depth of around 5cm using sUAS TIR imaging at live minefields in Chad.

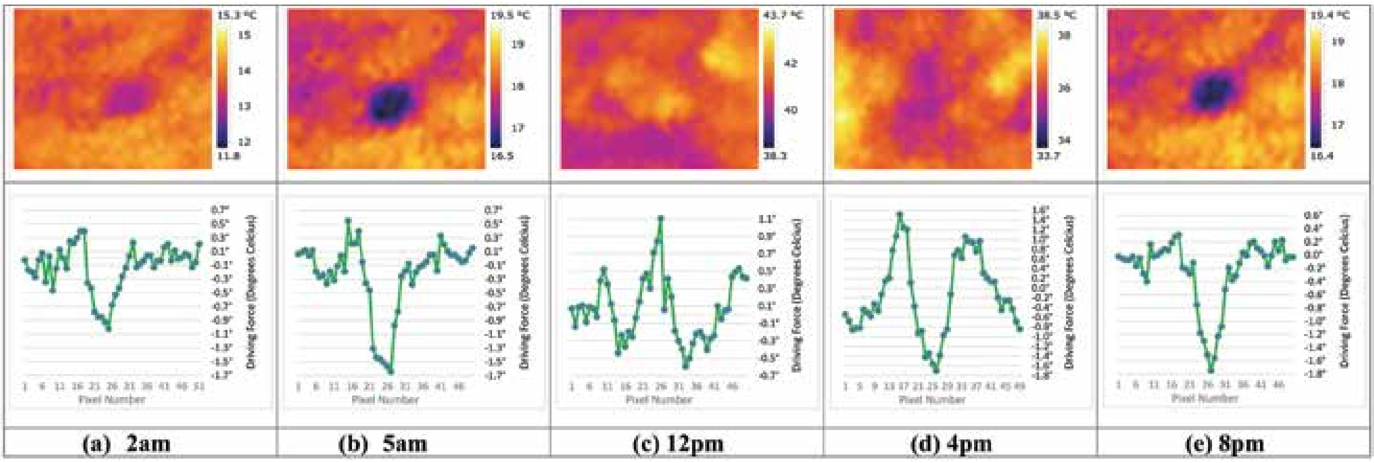


**Figure 6.** Above are examples of buried landmine TIR anomaly visibility by diurnal cycle. It shows that just before sunrise and just after sunset were the best times to operate (b) and (e), as TIR anomalies from a reference target at a 1cm depth were most prominent at those times.

## Validation

Due to the potentially life-threatening work in the HMA sector, validation at real-world, live minefields is required to prove any research or new methodology is actually viable.

Not just to prove that a technique works, but also to gain insight in how to operationalise new methods. For example, working at night for TIR imaging is a completely new paradigm in HMA. This introduces increased security considerations and risks, meaning that it may not be feasible to work in some locations at night, or that the additional risk may not justify the effort.

The validity of both MS and TIR findings was confirmed through collaboration with demining personnel from various organisations, who physically verified and ground-truthed the results obtained from sUAS aerial data (Photo 1 - see on next page).

Additionally, without collaboration with a HMA organisation capable of clearance operations, the research impact may be limited due to a lack of validation at live sites.

For more information see www.mr-au.com.

**Photo 1.** Above is a photo of one of the PMA-3 AP landmines that was identified in sUAS TIR imagery, with validation provided by deminers who excavated to show that it was buried at a depth of 4cm depth at a live, 30-year-old in situ minefield.


## Acknowledgements

*We would like to thank a number of people and organisations who made this work possible, including our donors, the GFFO and BUZA.*

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*In addition, we owe special thanks to the HI team around the world (past and present), particularly, Artur Korneievets, Ba Abdourahmane, Kheira Djouhri, and Aneirin Wenner. Not forgetting Scott Willan, our Australian scientific adviser.*


## References


[1] J. Fardoulis, X. Depreytere, P. Gallien, K. Djouhri, and B. Abdourhmane, "Proof : How Small Drones Can Find Buried Landmines in the Desert Using Airborne IR Thermography," The Journal of Conventional Weapons Destruction, vol. 24, no. 2, 2020.

[2] "DJI Mavic 3 Enterprise Series https://enterprise.dji.com/mavic-3-enterprise?site=enterprise&from=nav

[3] "PIX4Dmapper: https://www.pix4d.com/product/pix4dmapper-photogrammetry-software/

[4] "DJI Terra - https://enterprise.dji.com/dji-terra

[5] "ArcGIS Pro." https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

[6] "USB2000+ Spectrometer." www.oceanoptics.com

# Autonomous Mobile Manipulation for Safe and Efficient Landmine Disposal

*by* *Alessandra Miuccio[1], Timothée Fréville[2], Emile Le Flécher[1], Charles Hamesse[2], Geert De Cubber[1], Rob Haelterman[2]*

## Abstract

Landmines are a critical threat, endangering not only military personnel during conflicts, but also civilian population long after the conflict is over. This underscores the urgent need for safer and more efficient demining methods. In this paper, we explore solutions for the critical phase following mine detection, emphasizing autonomous collection and disposal processes performed by a robotic system. More specifically, this paper presents a theoretical framework for a novel mobile manipulation methodology for demining and explosive disposal operations. The challenges inherent in this operation are multiple, including identifying optimal grasping points, calibrating applied force, maintaining obstacle awareness, and overcoming visibility obstructions around the mine. Building upon recent developments in 3D computer vision and mobile manipulators, we propose a method for the autonomous handling and disposal of mines. The integration of a mobile manipulator combines the mobility of a mobile platform with the dexterity of a manipulator, allowing coordinated access to even the most challenging locations. The use of artificial intelligence (AI) improves scene comprehension including 3D reconstruction of the target area and the computation of the optimal gripping solution for target manipulation. By advancing these technologies, we aim to enhance the safety and efficiency of demining operations, ultimately reducing the risk to human operators and contributing to global efforts in landmine removal.

## Introduction

According to the Landmine Monitor 2024, at least 5,757 casualties from landmines and explosive remnants of war occurred in 2023, with civilians comprising 84% of victims. While landmines cost as little as $3 to $75 to produce, their removal using traditional methods averages $300 to $1,000 per mine [1]. This highlights the need for safer, more efficient demining methods. After completing a Non-Technical and Technical Survey to define the minefield area, the landmine clearance process follows four main phases: land preparation, mine detection, excavation and identification, and neutralization or removal (Figure 1). To address this challenge, robotic systems have been widely explored as alternatives to human operators and other biological agents already employed in demining. Extensive research has focused on mine detection, employing multi-agent robotics system [2] [3] and learning-based methods combined with metal detectors, thermal sensors, and hyperspectral imaging [4].

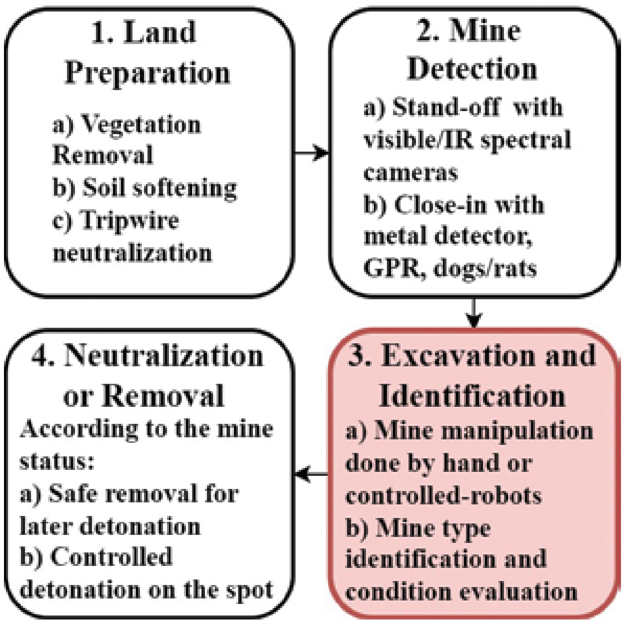


**Figure 1.** Phases of demining process. This paper focuses on Mine Manipulation highlighted in red.

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However, the subsequent phases, as excavation and identification, remain critical for safe disposal. This stage presents multiple challenges: both human operators and robotic systems must accurately determine grasping points and apply appropriate force to avoid detonation. Additionally, occlusion and surrounding obstacles complicate the action, particularly in robotic applications.

This paper presents a framework integrating a mobile manipulator with the latest advancement in computer vision for 3D reconstruction, aiming to improve mine manipulation to enhance demining safety and efficiency. Specifically, this article explores both the system architecture and the methodology used. The system architecture includes the mobile manipulator, sensor layout, and software architecture. Meanwhile, the methodology focuses on 3D reconstruction technologies, real-time grasping feasibility analysis, and motion planning.

## System Description

In this section we introduce both the hardware and software system description

### Mobile Manipulator

The mobile manipulator we employ in this research uses a differential drive robot as mobile platform, specifically the Clearpath Husky platform by Rockwell Automation [5]. And, a 6 degree of freedom manipulator, precisely the UR5e by Universal Robots [6] mounted on top. For manipulation we chose a parallel gripper, the Robotiq 2f-85 [7]. The robot is shown in Figure 2.

**Figure 2.** Mobile manipulator robot. It consists of a Husky A200 mobile platform, equipped with a UR5e robotic arm and a Robotiq 2F-85 gripper.

### Sensors Layout

The robot is equipped with multiple sensors. Proprioceptive sensors, such as Inertial Measurement Units (IMUs), track motion by measuring acceleration, angular velocity, and orientation, providing real-time feedback for position adjustments. Exteroceptive sensors, including cameras, depth cameras, and LiDAR, detect objects in the surrounding environment.

### Software Architecture

The software architecture is built on Robot Operating System 2 (ROS 2) [8], which facilitates communication across different software distributions, ensuring compatibility between robotic systems [9]. The UGV platform uses a CPU for tasks like motor control and basic sensor operations, while a GPU handles complex algorithms, particularly for image processing.

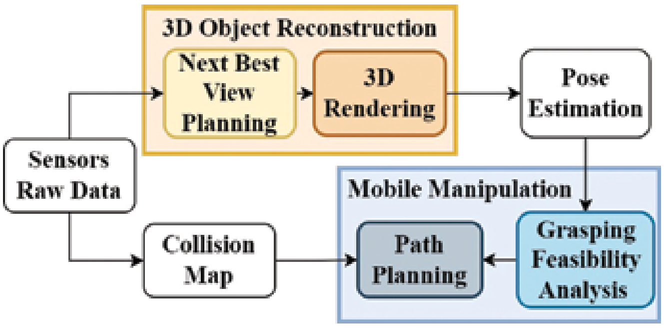


**Figure 3.** Principal steps of our methodology. Next Best View Planning; 3D Object Rendering; Grasping Feasibility Analysis; Path Planning.

## Methodology

In this section we discuss the principal steps of our methodology shown in Figure 3.

### Next-Best-View Planning

Automated 3D reconstruction follows an iterative four-step process: positioning, sensing, registration and update, and next-best-view (NBV) planning. The NBV step consists in finding the point of view that maximizes the coverage of unseen parts of the target and it is often the bottleneck in object reconstruction. One common approach is to determine the NBV using the Rapidly-exploring Random Tree (RRT) algorithm, selecting the branch that maximizes a gain function [10]. Another method solves the Tammes optimization problem within the space surrounding the object [11]. The goal of the latter approach is that given a number of points on a sphere surface the minimum distance among them is maximized.

### 3D Rendering

Neural Radiance Fields (NeRFs) [12] and Gaussian Splatting (GS) [13] have emerged as a leading machine learning method for 3D reconstruction rendering, offering advanced visual quality by learning and representing 3D scenes through deep learning models. Both NeRFs and GS utilize multi-view images to produce 3D models with photo-realistic accuracy, combining the strengths of deep learning and traditional 3D vision. GS with respect to NeRFs, is faster and requires less memory because needs a smaller dataset for scene reconstruction, these characteristics makes it more suitable for real-time rendering. The use of a robotic arm's motion capabilities enhance to perform 3D reconstruction on objects of varying sizes, translation speeds, and angles, assessing detection accuracy [14].

### Grasping Feasibility Analysis

Manipulating unseen objects is crucial for robots operating in unstructured environments. One approach is model-free reinforcement learning [15], which avoids reliance on explicit 3D models. Grasp feasibility can be assessed by projecting the grasp position onto a 3D reconstruction model [14]. Alternatively, given a masked depth image, an object's shell, grasp feasibility map, and grasp quality map can be predicted simultaneously, without prior knowledge. These maps identify grasp-feasible regions and relative grasp quality, aiding grasp planning and execution [16].

### Path Planning

In reaching the views computed by the NBV planning and once the grasping point is selected, the robot must compute a path to reach them. The optimized path planning combines the platform and arm movements to reach the goals, while considering constraints such as the arm's workspace and surrounding obstacles. The path can be planned using probabilistic methods like Probabilistic Roadmap (PRM) [17] or RRT [18], or through the Artificial Potential Field [19] approach, where the target is represented by an attractive field and obstacles by repulsive fields.

## Conclusion

In the context of landmine disposal, mine manipulation remains a challenge due to the need for precise grasping and handling. This paper proposed a mobile manipulator integrated with 3D reconstruction to enhance safety and efficiency in demining operations. We outlined the system architecture and methodology, focusing on 3D reconstruction, grasp feasibility analysis, and motion planning. Future work will validate the framework in real-world conditions to advance toward a safer and more effective robotic demining solutions.

## Acknowledgements

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## References

[1] Int Campaign to Ban. Landmines, "Landmine Monitor 2024," ICBL-CMC, Geneva, 2024.

[2] K. Hasselmann, M. Malizia *et al. A multi-robot system for the detection of explosive devices*, Yokohama, Japan: IEEE ICRA Workshop on Field Robotics 2024, 2024.

[3] E. Ghisoni, S. Govindaraj, *et al*, "Multi-agent system and AI for Explosive Ordnance Disposal," in *19th International Symposium Mine Action*, Dubrovnik, Croatia, 2023.

[4] A. Barnawi, I. Budhiraja *et al.* "A comprehensive review on landmine detection using deep learning techniques in 5G environment: open issues and challenges.," in *Neural Comput & Applic 34*, https://doi.org/10.1007/s00521-022-07819-9, 2022.

[5] Clearpath Robotics, "Husky A200 unmanned ground vehicle," [Online]. Available: https://docs. clearpath-robotics.com/docs/next/robots/outdoor_robots/husky/

[6] Universal Robots, "UR5e," [Online]. Available: https://www.universal-robots.com/products/ur5e/.

[7] Robotiq, "Robotiq 2f-85" [Online]. Available: https://robotiq.com/ products/adaptive-grippers#Two-Finger-Gripper.

[8] S. Macenski, T. Foote *et al.*, "Robot Operating System 2: Design, architecture, and uses in the wild," *Science Robotics*, 2022.

[9] Y. Maruyama, S. Kato *et al*, "Exploring the performance of ROS2," in *2016 International Conference on Embedded Software (EMSOFT)*, Pittsburgh, PA, USA, 2016, pp. 1-10.

[10] M. Naazare, F. G. Rosas, and D. Schulz, "Online Next-Best-View Planner for 3D-Exploration and Inspection With a Mobile Manipulator Robot," *IEEE Robotics and Automation Letters*, vol. 7, pp. 3779-3786, 2022.

[11] S. Pan, L. Jin, H. Hu, M. Popovi´c, and M. Bennewitz, "How Many Views Are Needed to Reconstruct an Unknown Object Using NeRF?," in *2024 IEEE International Conference on Robotics and Automation (ICRA)*, Yokohama, Japan, 2024.

[12] B. Mildenhall, P. P. Srinivasan, M. Tancik, *et al.*, *NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis*, arXiv, https://arxiv.org/abs/2003.08934, 2020.

[13] B. Kerbl, G. Kopanas *et al. 3D Gaussian Splatting for Real-Time Radiance Field Rendering*, ArXiv: https://arxiv.org/abs/2308.04079, 2023.

[14] D. Yang, T. Tosun,*et al.* , "Robotic Grasping through Combined Image-Based Grasp Proposal and 3D Reconstruction," in *2021 IEEE International Conference on Robotics and Automation (ICRA)*, Xi'an, China, 2021.

[15] S. Levine, P. Pastor, A. Krizhevsky,*et al. Learning Hand-Eye Coordination for Robotic Grasping with Deep Learning and Large-Scale Data Collection,* arXiv: https://arxiv.org/abs/1603.02199, 2016.

[16] N. Chavan-Dafle, S. Popovych, S. Agrawal, D. D. Lee, and V. Isler, *Simultaneous Object Reconstruction and Grasp Prediction using a Camera-centric Object Shell Representation*, arXiv: https://arxiv.org/abs/2109.06837, 2022.

[17] L.E. Kavraki; P. Svestka; J.-C. Latombe; M.H. Overmars, "Probabilistic roadmaps for path planning in high-dimensional configuration spaces," *IEEE Transactions on Robotics and Automation*, vol. 12, pp. 566-580, 1996.

[18] J. J. Kuffner, S. M. LaValle, "RRT-connect: An efficient approach to single-query," in *ICRA '00. IEEE International Conference on Robotics and Automation*, 2000.

[19] Z. Pan, C. Zhang, Y. Xia, H. Xiong, X. Shao, "An Improved Artificial Potential Field Method for Path Planning and Formation Control of the Multi-UAV Systems," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, pp. 1129-1133, 2022

# A clutter independent novel method for target detection

*by* *Pierluigi Falorni*[1], *Luca Bossi*[3], *Lorenzo Capineri*[2]

## Abstract

This paper presents a novel, clutter-independent method for target detection, addressing the critical need for high probability of detection and low false alarm rates in challenging environments such as humanitarian demining. Data is acquired using a programmable microwave CW signal generator (Analog Devices "Adalm Pluto") and a 3D-printed monostatic antenna, moved on a plane a few centimeters above the ground by a three axial scanning system (FESTO EXCM-30) mounted on a robotic platform. Traditional microwave imaging techniques, being reliant on strict Nyquist sampling and susceptible to distortions from clutter, uneven terrain, and imprecise data point positioning, often fall short in these scenarios. Instead, the presented method provides a positive number at each output location, effectively mapping the likelihood of a scatterer's presence. Notably, the input and output data points are independent in both number and location. The output data is visualized as a color mapped image, enabling clear identification of potential targets. The method's performance is shown through seven diverse use cases that showcase the algorithm's robustness, demonstrating its ability to accurately pinpoint target locations with undersampled and positionally imprecise input data. The proposed method offers significant potential for various applications, including airborne, manual, and terrestrial linear scanning for target detection in cluttered environments.

**Keywords:** humanitarian demining, microwave imaging, cluttered environment, landmine/target detection.

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## Introduction

Landmines present a persistent global crisis, causing significant casualties and hindering post conflict recovery. While precise figures are difficult to obtain due to reporting inconsistencies and the clandestine nature of mine placement, the International Campaign to Ban Landmines has estimated tens of millions of landmines remain scattered across the globe ([3] ICBL, 2022). These devices disproportionately impact civilian populations, long after conflicts have ceased, impeding agricultural activities, infrastructure development, and safe movement ([4] UNMAS, n.d.).

Current detection techniques, including metal detectors and mine-sniffing dogs, show limitations in speed, cost effectiveness, and safety ([1] Albertsson et al., 2003). Consequently, the development and implementation of advanced detection technologies, leveraging diverse approaches such as ground penetrating radar and hyperspectral imaging, are critical to accelerate demining efforts, reduce human suffering, and facilitate sustainable development in affected regions ([2] Gader et al., 2011). The urgency for innovative solutions is underscored by the enduring threat landmines pose to communities worldwide.

While metal detectors are widely used, they suffer from high false alarm rates due to metallic clutter ([1] Albertsson et al., 2003). Animal detection, though effective, is costly, time consuming, and logistically challenging ([5] ICAO, 2019). These limitations hinder productivity and the feasibility of rapid, large scale demining, emphasizing the need for more efficient and robust technologies.

The methodology proposed in this study centers on acquiring subsurface information through the utilization of an appropriate probing wave, followed by the application of a proprietary algorithm for data processing. Specifically, the subsequent examples will demonstrate the efficacy of this method when employing a narrowband 2 GHz radio frequency (RF) wave emitted and received by a monostatic antenna. While the experimental results offer a range of noteworthy observations, the primary focus of this paper is to rigorously examine the method's resilience to undersampled and/or spatially imprecise data. This robustness enables the realization of practical and effective use cases for target detection in challenging environments.

## Materials and Methods

The data acquisition process involved a spiral trajectory scan, covering a designated area of approximately 30 cm by 30 cm, conducted at an elevation of 13 cm above the ground surface.

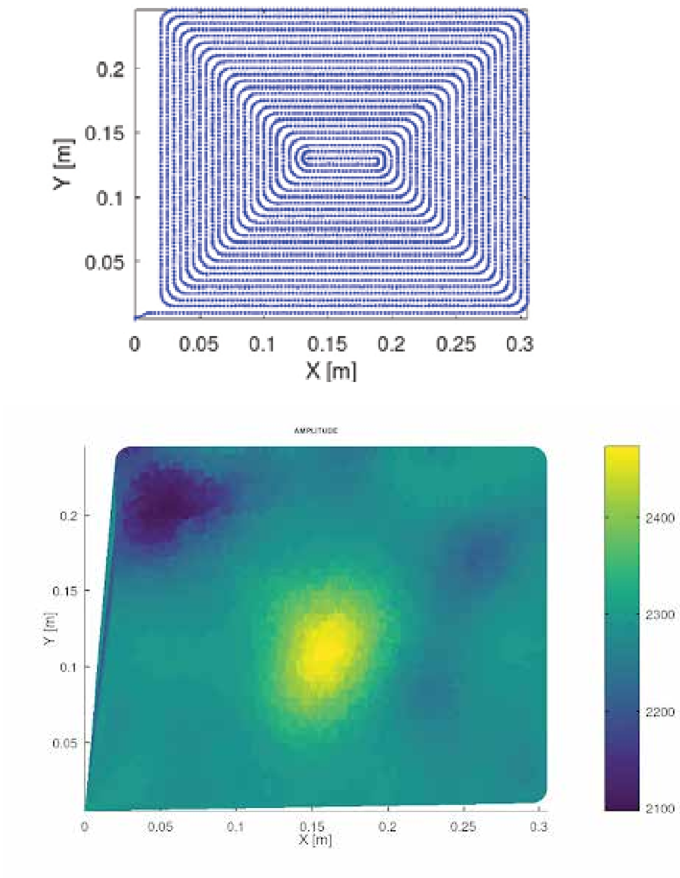



**Figure 1.** UP) Scanning path at height Z=13 cm where each dot is an acquisition location. DOWN) Amplitude of received RF signal at the above locations.

The target of interest was a buried Chinese Type 72 anti personnel mine, characterized by its minimal metallic content and physical dimensions of 78 mm width and 38 mm height. The mine was emplaced in an unprotected outdoor garden environment in Florence, Italy, approximately four years prior to data collection, at a shallow burial depth of roughly 3 cm. The resulting dataset comprised 4444 discrete data points. Each data point was associated with the following parameters: spatial coordinates (X, Y, Z) and the amplitude and phase characteristics of the received radio frequency (RF) field at a frequency of 2050 MHz, same as the transmitted sinusoidal RF signal.

Only data points located within a 1 mm tolerance ahead of the scanning plane along the Z-axis (height) were retained for subsequent processing. This selection resulted in a refined dataset consisting of 4358 data points.

In this case, the acquisition results in a very clear image that an operator can interpret as the presence of a scatterer in a cluttered environment.

Figure 2 shows the periodogram ([6] Bretthorst, 1998) of the original data; on the left side are annotated six kinds of artifacts: 1) average value 2) horizontal rows of scanning path 3) vertical rows of scanning path 4) aliasing 5) horizontal dot separation 6) vertical dot separation. On the right side the same periodogram with removed artifacts shows the presence of high spatial frequency features, with spatial wavelengths of 5 cm or smaller.

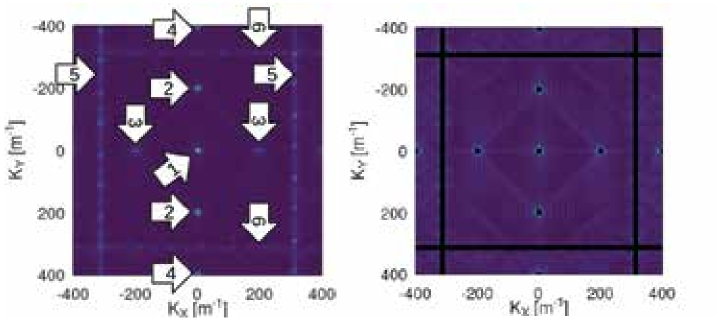



**Figure 2.** Periodogram of original data, (LEFT) with annotated artifacts, (RIGHT) with removed artifacts.

The presence in the periodogram of relevant features with short spatial wavelength suggests that the information in the original data can be reconstructed by Shannon's like methods ([7] Jerri, 1977) only with tight sampling.

## Results

The aim of this paper is to understand if it is possible to achieve detection: 1) in presence of undersampled input data and/or 2) when the positions of input samples are affected by cumulative errors.

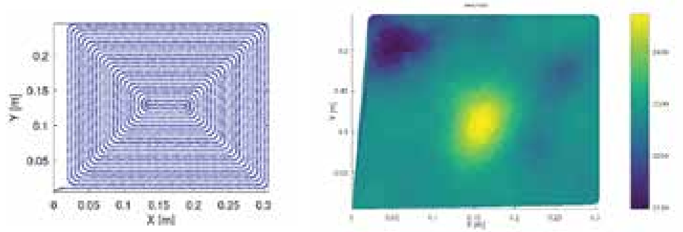
In the next table, seven different scenarios of data collection are presented and commented on for use cases enabled by the methodology. Data from each scenario has been elaborated by our proprietary algorithm and the result is shown as an image.

## Comments

*Descending spiral of 4358 points (100%)*

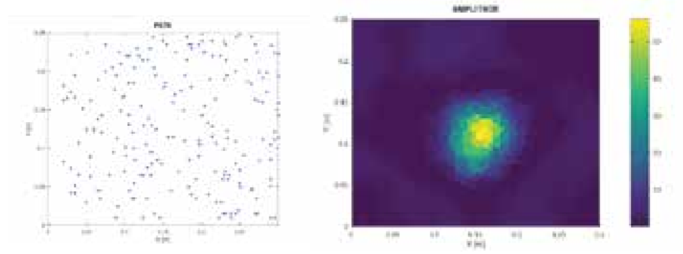
Original data, amplitude of the received signal at all available locations. The target is clearly visible in the center of the scanning area surrounded by a cluttered context.

PATH IMAGE



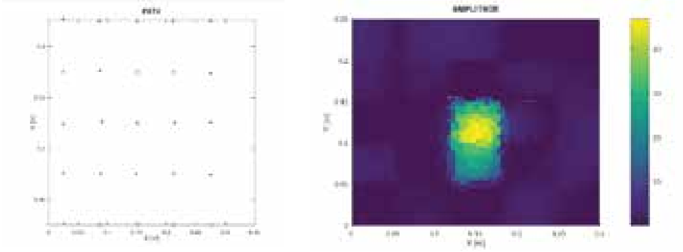

*200 random points (4.6%)*

The detection is enhanced with a sharper target and vanishing clutter. This case shows the ability of the method to be independent of the distribution of data points. This case enables the use of drones for airborne acquisitions.



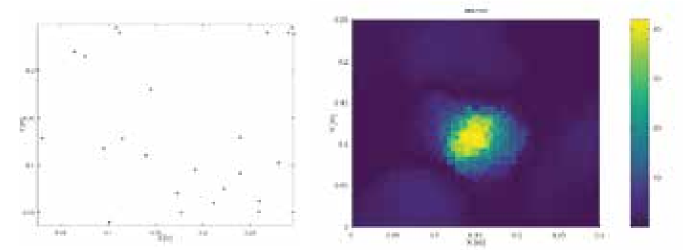
*25 points (0.6%) on regular grid*

The target is visible at the correct position but the shape is misrepresented due to some kind of aliasing. This case can be implemented with a bidimensional array of antennae, achieving the image without scanning.



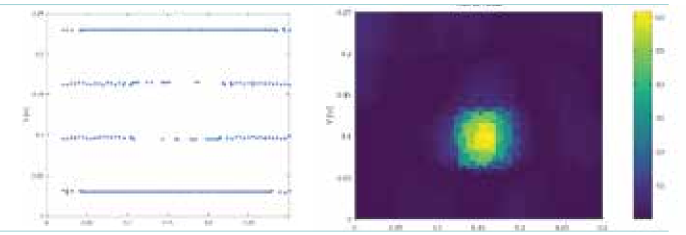
*25 random points (0.6%)*

The target is visible at the correct position but the shape is slightly altered in the direction where less data is available. With respect to the previous one, this case suggests that random location of antennae gives better results.



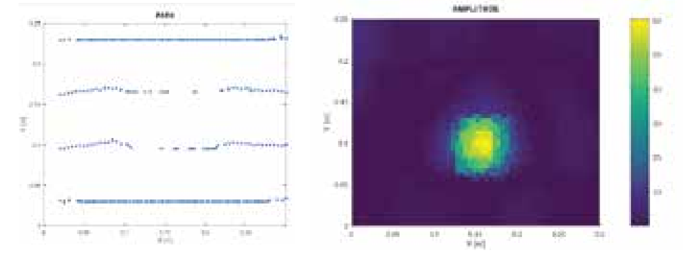
*268 points (6.1%) on four lines*

The target is visible at the correct position and clutter is depressed. This case can be implemented with a linear array of four antennae perpendicular to the motion direction.



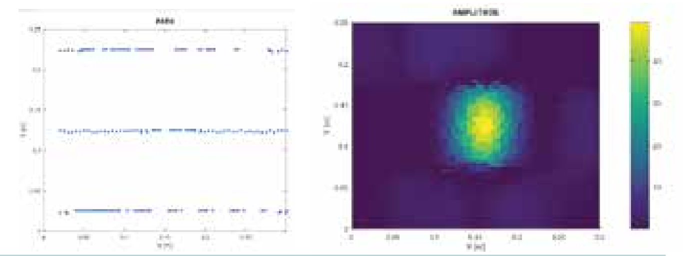
*268 points (6.1%) on four lines with 10% cumulative error*

Despite the positioning error, the target is visible at the correct position and clutter is depressed. This case enables the usage of low cost IMU for data location.



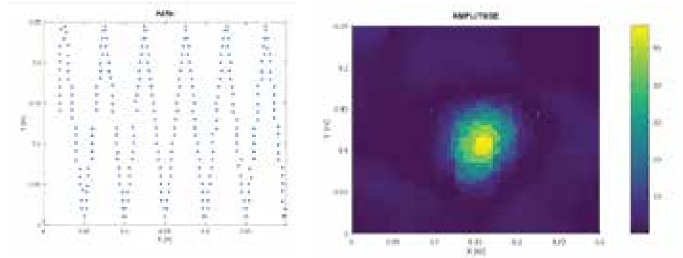
*162 points (3.7%) on three lines*

The target is visible at the correct position but the shape is slightly stretched along the direction of low density input data points. This case enables solutions where cost or complexity or weight is an issue.



*291 points (6.7%) on zig-zag*

The target is visible with a smaller size at the correct position. This case, along with the previous one about positioning errors, enables manual "swipe" scan with low cost IMU for data location.



## Conclusions

The microwave scattering data acquired from the subsurface using a holographic radar system can be significantly enhanced through the application of specialized algorithms. These algorithms aim to minimize the data acquisition effort and effectively mitigate the influence of environmental clutter.

Furthermore, the proposed methodology compensates for the adverse effects of cumulative errors in sample positions, thereby broadening the range of feasible survey scenarios and improving target localization accuracy. The presented case studies, utilizing experimental data obtained from a buried plastic landmine, demonstrate the potential of this approach for near term field applications.

## References


1. Albertsson, P., Axelsson, S., & Leijon, A. (2003). *A review of techniques for humanitarian demining*. The Journal of ERW and Mine Action, 7(1), 25-32.
2. Gader, P. D., LeVan, D. O., & Bennett, C. L. (2011). *Landmine detection using remote sensing technology*. IEEE Geoscience and Remote Sensing Magazine, 1(1), 8-21.
3. ICBL (International Campaign to Ban Landmines). (2022). *Landmine Monitor 2022*.
4. UNMAS (United Nations Mine Action Service). (n.d.). *The problem of landmines*.

   ICAO (International Civil Aviation Organization). (2019). *Landmine Detection Dogs*.
5. Bretthorst, G. L. (1988). *Fourier spectrum estimation: A Bayesian approach*. Springer Science & Business Media.
6. Jerri, A. J. (1977). *The Shannon sampling theorem—its history and various applications*. Proceedings of the IEEE, 65(11), 1568-1596.
7. Jolliffe, I. T. (2002), *Principal Component Analysis*. Springer 2nd Edition.

# Hyperspectral object detection with deep learning enhancement tested by classical methods

*by* *Milan Bajić*[1], *Milan Bajić*[2]

*Abstract: This work presents a small-scale experiment to compare deep learning-enhanced detection of explosive and unexploded ordnance, EO, UXO, and landmines with classical methods for hyperspectral object detection. Five hyperspectral cubes are used, and the results will be compared and discussed to better understand each approach's limitations.*

## Introduction

Hyperspectral imaging (HSI) is an electro-optic sensor-based technology for mapping spectral variability in spatial context. Three main approaches are point measure technology (non-imaging), push-broom line scanner, (ElMasry & Sun, 2010), and snapshot frame capture instrument like Ultris 5 from Cubert GMBH. Paraphrasing advantages of HSI compared to imaging or spectroscopy are that it handles both spatial and spectral components, is contactless, and does not require a laboratory setup. Most developed instruments are snapshot-based because they act as an array of thousands of point-based scanners. This is the most challenging technology as it produces large amounts of data. Object detection is enhanced by spectral features about objects, and because it is not spatially bound, can help with partially obscured objects. (Bajić & Bajić, 2021) Classical methods give reliable and precise results but are time-consuming and require much computer processing power. The algorithms most commonly used are spectral angle mapper, principal component analysis, and support vector machine, and much research has been published on them. The first is sometimes too precise, the second is used for dimensionality reduction, and the last is feature extraction focused. The main challenge in explosive ordnance detection is a lack of research and datasets for deeper understanding and accessibility to the research community, as well as possibilities and limitations, as HSI has its place in multi-sensor multi-platform fused solutions. Deep learning helps solve two challenges with a large amount of spectral spatial data produced by snapshot HSI instruments, reduction of data used for predictions, and customized feature extraction. Main objective of this work is to present our understanding of the possibilities and limitations of deep learning enhanced EO detection and how to solve them by using a step-by-step classic method before putting them in a black boxed deep learning solution. Our small-scale experiment helps us model the systematic use of snapshot HSI on board UAV for UXO and components of Improvised Explosive Devices based on their spectral spatial features. A tool that we are developing is a domain knowledge-based processing of HSI sensor data collected on board the UAV for real-time detection of explosive ordnances or other markers of a possible dangerous object. This could be useful either in land mine or route clearance scenarios.

## Methods

The hyperspectral data we used were recorded by the SPECIM IQ push broom instrument, which is a very good and reliable tool for HSI data collection in a fixed position. It has 512x512 pixels, 204 channels in a range from 400-1000nm, with the mean value of FWHM spectral resolution of 7nm across the range, and most of the sensors have much broader values on higher wavelengths that introduce a lot of noise. Therefore, we cut off 900-1000 nm wavelengths, due to increased sensor noise, evident in preliminary data analysis, and worked with reduced cubes 512x512 pixels and 170 bands. This range was removed after initial spectral analysis showed increased noise and signal instability beyond 900 nm, which could reduce classification accuracy. By focusing on the more stable 400–900 nm range, we ensured better feature extraction and reduced computational overhead. Acquiring one image takes 30 to 120 seconds, with calibration inside the camera and calculating

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reflectance values in the ENVI standard file format. All images are normalized on the min-max method from 0 to 1. We picked this sensor package as it is a very fast tool for image acquisitions with all processing of calibration and calculating reflectance values inside the photo camera size housing. The SPECIM IQ was chosen for its high spectral resolution and built-in calibration capabilities, simplifying data acquisition and ensuring measurement consistency. Its push-broom scanning approach allows for efficient and precise spectral capture, making it a practical choice for controlled experimental settings. With known limitations of fixed position during recording, it has high spatial and spectral resolutions, so its application for dataset creations is a good choice.

**Figure 1.**
RGB image of scene from our experimental dataset

In Figure 1, five objects for detection and a white balance card (WB) for camera calibration are placed on the surface covered with mixed grass and soil. We are aiming to detect all objects and not detect the WB card. The variability of materials in the objects is nice, as are the diverse colored plastics, rubber, metal, and wood.

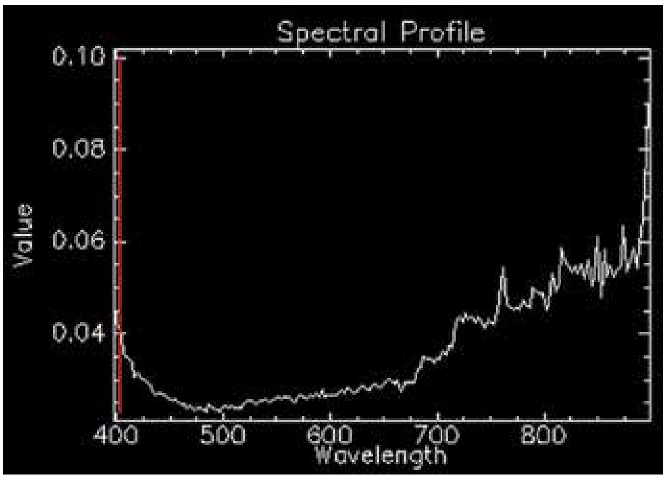


**Figure 2.a** Reflectance spectra of a hand grenade, rubber black part

The spectral signatures presented in images 2.a and 2.b are from one point inside the area of interest. Black rubber absorbs most of the insolation, and normalized reflection values are between 0 and 0.1,

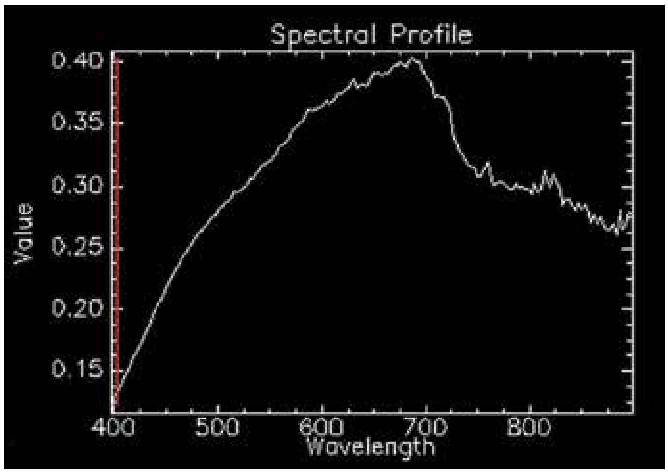


**Figure 2.b** Reflectance spectra of a hand grenade, the metal trigger.

The metal part values range from 0 to 0.4, with visible spectral values dispersion and value differences between the two parts, which are the same target. In the classical methods, we would either manually pick endmembers or use some algorithm for their extraction, then apply an algorithm for finding pixels with similarity in the spectral values across the bandwidth. In our work, we tested a U-net based (Long et al., 2015) deep learning model with specific optimization for hyperspectral images. We have five targets that are horizontally and vertically flipped, so out of 15 scenes, 12 were used for training and 3 for validation. We picked one image from each subset with a different number to use as the validation set. The results presented are from the validation part of the dataset. We used a paid service on an A100 GPU with 40 GB RAM and 85 GB system RAM.

## Results and discussion

Classical methods handle much better objects from one material. Because there were just 12 images for training and 3 for validation in our test dataset, we will present only the visualization of detections, predictions or masking, even though the metrics look nice. Preliminary testing suggests that classical methods like SAM achieve high precision (~85%) on objects made of uniform materials but struggle with mixed-material targets. Deep learning models showed improved adaptability to complex objects but exhibited a higher rate of false positives, particularly in cluttered backgrounds. While full quantitative analysis is beyond the scope of this experiment, these observations highlight the tradeoffs between classical and deep learning-based detection approaches. Deep learning metrics measured on validation set: Recall – 0.87, Precision 0.59, F1 0.70. There are 15 ground truth regions in the dataset, 22 predictions, and 13 matching predictions with ground truth, with coverage over 50%. Manual processing is much less time-consuming in data preparation, because for deep learning, we have to annotate the images, train the model, and make predictions. Also, larger datasets can be very hard to handle as each scene with 170 channels has 170MB of data processed on limited computing resources. In classical methods, the computation grows linearly because the total processing time increases as more scenes are added. Each scene requires a fixed amount of time to process, so if you have twice as many scenes, it will take twice as long to compute. In deep learning preprocessing, annotations depend on the volume. Training can present a challenge on its own with large datasets, for example, 100 scenes with 204 channels have 20GB of data for processing.

**Figure 3.** Object from one material

In Figure 3, UXO with a uniform spectral response over the entire object, as it is made from one material, is shown.

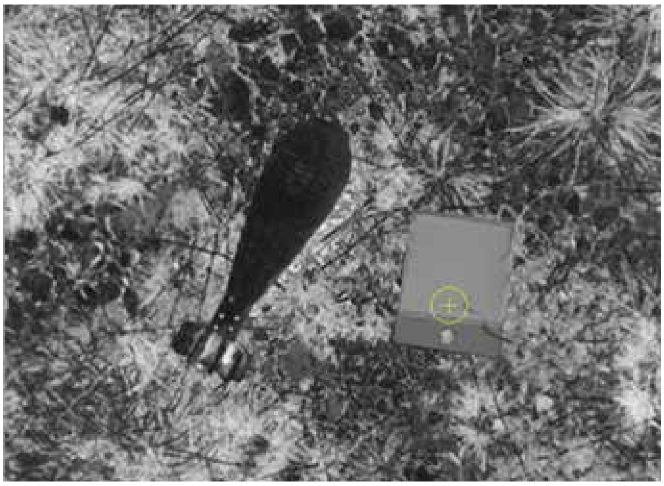

**Figure 4.** SAM is applied and object masked

Isolated target and its automatically obtained mask Figure 4, using only five spectral samples.

In the case of an isolated target, the SAM enables successful detection of the target, while the spectral angle mask delineates the target's boundaries very reliably. This helps gather exact data of the detected object dimensions, and shape. This process is very simple and fast, presenting results in a few seconds. When we tested selecting all targets made of different materials, a problem arose as the SAM created mean values of those spectral endmembers, and the angle difference in multidimensional vector space was different from any part of the target. We tried to understand if deep learning could solve that problem. Although it was much more time-consuming in the first phase, it later gave results in less than a second per scene. These are presented as probability heat maps, where red is 1.0 and a more reliable detection result.

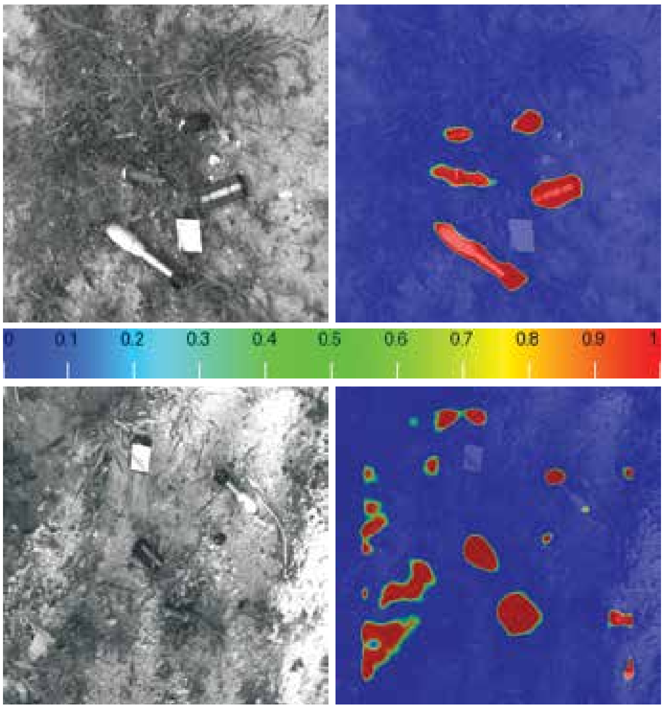


**Figure 5.** Model predictions on validation set

Figure 5 presents a range from very good object detections in the upper images to many false positives in the lower ones. The left images are one channel from the scene entering the model, and the right images are predictions on top of the original scene. A weighted loss function controls the reduction of false positives or false negatives in deep learning models. This study compared classical hyperspectral detection methods with a deep learning-enhanced approach for detecting EO, UXO, and landmines. Classical methods, such as SAM, performed well for objects made of a single material but struggled with mixed-material targets.

Deep learning, particularly U-Net, demonstrated improved object detection capabilities, especially in complex scenarios. However, its success depends heavily on dataset size, training effort, and computational resources. While deep learning offers real-time inference once trained, the small dataset size remains a key limitation. These results suggest that classical methods remain highly effective for specific cases, particularly for single-material objects, while deep learning holds promise for more complex detection tasks. However, dataset size, model optimization, and noise handling remain critical challenges. Ensuring reproducibility and refining spectral feature extraction techniques will be essential for future improvements. Future research should focus on:

- Expanding the dataset to improve model generalization.
- Reducing false positives through better training strategies and optimized loss functions.
- Exploring multi-sensor fusion to combine hyperspectral data with other modalities for enhanced detection accuracy.

This work is an initial exploration, highlighting the challenges and opportunities of integrating deep learning into hyperspectral object detection. Further advancements in training data and computational efficiency will be key to practical real-world deployment.

## References

Bajić, M., & Bajić, M. (2021). Modeling and Simulation of Very High Spatial Resolution UXOs and Landmines in a Hyperspectral Scene for UAV Survey. *Remote Sensing*, *13*(5), 837. https://doi.org/10.3390/rs13050837

ElMasry, G., & Sun, D.-W. (2010). Principles of Hyperspectral Imaging Technology. In *Hyperspectral Imaging for Food Quality Analysis and Control* (pp. 3–43). Elsevier. https://doi.org/10.1016/B978-0-12-374753-2.10001-2

Long, J., Shelhamer, E., & Darrell, T. (2015). Fully convolutional networks for semantic segmentation. *2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 3431–3440. https://doi.org/10.1109/CVPR.2015.7298965

# AI for Mine Action:
## Insights from the GICHD Innovation Session

*by* *Pedro Basto*[1]

## Introduction

Artificial Intelligence (AI) is a technology that enables digital systems to perform tasks typically requiring some level of human intelligence, such as language processing, image recognition, data analysis, and decision-making. Its rapid advance and status as a general-purpose technology – comparable to electricity or to the personal computer – suggest that AI will significantly transform all sectors of activity and society, including therefore, mine action.

Despite the growing debate and public exposure to the potential uses of AI in mine action, there is still a lack of common knowledge about what AI is and how it works. The need for clarity inspired the Geneva International Centre for Humanitarian Demining (GICHD) to host an Innovation Session on the topic, held from October 1–3, 2024. By bringing together experts from mine action and AI practitioners, the event aimed to develop a greater understanding about AI, it's possibilities, risks and limitations, as well as generating potential ways to harness it's potential to improve operational efficiency, data management, and decision-making in mine action.

## Key Takeaways

Two central themes emerged during the session. First, data is the cornerstone of AI applications. Experts emphasized the importance, not only of traditional structured data (e.g. NTS reports, and IMSMA data collection forms) but also unstructured data (e.g. pictures, briefs, pdf reports) in training AI models and extracting actionable insights. Establishing robust systems for data collection, storage, and sharing now, is critical for unlocking AI's full potential in the future.

Second, discussions underscored the importance of balancing generic AI tools with sector-specific adaptations. While AI technologies offer powerful capabilities, they often lack contextual awareness. Tailoring AI solutions to the regional, national, and technical nuances of mine action is essential for maximizing their effectiveness and reliability.

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## Event structure and proposed themes

The event was structured around cross-disciplinary knowledge-sharing sessions, thematic working groups, and collaborative project development. Initial briefings helped AI experts understand the complexities of mine action while enabling mine action practitioners to grasp AI's capabilities. Keynote speeches and discussions covered topics such as ethical considerations, geospatial AI, large language models (LLMs), and current information management practices.

Participants formed working groups to address pressing challenges in mine action using AI. Nine project ideas emerged from these discussions:

- **Global 3D reference database for automated image recognition of explosive ordnance**

*How can automated imagery recognition be scaled efficiently and cost-effectively, to improve safety in humanitarian contexts?*

Key bottlenecks to scaling imagery recognition applications are the access to AI models training data and include the resource-intensive process of model creation, the diversity of explosive ordnance types and designs, and access to explosive ordnance.

The establishment of a collaborative global 3D reference library of explosive ordnance training data would enable the development of multiple automated imagery recognition end-user applications tailored to specific humanitarian contexts and purposes. This library should be able to integrate technical and expert data, starting with textured 3D models and expanding continuously with enriched field-collected imagery data.

- **Early impact analysis**

*How can early impact assessments in mine action be enhanced to improve evidence-based planning and resource allocation, enabling humanitarian operators to prioritize areas where the explosive ordnance impact is most critical?*

Key challenges include limited integration of explosive ordnance contamination data with socio-economic and environmental data; resource constraints such as insufficient equipment, personnel, and time; the absence of effective prioritization tools; and underutilized opportunities for blending diverse data sources to support strategic decision-making.

A web-based platform to enhance early impact assessments, enabling data upload, automated inference, and visualization for improved planning was proposed. The platform would calculate impact scores by comparing benchmarks with input data, integrating explosive ordnance contamination, socio-economic, and environmental information. A mapping tool would overlay regions with zones, using colour-coded impact scores (e.g. heat maps) to identify priorities and guide resource allocation.

- **Advanced data analytics and interrogation of information management systems.**

*How can the multiple and diverse datasets collected by non-technical survey teams be more effectively analysed to identify information gaps, and ensure accurate planning and decision-making?*

Key impediments include limited labelled datasets, multiple different formats of data sources, environmental and operational constraints, and high costs associated with data management.

The development of AI-driven data interrogation models for pattern recognition and data query/extraction was suggested. It would integrate community input to incorporate local knowledge and context. This system would require fine-tuned LLMs and natural language processing (NLP) AI models to query and interrogate data, as well as dynamic dashboards, and tailored visualizations to support decision-making and planning in humanitarian contexts.

- **Generative AI for improving organizational processes.**

Accurate, timely and compliant documentation is essential to meet several knowledge management and reporting requirements, such as drafting national and international mine action standards, and international donor and convention reporting, among others. Such management processes can amount to up to 40 per cent of the costs of operations. *How can management processes such as the analysis of the existing body of knowledge and the production of documentation/reports be more efficient and effective?*

Key challenges include resource-intensive analysis of diverse sources of data, sometimes multilingual, slow, and error-prone manual processes, and the limitations of current pre-trained LLMs and generative AI applications.

The need to develop of a fine-tuned LLM for mine action was identified as a key step. Such generative AI application would be capable of accurately interpreting terminology, context, and translation of mine action. The model would be trained on a high-quality, cross-vetted dataset and tested rigorously in real-world scenarios, incorporating expert and user feedback. After the fine tuning of a mine action LLM, any other NLP application could be developed.

- **Impact of AI on community engagement within explosive ordnance risk education**

*How can the efficiency, reach and impact of digital explosive ordnance risk education be maximized while addressing multi-factor limitations in cost, speed, and accessibility?*

Key challenges include the digital divide preventing access to some communities, the need for accurate quality control of AI-generated content, ethical considerations around data collection and consent, and ensuring complementarity between digital and face to face explosive ordnance risk education methods.

Exploring AI-assisted tools to enhance efficiency in pre-and post-intervention assessments was suggested, generating tailored written, audio, and visual content, and deploy 24/7 chatbots for remote explosive ordnance risk education.

- **Information management systems, data integration and priority setting**

*How can current mine action information management systems be enhanced to support priority setting of demining activities and resource allocation, assisting the definition of prioritization criteria and implementation of transparent and evidence-based decision- making?*

Key challenges are the lack of comprehensive data integration from various socio-economic and environmental datasets, the balance between simple design and the complexity of factors that must be weighted in the definition of priority-setting criteria and indicators.

AI-assisted analysis, tagging and automated standardization of datasets from multiple sources and varying formats was defined as the initial step. The integration of this datasets into a digital interface reflecting pre-defined and agreed priority-setting criteria and indicators would follow. The system could be enhanced to perform sensitivity analysis of such criteria and indicators and recommend priorities for mine action activities.

• **Robotics and autonomous mechanical systems**

*How can safety be improved with robotics and autonomous systems in challenging environments such as urban areas, debris removal, enclosed spaces, tree lines and forests?*

Key obstacles include the limitations of existing systems in navigating complex terrains, detecting mines accurately, and ensuring cost-effectiveness for widespread use, while also addressing challenges related to productivity and user-friendliness.

Further work is needed to define the specific use cases and requirements for the development of robotic systems tailored to mine action. Advanced machine learning (ML), sensor fusion, and navigation technologies are already available and can be integrated into existing mechanical systems, from small, unmanned ground vehicles such as four-legged robots, explosive ordnance disposal robots, to light and heavy machinery rubble removal, ground preparation or mechanical demining machines. Cost-effectiveness remains a substantial challenge in mine action operations.

• **Satellite imagery processing and analysis**

*How can non-technical survey processes be enhanced with spatial indirect evidence collated from new technologies, namely satellite imagery, for more efficient and reliable non-technical survey outputs, minimizing the risk of overlooking hazardous areas and misallocating resources?*

Key challenges include the lack of knowledge, understanding, and trust in the capabilities of satellite imagery processing and analysis.

Next steps in the application of such technologies included the creation of a technical guide for identifying indirect evidence of contamination using satellite imagery, defining clear methodologies, data sources, thresholds, and workflows, all supported by AI-driven automation for analysis. The guide would be tested and refined through case studies, ground truthing, and stakeholder feedback. Integration into national mine action standards would be promoted to ensure alignment with operational practices.

• **Unmanned aerial vehicle-deployed sensor data fusion and analysis**

*How can the use of unmanned aerial vehicle-deployed sensor data in mine action be optimized for greater effectiveness and scalability? What steps are required to bridge the communication and information gap between solution developers, end users/operators, and national authorities?*

Key barriers include inconsistent testing and validation, inconsistent methods to define case studies and testing solutions, lack of accreditation processes within national mine action authorities.

The creation of an open-access library with use cases, requirements, case studies, and a glossary, alongside a technology forum for discussing tested technologies was suggested. A clear testing process would have to be collaboratively developed, identifying test facilities, standardized performance descriptions, and defined metrics and protocols. A curated data library with ground truth and multimodal data will support diverse testing.

## Outcomes and future direction

The Innovation Session showed that there is potential for AI to improve safety, efficiency and effectiveness in the mine action. However, a greater data preparedness is needed. AI applications rely heavily on high-quality data. Even if mine action sector has made strides in information management systems, it must further invest in data collection, management, and sharing frameworks to ensure AI readiness. Additionally, while AI tools offer broad capabilities, they must be tailored to the realities of mine action operations. Only customization will ensure that AI solutions account for regional variations and technical subtleties.

During the event, participants collaboratively developed project briefs departing from specific problem statements, defining key requirements, potential AI applications, and implementation roadmaps. The results emphasized the strengths of multidisciplinary and diverse collaboration, which combined mine action organizations, national mine action authorities, academia, as well as research and technology expertise.

The full project summaries and discussions from the session are available on the GICHD Innovation Session AI for Mine Action webpage, providing a foundation for future research, partnerships, and AI-driven advancements in mine action.

Looking ahead, all mine action stakeholders and interested partners are encouraged to take stock of the results of this session, promoting partnerships, mobilizing resources and contributing to the advance on innovative solutions. Their success will be our success!

# **MinesEye:** UAV-Based Unexploded Ordnance Detection System for Enhanced Demining in Ukraine

*by Ievgen Poliachenko[1,2], Vlad Kozak[2], Volodymyr Bakhmutov[1], Semyon Cherkes[1,2]*

## Abstract

The Postup Foundation has been developing a system for detecting and mapping landmines and unexploded ordnance (UXO), known as MinesEye, since 2022. This prototype was created to meet the needs of the State Emergency Service of Ukraine (SESU) for inspecting large agricultural fields. Ukraine faces severe landmine contamination as a result of the ongoing war, with an estimated 100,000 square kilometers of land — much of it agricultural — potentially affected. To effectively address this issue, high-speed, high-accuracy survey systems are essential. The solution combines passive sensors, utilizing a magnetometer to detect buried explosive objects and optical cameras to identify surface threats. This combination enables high detection rates in real-world conditions and has received positive feedback from Ukrainian end users. Since 2024, the MinesEye system has been undergoing validation in the Kharkiv and Mykolaiv regions in collaboration with SESU. The primary use cases include inspections during non-technical surveys to improve contamination assessments, as well as reconnaissance before mechanical demining operations. SESU has shown interest in deploying multisensor systems for these purposes, with the technology being operated by newly formed demining reconnaissance teams. Field experiments with HALO Trust in February 2024 demonstrated the system's added value over traditional visual inspections conducted by non-technical survey teams. In one case, MinesEye detected UXO that was missed by visual inspection. In another instance, the system identified what appeared to be an OZM-72 anti-personnel fragmentation landmine belt, while visual inspection had only spotted a single mine. Both experiments took place in the Kharkiv region (Chuhuiv district), highlighting MinesEye's potential to significantly enhance demining efforts.

## Introduction

Since the onset of Russian aggression in 2014, UXO contamination has become a severe threat to civilian and military personnel in Ukraine. By 2023, nearly one-third of Ukraine's territory was suspected of being contaminated with mines and UXOs. Traditional demining methods are time-consuming and hazardous, prompting the need for advanced detection systems. Recent developments in UAV-based magnetometer technologies have shown promise in improving UXO detection (Poliachenko et al., 2023, 2025; Kolster et al., 2022; Yoo et al., 2020, Nelson & McDonald, 2006). The MinesEye project aims to perform simultaneous measurement using magnetometry and optical methods for large-scale demining efforts in Ukraine, focusing on automating UXO identification to accelerate clearance and minimize human risk.

## Materials and Methods

***MinesEye System Configuration.*** The MinesEye system combines UAVs (Agras T30) with multi-sensor equipment, including magnetometer (SENSYS MagDrone R3), RGB cameras (Fig. 1) and Emlid GNSS RTK system. Magnetic data processing was performed using Oasis Montaj (Geosoft) and MagDrone DataTool (SENSYS) software. In recent cases, proprietary software has been used for system control (MinesEye Sensor Fusion System or SFS) and Postup Magnetic Anomalies Map (MAM) to illustrate survey outcomes. Surveys were conducted over contaminated areas in Ukraine, with varying altitudes and flight speeds depending on the terrain and target characteristics.

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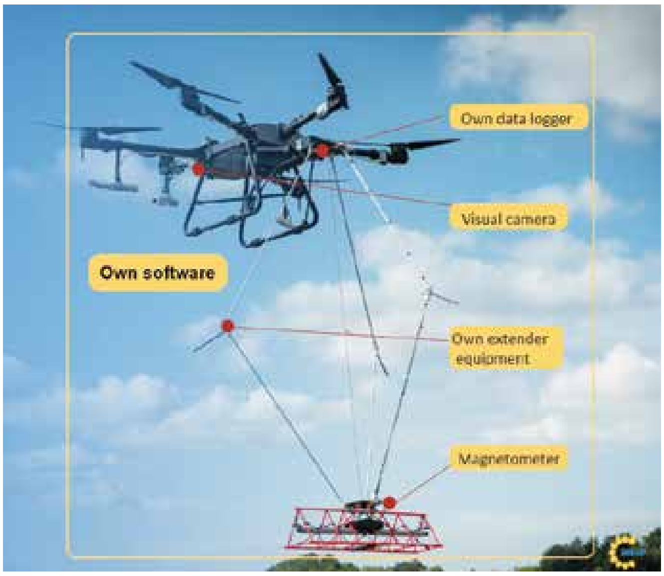


**Figure 1.** Illustration of MinesEye system

## Results

***Lab Testing.*** Initial lab tests focused on calibrating the UAV and magnetometer system to detect common UXO types in Ukraine. The tests confirmed that the MinesEye system could identify magnetic anomalies corresponding to ferrous UXOs, such as anti-tank mines, with high accuracy. Extender equipment were made to minimize electromagnetic interference from the UAV, reducing system noise to below 2.5 nT (Fig. 2).

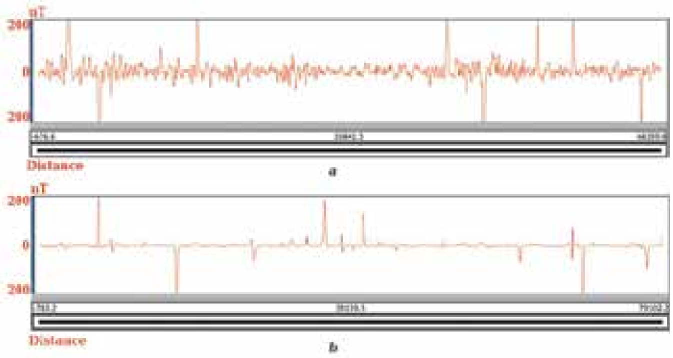


**Figure 2.** Comparison of magnetic parameters recording for different modifications of the magnetometer placement relative to the UAV:
a — directly under the UAV chassis,
b — 2 m below the UAV chassis. (Poliachenko et al., 2023)

This experiment was conducted to assess the capability of the MinesEye system to detect anti-tank mines buried under the surface in a known test site in the Kyiv region. The target was a mock anti-tank mine (TM-62M), buried at a depth up to 0.5 meters (Fig. 3).

**Figure 3.** Detection of sub-surface laid landmines TM-62 and MON-50. The experiment showed good detection of TM-62M and MON-50 based on 20 observations. Sensor height 50 cm above the surface.

The system successfully detected the magnetic anomaly produced by the TM-62M mine, despite being buried. The anomalies were evident as a clear signal after recalculating into an analytic signal with anomaly exceeding 5x system noise level.

The test showed the importance of maintaining a low-altitude flight to enhance the magnetometer's sensitivity to buried objects.

This experiment demonstrated the MinesEye system's ability to identify UXOs with a strong magnetic signature at shallow depths, proving it to be an effective tool for landmine detection.

## Field tests

Field surveys were conducted in the Kharkiv and Mykolaiv regions, covering approximately 30 hectares. Surveys identified multiple UXO-related anomalies, with MinesEye successfully detecting both surface-level and buried objects. Magnetic anomalies were mapped and validated through comparison with known UXO locations (Fig. 4).

***Real World deployment in Kharkiv Region.*** As part of the project, the Postup team conducted a field experiment to evaluate the effectiveness of the our UAV-based UXO detection system. The experiment was carried out in two distinct locations provided by Halo Trust (Fig. 4, Table 1): Nova Hnylytsia (7 hectares), Doslidne (4 hectares); surveyed area: 11 hectares in total.

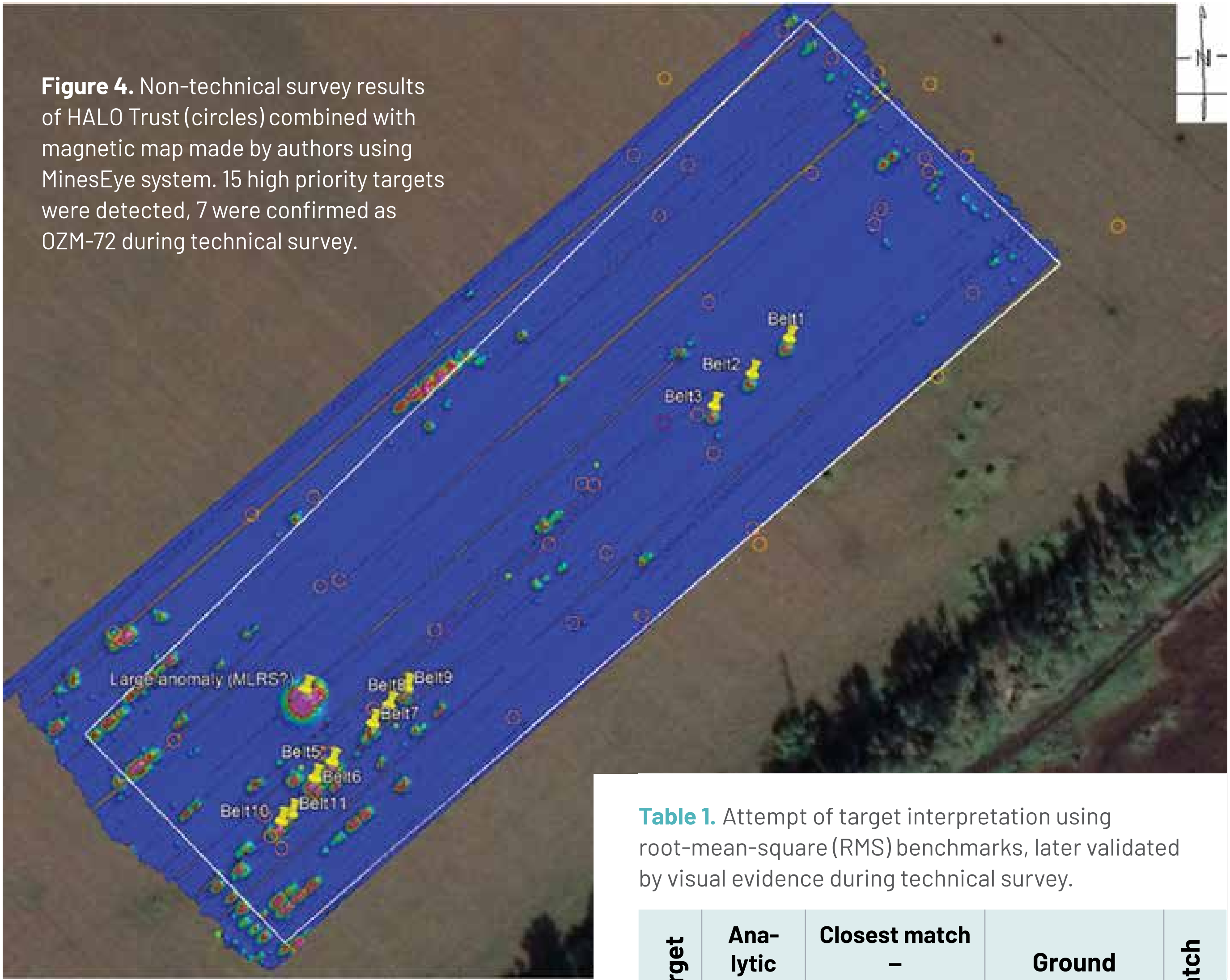


**Figure 4.** Non-technical survey results of HALO Trust (circles) combined with magnetic map made by authors using MinesEye system. 15 high priority targets were detected, 7 were confirmed as OZM-72 during technical survey.

***Key Findings.*** Nova Hnylytsia: 4 anti-tank landmines detected using visual methods (with Halo Trust guidance); 1 MLRS warhead detected using magnetic methods, confirmed by UAV imagery.

Doslidne: 15 high-priority magnetic targets detected and reported back to HALO Trust (Table 1), including one previously confirmed anti-personnel mine. Later, 7 targets were confirmed as OZM-72 based on ground truth data received after technical survey; 1 probable MLRS warhead identified via magnetometer and visual inspection, later confirmed during technical survey as 220 mm cluster munition container.

In order to categorize anomalies and focus on the most promising ones, root-mean-square magnetic anomaly benchmarks from the same class of objects were experimentally applied. These benchmarks were collected in the controlled environment and normalized to the standard measurement distance. As seen in a table 1, these benchmarks provided 56% identification accuracy and should be further scrutinized.

**Table 1.** Attempt of target interpretation using root-mean-square (RMS) benchmarks, later validated by visual evidence during technical survey.

| Target | Ana-lytic signal, nT/m$^2$ | Closest match – RMS bench-marking | Ground truth | Match |
|---|---|---|---|---|
| 1 | 34.2 | OZM-72 | OZM-72 | 1 |
| 2 | 31.4 | n.d. | n.d. | 1 |
| 3 | 47.9 | TM-62M | OZM-72 debris | 0 |
| 4 | 90.6 | OZM-72 | n.d. | 0 |
| 5 | 10.1 | OZM-72 | OZM-72 debris | 1 |
| 6 | 18.2 | TM-62M | n.d. | 0 |
| 7 | 88.4 | MLRS Uragan | 220 mm container | 1 |
| 8 | 43.2 | TM-62M | n.d. | 0 |
| 9 | 16.7 | OZM-72 | OZM-72 debris | 1 |
| 10 | 46.8 | OZM-72 | OZM-72 debris | 1 |
| 11 | 33 | OZM-72 | OZM-72 debris | 1 |
| 12 | 10.7 | OZM-72 | OZM-72 debris | 1 |
| 13 | 8.5 | TM-62M | n.d. | 0 |
| 14 | 32.8 | n.d. | n.d. | 1 |
| 15 | 19.2 | OZM-72 | n.d. | 0 |
| 16 | 15.5 | OZM-72 | n.d. | 0 |
| **Total match rate** | | | | **56%** |

## Conclusion

The MinesEye project presents a promising solution to the UXO contamination crisis in Ukraine. By leveraging UAVs and complementary sensors, such as magnetometer and optical camera, the system provides a safer, faster, and more efficient method for detecting and identifying UXOs in both sub surface and on surface settings. Future research will address current system limitations, aiming to further improve UXO detection accuracy and operational efficiency. By automating large-scale surveys, this system reduces the risk to demining teams while increasing operational speed. Continued research on machine learning algorithms for real-time anomaly detection will enhance the system's capability to pinpoint UXOs accurately. The ongoing research will focus on expanding the system's capabilities for underwater UXO detection and optimizing data processing methods to handle complex environments.

## References


Kolster, M.E., Wigh, M.D., da Silva, E.L.S., Bjerg Vilhelmsen, T., & Dössing, A. (2022). High-Speed Magnetic Surveying for Unexploded Ordnance Using UAV Systems. *Remote Sensing, 14*, 1134. https://doi.org/10.3390/rs14051134

Nelson, H.H., & McDonald, J.R. (2006). Airborne Magnetometry Surveys for Detection of Unexploded Ordnance. *Defense Technical Information Center (DTIC)*. Retrieved from https://apps.dtic.mil/sti/citations/ADA515639

Poliachenko, I., Kozak, V., Bakhmutov, V., Cherkes, S., & Varava, I. (2023). Preliminary results of UAV magnetic surveys for unexploded ordnance detection in Ukraine: effectiveness and challenges. *Geofizicheskiy Zhurnal, 45*(5), 126-140. https://doi.org/10.24028/gj.v45i5.289117

Poliachenko, I., Kozak, V., Bakhmutov, V., Cherkes, S., & Bilyi, T. (2025). Exploratory study of potential applications of UAV magnetic surveys for unexploded ordnance detection in coastline zone. Geofizicheskiy Zhurnal, 47(1), 97–107. https://doi.org/10.24028/gj.v47i1.316760

Yoo, L.-S., Lee, J.-H., Ko, S.-H., Jung, S.-K., Lee, S.-H., & Lee, Y.-K. (2020). A Drone Fitted with a Magnetometer Detects Landmines. *IEEE Geosci. Remote Sens. Lett., 17*(12), 2035–2039. https://doi.org/10.1109/LGRS.2019.2962062

# The Evolution of Underwater explosive ordnance Detection:

## Next-Generation Approaches

**by** *Branislav Jovanovic EOKHUB*


## Abstract

The evolution of underwater explosive ordnance detection stands at a crucial turning point as we face unprecedented challenges in maritime security and environmental safety. This comprehensive analysis explores the transformative journey from traditional detection methods to cutting-edge technologies reshaping the field. The article examines emerging innovations including advanced sonar systems, artificial intelligence-driven detection algorithms, autonomous underwater vehicles (AUVs), and machine learning applications in underwater operations. Special attention is given to the integration of multi-sensor platforms, enhanced imaging capabilities, and real-time data processing that are revolutionizing subsea threat identification. We delve into how these technological advancements are improving accuracy, reducing risks to EOD personnel, and accelerating clearance operations in complex underwater environments. The discussion encompasses both shallow water and deep-sea applications, with particular focus on solutions for the challenging conditions often encountered in coastal waters and marine infrastructure projects. By analyzing current technological trajectories and emerging methodologies, this article provides valuable insights into the future landscape of underwater explosive ordnance detection, offering a roadmap for professionals in the field to prepare for tomorrow's challenges.


## Introduction

The vast expanses of the world's oceans hide a silent and deadly legacy of past conflicts: millions of explosive ordnance (EO) items, ranging from naval mines to discarded munitions, lie buried beneath the waves. These remnants of war pose significant risks to marine ecosystems, shipping routes, and underwater infrastructure projects. The more challenge is that EO is often laid in the vicinity of chemical ammunition as well. Some figures say that there are more than 2 million tonnes of EO in the world's oceans and seas. For decades, the detection and clearance of underwater explosive ordnance have been among the most challenging and hazardous tasks in Explosive Ordnance Disposal (EOD) operations. However, a technological revolution is underway, transforming how we approach this critical mission. This article explores the evolution of underwater EO detection, from its rudimentary beginnings to the cutting-edge technologies shaping its future.

**Figure 1.** Map of underwater EO and CW risk

Credit: https://www.google.com/maps/d/u/0/viewer?mid=1ALnyOrN5JQ8H50znwJqI_Sj8lwE&ll=-3.8166656177562 2e-14%2C106.7984926700592&z=1

## A Historical Perspective: The Foundations of Underwater EO Detection

The history of underwater EO detection is rooted in the aftermath of World War II, when the scale of unexploded ordnance in coastal and marine environments became apparent. Early methods were limited by the technology of the time and relied heavily on manual effort and essential equipment.

## Early Detection Techniques (1945-1990)

**Hand-held magnetometers**:
These devices, capable of detecting metallic objects, were limited to shallow depths of 2-3 meters and often produced false positives due to natural magnetic anomalies.

**Side-scan sonar systems**:
Early sonar systems provided low-resolution images of the seafloor, making it challenging to distinguish EO from other debris.

**Diver-based visual inspections**:
EOD divers conducted risky, time-consuming searches in often murky and hazardous conditions.

**Simple metal detectors**:
While useful in some scenarios, these tools were prone to high false-positive rates and limited by environmental factors.

▲ **Figure 2.** A diver using a Ebinger UWEX® 725.
Credit: ITF Enhancing Human Security (ITF)

## Traditional Challenges

**Environmental limitations**
Turbid waters, magnetic interference from natural deposits, and weather conditions often hindered operations.

**Operational risks**
Divers faced significant dangers, including the risk of accidental detonation.

**Inefficiency**
Manual search patterns were slow and labor-intensive, limiting the area that could be covered in a given time.

## The Modern Era: Advanced Detection Systems (1990-today)

The turn of the 21st century marked a significant leap forward in underwater UXO detection, driven by advancements in sonar, magnetometry, and sub-bottom profiling technologies. These modern systems have dramatically improved detection accuracy, efficiency, and safety.

**Advanced Sonar Solutions**
Modern multi-beam sonar systems operate at frequencies of 400-900 kHz, providing high-resolution images of the seafloor. With coverage rates of up to 1 $km^2$ per hour and resolution capabilities down to 5 cm at 50 meters, these systems enable real-time 3D mapping with centimeter-level accuracy. Integration with differential GPS ensures precise positioning, allowing operators to pinpoint potential UXO with unprecedented precision.

**Magnetometry Arrays**
Magnetometers have evolved into sophisticated arrays capable of detecting subtle magnetic anomalies. Modern systems boast total field sensitivities of 0.004 $nT/\sqrt{Hz}$ and sampling rates up to 100 Hz. With multiple sensors configured in gradiometer setups, these arrays can detect UXO buried up to 6 meters in sediment, significantly reducing false positives.

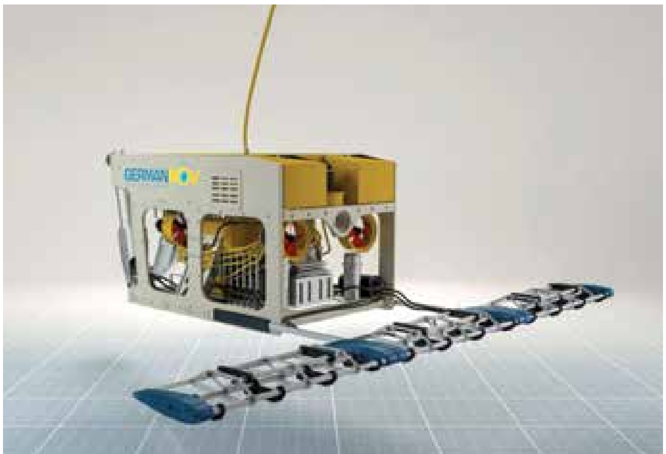

**Figure 3.** ▶
Sensys Magnetomerty Array

### Sub-bottom Profilers

Sub-bottom profilers, operating at frequencies of 2-16 kHz, penetrate up to 40 meters into soft sediment, providing detailed images of buried objects. With vertical resolutions of up to 6 cm and real-time data visualization, these systems are invaluable for mapping EO in complex environments.

## Next-Generation Technologies: The Future of Underwater EO Detection

The latest advancements in underwater UXO detection are driven by artificial intelligence (AI), autonomous systems, and advanced imaging technologies. These innovations are revolutionizing the field, offering faster, safer, and more accurate detection capabilities.

### Artificial Intelligence and Machine Learning

AI-powered systems are transforming data analysis in UXO detection. Neural networks trained on vast datasets of UXO images can classify targets with up to 90% accuracy, significantly reducing false positives. Real-time classification and automated report generation streamline operations, allowing EOD teams to focus on high-priority targets.

### Autonomous Underwater Vehicles (AUVs)

AUVs equipped with advanced sensors are becoming indispensable tools in underwater UXO detection. Capable of operating at depths of up to 300 meters and enduring missions of 12-24 hours, these vehicles can survey large areas with minimal human intervention. Automated mission planning and real-time data transmission via acoustic modems enhance operational efficiency and safety.

### Advanced Imaging Systems

Synthetic Aperture Sonar (SAS) systems offer resolutions as fine as 2.5 cm, enabling detailed imaging of UXO targets. Multi-aspect imaging and 3D reconstruction algorithms provide comprehensive views of objects, while AI integration enhances target recognition and classification.

### Crawlers

Underwater EO detection has been revolutionised by modern crawler systems. These sophisticated platforms combine multiple sensors, real-time detection capabilities, and AI-powered software to create a comprehensive detection solution. Modern crawlers serve as stable platforms in challenging nearshore environments, integrating magnetometers and video systems while keeping human operators at a safe distance. Recent advances have brought autonomous capabilities and enhanced sensor fusion technologies, marking a significant leap forward in underwater ordnance detection. The integration of smart grabbers and advanced data processing has transformed these machines from simple detection tools into complete UXO clearance solutions.

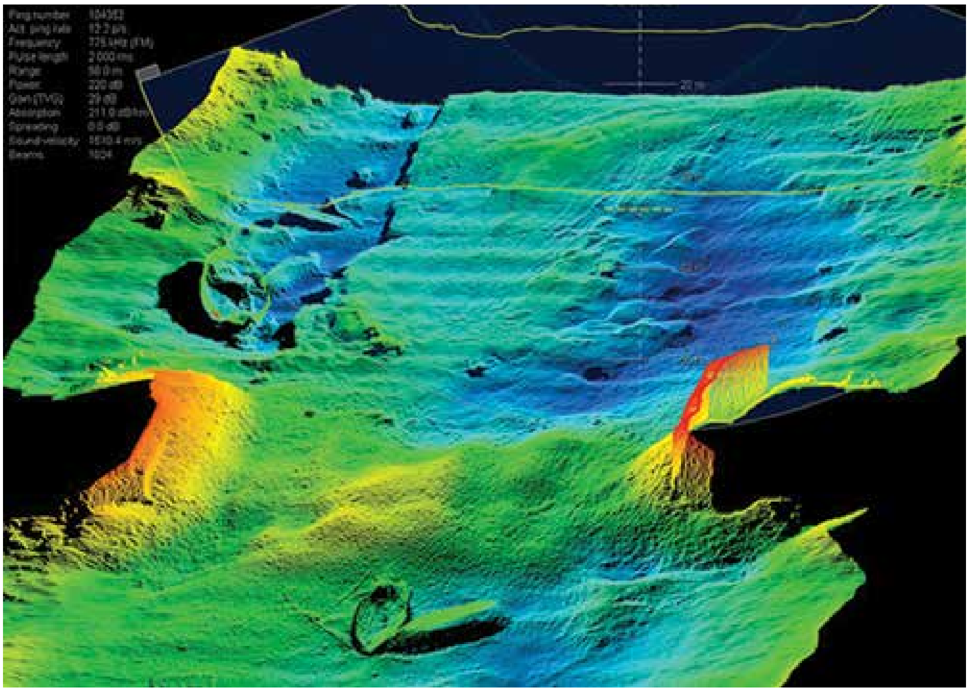

**Figure 4.** Synthetic aperture sonar(MINSAS) image of an unknown shipwreck off of Nantucket. Credit:Kraken

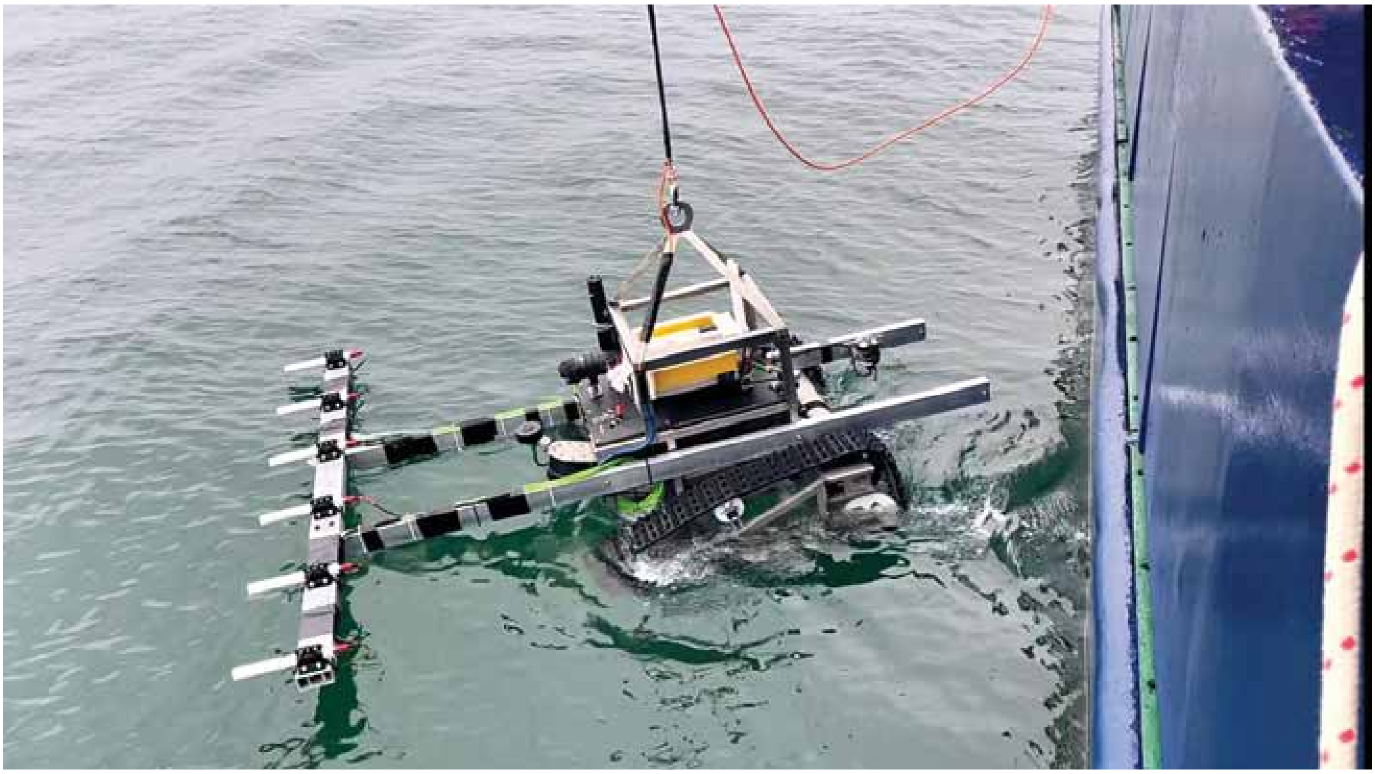

**Figure 5.** SeaTerra Techologies Norppa 300 crawler launched for a magnetic survey

## Looking to Tomorrow's Horizon

As quantum magnetometers emerge and swarm robotics become reality, the future of underwater EO detection looks increasingly sophisticated. Yet the fundamental challenge remains unchanged: keeping our waters safe from the deadly legacy of conflict.

Bio-inspired detection systems may soon mimic nature's own solution-finding abilities. Standardized data formats will help teams share discoveries across borders. And through it all, the human element remains central - the expertise to interpret, the wisdom to adapt, and the courage to face what lies beneath.

## Instead of conclusion: The Human Element: Where Technology Meets Experience

The evolution of underwater Explosive Ordnance detection represents a complex marriage between technological advancement and operational expertise. As detection systems become increasingly sophisticated, the fundamental challenge lies not in the technology itself, but in its effective integration with decades of accumulated field experience. This is particularly evident in the diverse operational environments of rivers, lakes, shallow waters, and transitional areas, where environmental conditions often test the limits of both equipment and expertise.

## Operational Dynamics in Regional Markets

The underwater EO detection sector presents a striking contrast between large-scale operations and regional specialists. While major industry players have developed sophisticated, custom-engineered solutions, Small and Medium-sized Enterprises (SMEs) face a different reality. These organizations must navigate complex technical implementation challenges, from system integration and calibration requirements to data processing demands and environmental adaptations. The resource allocation landscape adds another layer of complexity, as companies balance capital investment limitations with operational costs while maintaining necessary training and certification standards.

The development of effective underwater EOD detection capabilities demands a comprehensive understanding of technical infrastructure requirements. Organisations must carefully consider equipment selection and validation processes, ensuring proper system integration while maintaining robust data management protocols. Strong personnel competency frameworks must support this technical foundation, including rigorous certification requirements and continuous professional development programs that facilitate effective knowledge transfer between experienced operators and new technicians.

**Figure 6.** Crawler experts during the testing
Credit: SeaTerra GmbH

## Strategic Integration and Market Development

The advancement of underwater EO detection capabilities has spurred innovative approaches to technology acquisition and implementation. Organisations increasingly explore collaborative models that maximise resource utilisation while maintaining operational effectiveness. These approaches include technology access models that leverage shared resources and technical partnerships, enabling smaller organisations to access advanced capabilities without overwhelming capital investments.

The implementation of advanced detection technologies follows a structured pathway that begins with thorough assessment of operational requirements and technology capabilities. This initial evaluation leads to comprehensive planning that addresses technology acquisition, training requirements, and integration timelines. The execution phase focuses on system implementation and personnel training, culminating in rigorous performance validation. The final sustainability phase ensures long-term capability maintenance through continuous improvement protocols and structured knowledge retention strategies.

## Future Considerations and Industry Evolution

The future of underwater EO detection rests on several critical pillars. Technical advancement must be balanced against operational efficiency, ensuring new capabilities enhance rather than complicate existing processes. Organisations must focus on enhancing service delivery and competitive positioning while developing clear value propositions for their client base.

Integrating advanced underwater EO detection technologies with operational expertise represents a critical challenge for the industry. Success requires a balanced approach that combines technical capability development with practical operational considerations. Organisations must develop structured implementation strategies that address technical requirements and operational realities while focusing on sustainable capability development.

The professional evolution of underwater EO detection demands continuous attention to technological advancement and expertise development. As detection systems become more sophisticated, the human element becomes increasingly critical. Operators must not only understand their equipment's technical capabilities but also possess the judgment and experience to interpret results effectively in varying operational conditions.

In this complex operational environment, the key to success lies in maintaining a balanced approach that recognises the equal importance of technical capability and human expertise. Organisations must invest in both aspects to ensure their underwater EO detection capabilities remain both effective and commercially viable. This dual focus ensures that technological advancements serve to enhance rather than replace the crucial human element in underwater EOD operations.

The path forward requires careful consideration of how new technologies can best serve operational requirements while maintaining the high standards of safety and effectiveness that characterise professional EOD operations. As the industry continues to evolve, the integration of technology and expertise will remain central to successful underwater EOD detection operations.

# From Threat Detection to Neutralization:
## AIDEDex, CONVOY and GENIUS

*by Carolina Marta Bustillo Moran[1], Shashank Govindaraj[2]*

The Directorate-General for Defence Industry and Space (DG DEFIS) of the European Commission launched the first European Defence Fund (EDF) Technological Challenge, focusing on advanced technologies for detecting improvised explosive devices (IEDs) and landmines.

This initiative was a key step in strengthening the European Union's defence capabilities, as IEDs and landmines pose significant threats in modern conflicts, peacekeeping operations, and humanitarian missions.

The increasing threat posed by Improvised Explosive Devices (IEDs) and Unexploded Ordnance (UXOs) requires innovative solutions that enhance detection accuracy, operational efficiency, and adaptability to evolving threats. Traditional methods often struggle with reliability and scalability, prompting the need for advanced technologies that leverage artificial intelligence, robotics, and multi-sensor data integration. Aside from the devastating loss in human lives, the use of IEDs by adversaries also significantly hampers and slows down military operations, as the process is very slow, tedious and costly.

## AIDEDex

AIDEDex aims to address the threats of IED, EOs and UxOs issue by developing an AI-enabled robotic swarm with advanced EO detection and classification, and automated mission planning capabilities, that can be sent out in advance to detect and classify threats in the terrain, thereby keeping the human soldiers out of harm's way. The project is coordinated by Space Applications Services NV/SA and involves 6 organisations with a good level of cross-border defence collaboration. The key features of AIDEDex are:

• The heterogeneity of the sensors and their varied sensing modalities help in gathering data from multiple sensing perspectives, when fused, provide a progressively improved picture of positive or false detections and overall probability of detections.

• A fleet of heterogeneous robots having the required capabilities to host sensors due to their power, mass and data requirements, and having different kinematic and dynamic constraints.

• Integrated mesh communications with both a central and distributed control centers setup make up the data handling and situational awareness system.

## CONVOY

CONVOY integrates robotics, drones, and AI-powered sensing technologies to improve the detection, classification, and neutralization of IEDs and UXOs. The project aims to enhance autonomous systems and cloud-based tactical infrastructures to support defence forces. It is coordinated by GMV and involves the participation of nine leading companies and entities from five European countries, fostering international collaboration in defense innovation.

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The key objectives of the project CONVOY are:

- Combine intelligent robots and drones for coordinated threat detection.
- Leverage AI and cloud-based tactical networks for enhanced data processing.
- Improve UXO/IED recognition and classification through advanced sensing technologies.
- Information fusion from these advanced sensors.
- Modularity and scalability through an open architecture and standardized interfaces, allowing seamless integration of sensors, platforms, AI components, and other technologies.
- Integrate with Command and Control (C2) Systems, including the Battle Management System (BMS) for squad-level operations and the Dismounted Soldier System (DSS) C2 for individual combatants.



## GENIUS

Building upon AIDEDex and CONVOY, GENIUS focuses on neutralization strategies by integraing autonomous decision-making, multi-robot collaboration, and advanced intervention technologies. GENIUS aims to move beyond detection and develop next generation counter-IED and UXO solutions. The GENIUS project unites a diverse consortium, including 1 mid-cap coordinating the project, 3 large companies, 6 SMEs, 5 RTOs and 3 Academic Institutions from 7 EU Member States, fostering cross-sector collaboration. Traditional methods of detecting and neutralizing these threats often fall short, posing significant risks to human safety and operational success. GENIUS will change all that by pushing back the current boundaries. With a comprehensive, high-tech approach that integrates advanced sensors, unmanned platforms, and artificial intelligence, the project aims to deliver unmatched accuracy and reliability in threat management while reducing risks to personnel and increasing mission effectiveness.

The key objectives of the project are:

- Multi-Sensor Integration: Employs ten different sensory technologies to ensure precise detection and mapping of explosive threats.
  AI-Driven Classification: Advanced AI algorithms enhance the accuracy of threat classification and localization, leveraging data from multiple sensors.
- Autonomous Neutralization: Includes tools for threat neutralization such as high-pressure water systems, explosive ordnance, robotic hands, high-power lasers, and electromagnetic impulse devices.
- Threat Decoying: Features low-cost, disposable UAVs and UGVs designed for decoying threats to minimize human and equipment risk.
- Adaptive Jamming: Equipped with a versatile jamming system to disrupt threats while avoiding interference with friendly systems.
- Obstacle Breaching: Utilizes robust end-effectors for breaching a variety of obstacles, including windows, lightweight barriers, and doors.
- Operational Validation: Conducts extensive evaluation campaigns to validate technology performance and ensure effectiveness in real-world environments.

**Funded by the European Union**

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Predanost
naših radnika je
energija
koja pokreće
Hrvatsku
HEP Više od
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# APPROACHING MINE ACTION STRATEGICALLY: GLOBAL LESSONS LEARNED AND FUNDING CHALLENGES

# Matching Training and Operational Needs

*by Dr. Karl Strobl[1] and Iryna Shkatula[2]*

## PCM and MAT Training of Ukrainians So Far

MAT Kosovo, a dedicated EOD training establishment, is the alma mater of

- 1000s of deminers
- from 70 countries, receiving
- training in 7 different languages
- across 280 distinct projects.
- of which >50 projects were delivered to government agencies (police, army, navy)

For Ukraine, this unique strategy remains justified in hindsight because (i) it met the urgent needs of Ukraine with immediate readiness — no product development or time delays and low to no capital investments; training could immediately commence in significant numbers; (ii) Ukrainian agencies were swift to arrange for their staff to be sent abroad for training; and (iii) it upheld our sovereignty concerning quality and product control: A MAT certificate in Ukrainian retains equal validity and credibility as MAT and PCM certificates awarded elsewhere in the world.

Since November 2021, MAT Kosovo and the PCM group have trained over 440 persons in Ukrainian courses, primarily from national agencies, with an unprecedented proportion of them women. Many returned, after their IMAS EOD Level 2, for advanced training. MAT Kosovo leads in training Ukrainian specialists at EOD Levels 3 (155 graduates) and above, as well as specialist CBRN training, and Train-the-Trainer (TtT) programmes, culminating in the opportunity to deliver mentored training with us.

Most of the courses have taken place at MAT Kosovo, with some training conducted in Ukraine. This is set to change, but the focus on training in Kosovo has been the right strategy thus far, even though this contrasts with the PCM group's general approach of training mostly in-country on larger projects.

Thus, from a strategic perspective, utilising the existing brand, training product, and infrastructure to train in Kosovo was the right decision. Donors and beneficiaries benefited from immediate training outputs, adhering to the widely recognised MAT Kosovo standard. Training commenced immediately, with no ramp-up costs or delays.

Clearly, this approach is neither scalable nor sustainable indefinitely. While *the facility accommodates up to three concurrent courses, with full life support, demolitions on live targets, housing and training 60 students in different languages simultaneously and serving up to 300 meals a day*, it remains a physical facility and in global demand, with limited capacity.

Also, if the ultimate goal is to build up capacity for Ukraine to train her own, in-country training eventually is a must.

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2 Director, Representative Office of PCM Group in Ukraine, iryna@pcm-erw.com

## The "Big" Strategic Questions for Training in Ukraine

### Strategic Objectives

In war, mine action and EOD conditions change rapidly, and with them the training needs, raising the following questions:

- How to best meet the operational need?
- How to best reconcile the need for international standards, recognition of qualifications and certificates, with the need to adapt to evolving threats, needs, and objectives?
- Does Ukraine need IMAS?
- Does Ukraine need STANAG?
- Has a proper TNA been done for (at least most of) the national capacity?

### Strategic Priorities

Any business needs to prioritise amongst:

- the priorities of the beneficiary,
- the priorities of the donor, and
- the demands on the bottom line.

When put like this, it may not be surprising that outcomes differ between private businesses and listed ones, large businesses and small ones, for-profit businesses and NGOs, as well as owner-operated businesses vs others. In short different structures sometimes predetermine different compromises and lead to different outcomes. What remains essential is for there to be no conflict between the strategic priorities above. It has always been our view that, in the long run, the beneficiary has to come first. This is as true for the "business" as it should be for donors.

### Beneficiary First

"Beneficiary First" simply reflects the motivation of why we do our job. It also reflects commercial reality: donors may come and go, but the beneficiaries and their needs remain.

Our stance is paying off: The trust built with our beneficiaries has allowed us to perform a training-needs analysis on them and with them, at their sites in country. Furthermore, and while we've been busy leveraging our massively enlarged facility in Kosovo, we've been equally busy establishing cooperations with local and international partners to support us in country, for operations, logistics, security, life support, ranges, live targets and training areas.

### A Concrete Plan for Concrete Needs

We are not interested in building a global training infrastructure for us to own, nor would we expect a donor to pay for it. We aren't interested in maximising capital expenditure for our advantage or managing camps or buildings. In any case, no-one will replicate MAT Kosovo, which just celebrated its 25th anniversary; not even we will. It remains unique to this day. People sometimes are surprised that we aren't "building a school" in Ukraine, but there are plenty of suitable facilities already for us to use, with the right partnerships, which we now have. This is how we have always operated, worldwide.

Our interest is in capacity building. We have worked towards our partnership plans for a long time, because they allow us to focus on what we are good at, i.e., delivering training at every level, EOD and IEDD, APSSM, Quality Management in Mine Action, etc. The need is well documented, and we have been explicitly tasked with providing such *training to >600 PAX, subject to funding*, in the next 12 months.

We did not and will not duplicate the already existing training *facility* capacity in Ukraine. Instead, we have trained much more than anyone else at the highest levels where we had the capacity ready and have done so at a fraction of typical costs. We are ready to do this in-country, in Ukraine today, not tomorrow, with our current partnerships.

## What Makes a Training Organisation?

The question of how to build a training organisation is not rocket science. It works the same way for training in any field: nurses, specialist drivers, carpenters, pilots or divers. Components to pay attention to are product development, progressivity of training, multi-lingual capacity, product Management, IP management and protection, etc.

You need basically the same intellectual support structure to train for any sector. It's a business-school problem, not an EOD problem, so — almost by definition – EOD SMEs don't get you there. *This* is *not* what they are experts in! You can't *"hire surgeons to build a hospital"*. Yet, people try...

## International vs. National Standards

The role of IMAS has always been a subject of discussion, especially in Ukraine. But it has evolved, from initial scepticism and the conviction that a national set of standards obviates the need for IMAS, to a recognition that IMAS is a framework on which to *build* a national set of standards (NMAS), organisational standards, and SOPs. In other words, IMAS is a *guideline and a baseline*.

It is also a reference frame, enabling concise communication of principles, ideas, threats, and even organisational issues such as procurement, quality control, etc. IMAS provides a "*universal language*" to clearly spell out how local, organisational, and other needs *differ* or are more specific than IMAS.

Three years on, everyone in Ukraine has understood *the value of IMAS as a lingua franca amongst operators, organisations, authorities, donors, beneficiaries, and training and equipment suppliers.* It's understood that one can, and generally needs to, customise knowledge, procedures and standards (as IMAS suggests one should), but also it's generally accepted that IMAS makes cooperation and communication more efficient, effective, and safe!

## Operational and Training Needs

What should be the balance between training needs and operational needs? Ad-hoc requirements may be phrased like this:

- Train us for what we do precisely
- Train us in the operational environment we are in, or as close to as possible
- Train us for the precise threat we face

Some examples will make it self-evident that this is not the right balance between operational and training requirements:

- Training must always prioritise general principles over specificities. Especially in EOD, where doing the wrong thing even just once can have a very high cost indeed! It doesn't matter much if you know the exact type-number of any munition in 99.9% of all encounters. *Any* amount of specific knowledge will leave room for situations where you have to work things out from first principles.

- The same is true about locations and threat patterns. It's much better to add specific briefings on top of general training than the other way around! There is hardly any advantage in training people in the exact place where they will work. Diversity of environments in training is a strength and not a weakness.

Therefore:

- Product development has to be "sticky": wedded to the general training principles worked out over generations (IMAS, SOPs, training content and lesson plans) and modified *by increments*. Product development has to be evolutionary, neither revolutionary nor ad-hoc.
- Drive home the general principles first. Customisation, localisation, and specific threats, items, and tactics are important, but they are add-ons, icing on the cake. Encyclopaedic *knowledge* may make the operator *faster*. *Understanding* is *safer*.
- Teach flexibility and adaptability.
- Teach context: Every job and every task has a role within a much bigger picture. Understanding this teaches graduates how to *stay* current and relevant long after they have left the training.

## Conclusion

3 ½ years on from our first ever Ukrainian-language course, the beneficiaries which we have trained have

- embraced IMAS as a baseline and guideline and a *lingua franca* on which to build (i) higher levels of training, (ii) inter-operability, and (iii) clearer communications with donors
- allowed us to conduct a TNA, resulting in identified and *confirmed* needs, such as 385 IMAS EOD units and 250 IATG APSSM units to be delivered to various branches in the next twelve months.
- embraced the idea that training has to be to first and general principles and that the specifics of the threats, tasks, and items operators face are *add-ons* to progressive training.

This follows the logic of how one would organise training in *any* sector. PCM group, having been purely focused on training and nothing else for over 15 years, has practiced and preached these training principles for a long time. When PCM got involved with Ukraine, a country with a massive head-start in terms of the breadth and depth of technical expertise already present in-country before we even got invoved, the process of discovering and agreeing on these principles became doubly interesting and doubly rewarding.

Now, we reap the benefits of our ethics and philosophy, applied over all these years, and – not a moment too soon – true capacity-building can begin.

# Lessons Learned from Iraq and Syria Debris Management and Rubble Clearance

*by Stephen Ingram*[1]

**Drawing from MAG's 30 years of experience in Iraq and its work in post-ISIS clearance operations in northeastern Syria, this paper explores the progress still needed and the lessons learned from past efforts. It also looks ahead to the future of debris management and rubble clearance in Lebanon, Gaza, and Syria, highlighting the strategies and innovations required for safe, effective, and efficient post-conflict recovery.**

In the lead-up to Mine Action 2025, the BBC released an article, 'Mosul's landmarks rise again after IS destruction' (Usher, 2025), showcasing the rebuilding of Mosul and some of its key landmarks. This article vindicates many of the mine action professionals who worked tirelessly in northern Iraq clearing rubble post-ISIS.

Since the ISIS offensive in 2014, MAG's work in Iraq and Syria has led to the removal and destruction of nearly 150,000 items of unexploded ordnance, including 50,000 Improvised Explosive Devices (IEDs). In light of this, and on the 10th anniversary of the Sinjar massacre—ISIS's attack on Iraq's Yezidi ethnoreligious minority - MAG commissioned an independent study on the impact, challenges, and best practices from its work in the Sinjar and Tel Afar districts (MAG, 2024). The report provides clear evidence of the importance and impact of mine action in enabling stabilisation, recovery, and development activities in these regions. However, it also outlined nine key areas for improvement. Much of the clearance conducted by MAG was in densely contaminated urban environments, focusing on debris management and rubble clearance. Therefore, Recommendation 7 of the report recommended the development of a good practice guide for planning and managing mine action in urban environments. This initiative began in 2021 when MAG was looking to trial the now-unreleased GICHD Urban Approach Model paper, this was put on hold due to the COVID-19 pandemic. However, most experts in the field would agree that despite the excellent work completed in Iraq and Syria, there are many lessons that could improve the efficiency and effectiveness of debris management and rubble clearance.

These lessons are now more relevant than ever, as many countries affected by recent conflicts face similar challenges. In Gaza, the most recent estimates from UNEP calculate the total debris quantity at over 50 million tons (UNEP, 2024) - a staggering amount compared to even the massive estimated 8 million tons of debris in Iraq (DDG, 2019). Similarly, the current debris contamination in Lebanon is expected to be 8 Million Tons (UNH, 2024)  Considering the size of the geographical areas affected in Gaza and Lebanon, and the socio-economic challenges pressing population returns, the time and investments required for rubble management and rubble clearance, and the immediacy of the response will be more dire compared to Iraq.

Sources in Ukraine have put a rough estimate of 600,000 Tons of rubble. (UST, 2024), though this is likely an underestimate, as it doesn't account for occupied territories and other active conflict zones. This is not an exhaustive list of the many ongoing conflicts, nor does it cover unfinished work in underfunded and heavily damaged cities like Sirte in Libya and Raqqa in Syria. With funding instability and new operations on the horizon, it is more important than ever that the safety, efficiency, and effectiveness of debris management and rubble clearance operations are prioritised.

This brief paper explores the initial steps toward developing a good practice guide for planning and managing mine action in urban environments, drawing on 10 key lessons learned from debris management and rubble clearance in Iraq and Syria. The lessons have been distilled into a mind map that can be seen below, which explores various areas where learning has occurred. The second part of this paper will briefly discuss how these lessons are being applied as MAG begins its work in Lebanon and plans for  Gaza.

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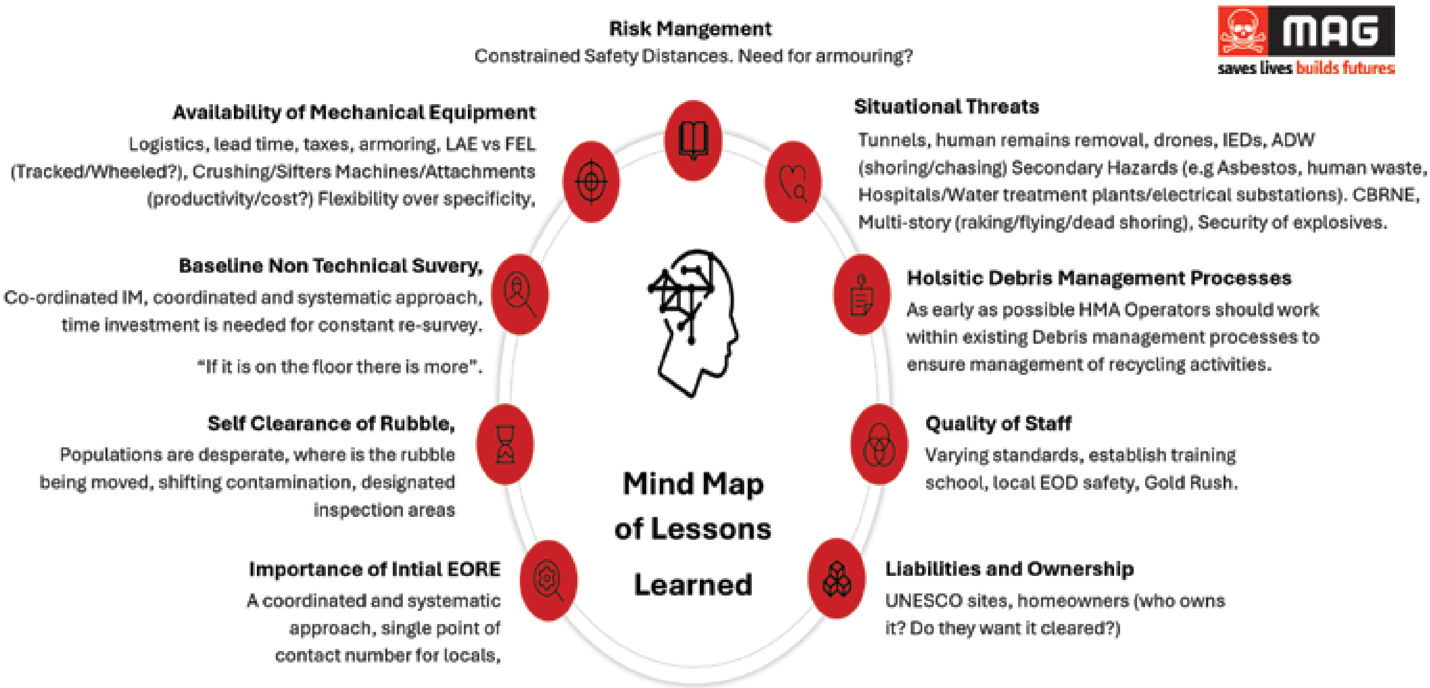


Humanitarian Mine Action (HMA) clearance remains a small part of the larger debris management process. The question of how involved HMA operators and National Mine Action Authorities (NMAA) should be is context-dependent and varies according to individual organizational strategies. HMA operators often overstep into debris management activities without considering the full range of expertise needed to rehabilitate urban environments. Ultimately, it depends on the capabilities of operators, logistical restrictions and the balance between Explosive Ordnance (EO) risk and other threats. HMA operators must engage with a broad array of stakeholders to ensure that complex issues, such as environmental management, recycling, and housing, land, and property (HLP) rights, are addressed.

The importance of context-adapted and continuous Explosive Ordnance Risk Education (EORE) relevant to the needs and circumstances of affected populations cannot be overstated. The highest casualty rates among civilians typically occur during the early stages of conflict as civilians flee to safety out of or through highly contaminated zones, and soon after access allows eager - and too often, resource deprived - populations to return to their homes and reclaim their sources of livelihood. Immediate and targeted in-person EORE activities, supported by mass media and digital EORE, should always be a priority at the onset of HMA interventions, and in parallel to clearance operations.

As rebuilding efforts demonstrate, local populations will not wait for the slow mobilisation of funds for HMA and debris management operators and traditional funding levels do not account for the scale of debris in areas like Gaza. In the meantime, EO risk education and community liaison are the only means possible to mitigate populations' risk of injury and death from EO. In MAG's experience, EORE has as well proven to be critical for the safety of civilians taking immeasurable risks during active conflicts, notably in highly populated and built-up areas such as Gaza and Lebanon, while attempting to rescue loved ones from collapsed buildings or hasten to retrieve their sparse belongings amidst EO infested rubble. Lastly EORE is necessary to safeguard first responders and those who will clear contaminated rubble regardless of the inherent dangers, as well as aid workers and rubble management contractors who may encounter EO in "low-risk" areas and need guidance on risk mitigation.

Conducting a baseline survey in urban environments presents significant challenges, but it is vital to take a coordinated and systematic approach to prioritise high-risk areas. Tasks should be prioritised based on the balance between the likelihood of threats, using both direct and indirect evidence, and land use considerations. Given that HMA clearance capabilities are limited and urban clearance is time-consuming, assets must be concentrated on the most pertinent tasks. MAG's experience has shown that the adage "if it's on the floor, there's more" often holds true when it comes to EO contamination in rubble. However, in Gaza, Lebanon and Syria, the increased use of sophisticated guided weapons and drones, coupled with surface contamination being swiftly removed for various reasons, complicates the assessment of whether tasks are truly "high threat." As a result, non-technical surveys increasingly require more technical expertise, and the IMAS Technical Note for Mine Action 10.10/03 Explosive Hazard Risk Assessment in Debris Management (Rubble Removal) Operations (IMAS, 2018) remains highly relevant.

The availability of mechanical equipment has proven to be a force multiplier in HMA clearance. In Iraq, thanks to generous donor support, MAG has trialled nearly every permutation of equipment and attachments used in demolitions and clearance. Creating a pipeline for the procurement and support of such equipment is crucial. MAG has found that simplicity and flexibility in equipment, as opposed to overly specialized, single-purpose tools, are optimal. This is demonstrated by the robust tracking of mechanical operational outputs versus costs. It is critical that lessons learned from previous operations are applied to prevent the purchase of ineffective "white elephants."

In EOD, there has always been an unwritten rule advocating for a pragmatic approach to risk. This balance is particularly critical in urban clearance environments. Experienced EOD operators with a solid understanding of explosive effects are required to make nuanced risk mitigation decisions. For instance, it is nearly impossible to consistently achieve the necessary safety distances or protective works to render a 2000LB Mark 84 bomb safe in dense urban environments like Gaza. Accepting this reality, along with establishing a clear and robust risk mitigation chain, is essential for both HMA operators and NMAAs. Furthermore, the deployment of difficult-to-acquire armoured machinery should be targeted and relevant. It is important to remember that, like demining PPE, machine armouring is not designed to protect against high-velocity fragmentation, which opens the possibility for more selective use of unarmoured machines where appropriate.

Situational threats and secondary hazards remain prominent in HMA clearance. A non-exhaustive list includes tunnels, human remains removal, drones, IEDs, anti-detonation walls (ADWs), multi-story damaged buildings (and their remediation), secondary hazards (like asbestos, human waste, electrical and water management systems, and critical infrastructure such as hospitals, water treatment plants, and electrical substations.) CBRNE threats, and securing EO found all require coordinated and specialised capabilities. Where possible, coordination of resources should be considered, with preparations made before threats materialise.

The availability and training of staff with all these specialized skills and qualifications require decades of experience. It is essential that these varying levels of expertise are integrated using agile team methodologies to ensure decision-makers are appropriately empowered and advised.

In conclusion, the lessons learned from MAG's extensive work in Iraq and Syria provide invaluable insights for future debris management and rubble clearance efforts in post-conflict environments. As regions like Gaza, Lebanon, and Ukraine face similar challenges, the need for efficient, safe, and well-coordinated operations has never been more critical. By applying the lessons from past operations, prioritising risk education, and leveraging mechanical equipment and technical expertise, the humanitarian mine action community can better navigate the complex tasks of post-conflict recovery. Moving forward, continued innovation and collaboration will be key to addressing the growing scale of debris contamination and ensuring sustainable, effective recovery in urban environments.

## Bibliography

DDG. (2019, Feburary 19). *Hidden Bombs and Eight Million Tonnes of Rubble Keep the People of Mosul from Returning Home*. Retrieved from https://danishdemininggroup.dk/news/hidden-bombs-and-eight-million-tonnes-of-rubble-keep-the-people-of-mosul-from-returning-home

IMAS. (2018, July 1). *IMAS 10.10/03 Explosive hazard risk assessment in debris management (rubble removal) operations*. Retrieved from https://www.mineactionstandards.org/standards/10-10-03/

MAG. (2024). *Evaluation of MAG's Mine Action Responses in Sinjar and Tel Afar district, Ninewa Governate, Republic of Iraq*. UK: MAG.

UNEP. (2024, December 1). Retrieved from https://wedocs.unep.org/bitstream/handle/20.500.11822/46832/Gaza-Debris-Quantities.pdf?sequence=1&isAllowed=y

UNH. (2024). *UN Habitat- LEBANON – BUILDING DESTRUCTION AND DEBRIS QUANTITIES ASSESSMENT*. 29 November: UN Habitat.

Usher, S. (2025, Feburary 5). *Mosul's landmarks rise again after IS destruction.* Retrieved from https://www.bbc.co.uk/news/articles/cjw4zv533g7o

UST. (2024, July 10). *Ukraine Support Team*. Retrieved from Communities can assess the debris amount by the unified method: https://ustcoalition.com.ua/en/gromady-zmozhut-rahuvaty-kilkist-vidhodiv-vid-rujnuvan-za-unifikovanym-metodom/#:~:text=According%20to%20official%20data%2C%20there,temporary%20storage%20sites%20or%20landfills.

# SeaTerra's 2024 survey and clearance campaign in the Baltic Sea within the German "Sofortprogramm"

*by Dieter Guldin*[1]


## Abstract

UXO clearance operations in German territorial waters began in the early 1950s but developed slowly. In contrast, UXO land clearance procedures and operations advanced much more quickly. This changed around 2010 when the North Sea and Baltic Sea became increasingly attractive to the industry due to the construction of renewable energy wind farms, offshore cables, and pipelines. While the growing interest of the offshore industry spurred the development of new technologies and methods, only a small portion of the 1.6 million tonnes of dumped ammunition in German territorial waters has been cleared. In 2021, the German government decided to address this issue by establishing the so-called "Sofortprogramm" for UXO clearance and the disposal of UXO dumping grounds. SeaTerra participated in the survey and clearance of two ammunition dump sites and developed new methods, equipment, software, and procedures to efficiently and safely clear ammunition dump sites in the future.


## Introduction

More than 1.6 million tonnes of unexploded weapons pollute the North Sea and Baltic Sea. In 2021, the newly elected German government decided to address this huge problem for the first time on a larger scale—at a governmental level—and introduced a pilot project, the so-called "Sofortprogramm." It was a long journey until the Sofortprogramm was initiated. Several steps marked a significant recognition process on the political side, from neglecting the problem to accepting the fact that ammunition had been dumped but was better left in place, to arguing that no technical solutions were available to initiate a clearance process.

We've seen all kinds of arguments not to act, but in the end, scientific research—along with the results of countless scientific surveys, monitoring, and testing projects—delivered such a large volume of data about the release of carcinogenic substances that those findings raised the alarm, from NGOs up to political decision-makers.

**Figure 1.** Map of dump sites along the German coast (Credit: European Atlas of the Seas/EMODnet).

## A very short history of UXO clearance in Germany

Why looking back if the problem ahead is so huge?  The answer is that we, by looking back, may learn something about the process of why and when action begins to address a problem. UXO clearance in Germany started right after WWII, but it primarily began on land. The reason behind this is obvious: agricultural areas, cities, and industrial sites had been heavily bombed, and to rebuild the infrastructure, UXO clearance needed to start immediately—even during the war.

The situation in the North Sea and Baltic Sea is completely different. While about 1.4 million tonnes of bombs were dropped on land, around 100,000 tonnes are expected to remain in 2024. In the North Sea and Baltic Sea, around 1.6M tonnes were dumped, but so far, only about 32,000 tonnes have been cleared.

The reason behind these vastly different numbers is that until the development of offshore wind—until renewable energy projects began—nobody felt the pressure to act, since nobody "needed" the oceans. Shipping lanes were cleared by the navy after the war, and fishermen were advised to sail around the known dump sites.

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After taking a closer look at the UXOs that have been cleared in the North Sea and Baltic Sea so far, we must acknowledge that even the 32,000 tonnes removed did not come from known dump sites but were instead "chance finds". They were discovered and cleared along new cable routes, pipelines, beaches, or within offshore wind farms. These UXOs were dropped by planes on their way back to save fuel, lost during the war, or left as remnants of former mine belts, to name just a few possible scenarios.

## The German Sofortprogramm indicates a change of paradigm

Until the Sofortprogramm started in 2024, UXO clearance offshore took place outside known dump sites. Sites that have been documented in historical records, by fishermen, or identified through recent scientific surveys were left out. This is because everyone tried to avoid building new infrastructure in such areas for safety and financial reasons.

The German Sofortprogramm, therefore, marks a shift in paradigm. For the first time, Germany acted at a governmental level on this issue due to environmental concerns and the obvious threat to the marine ecosystem. This is something new. It is a remarkable step not only in UXO clearance offshore but also in politics, since confronting problems inherited from previous generations—rather than neglecting them—has not been a common approach so far.

As mentioned before, science played a crucial role in this process. Due to scientific work and published papers, it became clear that the process of corrosion leads to the release of more carcinogenic substances into the sea, and therefore into our food chain. Not going into more details about this topic, this paper and the presentation is based on scientific research from: J. Greinert; T. Frey; A. Beck, from the Geomar Helmholtz Centre for Ocean Research, E. Maser from the Kiel University, J. P. Scharsack, from the Thünen Institute, and M. Brenner from Alfred-Wegener-Institute Helmholtz-Zentrum für Polar- und Meeresforschung.

However, it was not science alone that pushed the process of bringing the Sofortprogramm to life; the German election in 2021 also played a crucial role. The "Die Grüne" party mentioned the urgent need for UXO clearance for the first time in their election program and included the topic in the so-called coalition treaty. By 2021, it had become a common understanding that Germany must take responsibility and address the problem of UXO dump sites in German territorial waters. Keeping the described process in mind of how UXO clearance offshore developed, the Sofortprogramm is meant to become the starting point  for UXO clearance of ammunition dump sites and SeaTerra did its very best to assist in this important process.

## The survey operations

The Lübecker Bucht is a bay of the Baltic Sea that belongs entirely to Germany. As part of the Bay of Mecklenburg, it forms the "southwestern corner" of the Baltic Sea. It is bordered to the northeast by a line from Dahmeshöved near Kellenhusen to Großklützhöved. The Lübecker Bucht is well known for its wonderful beaches and tourist attractions, but it is also known among scientists and EODs for its high density of ammunition dump sites. In August 2024, SeaTerra began a Multibeam, SideScanSonar, and Magnetometry survey.

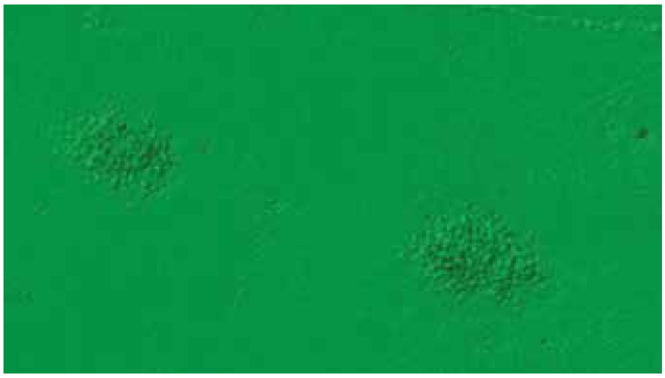

**Figure 2.** Multibeam data of Haff_00002 with 2 dump sites of about 30m in diameter.

Within all different sets of data, the different dump sites have been visibly quite clear, matching with the photogrammetric survey data from Geomar. While the magnetic anomaly of Haffkrug appeared as one big dipole, the data from Pelzerhaken was a big surprise for all parties involved.

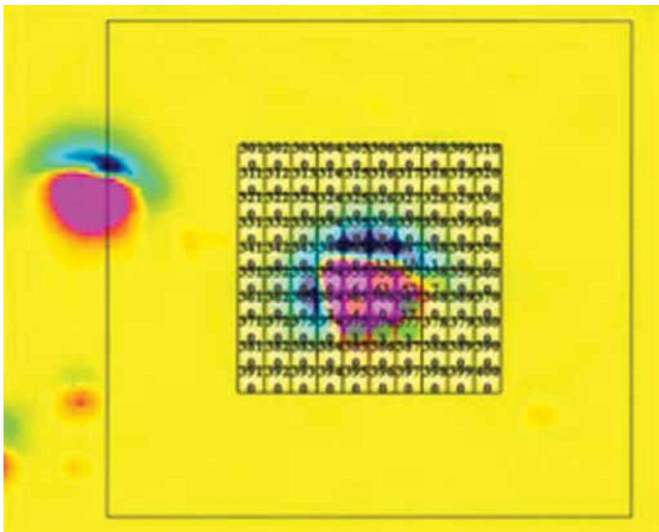

**Figure 3.** Magnetic data of Haff_00002 overlayed with 5m x 5m clearance grit.

Here the Multibeam/Side Scan data indicated an almost clean area while the magnetic data showed ten thousand of anomalies of all sizes from 0.1Am$^2$ up to 1000Am$^2$.

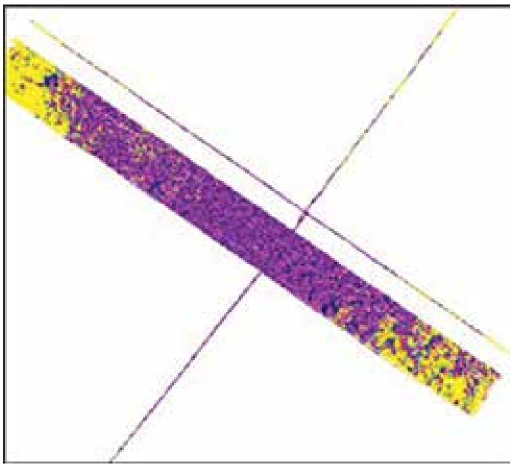

**Figure 4.** Pzhk.- Magnetic Data (0,1nT colour-step).

Since hundreds of verified UXOs, visible on the surface, matched in position with the magnetic anomalies, there is a strong indication that this area might be an unknown dump site of huge dimensions. Based on sub-bottom profiler data, it turned out that the magnetic anomalies detected are buried in a geological depression of soft sediments with a thickness of up to 8 meters, which explains the initial impression—based on multibeam/SSS data—that the area was almost "clean," showing only a few single spots of dumped ammunition on the surface. Further investigations may prove that those spots, visible on the surface, are just the "tip of the iceberg," while the real amount of UXOs is covered within thick layers of soft sediments.

## The clearance operations

Months before the "real work" started, SeaTerra developed new hydraulic grabber tools with software-controlled pressure functions, a small crawler with manipulator, cameras, lights, ARIS sonar. For UXO storage at the wet- storage area, special containments have been built and for documentation of all kinds of data, and to grant full transparency towards all parties involved, we set up GIS platform where all processes have been displayed in real time. For bringing this spread into the field, a spud-barge of 56m x 14xm length/width has been mobilized. Fully equipped the barge has been set-up as a kind of "toolbox", able to cope with the most scenarios we expected to be confronted with.

Following the main idea of the Sofortprogramm, the operations in Haffkrug and Pelzerhaken tested new ways to learn and get a better understanding of which tools and procedures are best for a safe and efficient clearance process in the future. Positioned right next to the dump site, the work started with an initial ROV and diver investigation and a visual identification phase. The site revealed hundreds of wooden boxes, some of them open, most of them closed, but in reasonably good condition, at least on the first layer which changed as we got deeper into the sediment.

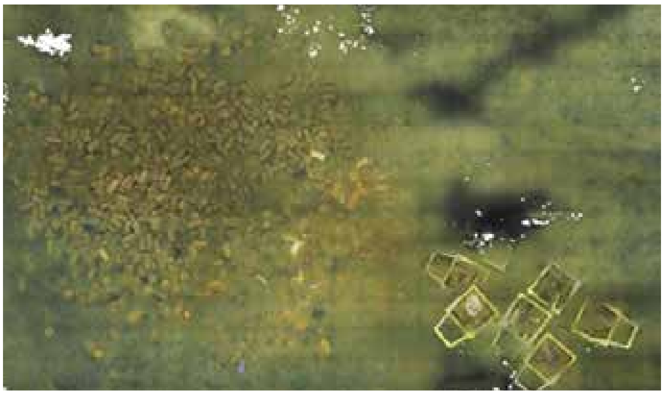

**Figure 5.** Haffkrug clearance area with hundreds of wooden boxes and clearance baskets close by. (Credit: Geomar)

From day one onward, the clearance followed a step-by-step procedure of identification, moving boxes into the offshore-baskets, lifting on to the deck, sorting, documentation, packing into storage facilities, and re-storage in the wet-store area.

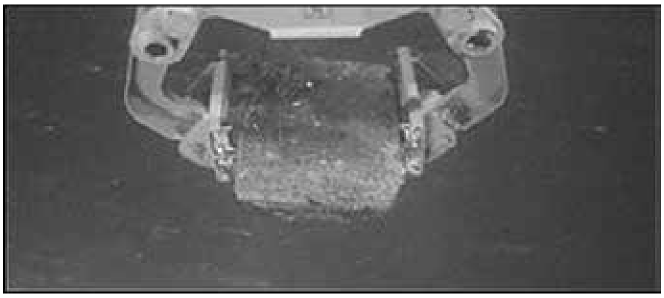

**Figure 6.** Grabber with picked up wooden box of 2cm-granades ammunition

Almost 200 wooden boxes, 6 tonnes of 2cm grenades have been cleared on that spot until we moved on to a second site.

**Figure 7.** Sorting of 2cm ammunition on board the clearance vessel.

A new and interesting aspect at this spot was that we did not only find ready-to-use ammunition, but also quite a lot of semi-finished components. It appears that not only the ammunition stored in warehouses, depots, and at the front was dumped, but also that ammunition factories were emptied.


**Figure 8.** Paper sticker on ammunition boxes

A very strong indication of this could be paper stickers on some of the wooden boxes, indicating the origin of the ammunition as coming from „Deutschen Waffen- und Munitionsfabriken AG" in Lübeck. Possibly, not only the "ready-to-go" ammunition was dumped from there, but also semi-finished products and ammunition components.

## Conclusion

The "Sofortprogramm" was never meant to be a project focused solely on removing as much ammunition as possible. It was intended to provide space for new clearance approaches and to determine how the process of UXO clearance on ammunition dump sites can be initiated—how safety and efficiency can be combined—leading to new procedures. Therefore, it was called a "pilot project."

For the future, the Sofortprogramm will hopefully become the starting point for UXO clearance of ammunition dump sites in German territorial waters and possibly even beyond German borders. However, since we live in challenging times, we do not know today how priorities may change tomorrow. Nevertheless, we should keep in mind that we cannot choose whether corrosion takes place or TNT remnants diffuse into the oceans, but we can decide whether to act on the acute problems we have inherited or pass them on to our children—the next generations to come.

## References


Frey, T. (2025). A New Risk Assessment Model for Unexploded Underwater Military Munitions. Leipzig University, Leipzig. https://doi.org/10.5281/zenodo.14620239

Frey, T. (2020). Quality Guideline for Offshore Explosive Ordnance Disposal (1. Auflage). Beuth Verlag GmbH.

Greinert, J., Kampmeier, M., Buck, V., & Frey, T. (2024). Marine dumped munition: Example from Lübeck Bay where test clearance will start in 2024(128), 34–41. https://doi.org/10.23784/HN128-05

HELCOM EG Submerged (2024). HELCOM Thematic Assessment on Hazardous Submerged Objects in the Baltic Sea: Warfare Materials in the Baltic Sea. Frey, T., Czub, M., Bełdowski, J., & Meski, L. (Eds.). https://tinyurl.com/4zb-2drdd

Kampmeier, M., van der Lee, E. M., Wichert, U., & Greinert, J. (2020). Exploration of the munition dumpsite Kolberger Heide in Kiel Bay, Germany: Example for a standardised hydroacoustic and optic monitoring approach. Continental Shelf Research, 198, 104108. https://doi.org/10.1016/j.csr.2020.104108

Beck, A. J., Gledhill, M., Gräwe, U., Kampmeier, M., Eggert, A., Schlosser, C., Stamer, B., Greinert, J., & Achterberg, E. P. (2025). Widespread environmental contamination from relic munitions in the southwestern Baltic Sea. Chemosphere, 372, 144115. https://doi.org/10.1016/j.chemosphere.2025.144115

Maser, E., Strehse J., Bünning T., (2024). How contaminated is flatfish living near World Wars' munition dumping sites with energetic compounds? Archives of Toxicology 98(11):3825-3836.

Bergmann, S., Brenner M., Strehse J., (2024) Risk assessment of war wrecks -a comprehensive approach investigating four wrecks containing munitions in the German Bight/North Sea. Propellants Explosives Pyrotechnics 49(4)

# The Implementation of the Ottawa Convention in Croatia and a look into the future

*by* Josip Čerina[1], Igor Kulenović[2]

***Summary:*** *The paper presents a chronology of the landmine issue in the Republic of Croatia and the implementation of the Ottawa Convention, focusing on fulfilling the obligation to destroy anti-personnel mines in mined areas. Croatia has established a unique system for mine action, and the extended deadline for demining the remaining mine suspected areas is planned to be completed by 2026. Croatia has come a long and challenging way, transitioning from a recipient of aid to a country capable of assisting others. Croatia has the capacity and capabilities to support organizing and implementing mine action. After completing humanitarian demining operations, Croatia is obligated to engage in international cooperation and assistance, education, and to submit annual reports on the implementation of the Convention.*

***Keywords:*** *landmine issue, Croatia, Ottawa Convention*

## Introduction

The Republic of Croatia is among the 58 countries facing issues with anti-personnel landmines [1], a consequence of their use during the Croatian War of Independence (1991-1996). The contamination of land with mines has led to social, economic, developmental, and security challenges. Croatia committed to combating landmines by signing the 1997 Anti-Personnel Mine Ban Convention. The Croatian Mine Action Center (established in 1998), as the national body for mine action, was authorized to implement the obligations set forth by the Convention operationally. Priority was given to defining suspected hazardous areas. It took seven years of work by specialized teams to determine the spatial extent and scope of these suspected mine-affected areas. This was essential for establishing realistic goals for mine action in the subsequent period. Residential areas, parts of the infrastructure network, and agricultural lands were high on the list of priorities for demining. In contrast, forested and less accessible areas were scheduled for clearance in the final phase.

## Adoption and Ratification of the Ottawa Convention

The first global initiative toward a complete ban on using anti-personnel landmines occurred at a conference in Ottawa, Canada, from October 3 to 5, 1996. After finalizing the text, the United Nations General Assembly adopted Resolution 51/45 S, urging states to support the prohibition of the use, stockpiling, production, and transfer of anti-personnel landmines. To accelerate negotiations, the Austrian Government had previously circulated a Draft Agreement banning anti-personnel mines, with explicit prohibitions on their development, production, stockpiling, transfer, and use. This was followed by diplomatic efforts, particularly discussions on steps toward the ban, the definition of anti-personnel mines, verification, universality, and the choice of a negotiating body. The revised Draft Agreement was aimed to pave the way for formal negotiations and the adoption of the agreement. In late June 1997, the Belgian Government hosted the International Conference for a Global Anti-Personnel Mine Ban, an official follow-up to the 1996 Ottawa Conference. Of the 156 countries present at this conference, 97 signed the Brussels Declaration, which affirmed that the core elements of the agreement to ban anti-personnel mines included a comprehensive prohibition on the use, stockpiling, production, and transfer of anti-personnel mines; the destruction of all stockpiled mines and the removal of anti-personnel mines; and international cooperation and assistance in mine clearance in affected countries [2]. Countries that formally supported the Brussels Declaration were officially recognized as participants in the Diplomatic Conference on the Complete Anti-Personnel Landmine Ban, convened on September 1st, 1997, in Oslo, and were thus allowed to vote, while others,

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including representatives of the United Nations, were observers. At this conference, on September 18th, 1997, the Convention on the Prohibition of the Use, Stockpiling, Production, and Transfer of Anti-Personnel Mines and on Their Destruction (Ottawa Convention) was adopted. The signatory states were determined to put an end to the suffering and casualties caused by anti-personnel mine incidents, which hinder the social and economic development of affected communities. The general obligation (Article 1 of the Convention) requires signatories to a) refrain from using anti-personnel mines, b) refrain from developing, producing, acquiring, stockpiling, retaining, or transferring anti-personnel mines directly or indirectly, and c) not assist, encourage, or induce anyone to engage in any activity prohibited by the Convention. Implementation obligations (Articles 4, 5, 6, and 11 of the Convention) require signatories to destroy stockpiled anti-personnel mines, clear anti-personnel mines in suspected hazardous areas, engage in international cooperation and assistance, and regularly report on the implementation or enforcement of the Convention [3].

## The Landmine Problem in Croatia

Considering the methods and entities involved in demining operations, the resolution of the landmine issue can be divided into four periods. The first period relates to the wartime years from 1991 to 1995 when demining was carried out as part of military operations and aimed at establishing basic safety conditions for civilian movement near the frontlines. The Croatian Army and Police were responsible for demining during this time. The second period covers the post-war era until the establishment of the Croatian Mine Action Center. During this period, the Demining Act (1996) was adopted, assigning demining planning to the Ministry of the Interior. Meanwhile, humanitarian demining tasks were carried out by the state-owned company AKD "Mungos." The United Nations Mine Action Center (UNMAC) in the Republic of Croatia collected data on mine contamination and estimated the mine-affected area to be 13,000 square kilometers. The third period began with amendments to the Demining Act (1998) and the ratification of the Ottawa Convention. The Croatian Mine Action Center, as an independent public institution, took over the planning and coordination of mine action activities in Croatia, introducing a market-based model for demining operations. This period was marked by a significant increase in funding for demining and the establishment of commercial demining companies, resulting in a substantial rise in annual demining output. Comprehensive monitoring of mine action implementation began after completing a seven-year general survey aimed at precisely identifying mine-contaminated areas. The mine-affected area was then estimated at 1,174 square kilometers, which served as the basis for the National Mine Action Program for 2005-2009 [4]. It became evident that Croatia's goal of becoming mine-free was highly ambitious at the time [5], leading to the adoption of a ten-year mine action program (2009-2019). Special attention was given to marking suspected hazardous areas, with approximately 15,000 mine warning signs installed in the field. Public awareness campaigns were conducted through maps and panels displaying suspected mine-affected areas. This method of public communication was later replaced by the MISportal [6]. The fourth period began in January 2019 with a new seven-year mine action program, as the previous program had not been completed due to insufficient funding. During this time, the Croatian Mine Action Center was integrated into the Ministry of the Interior as part of the newly established Directorate of Civil Protection.

## Implementation of the Ottawa Convention

Each signatory state of the Convention committed to destroying or ensuring the destruction of all anti-personnel mines in its possession or under its jurisdiction or control "as soon as possible but not later than four years" after the Convention entered into force for that state. The Republic of Croatia destroyed all its stockpiled anti-personnel mines in 2002 (obligation under Article 4 of the Convention). When the Ottawa Convention was signed, the landmine problem in the Republic of Croatia was not precisely defined. Instead, the initial assessment was based on the UNMAC estimate, which focused on areas where military operations had taken place and were deemed unsafe for civilian movement. The Croatian Mine Action Center was responsible for precisely defining the mine threat. A comprehensive survey of the entire territory of the Republic of Croatia was completed by the end of 2004, forming the basis for the National Mine Action Program for 2005-2009. It became evident that, in many cases, minefields were not laid according to generally accepted military mining standards (e.g., record-keeping, documentation of changes, and marking). Minefield reconstruction was conducted based on analytical assessments and data from fieldwork for such cases. The clearance of minefields from areas designated for housing and infrastructure reconstruction and agricultural lands near settlements was prioritized for demining. Aligning priorities with local communities was essential for preparing annual demining plans. Humanitarian demining operated on a market-based model, with funding primarily from the State Budget and project financing by public companies for their own needs. At the same time, donor contributions were limited to the capacities of the Convention's signatory states. By the end of 2008, the mine-affected area in the Republic of Croatia was estimated at 954.5 square kilometers, prompting a request for an extension of the Ottawa Convention obligations by ten years. To this end, the National Mine Action Program (2009-2019) was developed [7]. In the early years of this program, there was no indication that it would not be fulfilled. However, as funding from the State Budget remained at previous levels instead of increasing significantly, the program's implementation was called into question. In this situation, there was no choice but to request a postponement of the Ottawa Convention obligations. The request was approved, allowing for the completion of demining by March 1st, 2026, following the adoption of a new National Mine Action Program for the period up to 2026 by the Croatian Parliament. This program is being implemented without significant deviations, and its completion within the planned timeframe is reasonably expected. Funding for humanitarian demining during this period is primarily sourced from ESI funds—program period 2021-2027—which was not practiced in the previous period. As of January 2025, the remaining mine-affected area in the Republic of Croatia was estimated at 49 square kilometers [8]. The Croatian Mine Action Center has been involved in preparing and organizing demining operations in areas managed by the Ministry of Defense, as the Croatian armed forces lack sufficient capacity for the accelerated removal of mine threats in military training areas, abandoned storage sites, and other military facilities [9]. In addition to humanitarian demining, other implementation obligations under the Convention have been met on time. International cooperation and assistance have been carried out in accordance with available resources, while mine risk education has been conducted to the greatest extent possible. Reports on the implementation of the Convention have been submitted regularly (obligations under Articles 6 and 11 of the Convention).

## Socio-Economic Impact of the Landmine Problem

In the context of social and economic development, the landmine issue can be viewed in terms of its impact on the safety of movement for people and goods and the ability to engage in various economic activities. In the first decade following the aggression against the Republic of Croatia, approximately one million citizens were forced to live and move near areas marked as suspected minefields. This led to a high number of mine incidents, resulting in civilian casualties [10]. To facilitate the return of displaced populations, in addition to the reconstruction of homes and infrastructure, clearing agricultural land and pastures of mines was necessary. The decade after the war, humanitarian demining focused on reconstructing homes, transportation, communal infrastructure, and areas close to settlements. This was essential to enable agricultural and livestock activities, which were the primary sources of income for most of the local population. The high risk faced daily by many people, coupled with limited livelihood opportunities, directly impacted the planning of mine action. Special care was taken in setting priorities aimed at creating conditions for the social and economic development of local communities. Transportation infrastructure development, particularly highways, created the preconditions for faster economic growth. Numerous economic zones were established in the counties through which the Zagreb-Split highway passes, many of which required prior demining of the areas where they were built. A significant challenge for the economy was the presence of mine-contaminated forest areas. Forestry management was restricted for over twenty years to areas outside the zones of military operations. Systematic demining of the forested regions began in the third decade of humanitarian demining efforts. The landmine problem not only posed a direct threat to human life but also hindered economic recovery and development. By addressing these challenges through targeted demining efforts, Croatia has gradually restored safety, enabled the return of displaced populations, and created conditions for sustainable economic growth. However, the process has been lengthy and resource-intensive, underscoring the long-term socio-economic consequences of landmine contamination.

## A View to the Future

The purpose of mine action was not solely demining but also to address the impact of landmine contamination on individuals and communities. This involved reducing the risk of mines and enabling a safe living environment where the landmine issue no longer hinders social and economic development. While resolving the landmine problem, it was essential to establish communication with local communities and citizens. Initially, this was done through direct contacts and the publication of overview maps showing mine-affected areas, followed by establishing the MISportal as an e-service for real-time information on mine threats. This significantly contributed to reducing mine incidents. Funding for demining was provided through public resources, and information on using these funds was made accessible to the public via annual mine action reports. The cost of demining for each project was transparently disclosed through public procurement processes [11]. Upon completion of demining operations, a certificate and map of the cleared area were issued to the local community and landowners. However, these documents were not initially available in digital format or accessible to the broader public. Considering the above, once the demining process is completed, it would be desirable to maintain the MISportal as an e-service that is now serving a different role. Even though this is not an obligation under the Convention, the portal would provide instantly available information to concerned parties as a repository of demined areas in its new role. This type of information dissemination was not available when the Ottawa Convention was drafted. The technology has progressed to such a degree that the existing information infrastructure enables the transformation of the current web GIS service to the peace-time repository of demined areas. Additionally, citizens have the right to access information to understand the history of land use in the present and the future. Through the web GIS service for demined areas, individuals and legal entities could gain insight into all areas that have undergone humanitarian demining, potentially fostering positive social and economic development. The practice has shown the need to maintain operational capabilities for responding to reports of unexploded ordnance, enabling follow-up inspections of suspected areas [12]. Croatia is very close to destroying anti-personnel mines in mined areas, with the remaining suspected hazardous areas posing a threat to civilians, planned to be cleared by 2026 [13]. Croatia has transitioned into a provider of mine action assistance, participating in international development cooperation programs and humanitarian aid initiatives, such as those in Ukraine. Further efforts should create conditions to promote the Croatian model of mine action by engaging with international organizations and bodies. This includes offering expertise and technological advancements needed to define suspected hazardous areas, prepare areas for demining, and continue specialized training for personnel involved in mine action activities. By doing so, Croatia can solidify its role as a leader in mine action and contribute to global efforts to eliminate the threat of landmines.

## Conclusion

Croatia began addressing the landmine issue immediately after the end of the Homeland War, and with the signing of the Ottawa Convention, a systematic approach to resolving the problem was initiated. A unique mine action system was established, characterized by its organizational structure, funding mechanisms, and transparency in operations. Croatia is steadily progressing toward a "Mine-Free Croatia," having become a safe country and an attractive destination for economic investments. In terms of fulfilling its obligations under the Ottawa Convention, Croatia has implemented the general provisions, completed the destruction of stockpiled anti-personnel mines, and is nearing the completion of clearing mined areas (with a deadline of 2026). The obligations of international cooperation and assistance, education, and annual reporting on the Convention's implementation remain ongoing. Croatia can assist other countries in organizing and implementing mine action activities, including developing legal frameworks, establishing mine action centers, conducting specialized personnel training, setting up e-services accessible to citizens, sharing knowledge in robotics, procuring demining machinery and equipment, and more. Domestically, it is prudent to maintain operational capabilities for responding to reports of unexploded ordinance and to continue educating the civilian population about the dangers of explosive remnants of war. In the public interest, it would be beneficial to establish a web GIS portal where citizens can access information on which areas have been cleared of mines. This could have a positive impact on the social and economic development of local communities. By continuing to build on its achievements and sharing its expertise, Croatia can further solidify its role as a leader in mine action, contributing to global efforts to eliminate the threat of landmines and explosive remnants of war.

## References


[1] International Campaign to Ban Landmines, Landmine Monitor 2024. https://backend.icblcmc.org/assets/reports/Landmine-Monitors/LMM2024/Downloads/Landmine-Monitor-2024-Final-Web.pdf (accesed on January 20th 2025.).

[2] Geneva International Centre for Humanitarian Demining (2004) A Guide to Mine Action. Geneva: GICHD.

[3] Ottawska konvencija https://narodne-novine.nn.hr/clanci/medunarodni/1998_05_7_53.html (accesed on January 20th 2025.).

[4] According to this document, in the mined areas at that time, there were 103,419 mines recorded, of which 69,346 were anti-personnel mines, and 34,073 were anti-tank mines—source: https://narodne-novine.nn.hr/clanci/sluzbeni/2009_10_120_2959.html (accessed on January 20th, 2025).

[5] In those five years, only 280.5 square kilometers were cleared of mines.

[6] MISportal has been active since 2009 and has made a significant contribution to the safety of citizens. Currently, access is available through the website of the Directorate of Civil Protection: https://civilna-zastita.gov.hr/podrucja-djelovanja/razminiranje/minska-situacija-u-rh/145 (accessed on February 12th, 2025).

[7] National Mine Action Program of the Republic of Croatia 2009-2019. Source: https://narodne-novine.nn.hr/clanci/sluzbeni/2009_10_120_2959.html (accessed on January 20th, 2025).

[8] Mine situation in the Republic of Croatia. Source: https://civilna-zastita.gov.hr/minska-situacija-u-rh/145 (accessed on January 20th, 2025).

[9] The demining of military sites and/or structures is planned to be completed by the end of 2026. Source: https://vlada.gov.hr/vijesti/297-sjednica-vlade/42217?lang=hr (accessed on February 12th, 2025).

[10] In the period from January 1, 1996, when active war operations ceased, to the present day, 428 mine incidents have been recorded, involving 606 victims, of which 204 were fatalities. Assistance to victims of mines and ERW (Explosive Remnants of War) during this period was provided under the positive regulations of the Republic of Croatia, applicable international conventions, international humanitarian law, and human rights—source: https://narodne-novine.nn.hr/clanci/sluzbeni/2023_02_21_352.html (accessed on February 12th, 2025).

[11] According to annual reports on mine action, approximately 1.1 billion euros have been spent on demining from 1998 to 2024, while an additional 75 million euros is needed to clear the remaining mine-suspected areas.

[12] According to annual reports on mine action, between 2018 and 2022, 47 reports of explosive remnants of war (ERW) were found in areas subject to demining, and 24 reports of ERW were found in areas not previously recorded as mine-suspected.

[13] According to the National Mine Action Program of the Republic of Croatia, until 2026, Croatia has the capacity and capability to conduct demining of up to 50 square kilometers annually—source: https://narodne-novine.nn.hr/clanci/sluzbeni/2023_02_21_352.html (accessed on February 12th, 2025).

# General Updates on Mine Action in Azerbaijan

*by Samir Poladov*


## Abstract

The Republic of Azerbaijan has faced significant challenges in mine clearance following the liberation of its territories. The Mine Action Agency of Azerbaijan has undertaken extensive demining operations to support reconstruction and the safe return of internally displaced persons (IDPs). This paper provides an overview of ongoing mine clearance efforts, including the scale of contamination, innovative survey and clearance methodologies, and the impact on reconstruction and regional stability.

Key topics include the estimated 1.5 million landmines in liberated territories, the discovery of improvised explosive devices, and the human toll of mine incidents, with 3,461 recorded victims. The role of international partnerships in demining operations is highlighted, including collaboration with the United Nations and the establishment of female demining teams. Additionally, technological advancements such as remote sensing and mine detection using trained animals are explored.

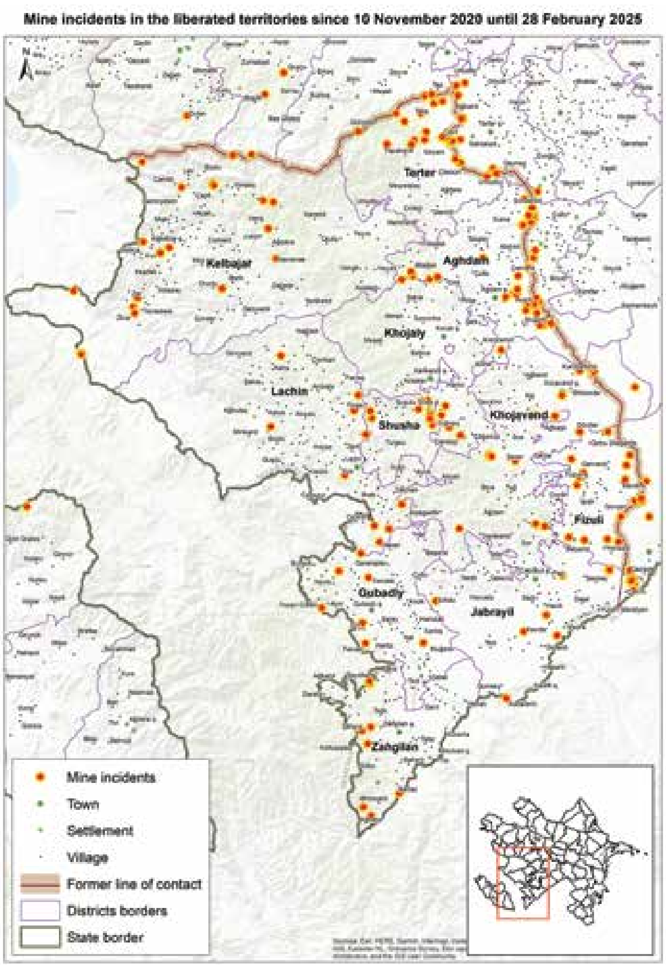
The discussion also addresses the broader implications of mine contamination on socio-economic reintegration, infrastructure development, and environmental restoration. The ongoing clearance efforts aim to enhance safety, facilitate the return of IDPs, and contribute to regional peace and stability.


## Introduction

Landmine contamination remains one of the most pressing humanitarian issues in Azerbaijan following the former conflict. The Mine Action Agency of Azerbaijan (ANAMA) is responsible for conducting, coordinating, and planning humanitarian demining activities, ensuring safe reconstruction, and enabling displaced populations to return home. This paper explores landmine contamination in Azerbaijan and its impacts, the progress of mine clearance efforts, the challenges encountered, and the methodological solutions adopted using the most effective approaches to accelerate the process.

## Scope of Contamination

Azerbaijan faces a severe landmine and ERW problem due to nearly three decades of Armenian military occupation. Landmine contamination continued even after the 2020 conflict, persisting until Armenia's full withdrawal in 2023. Surveys indicate approximately 11,667 square kilometers—13.47% of Azerbaijan's territory—are affected, with an estimated 1.5 million landmines, hindering development, reconstruction, and the safe return of former IDPs.



## Humanitarian and Social Consequences

Over the last 30 years, the cumulative toll of landmine victims in Azerbaijan is more than 3,400 people including 359 children and 38 women. Awareness programs and explosive ordnance risk education initiatives have been implemented to reduce casualties and ensure public safety.

## Demining Operations and Strategies

ANAMA has employed various demining techniques to enhance operational efficiency:

- **Manual Demining**
Highly trained deminers conduct precise and targeted mine clearance operations.

- **Mechanical Demining**
Specialized mechanical demining machines assist in large-scale clearance.

- **Mine Detection Dogs (MDDs)**
Trained dogs are deployed to detect explosives in complex environments.

- **Mine Detection Rats**
Utilizing the olfactory capabilities of rats to detect landmines.

## Impact on Reconstruction and Rehabilitation

The presence of landmines poses major obstacles to post-conflict reconstruction, including:

- Delays in rebuilding critical infrastructure such as roads, bridges, and water supply systems.
- Challenges in reviving agriculture and economic activities in contaminated regions.
- Threats to the safe return of former IDPs and resettlement efforts.
- Damage to cultural and environmental heritage, including forests and water resources.

## International Cooperation and Capacity Building

ANAMA collaborates with countries such as Turkey, Saudi Arabia, the United Kingdom, the United States, Croatia, United Arab Emirates, Japan, Canada, France, Belgium, Hungary and international organizations such as the European Union, UN agencies and International NGO's to enhance technical expertise, capacity building, EORE, implement training programs, and support gender-inclusive demining teams. Notably, the first female demining team in Azerbaijan was established under these initiatives, contributing to increased workforce diversity and community engagement.

## Conclusion and Future Prospects

Azerbaijan's mine action program is vital for national security, reconstruction, and sustainable development. Continuous investment in modern demining technologies, international cooperation, and community engagement will accelerate progress. The goal is to establish mine-free zones, enabling safe habitation, economic recovery, and long-term regional stability.

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# THREE YEARS AFTER FULL-SCALE INVASION ON UKRAINE: INSIGHTS AND LESSONS LEARNED

# NGO as a civilian safety factor

*by Đurđa Adlešič[1], Mihaela Boltižar[1],Tymur Pistriuha[2]*

Croatian experts have been sharing their extensive experience in mine action with their Ukrainian counterparts since the onset of the war in Ukraine. From the beginning, the focus has been on caution and minimizing mine-related casualties through the education of civilian population. It is essential that the method of educating civilians is adapted to the local context, as this ensures that the most at-risk target groups are reached. For example, during the migrant crisis that began in 2015, Croatia experienced cases where migrants were injured while unknowingly moving through mine-suspected areas. Therefore, continuous education and information dissemination are key to reducing the risk of casualties.

The main methods of educating civilians are: field education (face-to-face training), digital and multimedia campaigns, distribution of educational materials, school programs, and involving local communities, along with the proper marking of hazardous areas. Experience has shown that the best approach is to combine all these methods, and Association Croatia Helps does exactly that through its educational initiatives. The greatest emphasis is always placed on children for several reasons: children quickly absorb new knowledge and are eager to share it with others, especially with family members and peers. When safety information is conveyed to them through engaging and interactive methods, there is a high likelihood that they will pass it on to their parents, siblings, and friends. When children warn their parents, it often happens that a child's concern for their safety encourages the parent to pause and think more deeply about the issue.

Educating children about the dangers of mines is not only a way to protect them, but also a powerful tool for spreading safety information throughout the community. Children not only learn quickly but also have a unique ability to influence their families and peers. Creativity and connecting with positive emotions encourage easier learning and the adoption of safe habits. For this reason, Association Croatia Helps has integrated mine risk education for children with their stay in Croatia, primarily along the Adriatic coast. Through a combination of fun activities—such as sports competitions, artistic expression, and swimming lessons—and cultural-educational visits to museums and historical sites, children are also trained in explosive safety and first aid.

1 Association *Croatia Helps*
2 Ukrainian Deminers Association

Non-governmental organizations (NGOs) are key in organizing educational activities due to their ability to operate locally and focus on specialized groups within society. This approach allows them to reach various segments of society and more effectively engage with the civilian population. Local civil society organizations have the best understanding of their local context and, due to the nature of their existence, can often act faster than formal institutions.

With the support of actors such as relevant ministries and private donors, NGOs successfully serve as educators of the civilian population—acting as a connecting link between these two levels. This is the key to the success of non-governmental organizations: their reach, speed, and efficiency.

A notable example of good practice are the international development cooperation projects between Croatia and Ukraine, funded through public calls by the Ministry of Foreign and European Affairs of the Republic of Croatia. Through these projects, non-governmental organizations implement initiatives aimed at reducing the risk of casualties from mines and explosive devices.

With the support of the Ukrainian organization Ukrainian Deminers Association and other Ukrainian institutions, Association Croatia Helps has been implementing projects for several years. A key component of these projects is hosting Ukrainian children in the Republic of Croatia, with integrated education on the dangers of mines.

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