MINE ACT

MINE ACTION
2026

Book of Papers 2026

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MINE ACTION 2026

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UKRAINE – ACHIEVEMENTS, CHALLENGES AND NEEDS

Civil Society and Mine Action: Looking Back and Looking Forward

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

Mine risk education represents one of the key components of mine action, particularly in periods when mine contamination directly threatens the safety and everyday life of local communities. In this context, civil society organizations often play a distinct role due to their flexibility, close engagement with local populations, and ability to adapt to specific social and cultural circumstances.

The Association for Support and Promotion of Unity Hrvatska pomaže began its activities in 2014, operating in the field of civilian protection with the objective of reducing casualties caused by landmines and other explosive remnants of war (ERW). Target groups were identified based on actual needs and casualty data, with priority given to social groups that had experienced the highest number of incidents.

Farmers represented one of the most vulnerable groups in this regard. As demining efforts were primarily conducted in areas considered drivers of economic recovery—such as industrial zones and tourist regions—the clearance of agricultural land progressed more slowly. In attempts to resume cultivation, agricultural workers were frequently exposed to mine-related risks and accidents. They were followed, in terms of casualty rates, by forestry workers and hunters, particularly younger individuals born during or after the war who often lacked direct experience with or awareness of explosive hazards. Children were also identified as a high-risk group, but at the same time recognized as effective multipliers of knowledge within their families and communities.

The Association Hrvatska pomaže developed an innovative model of mine risk education in which Croatian Homeland War veterans serve as educators. This approach generates mutual benefits for both society and the participating veterans. On the one hand, the veterans possess specific technical knowledge related to explosive ordnance; on the other, they enjoy a high level of trust within the civilian population. This was particularly evident in areas with significant returnee populations, where communities often demonstrated greater openness toward civilian educators than toward official (uniformed) representatives. The trust placed in veteran educators by different social groups contributed to increased receptiveness among participants and to a more serious understanding of the safety messages being conveyed.

Photo 1. Mine risk education session conducted for hunters

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In order to ensure the highest possible quality of implementation, the Association Hrvatska pomaže initiated training programmes, including Training of Trainers (ToT) activities, conducted in partnership with veterans' associations. Their members participated in capacity-building sessions focused on communication and presentation skills, enabling them to effectively deliver mine risk education.

Each target group presents specific characteristics, requiring tailored approaches and pedagogical adaptation. The training therefore emphasized not only technical knowledge, but also methods of engagement adapted to different audiences. Upon completion of the programme, the veterans were prepared to deliver mine risk education to diverse groups within the civilian population, adjusting their lectures according to age group, occupation and level of professional exposure to risk, as well as cultural and ethnic background.

Work with children represented a particularly important component of the programme. Mine risk education for children was implemented not only in schools but also through integrated programmes combining educational activities with psychosocial support and structured recreational activities. In addition to Croatian children, the Association worked with children from Bosnia and Herzegovina, Armenia, Iraq, and other mine-affected contexts. Some of these children had unfortunately already experienced mine-related incidents, while others were exposed to peers whose experiences illustrated the severity of explosive hazards and the potential consequences of unsafe behaviour.

Although working with such diverse and, at times, highly sensitive groups required careful facilitation, this integrated approach proved effective in strengthening children's risk awareness and fostering greater caution in mine-contaminated environments.

Through its experience in working with Croatian children from war-affected areas in the field of psychosocial empowerment, the Association developed a programme that it continues to implement and further refine. This model has subsequently been transferred to mine-affected countries through various international cooperation initiatives.

Photo 2. Children from Iraq participating in activities in Croatia

Looking Forward: International Cooperation and Knowledge Transfer

With the completion of the demining process in the Republic of Croatia, a new phase of civil society engagement in mine action has emerged. Rather than focusing on the direct implementation of activities at the national level, increasing emphasis is now placed on the transfer of knowledge, experience, and good practices to other countries facing significant mine contamination.

Croatia's experience as a country that has successfully completed the full cycle of mine action represents a valuable resource for the international community. Recognizing this need, in 2021 the Association Hrvatska pomaže established a partnership in Ukraine with the NGO Ukrainian Deminers Association. Since then, cooperation with Ukrainian partners has focused on the transfer of Croatian expertise in various components of mine action.

In addition to its initial partners involved in international development and humanitarian cooperation projects funded by the Ministry of Foreign and European Affairs of the Republic of Croatia, the Association has gradually expanded its network, developing further partnerships with organizations across Ukraine.

Photo 3. Mine risk education sessions conducted in Ukraine

Photo 4. Training of Trainers (ToT) session organized for SESU in Croatia

Educational sessions were organized in partnership with the Ukrainian Deminers Association in Ukraine, including Training of Trainers (ToT) for members of the State Emergency Service of Ukraine in Croatia, as well as numerous psychosocial support programmes for children.

From the beginning of our work with Ukraine in 2015—when initial mine risk education sessions were conducted for hunters (hunting associations from Ukraine) and the first two groups of Ukrainian children visited Croatia—up to the time of writing, more than 870 Ukrainian children have participated in psychosocial empowerment programmes in Croatia organized by the Association Hrvatska pomaže, incorporating integrated mine risk education.

This approach often plays an irreplaceable role in mine action, owing to the flexibility and rapid response capacity of the civil society sector. Although the Republic of Croatia was officially declared mine-free as of March 2026, the civil society sector continues to contribute to risk reduction and to strengthening the resilience of war-affected communities.

Photo 5. Ukrainian children participating in programmes in Croatia

INCLUSION OF NOVEL TRAINING / CAPACITY-BUILDING APPROACHES

From Support to Lead – the capacity development experiences of UDA and MAG in Ukraine

by Tymur Pistriuha[1], Niamh McNamara[2]

Abstract

Capacity building of people, authorities or operators can mean many different things and often limits itself to short term training, sub-contracting or provision of equipment. This presentation and paper will chart the relationship between UDA and MAG in Ukraine since 2022, and UDA's journey from being a supplier to an international mine action organisation to a leading partner on joint bids. It will take into consideration active and passive capacity building, reflections on mandatory versus optional localisation strategies from donors, tools and lessons learnt. It will look forward to what capacity building remains – including UDA's upcoming mechanical accreditation – and how organisations can define when capacity is 'built' including what lessons can be learnt from the sustained national capacity approach in Croatia.

Introduction

Ukraine is widely understood to be one of the most mine-affected countries in the world with 946km² of land[i] confirmed or suspected to be contaminated with extensive and varied mine and other EO contamination. Ukraine is also a pivotal country for global food production and regional security; prior to the full-scale invasion in 2022, Ukraine's agricultural production fed 400 million people worldwide annually. As a result of occupation, damage or explosive contamination, nearly one-third of previously cultivated agricultural land in Ukraine has become inaccessible to farmers. The response to the mine contamination has also been at scale by national and international operators across government, commercial, national and international NGO operators. Between 2022 and 2025 the number of entities registered with the NMAC as mine action operators rose from 20 to 132.[ii] In this context, how can capacity development take place in a meaningful way that reflects capacity, urgency, spread and diversification of actors and how could it be considered achieved or completed?

Background

The Mines Advisory Group (MAG) is a global humanitarian and advocacy organisation that finds, removes and destroys landmines, cluster munitions and unexploded bombs from places affected by conflict. MAG also provides education programmes, particularly for children, so people can live, work and play as safely as a possible until the land is cleared. MAG also works in communities to reduce the risk of armed violence through weapons and ammunition management programmes which keep guns and munitions safe and secure. Since 1989, MAG has helped over 20 million people in 70 countries rebuild their lives and livelihoods after war.

MAG has been operational in Ukraine since 2022 and in that time has:

- cleared 930,700 m² of land
- reduced 1,342,437 m² of land
- identified 36 hazardous areas totalling 6,623,518 m² for future clearance
- delivered 13,033 explosive ordnance risk education (EORE) sessions to 112,139 people
- reached over 40 million people through digital risk education campaigns

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MAG currently employs 453 staff members (426 national and 27 international), including 33 operational teams and support functions.

The first and biggest national non-governmental mine action organization – The Ukrainian Deminers Association (UDA) – was founded in November 2018. UDA is listed in the National Mine Action Authority database as a certified mine action operator as well as in the database of the Mine Action organizations of the Geneva International Center for Humanitarian Demining and is a permanent member of the UN Protection Cluster and the Mine Action Area of Responsibility (AoR, former Mine Action sub-cluster) and others. Since 2018 UDA has:

- trained more than 165,000 people in mine safety through face-to-face sessions and online platforms
- processed 1,492 victim assistance requests, providing cash support to 383 survivors, psychological assistance to 53 individuals, legal aid to 23 people, and referrals to specialized partners for 71 beneficiaries, while 800 people participated in mental health and psychosocial support

In 2025 UDA

- conducted non-technical surveys (NTS) covering 278.9 million m^2 across Ukraine
- submitted 438 official NTS reports
- supported the release of 19 hazardous areas totaling almost 1.4 million m^2, in Kyiv, Kharkiv, Dnipropetrovsk, Donetsk, and Kherson oblasts.
- employs 149 staff members

UDA is funded both directly by institutional donors (e.g., Global Affairs Canada) and through partnerships with international NGOs. **UDA is currently implementing 15 active projects** in collaboration with various organizations, including: MAG, UN OCHA, UN Women, Save the Children, INTERSOS, Canada-Ukraine Foundation, Danish Support Group Ukraine, Swiss Foundation for Mine Action, Humanity & Inclusion (HI), GlobalGiving, Croatia Helps, CESVI, among others.

Partnership Journey

MAG and UDA began working together in 2022 immediately after the full-scale invasion by the Russian federation. Initially MAG sub-contracted UDA to provide EORE whilst MAG was establishing itself in Ukraine and also provided some equipment through early donations. As the largest and most established HMA operator in Ukraine at this time UDA had multiple options. This period reflected what is often called capacity building but, in reality, is the establishment of a relationship for access or convenience for both parties – whether geographic, legal, financial, technical, credibility or contextual. Although MAG undertook a due diligence process with UDA this did not include a plan to provide further development to fill any gaps noted. As 2023 progressed and both need and opportunity were present, the partnership continued to develop; in this time, donors in particular have pressed for localisation and capacity building, although also often with differing definitions and motivations.

UDA has prioritised capacity development as a core strategic direction since its establishment in 2018. From the beginning, UDA understood that building a strong national mine action operator requires more than technical training — it requires institutional systems, leadership, and trusted partnerships.

UDA's early cooperation with Croatian experts and the NGO Croatia Helps from 2020 provided valuable operational foundations and exposure to post-conflict European experience. However, a significant acceleration of UDA's institutional growth began in May 2022, when UDA and MAG strategic partnership was launched. Since June 2022, when the first joint EORE project started, this cooperation has evolved into a comprehensive and truly strategic partnership. Through joint project implementation, operational mentoring, quality management alignment, and structured donor compliance processes, MAG has played a key role in strengthening UDA's institutional maturity.

What has worked particularly well is the "learning by doing" approach. Joint field activities, shared planning, and continuous professional dialogue have strengthened not only operational capacity but also governance systems, financial accountability, safeguarding, and long-term strategic thinking.

At the technical level, MAG has supported UDA through embedded technical oversight, support and mentoring, training in battle area clearance (BAC), and basic demining, which included technical survey and manual mine clearance techniques, and equipment provision to support more efficient clearance activities. Lessons were learnt through MAG's partnership with a national HMA operator in Azerbaijan and the same technical advisor was able to work on both projects bringing multiple layers of experience to the work.

At the institutional level MAG and UDA jointly identified capacity development needs based not only on MAG's due diligence of UDA, but also on UDA's perceived needs and priorities. The areas covered by the capacity development plan have been logistics and procurement, security, anti-corruption, information management, and project cycle management, especially regarding proposal writing and reporting.

In parallel, MAG has supported UDA to strengthen their gender and inclusion and conflict sensitivity approaches through dedicated studies, training and action planning. The support provided has not been limited to training sessions and workshops, MAG has and will continue to provide coaching, mentoring, and on-the-job training (OJT) to UDA's staff.

The OJT training encompass various methods, including demonstrations, shadowing, and job rotation allowing UDA to gain hands-on skills and procedures via direct experience in the work environment, thus providing a holistic approach to strengthening UDA's capacities.

The partnership has delivered £5.7m to UDA, which equates to 21% of applicable funding. In January of 2026 UDA submitted and was successful in a bid to the UN's WFP where MAG plays a secondary, sub-contracted role in limited delivery, thus the contractual balance of the partnership is starting to shift. In the course of the next three years with Swedish support, MAG will support UDA gaining their mechanical demining accreditation and then donate a demining machine following OJT and mentoring. In another pending bid UDA has been invited to join a localisation advisory committee for MAG to facilitate replication of this level of integrated, multi-factored partnership in other countries.

Reflections and Future

Importantly, the partnership has been based on trust, transparency, and mutual respect, which are essential elements of genuine capacity development.

At the same time, capacity development remains a long-term investment. It requires predictable multi-year funding, continuous leadership development, and systematic integration of advanced capabilities such as mechanical demining, Animal Detection Systems, drone technologies, and other innovative tools.

In our view, capacity development is never fully completed. However, it can be considered institutionally mature when a national organisation demonstrates sustainability, operational in de-pendence, compliance with international and national mine action standards, diversified funding streams, and strong internal governance structures. But partnership between international and national organisations, like MAG–UDA, is not only about capacity development of the local organisation, it is a win-win cooperation when both organisations learn from each other, grow together, and keep pace with the times.

In time the partnership will lead to a strong and sustainable mine action capacity in Ukraine, which will set the example to others on how create equal partnerships beyond sub-contracting for access or regulatory ease or to meet a donor requirement.

i Ukraine Mine Action Newsletter - Issue 6, 2026-02 EN.pdf - Google Drive
Demine Ukraine Newsletter Issue 6, February 2026

ii Ukraine Mine Action Newsletter - Issue 6, 2026-02 EN.pdf
Demine Ukraine Newsletter Issue 6, February 2026

EOKHUB Directory: A Verified Knowledge Exchange Platform for the Global EO Sector

by Branislav Jovanović[1]

Abstract

This paper introduces the EOKHUB Directory, a quarterly-verified digital platform designed to serve as a **centralized intelligence nexus** that synthesizes multi-stakeholder data. By providing a framework for **community-driven verification** and shared accountability, the Directory acts as a collaborative bridge across information silos. It allows practitioners to contribute to a growing body of decision-grade intelligence, facilitating safer partnerships and technical collaboration in active conflict zones.

Introduction: The information challenge

In an era of information overload, the EO sector operates at the intersection of extreme risk and fragmented data. Traditional landmine contamination—characterized by predictable signatures—has increasingly been supplanted by IEDs that incorporate anti-handling measures, minimize metal content to evade detection, and evolve rapidly in response to countermeasures.

Statistical reporting indicates that civilians account for the majority of IED casualties, underscoring the urgent need for accurate, field-grade technical intelligence and verified organizational capability data.

Since 2019, EOKHUB has operated as an independent platform dedicated to "bringing knowledge to the field." However, systemic failures in humanitarian information management—where static catalogues become obsolete the moment they are printed—necessitated an evolution toward a dynamic, continuously maintained, and verifiable directory model.

1 EOKHUB, eodworld@gmail.com

The genesis of the EOKHUB Directory

Throughout 2025, EOKHUB transitioned from a magazine format to a comprehensive directory to address siloed intelligence in post-conflict regions. The platform is built on four principles:

1. **Voluntary participation:** Organizations represent operational reality rather than marketing aspiration.
2. **Quarterly verification:** Entries undergo at least four review cycles annually to maintain technical accuracy and relevance.
3. **Shared accountability:** EOKHUB assumes editorial responsibility for verification, reflecting shared-responsibility models used in other high-risk domains.
4. **Community validation:** Field professionals contribute to verification, strengthening "ground truth" through peer experience.

Core verification pillars

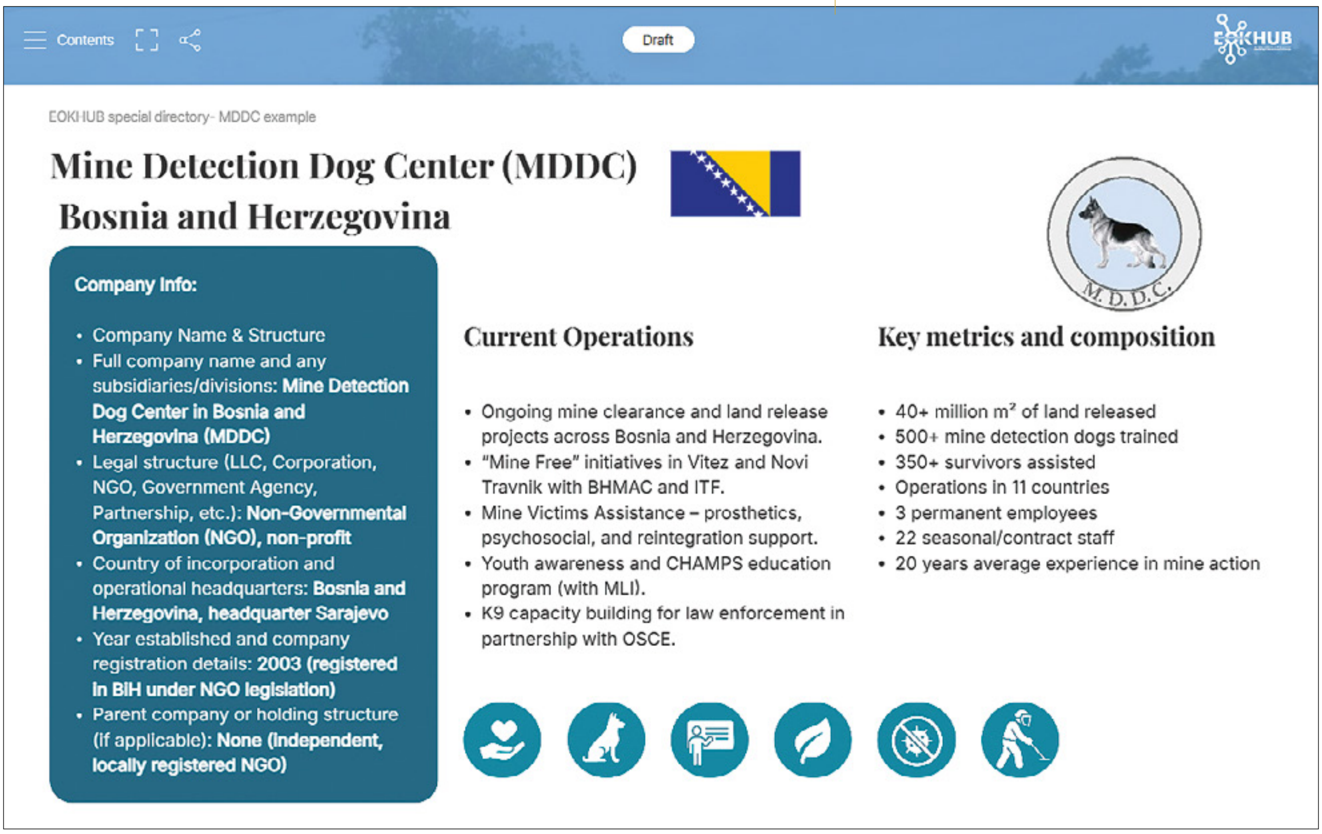
To maintain integrity, EOKHUB applies a four-pillar verification protocol:

- **Technical specifications:** Cross-referencing equipment and service claims with field reporting, certificates of conformity, and credible documentation.
- **Capability claims:** Specialized expertise (for example, underwater EOD or AUV deployment) must be supported by documented operational evidence.
- **Personnel credentials:** Subject matter experts (SMEs) are confirmed through professional networks and institutional validation to reduce the risk of unvetted "expert" positioning.

- **Community feedback:** A peer-to-peer layer of trust, informed by professionals who have worked alongside listed organizations.

The objective is not simply to publish profiles, but to create verification paths that allow stakeholders to assess credibility and reduce uncertainty in high-consequence decisions.

Illustration 1: Example of an organisation page



The digital core: Why Turtl

Static publications cannot keep pace with shifting conflict dynamics or evolving demining technologies. EOKHUB selected the Turtl platform for several strategic reasons:

- **Dynamic updating:** Amendments can be deployed immediately without reprinting.
- **Security:** ISO 27001-aligned security posture and encrypted data handling support professional expectations for sensitive B2B environments.
- **Behavioural analytics:** Deep engagement signals allow EOKHUB to understand reader intent, identify high-demand topics (for example, mechanical demining or UAV-based magnetometry), and refine information pathways accordingly.

In practice, this architecture supports a living repository: one that can be updated, verified, and navigated as operational needs change.

Stakeholder architecture and use cases

The Directory is structured to reflect the distinct information needs of the EO ecosystem.

Stakeholder	Primary use case	Value driver
Procurement specialists	Vendor identification and capability comparison	Risk reduction in sourcing and supplier selection
Journalists	Background research and expert sourcing	Accuracy in reporting on complex technical threats
Decision-makers	Strategic planning and partnership evaluation	Geopolitical risk mitigation and resource optimization
Researchers	Institutional mapping and collaboration	Longitudinal data access and peer validation
EO professionals	Technical exchange and networking	Methodology sharing, career pathways, and collaboration

Procurement in humanitarian operations is often cited as a dominant cost driver. In EO, where outcomes are difficult to define and supplier failure carries high consequences, verified capability claims and clearer organizational mapping reduce "leakage" to unvetted or off-contract suppliers.

The key personnel debate: Decision-makers and SMEs

One of the most consequential design questions behind the Directory was deceptively simple: **who counts as key personnel?**

In EO operations, success depends on both strategic coordination and granular technical expertise. Procurement officers often need decision-makers to align contracts, governance, and organizational intent. Technical teams need SMEs for collaboration on device types, environments, and methodologies.

The Directory therefore maps personnel with a dual lens:

- **Leadership and decision-makers** for governance, partnerships, and procurement alignment
- **Technical leads and SMEs** for operational problem-solving and knowledge exchange

This structure also mitigates personnel transition risk by supporting continuity when individuals move roles or organizations.

Future trajectory: Toward an antifragile knowledge commons

As the EO community prepares for 2026 and beyond, the Directory's development priorities include:

- **AI-assisted verification loops:** Behavioral integrity checks and anomaly detection to flag inconsistencies in reported data.
- **Regional hubs:** Localized intelligence for emerging hotspots, cross-verified against global standards.
- **Impact auditing:** Standardized measures for safety culture and community trust, informed by field feedback.

The strategic goal is an antifragile knowledge commons: a system that becomes more reliable as it is used, tested, and continuously updated.

Conclusion

The EOKHUB Directory exists because the sector can no longer afford the cost of informational uncertainty. By moving toward a quarterly-verified, digital-first model, the global EO community strengthens the foundations for safer procurement, more credible partnerships, and faster operational learning.

In the pursuit of a safer world, accuracy is not a luxury—it is an operational necessity. The EOKHUB Directory aims to bring the right knowledge to the field at the right time.

Demining Apron, made in Lithuania.

INSTITUTIONAL / MARKET-BASED MODELS AND GOVERNANCE CHALLENGES

General Updates on Mine Action in Azerbaijan

by *Ramil Azizov*[1]

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 more than 1 million landmines in liberated territories, the discovery of improvised explosive devices, and the human toll of mine incidents, with more than 3,400 recorded victims.

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 former 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 population 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

Surveys indicate approximately 11,667 square kilometers, 13.47% of Azerbaijan's territory, are affected, with an estimated more than 1 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 362 children and youth, 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.

1 Mine Action Agency of the Republic of Azerbaijan (ANAMA); ramil.azizov@anama.gov.az

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.

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.

Zimbabwe Update on Article 5 Implementation

by *Colonel Cletus Maregere*[1]

Introduction

Zimbabwe had envisaged completing demining programme by 31 December 2025. However, due to funding cuts, natural disasters in the form of cyclone Idai, and the devasting effects of Covid-19 and equipment shortages, this is no longer feasible. In this regard, the country was granted an extension upto 2030. Following the funding cuts by USA, Anti-Personnel Landmine Detection Development Product (APOPO) ceased operations in country. To date, Zimbabwe has three (03) International Non-Governmental Organisations (INGOs) and one Zimbabwe National Army demining entity operating in the country. The INGOs are hazardous Area-Life Support Organisation (HALO) Trust, Nowergian Peoples' Aid (NPA) and Mines Advisory Group (MAG) and the Army entity, which is National Mine Clearance Unit (NMCU).

State of Minefields in Zimbabwe

The inherited minefields covered an area of approximately 310.65km^2, with a linear distance of approximately 850kms.

Landmines have had a significant and detrimental impact in Zimbabwe, particularly in regions affected by past conflicts, such as the liberation war in the 1970s. The presence of landmines poses serious risks to civilians, hindering access to land for agriculture, which is crucial for food security and livelihoods. Efforts to clear landmines have been ongoing, but challenges remain due to funding, technical expertise, and the sheer scale of contamination.

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Progress To Date

Our mine action programme is guided by the National Mine Action Strategy. The current Strategy, which expired on 31 December 2025, presented the overall vision, mission, goals and objectives of Zimbabwe's mine action programme for the period 2018-2025. Following the country's granting of requested extension, an updated National Mine Action Strategy 2026 – 2030 is being formulated. The strategy's timeline will correspond to Zimbabwe's Article 5 Extension Period of clearance obligations under Article 5 of the Anti-Personnel Mine Ban Convention (APMBC).

As at 31 January 2026, the area cleared since independence amounts to **301,34 km²** which translates to **97%** total area released. The remaining contamination is at **9,31 km²** translating to **3%** to be tackled up to December 2030.

Exchange Visit

Zimbabwe had the opportunity to host three national authorities, thus Ethiopia, Angola and Guinea Bissau in March and September 2025. The main purpose of the visits was to share information on how Zimbabwe coordinates with operators and other government entities. As a way of reciprocating, in November 2025, Guinea Bissau invited Zimbabwe to a working visit, which was aimed at showing commitment and seeking ground guidance on how to implement lessons learnt from Zimbabwe's visit. The visit to Guinea Bissau is still pending and will be conducted once all logistical arrangements are in place. As we approaching completion of mine clearance, the country is expected to visit other countries that have completed mine clearance to learn how they have managed the residual risk contamination and post clearance related matters.

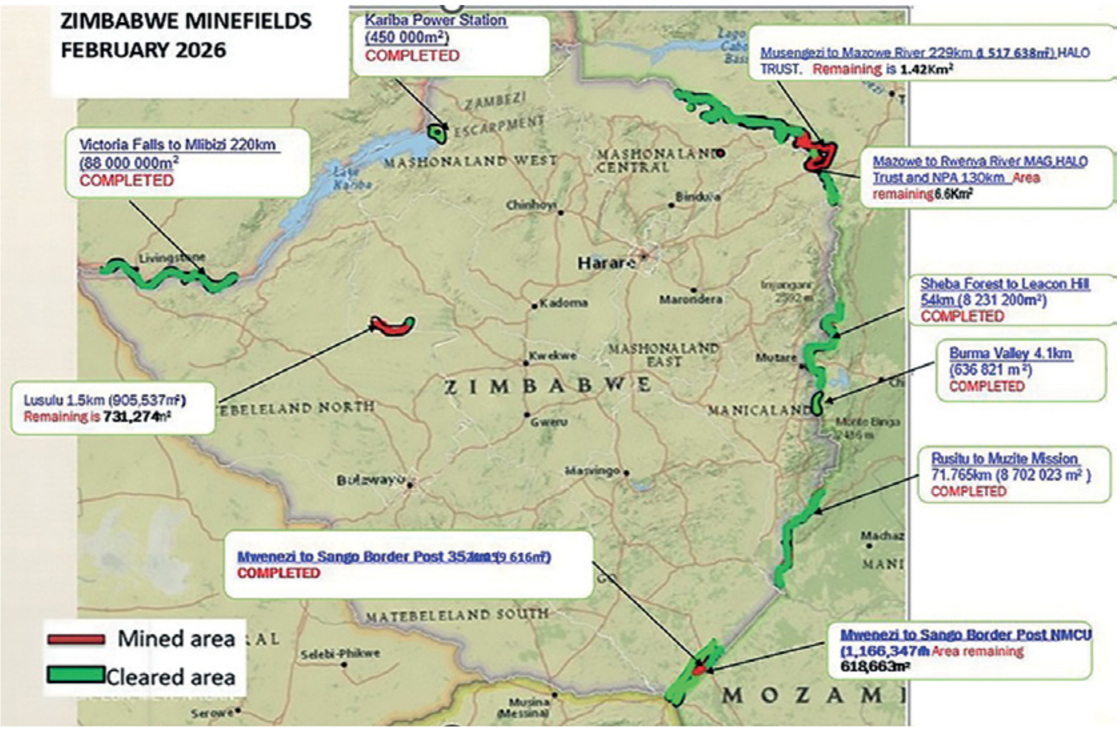


Photo: Map showing the minefields and remaining challenges

Capacity Building

Capacity building plays a crucial role in Zimbabwe's demining programme, focusing on the sustainable development of local expertise and the operational effectiveness of the Zimbabwe Mine Action Centre (ZIMAC). This involves comprehensive training programmes for local community members and ZIMAC staff, ensuring they are equipped with the necessary skills and knowledge to conduct safe and effective mine clearance operations. Both local and international training courses provided by operators accredited to Zimbabwe and institutions, such as the Geneva International Centre for Humanitarian Demining (GICHD), are essential to this initiative. By participating in these courses, trainees gain insights into best practices, advanced demining techniques, and safety protocols. Additionally, investments in equipping ZIMAC offices with modern tools and resources enhance our operational capabilities, facilitating more efficient coordination of demining activities. Together, these efforts foster local ownership and sustainability in the mine action ecosystem, ensuring that Zimbabwe is better prepared to address the challenges posed by landmines and unexploded ordnance.

Government Commitment

Zimbabwe is committed to achieving its obligations. The government's decision to wholly fund ZIMAC and NMCU through the Annual National Budget underscores its commitment to effective management of the mining sector. However, this funding approach also necessitates careful oversight and strategic planning to mitigate potential challenges while maximising the positive impacts on the demining sector and broader economic development. It is pleasing to note that in 2025 the government disbursed US$2 million dollars it pledged and procurement of equipment to fully capacitate NMCU is currently underway. Government does everything possible with the resources available against completing national needs. Additionally, the country continues to plead with our donors for continuous and increased support, and also solicit for others to come on board. The birth of linking mine action with community resilience projects being spearheaded by UNDP is also a noble initiative, which has full support of the government.

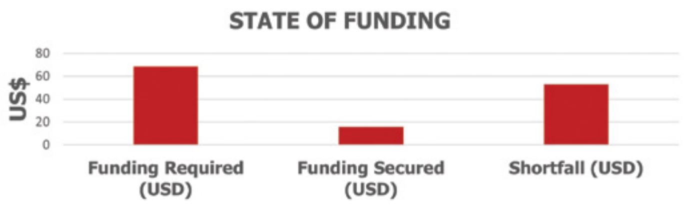
International NGOs are doing their best on the uneven ground of donor funding challenges. Following funding cuts from some donors, Anti-Personnel Landmine Detection Development Product (APOPO) halted its operations in the country in March 2025. Currently, Zimbabwe has three International Non-Governmental Organizations (INGOs) and one Zimbabwe National Army demining entity operating in the country. The INGOs include the Hazardous Area Life Support Organisation (HALO Trust), Norwegian People's Aid (NPA), and Mines Advisory Group (MAG). The Zimbabwe National Army demining entity is the National Mine Clearance Unit (NMCU).

Mobilisation of Resources

In February 2025, Zimbabwe in collaboration with the ISU and support from the EU, organized a national stakeholder dialogue on Humanitarian Demining and Victim Assistance. The dialogue aimed to update stakeholders about the current situation in Zimbabwe and discuss Zimbabwe's needs for increased support.

Graph of the funding gap

Funding Required (USD)	Funding Secured (USD)	Shortfall (USD)
$68.3 million	$15.52 million	$52.78 million



Notwithstanding positive signals, Zimbabwe will require support as soon as possible to stay on track and avoid delays in implementation. The country received funding boast from Japan through UNDP. These funds will see the birth of a programme linking demining with Sustainable Development Goals in Rushinga and Mudzi Districts where HALO trust and MAG are operating.

Challenges that Affected Zimbabwe Programme

Zimbabwe like any other State Parties was affected by natural disasters. Furthermore, there was a drastic cut in funding to our demining partners, leading to capacity reduction. This led to cessation of operations by Anti-Personnel Landmine Detection Development Product (APOPO) while other three (03) international demining organisations accredited to Zimbabwe had to lay-off a sizeable number of demining teams.

Conclusion

Apart from the challenges that were faced by the nation, The Zimbabwe Government remains fully committed to meet its obligations under the APMBC Convention. This will be necessitated by the maintaining or increasing the current funding. However, the challenge is beyond the Government's resources and as such, international assistance is highly sought. Also, the government is re-equipping NMCU to speed up its momentum and cater for residual risk contamination. We'd like to thank our donors, the GICHD and the ISU, for their ongoing support of our operations.

Energy Connects

JANAF

R&D AND THE APPLICATION OF ADVANCED TECHNOLOGIES – AI, ROBOTICS AND MULTI-SENSOR APPROACHES

Methodological challenges in the approach to complex humanitarian demining

by *Marko Mladineo[1], Nenad Mladineo[2], Katarina Rogulj[2], Davor Laura[3]*

Abstract

There are currently more than 60 different conflicts of lesser or greater intensity active in the world. These conflicts will generate many mine-suspected areas. A special problem represents Ukraine, where, assuming a quick end to the war, the world community will be faced with the challenge of complex demining problem on more than 139.000 square kilometers of mine-suspected and UXOs areas. There are certainly many experiences from various countries, including Croatia, but the complexity and size of the problem in Ukraine is not comparable to anything solved so far in humanitarian demining. Documents from leading world institutions in humanitarian demining, such as GICHD and UNDP Mine Action Team, state that the key problem is to have demining priority-setting, in order to obtain the most favorable ratio of invested funds and achieved benefits. The documents indicate that priority-setting in the national mine action program requires the unification of a number of interrelated processes and decisions. This paper will highlight possible methodological approaches using Decision Support Systems (DSS) by combining Multi-Criteria Analysis (MCA) and complex GIS tools. The goal is to unify the complex characteristics of the problem into one efficient and transparent information system for managing recovery and priority-setting in humanitarian demining, with the aim of post-conflict reconstruction of the country and its social and economic rehabilitation. Such an information system must support a multi-level approach (strategic, tactical and operational). Where each level has its own sets of criteria that are generated from GIS layers, grouped into homogenous zones and evaluated with the multi-criteria analysis algorithm, to support and improve human decision-making.

Keywords: humanitarian demining, decision support system, multi-criteria analysis, GIS, priority-setting

Introduction

The ongoing conflicts in the world, estimated at more than 60, are generating suspected hazardous areas (SHAs) consisting of mine-suspected areas and areas with unexploded ordnances (UXOs). The conflict in Ukraine is representing a special problem due to a size of the front line that is resulting with enormous SHAs. At this moment, more than 139.000 square kilometers of territory [1] are SHA consisting of huge mine-suspected areas and UXOs areas. For comparison, that is literally more than two total areas of the Republic of Croatia.

Since Croatia is the country with enormous experience in humanitarian demining [2], some of that experience is used in this research to present an approach to address complex humanitarian demining problems. In the late 1990s and beginning of 2000s, a very efficient system for demining priorities selection was developed. It was using the multi-criteria analysis PROMETHE method in combination with GIS platforms [3]. The development was continued in the European FP7 project TIRAMISU (Toolbox Implementation for Removal of Anti-Personnel Mines, Submunitions and UXO) from 2012 to 2015. The methodology for demining priorities selection was elaborated in more detail, and new Web GIS application was developed [4], which was widely used in the following years by the countries with mine-suspected areas (Fig. 1).

For more than two decades, the documents of the world's leading institutions in humanitarian demining, such as GICHD (Geneva International Center for Humanitarian Demining) and UNDP

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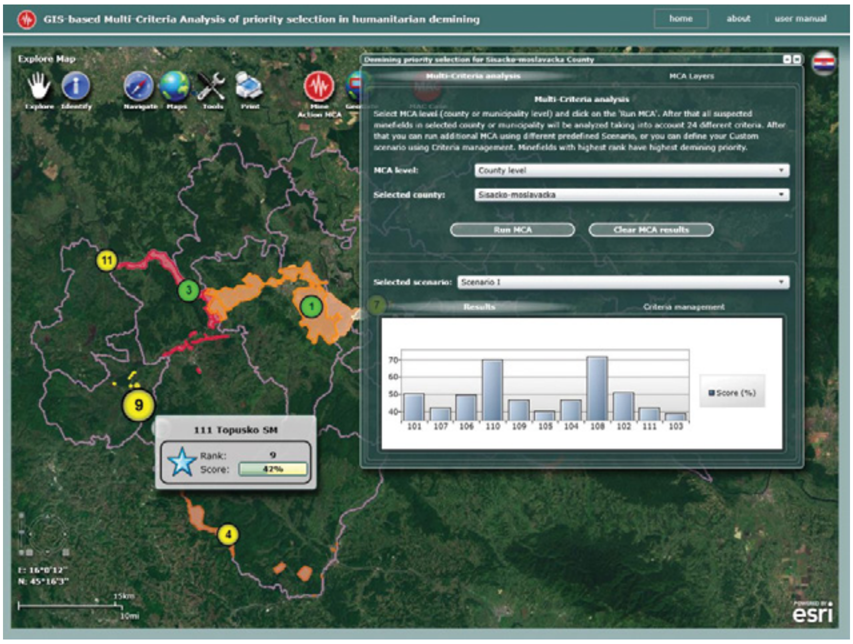

Figure 1: Web GIS application developed within the TIRAMISU project

Mine Action Team, agree that key problem is the proper setting of demining priorities in order to obtain the most favorable ratio of invested funds and achieved benefits [5]. It has been indicated that setting priorities in the national mine action program requires the unification of a number of interconnected processes and decisions. The national mine action programs may have excellent procedures for prioritizing tasks, but to provide the greatest value for money, they must establish a coordinated process that ensures that the most funding is allocated to the most severely affected regions.

Recently, one such a priority setting platform was developed in Ukraine: GRIT (Ground Rehabilitation through Innovation Technologies), which is a national big-data platform for smart demining and land recovery planning [6]. It combines different data-sources including data on soil types, regional economic activity, the condition of social infrastructure, the number of people in some community, etc. The GRIT platform was developed as part of a pilot project for prioritization in humanitarian demining in Kharkiv region.

From the available information about the GRIT platform, it is not possible to determine whether the system has developed approach to identify different hierarchical levels of mine-suspected areas, or whether the prioritization criteria sets are defined for each of the hierarchical levels. These issues are discussed in this research with focus on Decision Support System (DSS) and advanced GIS tools.

Methodology

The goal of this research is to unify the complex characteristics of the problem into one efficient transparent information system for recovery management. With focus of selecting priorities in humanitarian demining with the aim of post-conflict reconstruction of the state and its social and economic rehabilitation [7]. Such an information system must support a multi-level approach with at least three levels (strategic, tactical and operational), where each level has its own sets of criteria that are generated from GIS layers. These layers and criteria are used by advanced algorithm for multi-criteria analysis to support and improve human decision-making.

When dealing with multi-level approach it is obvious that mine-suspected areas have to be unified with certain logic, especially on strategic and tactical level. One possible approach is to form "homogeneous zones" [8] consisting of larger number of mine-suspected areas that have some common characteristics (for example: density of landmines and UXOs, vegetation cover, economic importance, etc.). These and other characteristics will be used as criteria set in MCA to select demining priorities. Nevertheless, these characteristics belong to different GIS layers, therefore advanced GIS tools can be used for automated process of formation of "homogeneous zones" and extraction of data about them. An example of the concept of hierarchical levels is presented in Fig. 2.

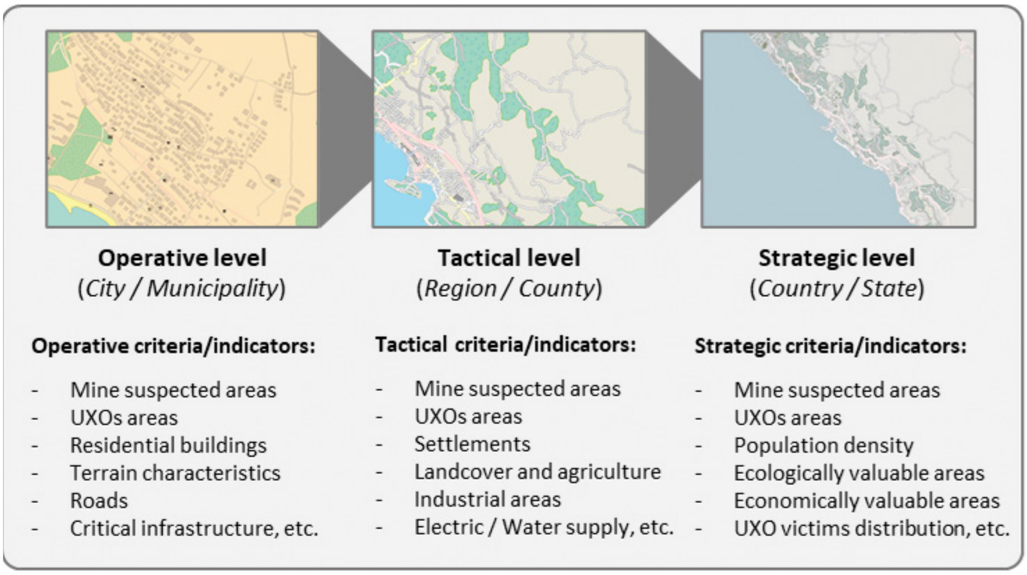

Figure 2: Concept of hierarchical levels with different criteria (indicators) sets

As presented in Fig. 2, "homogenous zones" and criteria used on different hierarchical levels want to cover following details and answer following questions:

- *Strategic level* – Country/State level, on which all important data and indicators are aggregated and evaluated to make strategic decisions: What? Where?
- *Tactical level* – Region/County level, on which all important data and indicators of a single region are aggregated and evaluated to make tactical decisions: Who? What? Where?
- *Operative level* – City/Municipality level, on which all important data and indicators of a single municipality are evaluated to make operative decisions: Who? What? Where? When? How?

Results

Based on the experience in humanitarian demining in Croatia, the multi-level and multi-stakeholder decision support system is proposed for quick response and resilience building in the post-conflict mine action and post-war rebuild and recovery operations.

The idea is to combine all important spatial data and real-time data with powerful tools for multi-criteria analysis and GIS-based big data analytics, thus enabling successful mine action management together with rebuild and recovery operations. To achieve these ambitious aims, the proposed DSS consists of four different layers:

1) *Operational layer* – provides all important data and apps for the end-users from country's civil and military institutions. The end-users, depending on their organizational role, can also have permission to edit data. The field data collection is a primary reason to edit data and it represents manual data input from reports about UXO and damage, or reports about personnel, vehicles and equipment distribution. Beside Mobile apps that can be used for field data collection, an automated data collection through Internet of Things (IoT) via MQTT protocol can be considered, as well.

2) *Data layer* – should be based on spatial database (GIS), since more than 80% of decisions are spatial decision. Considering security reasons, it is better to have decentralized database, therefore BlockChain database should be used. Beside the BlockChain database for user profiles, an intention is to have a BlockChain database for spatial data, as well. It is, so called, GeoBlockChain which records not only that some value or property changed, but it also records where the change occurred. However, many GIS data (imagery, etc.) are memory consuming, therefore classic Database Server should be used for that kind of data. Another important aspect is connection to satellite imagery and similar data, and country's civil and military institutions data. The specific data adapters should be designed to allow interoperability and data synchronization by using WFS, WMS or KML standard.

3) *Cognitive layer* – many data collected on field could eventually become big data, so AI and GIS-based big data analytics is needed for data clustering and trend prediction of important indicators. Another important aspect is the multi-criteria analysis algorithm which could automatically fill criteria matrix by extracting the spatial and non-spatial data from the database, providing the ranking of alternatives in cases of priority-setting for demining operations or infrastructure rebuild operations, etc.

4) *Managerial layer* – the top of the system are maps and apps for managerial purposes. The awareness map about UXO and damage should be open for public, and all other maps and apps should be non-public. The situation maps (with data about infrastructure, military, etc.) should be combined with decision-making maps (for priority-setting in rebuild or demining actions) and hubs (dashboards with tracking and prediction of important indicators) in order to secure transparent strategic planning and execution of operations.

Conclusions

It is not hard to conclude that landmines and UXOs contamination is one of the main obstacles to economic recovery and other types of progress in post-war recovery. Unfortunately, due to ongoing conflicts in the world, the need for humanitarian demining is increasing. The primary goal of mine action is to clear all mine suspected areas and make them available for their previous use. The issue of financial shortfalls results in the need for priority-setting in the mine action process. This research investigates a new approach to priority setting in complex humanitarian demining. The multi-level and multi-stakeholder decision support system, for mine action management. The proposed DSS is based on a combination of advanced GIS tools and semi-automated multi-criteria analysis in order to enable efficient and effective mine action management.

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Model-Based GPR Landmine Detection Using Full-Wave Inversion: Experimental Results from the CONVOY Project

by *Miguel Freixo Gonçalves[1], Piotr Bielski[2], Sébastien Lambot[3], Émile le Flécher[1], Geert De Cubber[1]*

Introduction

Landmine contamination remains one of the most pressing humanitarian challenges worldwide. Ukraine alone has approximately 23% of its territory requiring survey, with estimated demining timelines of 5 to 10 years [1, 2], creating urgent demand for faster, safer, and more automated detection solutions.

Ground-penetrating radar (GPR) is among the most promising technologies for buried mine detection, particularly for low-metal content mines invisible to electromagnetic induction sensors. As highlighted by Sato [3], the combination of GPR with synthetic aperture radar (SAR) processing and robotic platforms represents a key direction for automated demining. However, conventional GPR systems produce raw subsurface images that require extensive signal processing before targets can be identified, typically including filtering steps to suppress surface reflections and soil clutter, followed by hyperbola detection in the B-scan to localise buried objects, making automatic target recognition (ATR) on mobile platforms particularly challenging.

The gprSense® (www.gprsense.com) system addresses part of these limitation through integrated full-wave inversion (FWI) [7] of calibrated stepped-frequency continuous-wave (SFCW) measurements [5]. While SFCW systems inherently benefit from instrumental calibration [5], the adopted full-wave radar formulation further models antenna-medium interactions and normalizes the measured data into an equivalent Green's function representation, effectively decoupling radar-system effects from the intrinsic subsurface response. In gprSense®, this normalization is additionally stabilized through temperature-dependent model compensation to ensure repeatability under varying environmental conditions. The inversion provides subsurface images together with physically meaningful parameters, including soil permittivity ε_r, sensor height *h*, and a model misfit term ϕ quantifying inversion residuals, directly usable as ATR features without additional preprocessing. The FWI framework has previously been validated for landmine detection under laboratory conditions [4, 8] and applied to drone-based soil moisture mapping [6, 11]. In this paper, we present the first field results of this system mounted on a mobile robot, tested at the Belgian DOVO demining centre in the framework of the European Defence Fund project CONVOY [9].

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System and Experimental Setup

The gprSense® SFCW-FWI Sensor

The gprSense® is a SFCW radar operating in the 550–6000 MHz range. In this configuration, the system sweeps through a range of user-defined discrete frequencies. At each frequency step, it measures the complex reflection coefficient $S_{11}(f)$ representing the ratio of the signal reflected back to the antenna to the signal transmitted into the ground, using a vector network analyser (VNA). This procedure builds the full frequency-domain signature of the subsurface and provides the phase-coherent acquisition, which is a prerequisite for full-wave inversion.

The inversion is based on the electromagnetic model introduced by Lambot et al. [7], who proposed representing the complete VNA-antenna-soil system as a set of linear transfer functions describing global reflection and transmission coefficients, which are frequency-dependent and complex-valued. The antenna transfer functions are determined by calibration measurements above a planar metal sheet, characterising the antenna response independently of the soil and rendering the formulation platform-agnostic. This allows the model to predict $S_{11}(f)$ for any homogeneous half-space parameterised by the soil permittivity ε_r and the sensor height h. At each acquisition point, the inversion minimises the objective function:

$$\phi = \left\| G_{xx}{}^{meas}(f) - G_{xx}{}^{model}(f, \varepsilon_r, h) \right\|^2$$

where $G_{xx}{}^{meas}(f)$ denotes the measured Green's function obtained from $S_{11}{}^{meas}(f)$ through the radar equation formulation [7] and $G_{xx}{}^{model}(f, \varepsilon_r, h)$ is the modelled Green's function of a homogeneous half-space. The residual ϕ quantifies the model misfit. These three outputs are physically normalised quantities, ensuring comparability across acquisition campaigns and sensor platforms. When no buried object is present, ϕ remains low and stable. A buried target violates the half-space assumption, producing a localised increase in ϕ, while the estimated ε_r provides complementary classifi-cation: plastic and metallic targets produce distinct signatures due to their contrasting dielectric properties. Together, ϕ and ε_r enable detection and preliminary classification of buried objects without any additional signal-domain preprocessing, as shown in the results section.

Robotic Platform

The gprSense® sensor was mounted on a Robotnik Summit-XL mobile ground robot managed through ROS2 on an onboard NVIDIA Jetson Orin. Accurate georeferencing of detections is a critical operational requirement, addressed by the gprSense® embedded Emlid M2 RTK-compatible GNSS receiver in open environments, and by SLAM-based local mapping using a Livox Mid-360 LiDAR and Xsens MTi-680 GNSS/INS in GNSS-degraded conditions. A key integration constraint is that the antenna must be kept at sufficient distance from the robot to avoid electromagnetic interference not accounted for during calibration. A plexiglass crane arm held the sensor at 0.7 m standoff from the chassis. This prototype lacked structural stiffness, inducing vibrations that affected the quality of the collected data. A stiffer mechanical solution is under development.

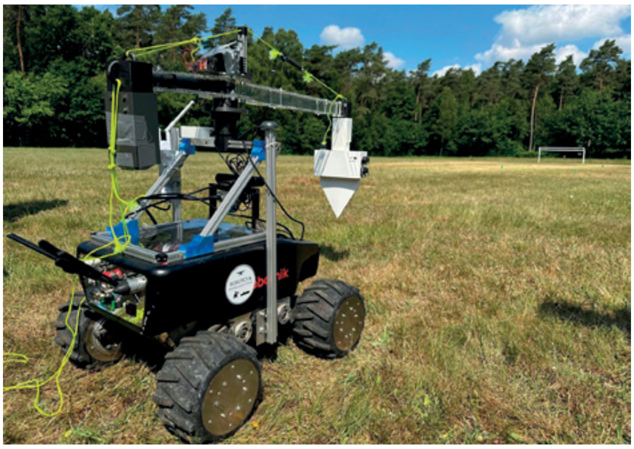


Figure 1: Robotnik® Summit-XL mobile robot with gprSense® during data collection.

Field Tests

Tests were conducted at the DOVO Belgian military demining centre in June 2025, on loess-derived silt loam soil [10]. Several targets of varying material and geometry were buried at depths ranging from 5 to 15 cm. Data was collected by teleoperation of the robot, performing back-and-forth passes over each target from two orthogonal directions. Ground truth position was recorded in real time by manually triggering a keypress on the controller when passing over the known target location; these intervals are displayed as shaded bands in the plots of Table 2. Three representative targets were selected for results presentation (Table 1): a TMA5 plastic anti-tank mine, a jerrycan as plastic IED simulant, and a 105 mm artillery shell as metallic threat.

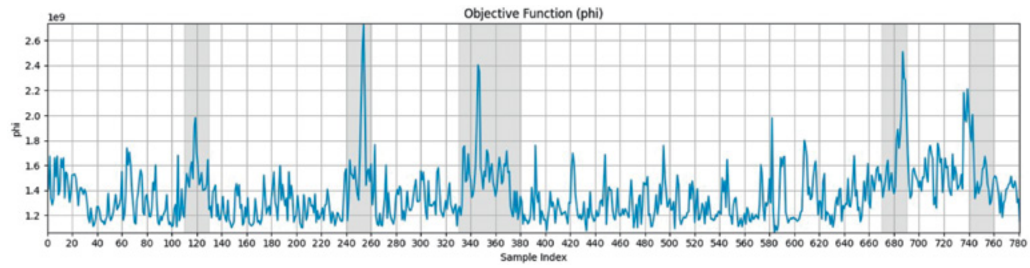
Results

Table 2 shows the model error ϕ and the estimated soil permittivity ε_r along the scan line for the three selected targets, with grey bands indicating known target positions.

Target (material)	TMA5 (plastic)	Jerrycan (plastic)	Anti-Tank (metal)
Buried			
Excavated			

Table 1: Buried and excavated views of the three targets selected for results presentation

The TMA5 is detected through localised ϕ spikes while ε_r remains at background level. The jerrycan produces both ϕ spikes and a clear ε_r rise to 6–7, reflecting its larger plastic volume. For the 105 mm shell, ϕ does not produce a clear localised increase, as the strong conductivity of the metal prevents the half-space inversion from converging correctly, while sharp ε_r increases to 10–13 within the grey bands serve as the primary detection feature. It is worth noting that in the presence of an object, the estimated permittivity becomes non-physical.

<table>
<tr><td rowspan="2">TMA5 anti-tank (plastic)</td><td>Model Error (ϕ)</td><td>
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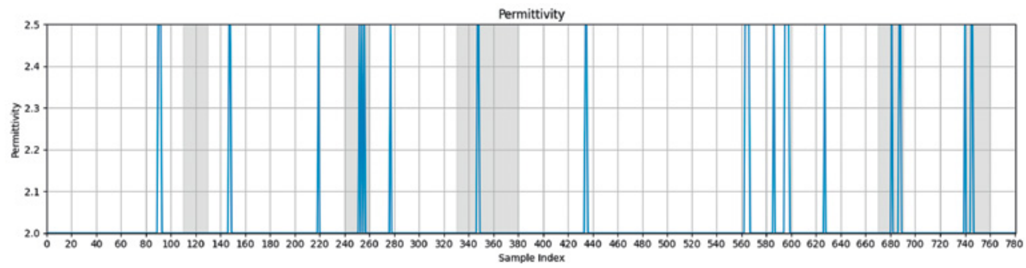
<tr><td>Permittivity (ε_r)</td><td>
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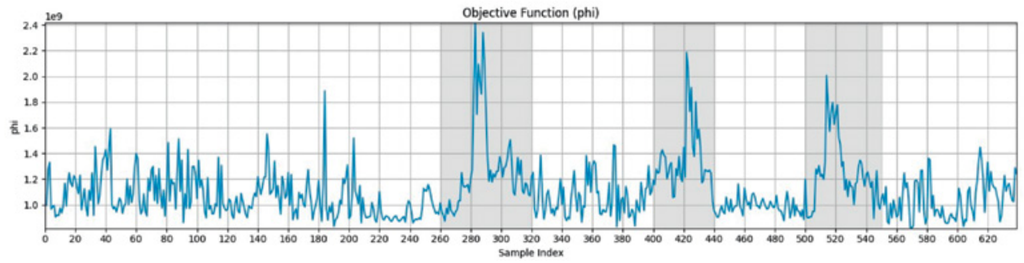
<tr><td rowspan="2">Jerrycan IED (plastic)</td><td>Model Error (ϕ)</td><td>
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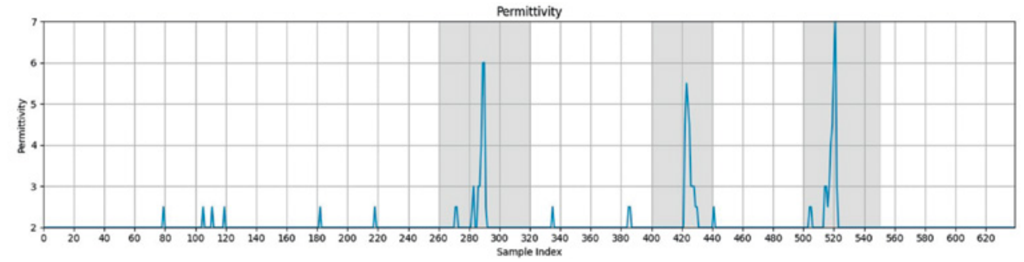
<tr><td>Permittivity (ε_r)</td><td>
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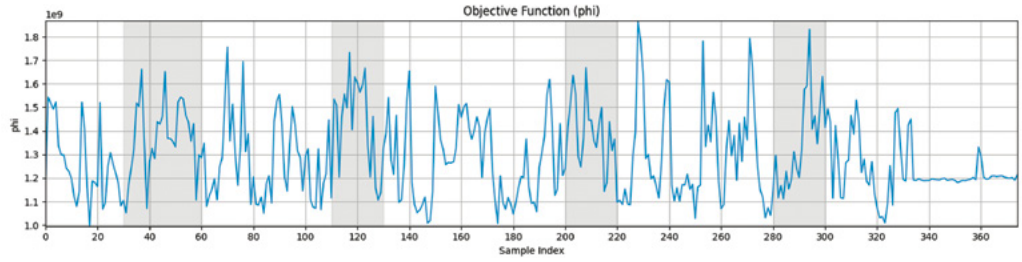
<tr><td rowspan="2">105 mm Shell (metal)</td><td>Model Error (ϕ)</td><td>
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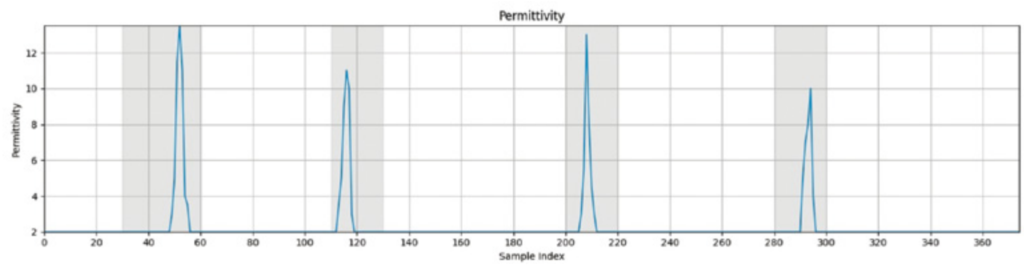
<tr><td>Permittivity (ε_r)</td><td>
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Table 2: Real-time FWI inversion outputs along the scan line for three buried targets. For each target, the top subplot shows the model error ϕ and the bottom subplot shows the estimated soil permittivity ε_r.. Grey bands indicate known target positions. The TMA5 is detected through ϕ spikes while ε_r remains close to background level. The jerrycan produces both ϕ spikes and a ε_r rise (≈ 6–7, characteristic of a plastic object). For the 105 mm shell, detection relies on sharp ε_r divergence (≈ 10–13), characteristic of a highly conductive object.

Discussion and Conclusions

These first field results confirm that the gprSense® SFCW-FWI system can reliably detect buried objects of diverse materials under realistic outdoor conditions, with model error ϕ and permittivity ε_r together enabling both detection and material classification in real time during robot traversal. The prototype mechanical integration induced vibrations during motion, affecting the stability of the inversion outputs. To address this, a rigid 2D scanning gantry is under development. Combined with synthetic aperture radar (SAR) processing parallelisable on the robot's onboard GPU, this will allow full 3D subsurface imaging. The compact form factor of the gprSense® also makes it suitable for drone integration, opening the perspective of combined UGV and UAV multi-platform survey.

Acknowledgments

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Drone-Assisted Monitoring of Indicator Plants for Landmine Detection: Feasibility and Operational Insights

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Abstract

Large areas of Ukraine contaminated by landmines are predominantly farmland and open fields. These mines are often buried or concealed by vegetation, making aerial visual detection unreliable, while conventional detection technologies remain costly and impractical for rapid, large-scale deployment. This study investigates the feasibility of using plants as biosensors to detect nitrogen dioxide emitted during TNT degradation. While we have initiated the development of genetically engineered plants capable of changing leaf color in response to explosive compounds, this work does not focus on the genetic engineering process itself. Instead, we evaluate the scalability and operational viability of deploying such plants under realistic conditions. Key questions addressed include: Can these plants establish in diverse field environments? How can they be deployed at scale? And can they be reliably detected amid mixed vegetation using affordable UAV systems? Field trials were conducted in Ukraine and Denmark across different seasons using oilseed radish and winter rapeseed—species. We tested drone-based seeding and low-cost aerial imaging workflows for plant detection. Our findings highlight practical challenges such as growth variability, weed competition, and imaging constraints, while demonstrating that UAV-assisted monitoring of biosensor plants is technically feasible under optimized conditions. The study provides critical insights for scaling plant-based landmine detection systems and outlines considerations for future implementation.

Introduction

Landmines continue to render large areas unusable long after conflicts end. In Ukraine, an estimated 174,000 km^2 remain contaminated, including about 50,000 km^2 of farmland [1]. Although inexpensive to manufacture, land-mines are costly and slow to clear [2, 3]; at the current pace, full demining could take centuries. This highlights the need for scalable, low-cost complementary detection methods.

Plants offer a promising avenue for mine detection. As they absorb soil contaminants through their root systems, physiological and spectral changes can reveal the presence of explosive residues such as TNT and RDX. Previous studies have shown that these changes can be detected through multispectral or hyperspectral imaging under controlled conditions [4]. Earlier work by Aresa Biodetection proposed engineered plants that change leaf color in response to NO_2, a TNT degradation product [5]. However, past efforts did not evaluate large-scale deployment, field robustness, or detection from operational UAV altitudes.

Key questions therefore remain: Can indicator plants establish reliably under minimal soil

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preparation? What seeding strategies achieve sufficient coverage? And can they be detected amid heterogeneous vegetation using affordable UAV systems?

This study addresses these gaps by evaluating the operational feasibility of UAV-based monitoring of indicator plants. Through field trials in Ukraine and Denmark using oilseed radish and winter rapeseed, we assess seeding approaches, field preparation requirements, plant establishment, and aerial detection performance. The results provide practical insights for scaling plant-based landmine detection under real-world conditions.

Methodology

To assess the feasibility of the proposed approach, we conducted multiple large-scale field experiments across different seasons and locations. The selected sites were Kharkiv (Ukraine), Zhytomyr (Ukraine), and Taastrup (Denmark). These locations were chosen for their contrasting soil types and climatic conditions, enabling a broader evaluation of plant growth and soil treatment strategies.

Test Site: Kharkiv Region

Experiments were carried out during two spring growing seasons in 2024 and 2025 on a 0.63 ha field. The field was divided into multiple subplots with varying soil treatments and seeding densities. Oilseed radish and winter rapeseed were sown manually at four different plant densities: 80, 320, 560, and 800 plants m^{-2}. Due to the proximity to the frontline, UAV-based imaging was not feasible; instead, we used a Sony a6400 camera mounted on a Broge V3 selfie stick. Images were captured from a height of 5 m with a 30° tilt angle and sufficient overlap to enable subsequent image stitching.

Test Site: Zhytomyr Region

In Zhytomyr, plants were seeded mechanically in spring 2024 and using an agricultural drone in spring 2025. The 2024 experiment was conducted on a 0.196 ha field divided into 24 plots, with three replications per crop and seeding densities of 80, 320, 560, and 800 plants m^{-2}. Soil treatments included glyphosate-treated, untreated, and a control plot with no intervention. In 2025, only treated and untreated plots were used, omitting the control. Sowing was performed in areas with long-term natural weed cover (more then 3 years) and glyphosate-treated areas.

Test Site: Taastrup Region

Three field experiments were conducted in Taastrup between 2024 and 2025: one in spring 2024, one in autumn 2024, and one in spring 2025. Oilseed radish and winter rapeseed were sown mechanically in all trials. For the first two experiments, soil treatments included glyphosate-treated, untreated, and tilled plots. In the spring 2025 trial, the tilled treatment was omitted, and the experiment was relocated to a different field within the Taastrup area to account for site variability.

Data Acquisition

A DJI Mavic 3M Pro UAV was used for all test sites except Kharkiv. The platform is equipped with a 20 MP RGB camera and a 5 MP multispectral sensor capturing four bands: near-infrared (NIR), red, red edge, and green. Flights were primarily conducted at 12 m to balance spatial detail and coverage, with supplementary low-altitude flights at 3–4 m to obtain higher-resolution imagery. Mission planning was performed in DJI flight management software to ensure adequate forward and side overlap for reliable orthomosaic generation.

All imagery was processed in Agisoft Metashape [6] to generate orthomosaics for model training and evaluation. Plant detection experiments focused on the Zhytomyr site, where sowing was performed by drone. Each orthomosaic plot was manually annotated, and a medium-segmentation Ultralytics YOLOv11 model [7] was trained for its balance of accuracy and efficiency. Tile-level predictions were merged into full-patch maps using an overlap-aware stitching algorithm and compared against ground-truth masks.

Results

Plant establishment varied widely across sites due to environmental conditions and management practices. Although several plots achieved good growth, survival was often reduced by pest damage (e.g., slugs, rodents), drought stress, and competition from existing vegetation. Seasonal differences further contributed to variability among trials.

Overall, the main limitation for UAV-based seeding and monitoring was achieving consistent and dense plant stands. Broadcast seeding alone produced insufficient plant size and coverage, highlighting the need for soil preparation and weed control. Glyphosate treatment was especially important; untreated plots experienced strong weed competition and poor establishment.

Growth patterns strongly affected aerial detectability. Oilseed radish established well after broadcast seeding but developed tall stems and flowers that obscured the leaves, which are required for detecting color responses in engineered plants. This indicates that UAV flights should be scheduled before flowering. Both oilseed radish and winter rapeseed tolerated spring and autumn sowing, though environmental stress still limited establishment in some cases.

Initial detection models trained on orthomosaics achieved moderate accuracy (Table 1 and Figure 1). Performance was constrained by the visual similarity between indicator plants and surrounding vegetation, and annotation was often ambiguous. Low-altitude flights (3–4 m) produced clearer imagery and improved model accuracy compared to standard 12 m missions. Future work will incorporate multispectral imaging to increase robustness under diverse field conditions.

Plant	Rate	Glyph.	P (%)	R (%)	F1 (%)
WR	320	+	42	25	31
WR	320	-	23	34	28
WR	560	+	49	26	34
WR	560	-	36	56	44
OR	320	+	62	29	39
OR	320	-	42	14	21
OR	560	+	86	28	42
OR	560	-	78	12	21

Table 1: Detection performance by species (WR = winter rapeseed, OR = oilseed radish), seeding rate (Rate) in seeds m^{-2}, and glyphosate treatment (+ treated, – untreated). Columns: P = Precision, R = Recall, F1 = F1-score.

Figure 1: Winter rapeseed detection result example

Conclusion

The experiments demonstrate that UAV- assisted monitoring of indicator plants is technically feasible but highly dependent on agronomic and environmental factors. Reliable detection requires optimized growth conditions, including effective weed management and appropriate seeding strategies. If these conditions cannot be guaranteed, alternative approaches — such as flying at lower altitudes, employing higher-resolution sensors, or focusing on high-density zones — become necessary. Furthermore, multispectral or hyperspectral imaging offers promising potential to improve detection accuracy and should be prioritized in future research. Overall, while the concept of plant-based landmine detection is viable, operational success hinges on integrating biological, agronomic, and technological optimizations.

Acknowledgment

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Anomaly Detection Methods for UXO and Landmine Extraction on Multiband Images

by *Ivan Racetin[1], Andrija Krtalic[2]*

Abstract

This research deals with the detection of synthetic simulated landmines and unexploded ordnances (UXOs) on multiband images. In this study, six anomaly detection methods were implemented: cluster-based anomaly detector, global and local orthogonal subspace detectors and global, quasi-local, and local Reed-Xiaoli detector. Four landmine spectra and twelve unexploded ordnance spectra were used were interpolated to match spectral bands of different sensors. These data were used to create synthetic datasets with simulated UXOs and landmines on aerial and satellite multiband images of natural scenes. Different magnitude of simulated landmines and unexploded ordnances were created: 0,1%, 0,01%, and 0,001% of the pixels in an image. To simulate different geometrical forms that landmines and unexploded ordnances could exhibit, different reference shapes were defined. Specific geometrical shape, simulated position, and type of target (landmine or unexploded ordnance) were randomly simulated using the Mersenne Twister algorithm.

Key words: Anomaly detection, UXO, landmines, synthetic scenarios, RX algorithm

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Introduction

Information retrieval from hyperspectral or multispectral images can be achieved either by classification or target detection [1,2]. Target detection on hyperspectral and multispectral images is generally divided into spectral signature-based detection and anomaly detection [1]. Spectral signature-based detection or spectral matching refers to supervised learning methods that require a-priori data about targets [2]. Anomaly detection (AD) methods, on the contrary, are unsupervised learning methods that do not require data about target spectral signatures [2]. The mathematical framework for anomaly detection arises from signal detection theory and statistical hypothesis testing. A selection between two disjunct hypotheses needs to be made: a pixel belongs to the prevailing background, or pixel belongs to sparse anomaly.

In this work, reference spectres of specific landmines and UXOs were extracted and resampled to match spectral characteristics of one hyperspectral and one multispectral dataset. Then, these spectres were synthetically simulated and interpolated in images of the two aerial scenes covering Pristeg area and mine test site Benkovac (both situated in Zadarska County, Croatia). These datasets then served for assessment of standard anomaly detection methods like variants of Reed-Xiaoli (RX) [3] and Orthogonal Subspace Projection (OSP) [4], whose performance was analysed through Receiver operating characteristics (ROC) curves and Area under curve (AUC) values.

Reference spectra and test datasets

Acquisition of reference spectres of UXOs that were used in this work is described in works of Bajic [5,6]. Hyperspectral linear scanner ImSpector V9 was used for data collection, and raw data was further corrected for radiometric and atmospheric effects. Reference spectrum of each explosive ordnance was determined as an average of its spatial pixels, resulting in one reference spectrum in visible and near-infrared region for twelve selected explosive ordnances.

Reference spectres of four landmines (VS 50, PMN, VS-2.2, PMD-6) in visible, near-infrared and shortwave infrared portions of electromagnetic spectrum (250-2500 nm) were acquired from work by Makki [7]. In that work, a high-resolution spectroradiometer was used to collect calibrated reflectance data.

Reference spectra of both landmine and explosive ordnance samples were resampled to spectral bands of sensors used in the study, namely Cubert UHD 185 and Daedalus 1268 using Nearest Neighbour method.

As a basis for implementation of landmine and UXO spectra, aerial scene of Pristeg area acquired by multispectral system Daedalus 1268 and scene of Benkovac mine test area acquired by hyperspectral Cubert UHD 185 were used (Figure 1). These datasets, including reference UXO datasets, are owned by Croatian Mine Action Centre – Centre for Testing, Development and Training (HCR-CTRO) and were kindly provided for research purposes.

To simulate the shape of the landmines and UXOs on the scenes, thirteen characteristic shapes were defined, from one-pixel, linear shapes (up to 3 pixels in length) to rectangular 3x3 and circular 5x5 shapes.

Synthetic test datasets and accompanying ground truth were generated using Mersenne Twister pseudorandom generator to choose the desired shape and position of implemented landmine and UXOs on the scene. Therefore, test datasets were created by replacing original pixel values with reference spectres of landmines and UXOs (Figure 2).

For each of two scenes, six scenarios were simulated. Landmines and UXOs were simulated separately, varying share of replaced pixels at 0,001%, 0,01% and 0,1% of total image pixels.

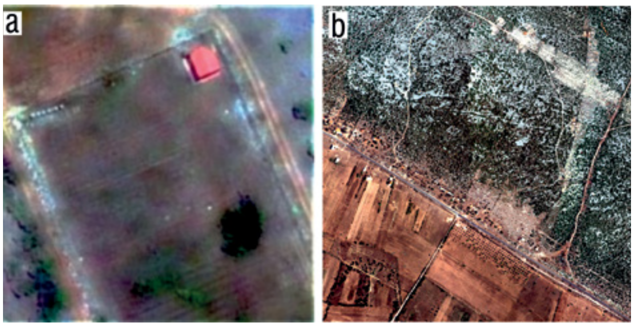

Figure 1: (a) RGB composite of Cubert UHD 185 hyperspectral cube of Benkovac test area [6], (b) RGB composite of Daedalus 1268 multispectral image of Pristeg area.

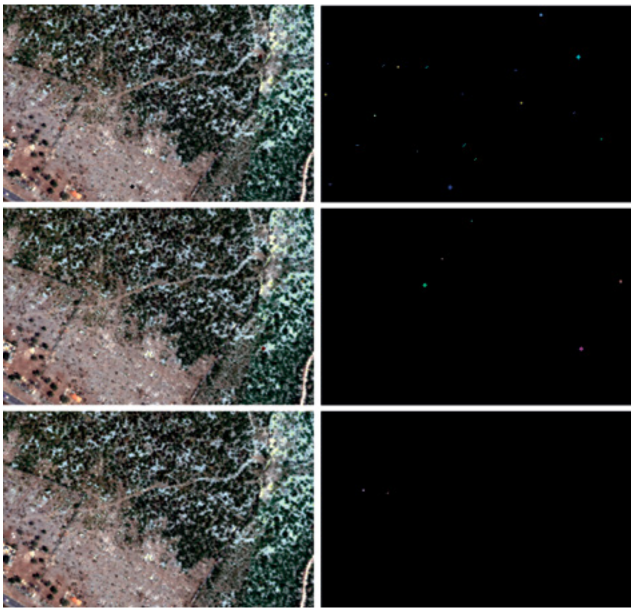

Figure 2: Example of simulated reference spectra in a multispectral image (Figure 1b). The left column consists of three subsets of RGB composites covering the same spatial extent, with simulated reference spectra of lethal agents. The right column contains ground truth images that will be used in the performance evaluation of the detector. The black color represents the background, while the colors indicate the locations of the simulated explosive ordnance. The first row represents the case with 0.1%, the second row the case with 0.01%, and the third row the case with 0.001% of simulated targets.

Implementation of anomaly detectors

For evaluation the performance, six anomaly detection methods were selected: the global RX AD (RX G), the local RX detector, the quasi-local RX detector, the cluster-based anomaly detector (CBAD), the local AD (OSP L) based and the global AD (OSP G) based on orthogonal subspace projection (Figure 3).

For local methods, the window size was determined such that it contains at least 10 times more pixels than the number of spectral bands of the given sensor. This number was chosen in order to ensure, as much as possible, a stable inversion of the covariance matrix. Furthermore, a dual sliding window was implemented, consisting of an inner guard window and an outer window used for computing the mean vector and covariance matrix that is needed for Mahalanobis distance [8] calculation.

For the CBAD, the K-Means [9] classification algorithm was selected, while for the OSP ADs, the PCA method [10] was employed.

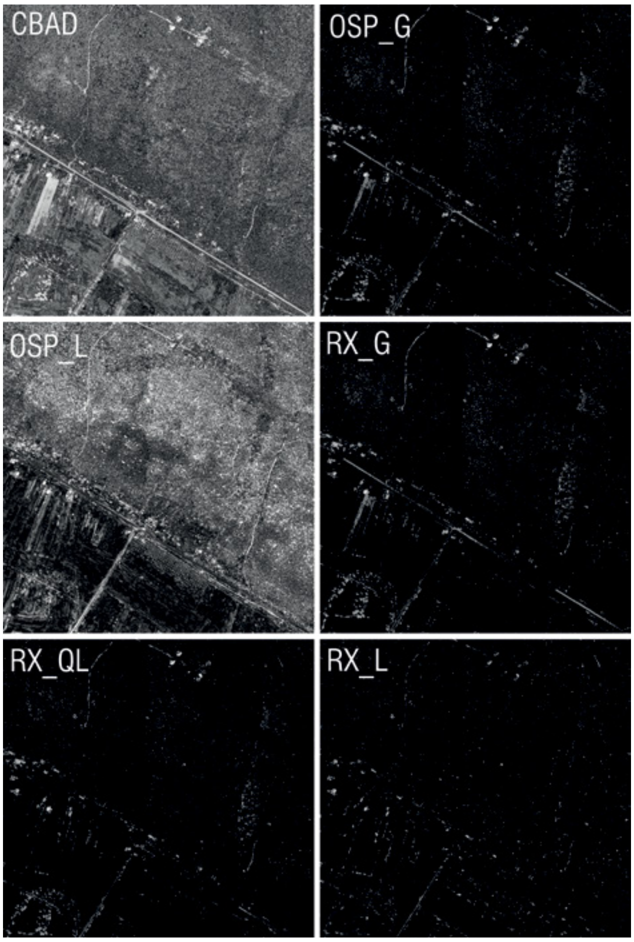

Figure 3: Results of ADs for the multispectral image (Figure 1b) with simulated 0.1% targets. Histogram equalization has been performed for all displayed detectors.

Results and Discussion

AD performances on twelve tested scenarios are presented on Figure 4 for hyperspectral dataset (Figure 1a) and Figure 5 for multispectral dataset (Figure 1b). Although quite large window sizes were used for local methods, it was not possible to invert covariance matrix due to rank defect for local RX AD in hyperspectral dataset resulting with one ROC curve less in Figure 4 than in Figure 5. Among tested ADs on hyperspectral dataset (Figure 4) RX QL achieved the highest AUC of 99.74, followed by RX G with 99.06 and CBAD with 98.53.

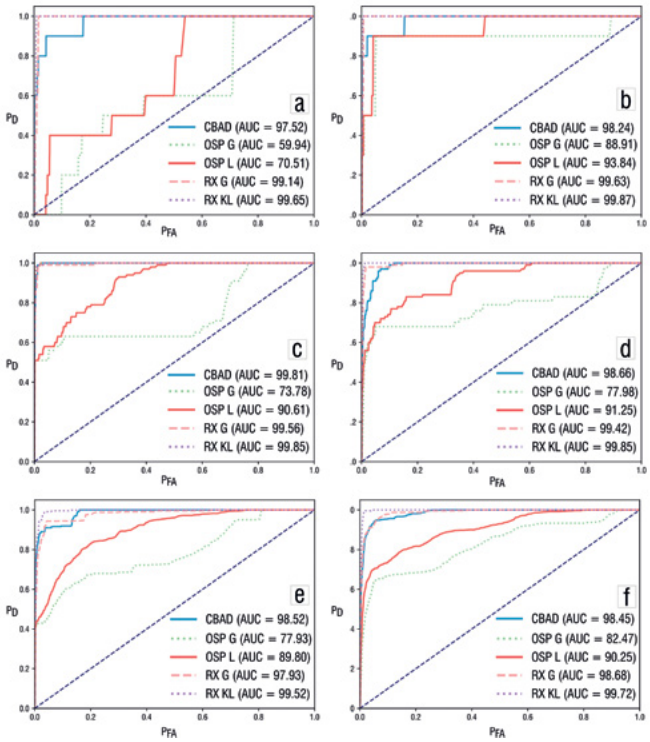

Figure 4: Experimental ROC curves of all implemented ADs on the hyperspectral image (Figure 1a). The left column represents scenarios with landmines: (a) 0.001%, (c) 0.01%, and (e) 0.1%. The right column represents scenarios with UXOs: (b) 0.001%, (d) 0.01%, and (f) 0.1%

For multispectral dataset (Figure 5), local RX detector showed the highest average AUC value of 98.61, followed by RX QL with 96.28, RX G 95.04 and OSP G with 95.00.

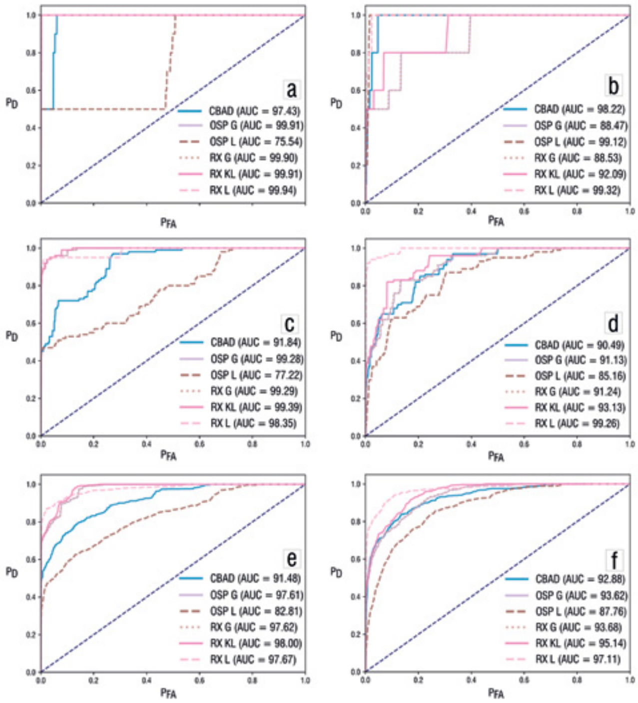

Figure 5. Experimental ROC curves and AUC values of all implemented ADs on the multispectral image (Figure 1b). The left column represents scenarios with landmines: (a) 0.001%, (c) 0.01%, and (e) 0.1%. The right column represents scenarios with UXOs: (b) 0.001%, (d) 0.01%, and (f) 0.1%

The lowest AD performance was noted for OSP L in scenario with 0.001% landmines (Figure 4a) on hyperspectral dataset, while the single highest AUC score achieved RX L in the same scenario but on multispectral dataset (Figure 5a). ADs showed slightly higher performance on multispectral (93.88) than on hyperspectral (92.38) test scenarios. Regarding target type, in landmine scenarios AUC score of 93.15 was achieved, with 1 percent higher result of 94.15 was exhibited in UXO scenarios.

Conclusion

This paper evaluated six common anomaly detection methods on hyperspectral and multispectral test dataset created by synthetically simulating landmine and UXO targets. Achieved average AUC scores higher than 95 for selected ADs indicate potential for application in humanitarian demining. However, as the performance was evaluated on synthetic dataset, additional tests must be conducted in more realistic and demanding conditions.

Acknowledgement

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Beyond Spectral Averages: How High-Order Moments Enhance Endmember-Based Material Identification

by *Milan Bajić*[1], *Milan Bajić*[2]

In this work, the authors research the influence and contributions of higher-order spectral moments on material signatures and their applications. In the classical approach to material detection using endmembers, compared are high-order moments enhanced endmembers as material fingerprints to endmembers based on spectral average and variance.

Introduction

Hyperspectral imaging as a research domain still presents more questions than answers, and the applicability of proposed solutions raises even more questions. A method proposed in 1996 for endmember selection relies on the purity of the pixel (Bateson & Curtiss, 1996). These "pure" pixels still contain a mixture of materials in a pixel, and purification brings a problem, that such a purified pixel representative of a material is rare in real life. One approach we tested is the use of more than one pixel for the detection of the target. As a detector, we applied the Spectral Angle Mapper (SAM) (Kruse et al., 1993) at 0.05 radian as the maximum distance to be accepted as matching material. SAM is used to map the spectral response inside the scene to something that is declared a reference spectrum. This spectrum can be obtained from the external library, or, in our case, by sampling a subset of pixels.

Methods and materials

The image used is captured with Specim IQ (Behmann et al., 2018) hyperspectral push-broom camera. Scene has 512x512 pixels and 204 channels from 397.32–1003.58 nm, with a spectral resolution of 7 nm. Reflectance values are calculated based on the white reference measured at the white balance card in the scene, and the dark current measured by blocking incoming light. We sampled a total of 8 spectral endmembers for use: 5 randomly selected individual pixels, one longest line of pixels over the target, one orthogonal line over the target and the whole target was selected as the representative spectra.

Figure 1: 5 individual pixel and 2 line pixels endmembers selection

In Figure 1, shown are red, green, blue, yellow and turquoise individual pixels and 15 pink and 35 light blue line pixels used as endmembers. Target, a metal part of the anti-personnel landmine, is in even lighting, so we reduced that variability.

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Figure 2: All target area endmember selection

In Figure 2, all 456 pixels of the target are used as endmembers. Detections are all measured at the same maximum angle of 0.05 rad (2.8648 degrees).

Results and Discussion

First of the interesting results is that of individual pixel detections, where the smallest count of detected pixels is 67, and the largest is 158.

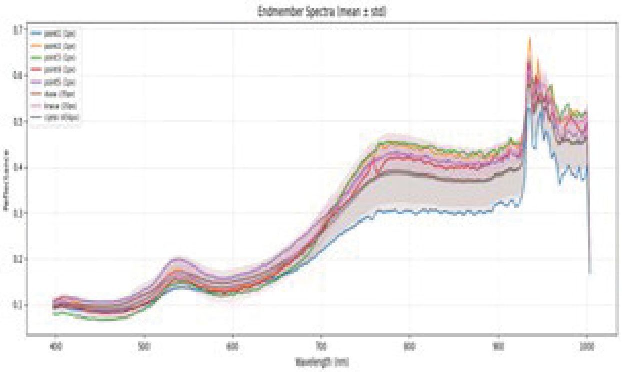

Figure 3: Five spectral responses of 1-pixel endmembers

In Figure 3, a similarity can be seen between all individual pixel endmembers used.

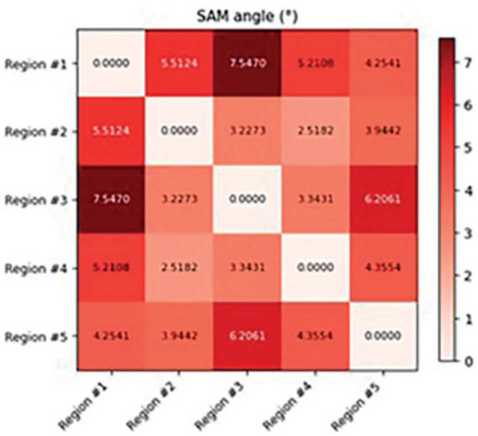

Figure 4: Pixelwise variability

In Figure 4, there is a matrix between individual pixels measured by SAM angle.

When using the average across selected pixels' spectral response over all available bandwidths, 15 pixels line had just 1 more detected pixel (159) than the best single pixel endmember detection. 35 pixel line had a little more detections when compared to all target pixels used as endmembers (456 endmembers). Line had 225 detected pixels, and all the target used had 222 pixels detected.

Because of the uniformity of lighting in a target, background and overall scene, we used, for example, detections we tested spectral skewness over a larger dataset.

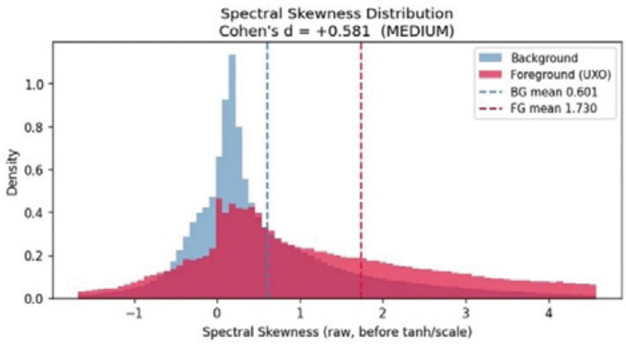

Figure 5: Spectral skewness distribution collected over a large dataset, masked area red (annotation of all objects of interest) and unmasked background blue colour.

Figure 5 validates the robustness that brings the use of spectral skewness as an additional dimension in spectral-based detections of targets in a hyperspectral scene, as objects are skewed differently than the background. This chart was created by calculating the average skewness for 134 scenes, where targets are less than 5% of the all image area.

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Comprehensive solution for georeferencing of humanitarian demining tools

by *Janusz Będkowski[1], Oleksandr Bilokon[2], Michał Pełka[3], Samer Karam[4]*

Abstract

This paper presents a comprehensive solution for the georeferencing of humanitarian demining tools, including handheld detectors, trained K9 units, wearable vests, and mobile robotic platforms (UGV/UAV). Accurate georeferencing of such tools is critical for reliable documentation, analysis, and decision-making in demining operations. The proposed approach integrates LiDAR, inertial measurement unit (IMU), and GNSS-RTK data to estimate both the sensor trajectory and a three-dimensional map of the surrounding environment with centimetric ac curacy. To ensure robustness in GNSS-denied or degraded environments, the system relies on LiDAR-Inertial Odometry (LIO), enabling continuous localization even in the absence of GNSS-RTK signals. Georeferencing is achieved through multiple complementary strategies, including alignment to existing point clouds (e.g., airborne laser scanning data), ground control points, control points, and GNSS-RTK observations. The framework supports a wide range of commercially available LiDAR sensors, including Livox, Ouster, Hesai, Robosense, and SICK devices, with extensibility to additional sensors. In addition, the proposed HDMapping-LIO framework provides a unified benchmarking environment for state-of-the-art LiDAR odometry and LiDAR-Inertial odometry methods, enabling systematic comparison in realistic field conditions. Experimental results from field deployments demonstrate that the proposed solution achieves accuracy and robustness comparable to established state-of-the-art approaches, while offering a flexible and practical georeferencing workflow tailored to humanitarian demining applications.

Challenges for humanitarian demining in Ukraine

Experts studying humanitarian demining argue that the problematic issues and challenges facing Ukraine are caused by the scale of mined territories. Although this certainly plays a significant role, the scale of territories is not the only factor that creates problems in humanitarian demining in Ukraine. To study the existing additional problematic factors, an analysis of modern research on problematic issues of humanitarian demining was conducted. Considering the problems and challenges of humanitarian demining facing Ukraine, experts cite four aspects explaining the challenges and problematic issues of humanitarian demining. Liudmyla Herasymchuk et al. argue that there is no example in the world of humanitarian demining processes taking place during war [1]. It is also stated that about 5-10 % of all potentially dangerous, mined territories amount to about 13 thousand km^2, which require technical inspection, and 2-8%- require clearance from explosive objects. The expert considers the clearance of the territories of Ukraine from explosive objects to be insufficient for the safe further

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use of the territories for agricultural work, and additional ecological and soil studies [1] are required. According to Oleksandr Valchenko et al and Valery Strelec et al., a second aspect of the problematic challenges appears, namely the issue of humanitarian demining of radiation-contaminated territories. Thus, Oleksandr Valchenko et al. in their research on humanitarian demining of radiation-contaminated territories claim that almost the entire territory of the exclusion zone is mined. In addition, humanitarian demining processes are carried out by deminers. In their study, Oleksandr Valchenko et al. develop a program to improve the training of deminers [2]. Along with this, Valery Strelec et al. researchers of humanitarian demining in conditions of radiation contamination formalizes the concept of a deminer and explores the functional purposes of these specialists. A deminer is an assistant to the operator searching for explosive objects [3]. In addition, according to the expert, a difficult situation is that for deminers, protective equipment should be combined, which is armor protection and radiation protection, which illustrates the complexity of implementing these functions by a person. Along with this, the expert lists the following functions performed by a deminer: (1) transportation or transfer, (2) search tools (3) disposal tools. In addition, it is emphasized that the conditions of radiation contamination do not provide for actions that are performed under normal conditions, for ex ample, in many cases under normal conditions, a deminer has the ability to neutralize an explosive object on site, which of course cannot be done under conditions of radiation contamination because it causes a number of negative factors. Therefore, in accordance with this, automation processes should be aimed at solving issues of search, transportation, and disposal. According to Volodymyr Blintsov et al., a third aspect of the challenges of humanitarian demining appears, which concerns water areas. In his study [4], he illustrates this aspect and claims that this is an applied scientific problem of humanitarian demining of shallow water areas using marine robotics. Diving technologies for humanitarian demining are characterized by extremely low productivity. Ways to improve this are the use of surface, underwater and or flying robotics. The key functional stages, according to the scientist, are (1) search operations, mapping, identification of explosive objects. (2) Neutralization and marking. (3) transportation both underwater and surface. (4) survey of territories [4]. Ac cording to Oksana Boyko et al., a fourth aspect of the problematic challenges ap pears, namely, assessing the scale of mined areas, developing effective methods and technologies for demining, as well as studying the impact of explosive objects on the environment and soil, as well as investigating the practical development of means for detecting explosive objects, etc. [5]. In general, in the practical development of explosive detection tools, researchers are exploring the following areas. For example, for the identification of explosives, the Research Group led by Andrii Podorozhniak et al. are developing an artificial intelligence-based system for identification using robotic means from a height and deep learning methods [6]. For the identification of anti-personnel mines in clay soils, the researchers are considering the problem of the detection and localization using ground- penetrating radar. The results demonstrate the system's ability to detect and localize explosives in clay soils [7]. Also, for the problem of identification and detection of explosives, hyper spectral machine vision is being explored for the study of large territories at altitude [8]. Also, to identify hidden underground explosive objects in random heterogeneous environments using ground penetrating radar, the following studies are conducted: [9] [10] [11] [12]. As a result, we have a set of key additional factors that emphasize the unique ness of the problematic challenges in the is sues of humanitarian demining in Ukraine. 1. Repeated control and inspection of potentially dangerous territories in war conditions. 2. Investigation of territories, namely soil sampling and implementation of ecological studies. 3. Lack of robotic and auto mated means for specialized conditions of radiation-contaminated territory in the process of humanitarian demining and situation assessment. 4. Issues of humanitarian demining in water areas of territories. 5. Com prehensive assessment of the situation and insufficient comprehensive coordination and information exchange. So all this shows that Ukraine currently has a special and unique nature of challenges that are not similar to the challenges in classical scenarios for humanitarian demining processes. In general, the current state of humanitarian demining in Ukraine is characterized by diversity - that is, it has a heterogeneous cascade of challenges that also multiplies existing problems. In addition, it should be emphasized that in the context of the georeferencing system, this comprehensive solution has a universal nature, capable of providing coherence to the entire humanitarian demining process and obtaining a source of spatial data displayed on a map with georeferences to improve the quality of monitoring and comprehensive coordination.

Challenges for humanitarian demining in Syria

The process of humanitarian demining work in Syria operates under two main conditions which are explosive ordnance (EO) presence and continuous absence of precise geo referenced spatial data needed for planning and operational activities and long-term risk management. After more than a decade of conflict the contaminated areas with explosive ordnance (EO) have expanded and they continue to hinder safe movement and agricultural operations and reconstruction efforts. The entire national contamination survey to identify the complete contamination extent and its geographic distribution re mains uncompleted which creates major un certainties about hazardous area location and density and priority status [13] [14]. The humanitarian impact is both severe and measurable. The Landmine Monitor re ports that Syria experienced 933 casualties from landmines and explosive remnants of war (ERW) during 2023 which represents one of the highest casualty counts world wide. The latest reporting about Syria shows that explosive ordnance (EO) contamination continues to endanger civilian lives especially when people return to areas which were previously contaminated without con ducting proper surveying and marking and risk education activities [15] [16]. The Syrian Science Council reports ongoing civilian casualties from explosive ordnance (EO) contamination affected children and returning populations who face greater danger be cause of these hidden dangers which prevent their secure return and recovery from contaminated areas [16].

The operational system experiences direct impacts because of this information short age. Mine action operations face challenges in Syria because many regions possess base line maps that various organizations and different regions maintain at different levels of accuracy and presence of missing information and mapping inconsistencies. The Mine Action Review states that unknown contamination levels exist because the country lacks a comprehensive national survey which creates difficulties for task assignment and land release operations and reporting activities [14]. All humanitarian evaluations verify that explosive ordnance (EO) contamination hampers both humanitarian operations and early recovery efforts across numerous sub-districts which creates a significant need for accurate spatial data throughout operational work. The absence of sufficient geo referenced data results in two main problems which involve deploying teams to under explored sites and checking existing hazardous zones while handling both cleared and suspected areas during time periods.

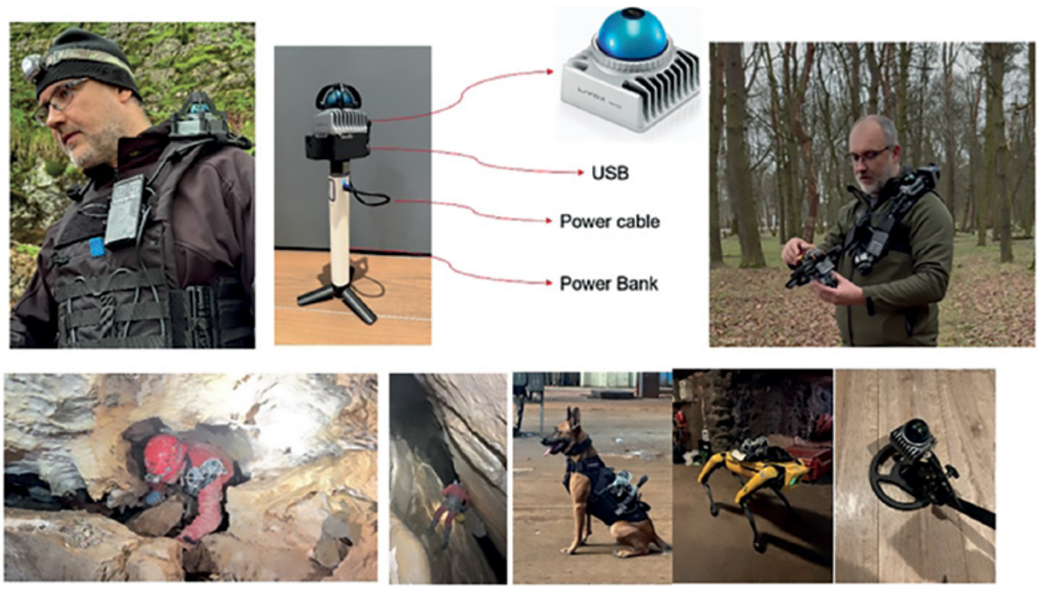


Figure 1: Wearable/mountable/hand held mobile mapping system in different applications.

The disorganized way data collection and information management systems operate creates a second major obstacle to overcome. The various locations conduct non-technical surveys and impact assessments and localized mapping initiatives but these actions fail to create a unified national spatial picture. Systematic field verification activities face limitations because access restrictions and security requirements and administrative barriers remain active and the accessible data may contain only estimated values in stead of full inventory data [14][17]. The recovery assessment process all over Syria has shown that spatial data which exists at both fragmented and outdated states hinders damage assessment and prioritization activities which strengthens the problem's systemic character [18].

The characteristics of the Syrian operational environment cause major difficulties for georeferencing activities which require precise referencing capabilities. Demining activities typically take place in dense urban areas which include partially destroyed neighbourhoods and complex built environments that create problems for GNSS systems to operate effectively. The geodetic infrastructure of Syria lacks suitable local control networks as well as local control networks that provide dependable local geodetic control networks which creates difficulties for different teams and technologies to maintain consistent spatial referencing throughout their operational phases [21].

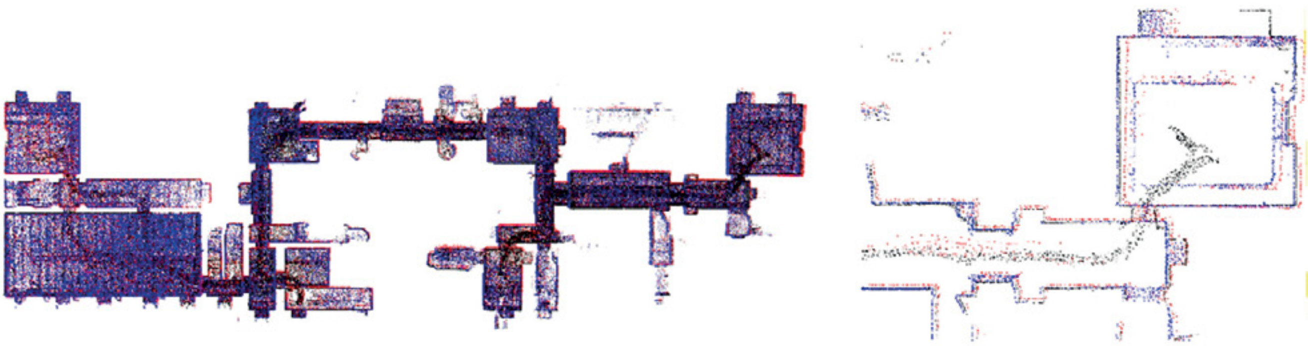
Figure 2: Light weight design for FPV drone.

The information management function for mine action in Syria serves as the primary requirement for establishing secure operations which enable responsible actions and unified coordination among different parties in volved in the operations [22]. International guidelines state that digital record standardization and consistent georeferencing systems are necessary requirements for effective monitoring and land release processes and decision-making activities in complex mine action operations which require these two functions as essential components [23].

The explosive hazard detection challenges in Syria extend beyond detecting explosive hazards because they require maintaining spatial reference points which enable multiple people to access survey results and clearance outputs and residual-risk information for future sharing. The situation requires georeferencing workflows that maintain their effectiveness even when GNSS signals be come weak which also need to handle multiple reference data sources and should prove useful for deployment in areas affected by post-conflict situations.

The proposed georeferencing framework provides a solution for an operational gap which humanitarian demining operations in Syria face as their most crucial operational requirement. The approach enables centimeter-level location accuracy through LiDAR and inertial and GNSS data fusion while it allows users to create solid spatial data by connecting existing spatial databases and control points. The required capabilities create a foundation for enhancing coordination between groups while they create permanent monitoring systems and solve operational uncertainties which occur during demining missions in Syria as a post-conflict location.

Figure 3: Bunker dataset (https://github.com/charleshamesse/dvi-mapping-system) [19]. Black colour correspond to ground truth, blue is our map, red is map obtained with FASTER-LIO [20].



Technological and Operational challenges

The deployment of georeferencing technologies supporting humanitarian demining [24] can be affected by numerous adverse disturbances. For example GNSS jamming and spoofing [25] affect the navigation and positioning services, thus these particular attacks can efficiently disable the ability to accurately georeference humanitarian demining tools. Jamming is an intentional transmission of a high-power radio frequency signal equal to or very close to the frequency of the device whose operation is to be prevented. A GNSS spoofing attack refers to the intentional transmission of fake GNSS signals to deceive the receiver into interpreting fake signals as authentic ones, and to falsify the receiver's location. Thus, the georeferenced position can be significantly different than the desired one. In such a situation the digitisation of humanitarian demining action can be considered questionable. Another challenge is related to humanitarian demining personnel training. We observed a significant growth in affected zones, thus an increasing number of humanitarian deminers is required. The training process is difficult to scale and requires plenty of effort to conduct. For this reason, we face the scaling problem. Last but not least, another challenge is indoor/outdoor positioning. The GNSS signal is not always of good quality, for example under canopies we observe much less GNSS accuracy than under open sky. To address the above-mentioned challenges, we designed an open-source project enabling centimetre-level positioning in GNSS denied environments. It is based on LiDAR, IMU (Inertial Measurement Unit) and GNSS fusion. It is lightweight handheld/wearable/mountable mobile mapping system for large scale surveys available at https: //github.com/MapsHD/HDMapping It uses an open-hardware measurement device available at https: //github.com/JanuszBedkowski/mandeye_controller We provide an end-to-end mobile map ping framework that does not require any installation, including:

- HDMapping_LIO: our implementation of LiDAR Inertial Odometry.
- HDMapping_Pose_GRAPH_SLAM to create city-level maps.
- HDMapping_Georeferencing (GNSS RTK, Control Points, Ground Control Points, Terrestrial Laser Scanner, Aerial Laser Scanner).

We have already tested this technology in the field [26][27][28][29]. Our system works in forest (figure 1), cave (figure 2), indoor (figure 3), outdoor, agriculture, city (figure 5, 6) and other challenging environments that can be contaminated by land mines.

Figure 4: Our system tested in under canopy conditions. It provides centimetric accuracy and precision.

Technology

This technology was initially elaborated at [30]. It provides simultaneous localisation and mapping capabilities based on LiDAR, IMU, GNSS, Ground Control Points, Control Points fusion. It is wearable/mountable/handheld (see figure 1). Our system enables simultaneous crawling, climbing, and mobile mapping. Our system can be mounted onto robots (air/ground), trained dogs and humanitarian demining tools. We provide software tools for integration of data from multiple systems into a single map. Our solution is lightweight (less than 400 grams), thus it can be mounted onto FPV drones (see Figure 2).

Figure 5: Large scale positioning experiment. We reached 70cm accuracy and centimetric precision against ALS (Aerial Laser System).

Experiments

In this section we present some experiments showing the main operational readiness level. Figure 3 shows our system working with the bunker dataset (https://github.com/charleshamesse/dvi mapping-system) [19]. Black color corresponds to the ground truth, blue is our map, red is the map obtained with FASTER-LIO [20]. Our solution is more robust for fast rotations. In Figure 5 we shown large scale positioning experiment. We reached 70cm accuracy and centimetric precision against ALS (Aerial Laser System). Figure 6 shows city level georeferencing. It is 250km of trajectories collected by our system (low cost GNSS u-blox F9P, 2x 3D LiDAR LIVOX MID 360) mounted onto shoulder. We were collecting this data using bicycle.

Conclusions

This paper presents a comprehensive solution for the georeferencing of humanitarian demining tools, including handheld detectors, trained K9 units, wearable vests, and mobile robotic platforms (UGV/UAV). Our system enables freedom in motion, thus we can climb and crawl with it. It is lightweight and suitable for mounting onto FPV drones. It is designed for the accurate georeferencing of humanitarian demining tools which is essential for reliable documentation, analysis, and decision-making in demining operations. The proposed approach integrates LiDAR, inertial measurement unit (IMU), and GNSS-RTK data to estimate both the sensor trajectory and a three-dimensional map of the surrounding environment with centimetric accuracy. To ensure robustness in GNSS-denied or degraded environments, the system relies on LiDAR-Inertial Odometry (LIO), enabling continuous localization even in the absence of GNSS-RTK signals. We tested our system in the field including indoor, outdoor, and city level scenarios. It is available as open-source software at https://github.com/MapsHD/HDMapping.

Figure 6: City level georeferencing. It is 250km of trajectories collected by our system mounted onto shoulder. We were collecting this data using bicycle.

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ROCX Mine Detection Campaign: Platform Trade-offs and Multi-spectral, Multi-view Sensor Fusion

by Rob Haelterman[1], Charles Hamesse[1], Hannes De Meulemeester[1], Sagar Lekhak[2], Emmett J. Ientilucci[2]

Abstract

Accurate detection and mapping of surface-laid anti-personnel mines remains challenging for humanitarian demining and defense operations, particularly in GNSS-denied environments where onboard sensors must provide both reliable material discrimination and precise spatial localization. To support research in this domain, we participated in the ROCX (RIT Open Community eXperiment), a large-scale collaborative effort involving 75 researchers from 24 organizations across 6 countries. A dedicated data collection campaign focused on PFM-1 anti-personnel landmines was conducted using both ground-based and airborne sensing platforms. Ground measurements were acquired using a portable, SWaP-C-optimized multi-sensor rig integrating multispectral, thermal, RGB, SWIR, and LiDAR sensors, while airborne hyperspectral and polarimetric sensors provided complementary top-down coverage. The resulting multi-modal, multi-view dataset enables investigation of platform trade-offs and multi-spectral sensor fusion for mine detection and is intended for open-access release to facilitate reproducible research.

Introduction

Recent geopolitical events, such as those in Ukraine, have by necessity reinvigorated research into mine detection. The widespread use of landmines, both anti-personnel and anti-vehicle mines, has created a continuing hazard for civilians and military personnel. Even after a conflict has passed, the use of mines creates a long-term humanitarian threat, blocking reconstruction efforts, limiting agriculture in the area and posing a dangerous risk to civilians, in general. As a result, there is a need for efficient sensing technologies that are able to safely and accurately detect and localize mines across large areas.

Traditional mine detection methods, such as metal detectors and ground-penetrating radar (GPR), remain popular but have some important limitations. Metal detectors are highly sensitive to metallic components but perform poorly for low-metal mines, which are increasingly common exactly because of their ability to fool metal detectors. GPR systems can detect buried mines based on dielectric contrast, but their performance depends strongly on soil conditions and moisture content. Both approaches typically require close proximity to the ground and manual operation, resulting in slow area coverage and increased risk to equipment or personnel. More recently, magnetometers have seen more widespread use for detecting land mines, especially from UAV systems [1]. Such systems measure disturbances in the Earth's magnetic field caused by buried or surface-laid ferromagnetic materials. A limitation of magnetometry from a drone is that the drone itself creates non-negligible magnetic interference, which is picked up by the magnetometer. This is usually solved

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by, i.a. suspending the magnetometer a sufficient distance below the drone, which is efficient but limits the maneuverability of the drone.

Imaging-based detection methods provide an attractive alternative, as drone-based camera systems are able to quickly cover large areas while maintaining a safe distance. Modern high-resolution RGB cameras are relatively inexpensive and lightweight, making them easy to mount on airborne platforms and enable the use of computer vision methods for mine detection. However, their effectiveness is limited when mines are visually obscured, such as when they are covered by vegetation or (partially) buried. This is because conventional imaging and computer vision methods rely, in large part, on the geometrical shape of landmines in order to detect them.

Hyperspectral imaging extends conventional imaging by capturing both spectral and geometric information, enabling detailed characterization of materials and objects within a scene.

Hyperspectral imaging is state-of-the-art for imaging-based material discrimination [2]; however, its high cost and the sensitive nature of mine detection have resulted in a limited number of freely available datasets, which hampers research progress.

Recently, several datasets have been introduced to address this gap, including a UAV-based VNIR hyperspectral dataset [3] and a UGV-based multi-sensor dataset [4].

Our work takes this one step further by incorporating both handheld multi-sensor and multispectral measurements alongside UAV-based hyperspectral imagery, enabling novel research into multiple sensing modalities, multi-view methods and different deployment scenarios.

In the next section, we discuss the ROCX measurement campaign and the roadmap for exploiting the resulting dataset.

Measurement Campaign and Sensor Platforms

The ROCX (RIT Open Community eXperiment) campaign brought together 75 on-site participants from 24 organizations across 6 countries, with the primary goal of creating an open-access remote sensing repository to support research into electro-optical sensing and target detection [5]. Within this broader campaign, a dedicated data collection effort was conducted focusing on the detection of PFM-1 anti-personnel landmines under realistic environmental conditions, including varying soil types, vegetation densities and illumination conditions to ensure representative operational conditions.

A controlled outdoor minefield test site was prepared where 3D printed PFM-1 mines (both green and brown, see Fig. 1) and surrogate targets were surface-deployed at known locations across five annotated regions, with ground-truth GPS positioning and spectral signatures captured using ASD, SVC and Trimble measurements. Ground-truth reflectance measurements were acquired for both targets and background materials using field spectroradiometers, enabling precise spectral characterization with as goal to support the quantitative evaluation of future detection algorithms.

Figure 1: The PFM-1s used as targets in the dataset. Both brown and green variants were deployed.

Ground-based data was collected using a SWaP-C optimized portable rig, built with custom 3D-printed mounts, integrating synchronized multispectral (NIR), RGB, panchromatic SWIR, thermal and LiDAR sensors in a geometrically calibrated handheld platform. This rig captured close-range, oblique electro-optical data across multiple daylight sessions and enabled simultaneous detection and 3D mapping of the minefield.

In parallel, airborne hyperspectral and polarimetric data was acquired using drone-based and aircraft-based platforms, providing complementary top-down coverage. An overview of this process can be found in Fig. 2. Drone-based acquisitions achieved high spatial resolution with ground sampling distances ranging from approximately 1 cm to 5 cm, while aircraft-based acquisitions provided wider-area coverage with ground sampling distances on the order of 1 m. Multiple hyperspectral imaging systems operating in the VNIR and SWIR spectral ranges were deployed, along with an imaging polarimeter mounted on a drone platform to capture polarization signatures of the targets and surrounding environment.

Geometric calibration and synchronization were performed to ensure spatial and temporal alignment between sensors (see Table 1. The integrated LiDAR measurements provide precise geometric context, enabling accurate localization of detected targets and supporting joint spectral-geometric analysis and sensor fusion approaches.

Road Ahead

This work presented the ROCX mine detection campaign and resulting multi-modal raw dataset collected using both ground-based and airborne sensing platforms. To prepare the full curated dataset, a processing workflow will be created to go from the raw data to the final properly calibrated, registered and labeled dataset.

The processing workflow will include radiometric calibration for the hyperspectral data and geometric calibration (intrinsics/extrinsics), followed by the estimation of the trajectory of the sensor systems in all data sequences (using LiDAR-inertial SLAM), then the registration between image and LiDAR to place all modalities in a common reference frame. For airborne data, the workflow includes orthorectification and mosaicking using GNSS/IMU and ground control.

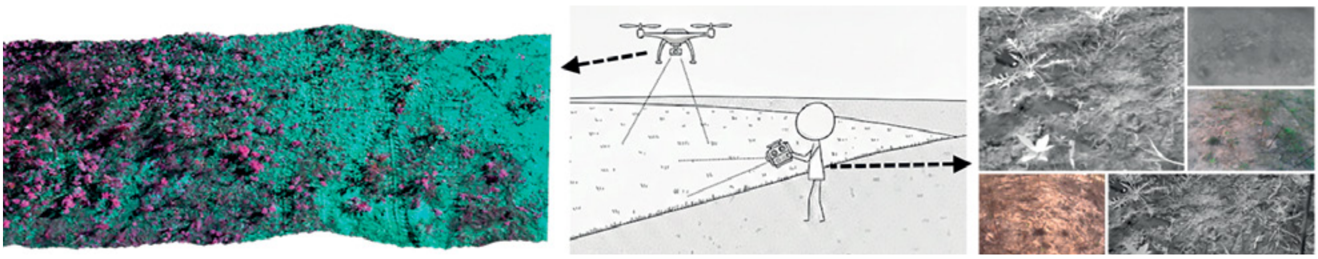

Figure 2: Overview of the ground-based and airborne sensing platforms used during the ROCX campaign. On the left, an ortho-rectified false color composite of a region can be found. On the right, example images of the 5 different cameras on the portable rig can be observed.

Dataset

The collected dataset represents a large-scale, multi-modal electro-optical sensing resource for surface-laid landmine detection. It combines ground-based oblique sensing with airborne nadir observations, enabling investigation of complementary sensing geometries and detection strategies. This multi-view configuration allows analysis of trade-offs between sensor cost, platform mobility, spatial resolution, and detection performance.

The current target annotations consist of georeferenced point locations from all target deployments, obtained by the Trimble measurements. To obtain the full pixel segmentation masks of the targets, first the target locations in the reconstructed 3D scene will be reprojected to the image data. Next, the masks will be refined by an active learning strategy where a limited amount of manually annotated targets will be employed to create a machine learning model that will generate the full masks.

Future work exploiting this dataset will focus on developing and benchmarking detection algorithms using this dataset, with particular emphasis on fusion approaches that leverage the complementary strengths of ground-based and airborne sensing.

The complete dataset will be released as an open-access resource to support research into mine detection, sensor fusion and operational sensing trade-offs in humanitarian demining and defense applications.

Platform	Name	Spectral range	Bands	GSD
Handheld	Luxonis Oak	VIS-RGB	3	≤ 1 cm
Handheld	AV Alvium u240c	VIS-RGB	3	≤ 1 cm
Handheld	AV Alvium VIS-SWIR	VISWIR	3	≤ 1 cm
Handheld	FLIR Boson 640	LWIR	1	≤ 1 cm
Handheld	Ximea RedNIR	RNIR	16	≤ 1 cm
UAV	HySpex (VS-620)	VNIR/SWIR	200/300	~ 5 cm
UAV	RIT MX-1 (Headwall Nano)	VNIR/SWIR	270/1	~ 5 cm
UAV	U of Dayton (Imaging Polarimeter)	VNIR/SWIR/LWIR	1/1/1	~ 5 cm

Table 1: Overview of the sensor systems used during the data collection.

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