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UKRAINE – HOW TO FINANCE MINE ACTION

Innovative Finance for Mine Action in Ukraine

Danielle Payne[1]

This paper originates from the publication "Innovative Finance for Mine Action: Needs and Potential Solutions", authored by the GICHD and Symbio Impact Ltd. This full publication will be publicly available in spring 2024.

Overview

Estimated funding needs to complete land release in Ukraine are in the billions of USD and represent the most significant known financial needs for a specific affected country currently within the mine action sector. The need for not only sufficient but stable, predictable funding for mine action in Ukraine is critical; innovative approaches can help address this need and enable the implementation of sustainable solutions.

Innovative finance mechanisms have already proven a success in the broader humanitarian and development sectors, demonstrated by example via the front-loading mechanism used for immunisation as well as thematic bonds used for peacebuilding. Innovative finance mechanisms have the potential to support the mine action sector with filling its significant funding gap, which is impossible to meet via traditional funding mechanisms alone.

Given the substantial funding gap in Ukraine specifically and the strong political will across the board to address contamination efficiently and effectively, an innovative finance mechanism specific for mine action in Ukraine can be envisaged. The proposed paper will seek to share lessons learned from GICHD's global feasibility study on innovative finance for mine action and how these may be applied to the Ukraine-specific context when assessing various innovative finance options.

Mine Action Funding Status in Ukraine

Reports of funding for mine action in Ukraine since February 2022 show an increase of US$141m to Ukraine when compared to 2021, bringing the 2022 total of international funding for mine action in Ukraine to US$162.3m. While stakeholder analysis confirmed that the trend of increased funding continued into 2023, some key donors to mine action in Ukraine have indicated the increase may also be short-lived due to competing priorities for funding and new emergencies[2]. Figure 1 shows a surge of support to mine action in Ukraine, beginning almost immediately after the start of the escalation of hostilities, as mine action is an early humanitarian emergency activity and one of the first humanitarian activities donors look to fund to enable further humanitarian relief and recovery.

Figure 1:
International funding to mine action in Ukraine during 2015-2022 (based on figures featured in Landmine Monitor annual reports)

1 GICHD, Switzerland, d.payne@gichd.org
2 The referenced exchanges with stakeholders, including several mine action donors, took place during the second half of 2023 during the conducting of the Innovative Finance for Mine Action Feasibility Study (to be published by the GICHD in 2024).

Private funding to mine action is however not included in this analysis as it is not reported consistently in the sector. The recent funding surge to Ukraine has also brought an increase in private sector funding to mine action, either through direct support to the country's national land release capacity, or to NGOs and commercial clearance organisations. One of the largest private supporters to mine action in Ukraine, The Howard G. Buffett foundation, reported donations of US$24m to Ukraine in 2022.[3]

Despite this surge in funding for mine action in Ukraine, some key donors to mine action in Ukraine have indicated, over the course of the data collection phase for the GICHD's global feasibility on innovative finance for mine action, that this increase may be short-lived due to competing priorities for funding. Additionally, the funding surge in Ukraine represents a fraction of the estimated costs needed to complete land release in the country. The cost to clear the contamination in Ukraine incurred since February 2022 was estimated to be 34.6 billion USD as of February 2024, as determined by the World Bank rapid damage needs assessment.[4] Although this figure was reduced by 3 billion USD since the prior rapid damage needs assessment undertaken in February 2023 (after the effects of survey operations allowed for an updating of needs assumptions), it nevertheless represents the most significant funding need for a given affected country to complete land release within the mine action sector at present time.

In order to address this vast funding need, solutions that enable stable, predictable levels of funding are essential to enable operations to be sustainably implemented. This is notably important as it would allow for scaled up programmes to remain at the necessary capacity to efficiently and effectively conduct operations rather than having to scale up and down according to potentially fluctuating funding levels.

Traditional funding methods, namely Official Development Assistance (ODA)[5], should be complemented by other funding avenues in order to fill the funding gap for mine action in Ukraine. To this effect, the mine action sector can assess the possibility of using innovative finance mechanisms as a potential solution for helping to fill this gap.

3 The Howard G Buffet Foundation, '2022 Annual Report' https://www.thehowardgbuffettfoundation.org/wp-content/uploads/2023/04/2022-HGBF-Annual-Report.pdf
4 The World Bank, "Ukraine Third Rapid Needs and Damage Assessment (RDNA3): February 2022-December 2023", February 2024, p. 183.3
5 ODA is defined as, "government aid designed to promote the economic development and welfare of developing countries. Loans and credits for military purposes are excluded." https://www.oecd-ilibrary.org/development/official-development-assistance-oda/indicator-group/english_5136f9ba-en#:~:text=Official%20development%20assistance%20(ODA)%20is,for%20military%20purposes%20are%20excluded.

Overview of Innovative Finance

Although the concept of innovative finance has existed for approximately two decades, initially to address the Millennium Development Goals (MDGs), as specified in the Monterrey Consensus on Financing for Development 2002[6], it remains a relatively new thematic for the mine action sector. Although there is no single universally accepted definition regarding innovative finance, the GICHD's global feasibility study on innovative finance for mine action has proposed the following definition for innovative finance specifically with regards to mine action: *"Initiatives that mobilise new funds at scale to narrow the funding gap for mine action, making use of financial mechanisms to channel public and private funds, and complementing existing funding arrangements in a way that increases equity, sustainability, efficiency and effectiveness."*

Mine action already adheres to the established humanitarian principles of humanity, impartiality, neutrality and independence, as well as the Core Humanitarian Standard on Quality and Accountability (CHS) and general good practice applied in humanitarian and development sectors. Potential innovative finance mechanisms for mine action shall also adhere to these principles and good practice while also incorporating the following characteristics to support the success of such mechanisms:

- Respond to a clearly identified specific need.
- Be simple in structure & provide measurable 'additionality'.[7]
- Make use of blended structures to de-risk investment.
- Be cost-efficient.
- Be cost-effective.
- Have strong stakeholder buy-in.

6 UN, International Conference on Financing for Development (2002) 'The Monterrey Consensus on Financing for Development' Monterrey, Mexico, 18-22 March 2002, https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.198_11.pdf.
7 'Additionality' refers to additional benefit that could not be delivered through traditional funding methods. As already noted, innovative finance should complement traditional ODA, rather than replace it.

The only operational project currently involving innovative finance in the mine action sector is a development impact bond funded by the UK and implemented by the operator Apopo in Cambodia, in partnership with Cordaid. The initiative combines land release with follow-on agricultural activities, where three investors front funding for the project and receive a 7% return on their investment from the backing donor once agreed mine action and follow-on agricultural outcome milestones have been met.[8]

A variety of innovative finance mechanisms also exist in other humanitarian and development sectors, including for example front-loading mechanisms (such as the International Finance Facility for Immunisation (IFFIm)) as well as impact investing thematic bonds (such as Peace Bonds). Such mechanisms could be replicated and scaled to adapt to the specificities of the mine action sector, and to the Ukrainian context in particular.

Potential for Innovative Finance for Mine Action in Ukraine

The Ukrainian context represents a strong case for the use of innovative finance to help fill the funding gap identified above with regards to mine action in the country. In addition to the substantial need, there is also significant political will to support Ukraine, notably including supporting mine action activities specifically to facilitate land release and the ability to use productive agricultural land once again.

As referenced above, a front-loading mechanism and/or a thematic bond, such as a bond linking mine action activities (namely land release) with agricultural activities could potentially be envisaged. A brief overview of these two mechanisms can be found below:

Front-loading

Model Structure: legally binding funding commitments from donors are converted into bonds and then sold on the capital markets to accelerate funding to a specific cause (mine action in this case)

Governance: requires an entity through which the funds from bond proceeds can be channelled in order to have the funds disbursed to relevant operational stakeholders.

Mine action agricultural bond

Model Structure: bonds that could be issued by a sovereign (the mine-affected government), a commercial entity, a Development Finance Institution (DFI), or a combination of entities all playing different roles in a blended structure. Bond proceeds would be channelled to projects integrating land release activities as well as post-land release agricultural economic activities; such activities are measured and monitored by independent third parties against agreed impact indicators and reported to investors via the bond issuers reports.

Governance: the management of proceeds could be implemented through a moderate grants management capacity. The bond would also require third party verification to monitor that funds are spent effectively and to measure and report on pre-agreed impact indicators (such as an auditing or monitoring and evaluation firm).

These are only two examples of innovative finance mechanisms that have worked in other humanitarian and development sectors, and which may be able to be adapted to the mine action sector in general as well as specifically in Ukraine. Any innovative finance mechanism to potentially be employed must however be appropriately tailored to the Ukrainian context; it must correspond to the exact needs and vision expressed by Ukrainian national authorities for the Ukraine national mine action programme, in line specifically with the Ukrainian national mine action strategy. Overall, a variety of options for innovative finance mechanisms can and should be explored to facilitate stable, predictable funding for mine action in Ukraine; this will ultimately support the sustainability of operations in the country as well as support the fulfillment of Ukrainian objectives regarding mine action.

8 Additional information on this initiative can be found here: https://golab.bsg.ox.ac.uk/knowledge-bank/indigo/impact-bond-data-set-v2/INDIGO-POJ-0291/#:~:text=Intervention,it%20aims%20to%20clear%20approx

WOMEN IN MINE ACTION

Advancing Gender Equality in Mine Action: Progress, Challenges, and the Path Forward

Kelly McAulay, Hannah Septembre Rees

Introduction

Due to the highly technical nature of activities, the mine action workforce traditionally has lacked diversity. Women have long been underrepresented, even as they often are disproportionately affected by the presence of landmines and Explosive Remnants of War (ERW) in conflict-affected areas.

To effectively address the specific needs of women and girls in mine action operations, it is imperative to foster diversity within the teams responsible for designing and implementing these operations.

Including women in both technical and leadership roles ensures a comprehensive understanding of gender-specific requirements, leading to more responsive and inclusive mine action initiatives.

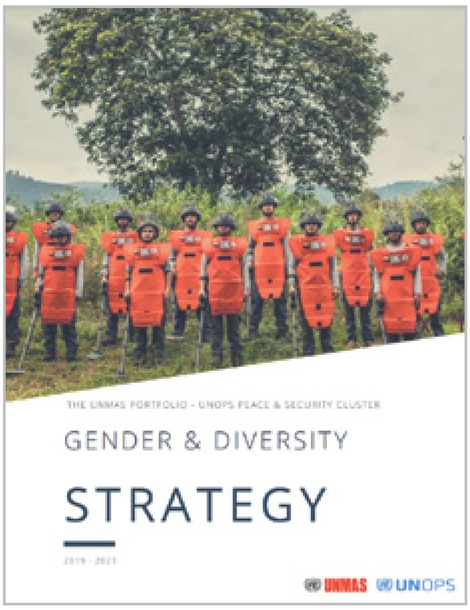
The impact goes beyond the demining field. Involving women in mine action empowers them at home and in their communities. This stems from both the financial independence gained through their work and a shift in how their roles are perceived within families and communities. This, in turn, leads to a more equitable division of household tasks and a positive change in gender relations.

Despite their proven capabilities, increasing the number of women in technical roles remains one of the greatest challenges in mine action.

Through proactive, strategic interventions, creative outreach, enabling policies, understanding the importance of men as agents of change, UNOPS has driven progress and reshaped the narrative of gender equality in mine action.

UNMAS - UNOPS Gender and Diversity Strategy

In response to this challenge, UNOPS embarked on a transformative journey in 2019 with the launch of its gender and diversity strategy, in support of UNMAS operations globally.

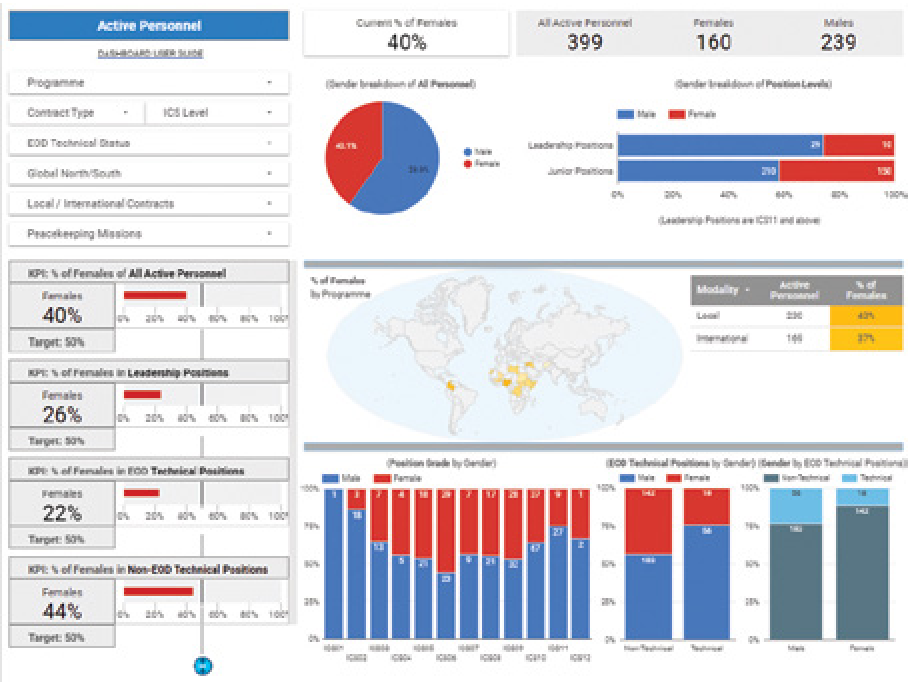


This strategy supports all 17 UN Sustainable Development Goals (SDGs) alongside the 2023 agenda; Security Council Resolution 1325 (2000) and the Women, Peace and Security agenda; and the Secretary General's System-Wide Gender Parity Strategy.

This strategy, a beacon of progress and inclusivity, aimed to address two key areas of improvement: 1) striving for gender parity in the workforce and 2) ensuring that the specific needs of women and girls are understood and responded to in mine action operations. This approach is essential as parity and mainstreaming cannot exist in isolation; without the other, change and progress are unattainable.

Striving for gender parity in the workforce

At UNOPS, the results speak volumes. Today 40 percent of UNOPS global mine action workforce being female, 28 percent of female personnel hold leadership positions, and 22 percent are engaged in explosive ordnance disposal (EOD) technical roles, surpassing industry standards.



Moreover, to ensure we retain female talent, UNOPs conducts analysis on exit interviews and focus groups to identify trends and drivers of female resignations which shape efforts by program leadership to cultivate a more inclusive workplace culture, one that challenges biases and inequalities.

Gender mainstreaming

Furthermore, UNOP" approach to gender equality goes beyond rhetoric and aims at bridging the gap between policy and implementation through focussed planning.

To strengthen the recruitment of women, vacancy announcements and terms of references are screened to eliminate gender-biased language and interview panels are trained in unconscious bias to ensure a fair selection process. As a result, in early 2023, 50% of hires in technical and management roles were female.

Having women involved in leadership roles, at all levels of decision-making, ensures that gender-specific needs, concerns, and priorities are addressed in mine action programming. This includes considerations such as women's access to resources, participation in clearance activities, and support for survivors.

Mali's appointment of a female Chief Operations Officer for its mine action program was a powerful symbol of a cultural shift driven by the program itself. This transformation was fueled by the crucial role of male team members who became champions of change, actively encouraging and supporting women in various roles across mine action. This demonstrates that lasting progress often requires not just empowering women, but also engaging men as allies and advocates.

Of significant note, in technology functions related to Information Management and Analytics, female representation rose from 45% to 62% in two years.

In South Sudan and Iraq, outreach events at educational institutions including the University of Mosul and Juba Institute for Mechanics, were attended by more than 150 people and showcased critical contributions of women to mine action and promoted opportunities. As a result, in Iraq 60% of new hires in 2022 were female and UNMAS South Sudan recruited their first female mechanic.

By mainstreaming gender considerations into all elements of project design and delivery, from gender sensitive procurement practices, technical guidance on mainstreaming for implementing partners and national mine action authorities, gender sensitive monitoring, and promoting gender responsive operational practices, UNOPS is setting new standards and a greater level ambition, for itself and its partners, as it strives for gender equality in mine action.

The roll out of a Gender Mainstreaming Toolkit resulted in 89% of UNOPS implementing partners developing a new or improved gender mainstreaming, diversity, and equal opportunity policy/procedure.

Further, UNOPS has bolstered its procurement practices, requiring each process to set ambitious criteria for women's participation and empowerment.

In South Sudan the Request for Proposal (RFP) required a gender balanced team which increased the role of female staff in visible technical functions, including in management roles; as a result, one implementing partner hired a female Programme Manager for the first time.

In Somalia, in line with the requirements of an RFP, a UNOPS implementing partner ensured that 22% of the trainees for a police mobile vehicle checkpoint (MVCP) capacity project were female, in an area of operations where women would typically be absent.

UNOPS PSC has been leveraging its pre-qualification (PQ) processes to strengthen our focus on gender and diversity mainstreaming and Prevention of Sexual Exploitation and Abuse (PSEA). As a result of gender-sensitive evaluation criteria in our PQ processes since 2018, 13 out of 20 suppliers developed a new or improved an existing PSEA policy/procedure. In addition, 6 out of 7 suppliers developed a new or improved an existing gender mainstreaming, diversity, and equal opportunity policy/procedure.

Source: *UNOPS website. Gender balanced implementing partners teams in South Sudan.*

In South Sudan, UNOPS promoted gender inclusive mine action by supporting the National Mine Action Authority in taking steps to create a gender equality policy, in partnership with GICHD. This policy was created with guidance from the Geneva International Centre for Humanitarian Demining and will be embedded in the Mine Action Strategy.

Today, 100% of our projects are monitored using gender sensitive performance indicators and all collect sex and age disaggregated data to help us understand how women and girls benefit.

Conclusion and way forward

UNMAS- UNOPS' gender and diversity strategy has demonstrably transformed the mine action landscape, not just by increasing female participation, but by fostering a culture of inclusivity and empowerment.

From leadership roles to technical expertise, women are making their mark, exceeding industry standards and reshaping the narrative. This success stems from a multifaceted approach: targeted recruitment, inclusive policies, and a relentless focus on mainstreaming gender throughout all aspects of operations.

As we move forward, UNOPS remains committed to setting ambitious goals, pushing boundaries, and paving the way for a more equitable future, where women and girls are not just beneficiaries, but architects across humanitarian, development and peace and security interventions.

References

1. UNOPS Gender, diversity and inclusion in our workforce Strategy (2022-2025)
2. UNMAS Portfolio- UNOPS Peace & Security Cluster Gender & Diversity Strategy (2019-2023)
3. UN Mine Action Strategy (2019-2023)

Gender in Mine Action: Perspectives from the Women of HALO Ukraine

Co-authors: Arutiunova, Svitlana; Bohovarova, Daria; Rosenberg, Rachael; Shumska, Valeriia

Background

To say the HALO Trust's Ukraine programme has seen dramatic changes since its establishment in late 2015 would be a massive understatement. In its initial incarnation, HALO began clearing explosive remnants of war in early 2016 from the conflict-affected eastern Ukraine's Luhansk and Donetsk regions from a base in Kramatorsk. With Russia's full-scale invasion of the country in February 2022, however, HALO Ukraine pivoted quickly to contribute to the rapid humanitarian response and evacuate its staff to safer ground before restarting operations in a completely different context from a new base in Brovary, Kyiv region in May 2022.

One of the most striking factors of the programme's transformation has been its evolving and deepening focus on gender, particularly as an employer. Since well before the full-scale invasion, HALO Ukraine was leading the way in promoting the inclusion and advancement of women in the mine action sector. In 2017, HALO became the first humanitarian mine action operator in Ukraine to hire and train women as deminers.[1] In an effort to reduce barriers to women's employment and career advancement, in 2021 HALO Ukraine began providing childcare support stipends to women national staff members with school-aged children as part of a global women's empowerment initiative. These stipends proved successful at improving recruitment and retention rates for women.

As of November 2021, approximately one-quarter of HALO Ukraine's total national staff were women, and among operational staff the figure was 22%. This has grown to approximately 30% at the time of writing, with HALO Ukraine taking active steps to increase the proportion to at least 35% in 2024. The ongoing initiatives in this regard in the post-invasion context are briefly outlined in the "discussion and closing" section of the paper.

The three women whose perspectives make up the main body of this paper have all worked for HALO Ukraine since before Russia's full-scale invasion in February 2022. All currently work in senior operational roles, forging ascendant career paths in a traditionally male-dominated, military-adjacent field. In their reflections, these women describe their experiences working for HALO Ukraine pre- and post-invasion, identify challenges for women in the mine action sector and share their hopes for the future[2].

1 Mine Action Review, "Ukraine", *Clearing the Mines* (2017), 218, https://www.mineactionreview.org/assets/downloads/Clearing-the-Mines-2017_Ukraine.pd

2 The following text has been edited for clarity. Daria Bohovarova's text has also been translated from Ukrainian to English.

Valeriia Shumska,
Sub-unit Commander

" I come from the Donbas region in eastern Ukraine, which first experienced the impact of hostilities in 2014. Before joining HALO as an interpreter in 2020, I graduated from university with a master's degree in law. With the full-scale invasion, I had to leave my hometown in the east and relocate to the Kyiv region. I became a monitoring and evaluation officer and then a programme officer, overseeing all phases of project development, implementation and reporting.

– In 2023 I underwent four months of extensive operational training in Sri Lanka, then returned to Ukraine and assumed a completely different role as a field officer. The transition from an office job to the field was neither swift nor easy. The learning process never ends, and I have to keep up with rapid changes and developments on the ground. My daily tasks include planning and overseeing operations, visiting teams on the ground, conducting trials and drawing up standard operating procedures. Sometimes it is quite challenging, but I stay motivated by seeing the results that the deminers and the team achieve every day. The scale of damage caused by the ongoing war is tremendous, and I am happy to be part of an organisation where I can make a difference and have equal career opportunities.

– Working for HALO operations is neither physically nor mentally easy, and the nature of the work requires resilience. There is still a gender-biased attitude when it comes to women in operational and technical roles, particularly in situations in which a female manager is supervising individuals who are senior to her in age. These could potentially be factors impeding greater female representation in mine action. Nevertheless, women have progressed from deminers to team leaders, supervisors and above across various departments."

Svitlana Arutiunova,
Explosive Ordnance Risk Education Senior Supervisor

" I am originally from Kramatorsk, an industrial city with a population of 200,000. It's a one-and-a-half-hour drive from the city of Donetsk. I joined HALO in 2018 as an explosive ordnance risk education (EORE) officer. I was part of HALO's first dedicated EORE team in Ukraine, after the organisation separated risk education activities from non-technical survey. It was the most difficult time for me in the workplace as the only woman on the team. Every day, I had to withstand the challenges of working with male former deminers. I had to assert my personal boundaries while gaining their trust and respect as an equal team member who was eager to contribute.

– As a woman, I have to deal with everyday battles, both big and small, in my career. For one: winning over a male audience of miners or farmers while conducting risk education sessions so that they will actually listen and follow the safety protocols. The most important factor to make them change their behaviour is their trust and attention—their acknowledgment of me as a professional who knows what a landmine actually is. It was a journey going from not knowing anything about weapons and their impact to being a person who knows the tactical characteristics of a landmine and its socioeconomic impact on both local and national levels.

– I realised that I was actually underestimating my achievements at work. One day, my partner said that I am doing very important things and that I should be proud of myself because I definitely have saved lives by promoting safe behaviour. I had to sit with this for a while. Then I started to notice that more and more people had the same thought. That was the moment when I completely changed my mindset and started trusting myself and the process. Today, I lead a great department of 50 dedicated professionals, who are working to make things better: saving lives, changing attitudes and promoting safe behaviour, even though the conflict is ongoing, and it may take decades to clear the land. We raise awareness and empower communities to make informed decisions, sustaining the impact of our risk education interventions.

– Mine action traditionally stems from the military world, where women were not typically in leading roles. This history contributes to the male-dominated nature of the field. It also comes from cultural norms and perceptions of women in Ukrainian society. Women in Ukraine do everything—build families, give birth, develop their careers—all at the same time. But it takes courage for a woman to be ambitious and take a step in a different direction than what is expected.

– Mine action should be inclusive and non-discriminatory in order to open new prospects for women, especially if we want to reach our long-term goals and be 'mine-free by 20XX'. For a start, career opportunities need to be advertised to women. Women can work as deminers, remote sensing or risk education specialists, in environmental roles, non-technical survey, GIS and conducting research to find and develop innovative ways to clear more square metres in less time. This not only increases efficiency but also destigmatises traditional gender roles and promotes gender equality in mine action, showcasing how multidimensional the sector actually is. As the saying goes, «where there's a will, there's a way". Women can do anything, and our contribution to safe land is crucial. This is a space in which women can dedicate time and effort, leaving our mark on the world's safety.

– Since 2022, more women have been serving in the military, as snipers and infantry, piloting drones and evacuating animals and civilians from frontline settlements. The war is continuously in urgent need of resources, both human and weapons. Mine action in Ukraine experiences this pressure like no other sector. While men are being conscripted to serve and defend our country, clearance operations take more time to complete, prolonging the land release process and leaving communities at risk. On top of all the operational challenges, we constantly struggle to recruit and retain enough personnel. We need to attract more women to mine action by demystifying the field and highlighting the diverse professional growth opportunities and impactful contributions they can make to ensure safety for present and future generations. Government-led recruitment programs, comprehensive health and life insurance and social support programs are crucial for this.

– I see myself as a female leader who empowers others, advocates for the development of the mine action sector and implements ambitious projects. There is no doubt that we women have the capacity to rebuild, recover and reform the country, and mine action is definitely the most challenging yet exciting area to make a lasting difference. My ultimate goal is to witness a Ukraine free from landmines, with thriving cities full of people free from fear, who are able to move freely and live unhindered lives. I want to retire knowing I played my part in making this vision a reality."

Daria Bohovarova,
EOD Team Leader

" I started working for HALO Ukraine in 2020 as a manual deminer. My career change was actually a spontaneous decision. I was a manager at a petrol station complex, and the guys I managed there had already accepted offers to join HALO Ukraine. They were the ones who encouraged me to switch careers and join HALO. 'You'll succeed!' they said. And today we are still colleagues here at HALO. I didn't regret my decision then, and to this day I like what I do for a living.

– My career began in the Donetsk region. I myself am from the city of Bakhmut, and that's where I did my training as a deminer, up to the level of team leader. I didn't have any difficulties with career growth—I know my job and perform all the tasks assigned to me with ease. This is probably what helped me reach higher-level positions in the organisation. After Russia's full-scale invasion, it was difficult to make the decision to leave home, knowing that my relatives were facing constant shelling. But HALO continued its work despite the situation in the country, and I realised that my specialised skills were needed even more now. I agreed to move, and soon my relatives joined me.

– I won't deny that there have been ups and downs at work, but I focussed on my goal and kept moving forward. I went through EOD officer training, repetition and more training, and now I hold the position of team leader for HALO Ukraine's first EOD team.

– Currently, few women work in such organisations, perhaps fearing that they will not be able to understand the specifics of our work, perhaps afraid of the danger associated with it. Perhaps they believe that it is not women's work. Believe me, it's not like that—it's both women's and men's work, and professional equality is possible in HALO Ukraine. Some women may still be influenced by people's opinions. I get different reactions—some people say, 'Are you really a deminer? How did you do it?' And other people say, 'Well done, not many women would choose such a profession'.

– This is not my final role—my goal is to grow further up the career ladder, and I will achieve it."

Discussion and Closing

As alluded to by the women featured in this paper, humanitarian mine action emerged as a distinct field relatively recently, and given this history, many humanitarian operators retain some shared DNA with military institutions[3]. It should, then, perhaps come as no surprise that gender mainstreaming has been relatively slower to emerge as a priority in the mine action sector compared to the broader humanitarian, development and peace nexus in which it sits. Lasting, positive change requires deeper engagement than "add women and stir" approaches that seek merely to increase the representation of women while maintaining the status quo. The particular context of post-invasion Ukraine, in which women are a source of untapped potential that can address the challenge posed by conscription, which chiefly affects men[4], may present a unique opportunity for operators to make the sector more inclusive from an employment perspective.

With this goal in mind, HALO Ukraine has already put a range of policies in place. Recruitment panels and events are gender balanced, and photos of women in operational roles are prominently displayed in recruitment materials. HALO Ukraine is also striving to increase access to advanced training courses, with its in-house training department regularly running courses at its headquarters in Brovary. Staff also undergo in-depth training on other HALO programmes, as Valeriia experienced in Sri Lanka. Amidst its rapid expansion post-invasion, HALO Ukraine also mainstreamed the childcare support stipends piloted in 2021, with the associated costs distributed proportionally across all donor budgets to ensure long-term sustainability. The stipends are now part of the standard HALO Ukraine benefits package for qualifying staff. Importantly, this now extends to include single fathers. HALO's parental leave policy also goes beyond Ukrainian statutory requirements and includes paternity leave. While small on its own, policies like these reflect the reality that "gender is not a synonym for women"[5].

Although the scope of this paper has by necessity been limited to women's participation in the mine action sector as leaders in operations, the other side of the equation—gender as it relates to mine action operations and impact on external actors (particularly beneficiaries)—is of the utmost importance. Much more work remains to be done to untangle these dynamics and identify new best practices. To this end, HALO Ukraine is now establishing a working group to provide ongoing input to the programme's gender strategy, with funding set aside for data collection to assess gendered impacts and to develop and action new initiatives as part of HALO Ukraine's evolving gender strategy. Thanks in no small part to the trailblazing women of HALO Ukraine, including the three whose perspectives are included in this paper, these new initiatives are hoped to make Ukrainian mine action both more effective and more equitable.

3 See GICHD, "Introduction and History of Mine Action", *A Guide to Mine Action* (2014), 13-31.
4 As of October 2023, women ages 18-60 with medical qualifications are also required to register. See "Women with Medical Education to Be Considered Eligible for Military Enlistment", *Kyiv Independent*, 7 September 2023, https://kyivindependent.com/women-with-medical-education-to-be-considered-eligible-for-military-enlistment/.
5 See Scott, Joan Wallach (1986), "Gender: A Useful Category of Historical Analysis", *The American Historical Review 91* (5): 1053–1075.

R&D AND NEW TECHNOLOGIES WITHIN MINE ACTION

An Innovation System's approach to Explosive Ordnance Risk Reduction

Pedro Basto[1]

Introduction

"Necessity is the mother of all invention." The idiom inspired by the Greek philosopher Plato has been reinterpreted over and over by many authors, economists and innovation management researchers and practitioners. And although invention and innovation should not be confused, it still holds a simple, yet relevant assumption, the greater the challenges, the greater the need for creative invention and successful innovation. In today's landscape, Explosive Ordnance Risk Reduction (EORR) faces substantial challenges, rendering innovation a critical need.

Conflicts are becoming increasingly intricate and prolonged, resulting in new contamination that compounds the enduring global aftermath of past conflicts. Developing and embracing new innovative tools, methods and approaches is an imperative not only to confront these evolving challenges of our work but also to pre-emptively address their repercussions on explosive ordnance affected communities.

While the challenges continue to multiply, funding remains a consistent constraint. Innovative tools, methods and approaches hold the potential to improve efficiency, conductive to greater impact with the available resources. Introducing innovative financing solutions can also contribute to greater impact, by bridging current funding disparities.

Technological and methodological advances are constant and must be welcomed in EORR. Tailoring and integrating them as part of the comprehensive toolbox from which diverse tools and methods can be selected to respond effectively to specific contexts, is paramount to keep abreast with constant new challenges.

This article emphasizes key innovation concepts such as innovation, innovation system, and the steering mechanisms involved in the process of innovation. It aims to set the stage for the debate and lay the groundwork for further systemic exploration of innovation in EORR.

Innovation and innovation systems

The word *innovation* can be used with multiple and diverse meanings, sometimes even "indiscriminately"[i]. The same applies to the scope and definition of composed terms like *innovation system*, *innovation management* or *innovation activities*. Innovation is interchangeably used to describe an outcome as well as to refer to the activities and processes resulting in, or aiming for the emergence, dissemination and adoption of innovation – in a nutshell the the process of innovating[ii].

Supported by the ISO vocabulary of innovation management[iii], *innovation* can be defined as the creation of a new or changed product or process that represents a degree of novelty and delivers a positive impact and/or an added value. It's worth noting that, although not explicitly mentioned, the idea of added value should be undissociated from the key driving principle that innovation addresses real evidence-based problems. This is supported by good practice in the field of Humanitarian Innovation[iv] [v]. The ISO further adds that the degree of novelty and value are relative and are determined by the perception of the relevant stakeholders, which means that practices already established in other sectors of activity can be considered innovative within EORR.

While useful, this definition remains generic and broad. It could apply both to breakthroughs at the cutting edge of science as well as new design features of products or forms of reporting. A model commonly accepted within Humanitarian Innovation[vi] that further refines the definition of innovation is the 4Ps innovation space model[vii], which introduces 4 types/dimensions of innovation:

- Product innovation – new or improved tools or services (e.g. mechanical demining assets, remote sensing tools);
- Process innovation – new of improved ways we use tools or deliver services (e.g. land release, quality management);

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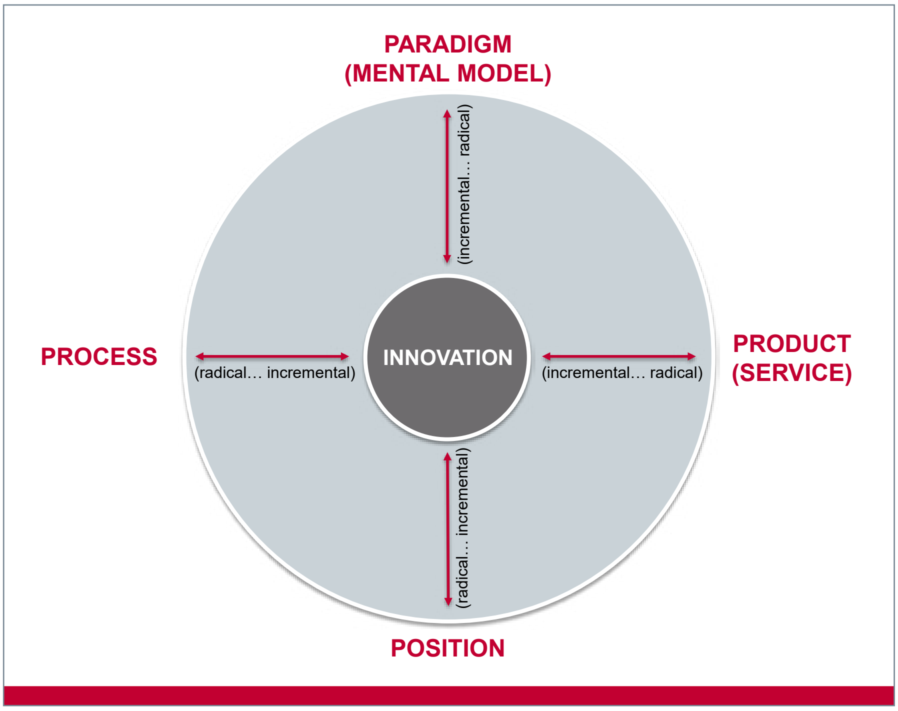

Figure 1: The 4Ps of innovation space. A single innovation can be mapped in any position within the innovation space Reference: Tidd & Bessant (2021)

- Position innovation – new approaches to how processes, tools and/or services are used/delivered (e.g. policies/initiatives linking mine action to SDGs and broad agendas);
- Paradigm innovation – new mental models for the way of work (e.g. land release).

As the example of land release depicts, the boundaries between these dimensions are not always straight lines. While land release is an innovation in process, it also changed the paradigm of the sector, away from a much narrower clearance focus. If we would wish to map land release in the 4Ps innovation space, it would be in the top left quadrant.

This model provides a useful mapping tool to consider not only different types/dimensions of innovation but also different manifestations of their degree of novelty. All types of innovation can manifest in a scale ranging from continuous improvement (or incremental innovation – *improve the rules of the game*) to disruptive innovation (radical innovation – *change the rules of the game*)[2].

Continuous improvement is often a natural outcome of learning processes and largely an intrinsic part of organizational dynamics. Within the field of EORR, it has been effectively harnessed, documented, and disseminated in various ways. Prominent examples include extensive research products, the formulation of national mine action strategies, national and international standards, and guidelines.

Disruptive innovation has also found its place within EORR, both in terms of tools and methods (e.g. land release, quality management, digital Explosive Ordnance Risk Education applications, Ammunition Inventory Management Systems). The sector has excelled in generating, disseminating, and codifying knowledge, as well as implementing these innovations. However, it is important to acknowledge that many other innovations, particularly technological, have demonstrated promise, but still encounter challenges both in achieving the outcome of changing the way the sector operates as well as in achieving widespread adoption.

One of the primary challenges associated with innovation lies in the need for active collaboration among various stakeholders (or building blocks). These include funding organizations, research institutions, technology developers, academia, operational agents, relevant standards bodies, and national authorities, among others. Each of these entities often pursue different immediate motivations and objectives. Their interactions, collaborative and/or competitive, are influenced by specific contextual factors, such as the country of operation, capacities, regulatory frameworks, available resources, market dynamics, among others. These interconnected building blocks, that collaborate to deliver innovation are often referred to as *innovation systems*[3]. While such systematic approach has been brought to light within the broader innovation management field[viii], it has been increasingly considered of crucial relevance within the humanitarian sector: *"(…) a characteristic of this system view is the emphasis on the notion of innovation not being a single-actor effort, but rather a dynamic and emergent process that is the product of multiple actors and their relationships."*[ix]

Innovation system could be defined as *the evolving set of actors, activities, and artefacts, and the institutions and relations, including complementary and substitute rela-*

2 ISO 56000:2020 refers to breakthrough (or radical) innovation, drawing a distinction with disruptive innovation, where the first encompasses a high degree of change as opposing to an incremental innovation, while the disruptive innovation encompasses the actual displacement of established offerings by completely novel products or processes. Discontinuous innovation is also found often in literature to refer to this type of innovation.

3 Innovation ecosystem is another term often used within the vast body of knowledge related to innovation management to describe the complex, dynamic, interconnected and collaborative nature of innovation systems. The term was coined drawing parallels with biological ecosystems, particularly, rainforests.

tions, that are important for the innovative performance of an actor or a population of actors, where *artifacts include products and services, tangible and intangible resources, technological and non-technological resources, and other types of systems inputs and outputs, including innovations*[x]. This general definition has found its place also within Humanitarian Innovation.[xi]

Why an innovation systems approach?

Exploring the benefits of the conceptual discussion and framework described above demands further consideration. As was noted and as we witness almost daily, innovation already emerges within the field of mine action and ammunition management, regardless of the present conceptual considerations. However, we also witness considerable challenges to "successful" innovation (what do we mean with "successful" innovation will be addressed later on). During the 2023 GICHD Innovation Conference some of these challenges have been described and highlighted: *silver bullet* bias, insufficient needs-based approaches, lacking collaboration and common legal/regulatory basis, reduced cost-effectiveness and limited funding and resistance to change. It is unsurprising to find a very strong co-relation between these and those identified in other Humanitarian Innovation systems. [xii] [xiii]

Given the complex and dynamic nature of innovation processes, identifying, and implementing corrective measures to overcome such challenges will very unlikely be achieved with linear single-actor actions (it would be lighthearted to consider there are *silver bullets* to tackle these challenges).

The innovation systems approach is valuable primarily because it serves as a framework for analysis. It aids in pinpointing areas where building blocks may be missing or insufficiently interconnected. Each of the challenges identified above constitutes one or multiple gaps in the system. Once the gaps are identified, as well as the missing relationships, measures can be implemented to promote the establishment of missing building blocks or to act as an interface to enhance communication among them, fostering partnerships and collaboration. These can be either tools, activities, strategies, or others. This represents a constant iterative cycle, rooted in a deep understanding and careful awareness of the sector's dynamics.

Furthermore, *"adopting a more deliberate and systematic approach can enhance innovation performance and facilitate better learning and cross-pollination of approaches within the sector."*[xiv]

Application to EORR

The collaborative principle behind the notion of innovation systems intuitively prompts a collaborative approach to its application to EORR. As such, defining innovation and innovation systems in context, as well as its measures of success, most critical challenges, priorities, and steering mechanisms, are not only essential initial steps for any successful systematic exploration of innovation[xv], but they must also be subject to open debate and scrutiny.

The following section elaborates on some additional considerations relevant for the definition of *innovation in EORR*.

The ISO vocabulary, expanded with the 4Ps innovation space model, presented in the previous sections, provides a good baseline. However, two aspects require further analysis: the establishment of the degree of novelty and the concrete measure of the impact and/or added value (the definition of successful innovation).

The degree of novelty may be relatively easily established by the level of codification in existing normative or legislative frameworks (e.g. IMAS, IATG and/or respective national standards).

The concrete measure of a successful innovation on the other hand may require further thought. Within Humanitarian Innovation, no holistic criteria for successful innovation can be found. Nonetheless, the following 3 criteria are commonly referenced[xvi]:

- Level of adoption: scale of use by stakeholders within the sector
- Measurable comparative improvement in effectiveness, quality or efficiency (how should safer, more effective and more efficient operations be measured?)
- Consolidated learning and evidence: new knowledge is generated, or the evidence base is enhanced (can this alone be considered innovation?).

Steering the Innovation System

As described above, the utility of the framework of analysis provided by innovation systems is indissociable with the notion that it can be influenced or steered, despite its complexity and dynamic features.

Good practice within other sectors suggests the need for institutional collaborative arrangements capable of convening the diverse stakeholders in an integrated platform where new knowledge is shared and disseminated, needs-based approaches are promoted, efforts prioritized, and the establishment of collaborative partnerships facilitated. An integrated platform "*for addressing the weaknesses of the [system] in a systematic and sustained fashion*", which would help "*building a shared vision within the sector, the ability to identify new capabilities (and resources) needed and facilitate a move from a 'reactive' innovation mode to a 'proactive' one*".[xvii]

Such platforms have received a wide range of labels: innovation hubs, accelerators, incubators, laboratories, platforms, boosters, forums, among others. With a varying degree of features and functions offered, these often share the following components:

- A multistakeholder steering body, providing strategic guidance;
- Multistakeholder collaborative technical advisory groups, capable of identifying, discussing, and analyzing cutting-edge technologies, products and processes that can be exploited or explored;
- A body of reference documentation (e.g. research agendas, roadmaps, taxonomies)
- The organization and/or promotion of innovation activities (e.g. conferences, workshops, prizes, challengers, trials);
- Funding mechanisms capable of supporting selected innovation initiatives throughout all the phases of the innovation process, from identification, to invention, testing and scaled adoption.

Concluding remarks

This article attempted to briefly state the case of why innovation is so much needed in EORR, as well as to shed some light over basic innovation concepts such as *innovation*, *innovation system*, *innovation system's approaches* and their *steering mechanisms*. Such exercise aims at providing food for thought on a theme that is very recurrent and highly regarded within the sector, even though, at times, insufficiently understood. It will hopefully generate relevant feedback that supports the advancement and streamlining of innovative tailored and sustainable solutions for EORR.

It is not a one-off effort, but rather must be the result of a collaborative iterative process, drawing on the lessons identified and the wide range of expertise available, that counts on the commitment from all.

Endnotes

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SpotlightAI: Enhancing NTS with Drone-based AI Landmine Detection

Jasper Baur[1], Gabriel Steinberg[1], Carl Case[1]

Abstract

SpotlightAI is a highly innovative AI drone image analysis tool designed for use by humanitarian deminers. Powered by Amazon Web Services (AWS), SpotlightAI harnesses state-of-the-art machine learning models optimized for landmine and unexploded ordnance (UXO) detection to rapidly process massive amounts of sub-centimeter-level aerial imagery collected by commercial off-the-shelf drones. After a user uploads a drone survey, the software processes the imagery with a machine learning model built from a dataset of hundreds of thousands of labeled images of 150+ unique types of landmines and explosive ordnance (EO) ranging from anti-personnel mines and cluster munitions to projectiles and aerial bombs. SpotlightAI automatically detects, labels, and GPS-tags surface EO, creating detailed maps and reports that provide actionable intelligence for both deminers on the ground and remote program managers for conducting non-technical surveys (NTS) and prioritizing areas for clearance. SpotlightAI is being actively used in Ukraine by humanitarian demining organizations, including The HALO Trust and Norwegian People's Aid, and Ukrainian government entities, such as the State Special Transport Service, to augment NTS. To date, SpotlightAI has detected thousands of real-world EO demonstrating its capabilities as a powerful new tool for humanitarian mine action (HMA) practitioners to significantly boost the value they get from NTS, saving money, time and reducing danger throughout the entire land release process.

Introduction

We present SpotlightAI: the first AI drone image analysis tool built for deminers. SpotlightAI is a web-application designed to help HMA practitioners analyze drone imagery of suspected hazardous areas (SHAs) by creating maps of the surveyed area, detecting and locating surface EO, and allowing users to plot points and polygons to define confirmed hazardous areas (CHAs), all through a simple user interface. SpotlightAI was designed for the Ukrainian use-case but is globally applicable.

An estimated 30% of Ukraine is contaminated with landmines, UXO, and other explosive ordnance, restricting land use in much of Eastern and Southern Ukraine and causing civilian casualties. The immense scale of the contamination requires new, innovative solutions that can quickly, accurately, and affordably assess land for explosive contamination. To this end, uncrewed aerial vehicles (UAVs) are becoming widely adopted as a standard surveying procedure by most HMA organizations. Employment of UAVs for NTS significantly enhances access of survey teams to investigate large or extensive SHAs that would otherwise limit broader investigation.

Drone imagery is rich in information including visible landmines, craters, and EO indicators, but manual analysis of this imagery presents yet another problem of scale. Depending on factors such as the analyst's experience, the surveyed environment, and the resolution of the image, we estimate it takes an image analyst 3-7 minutes to effectively search a single drone image for EO. Figure 1 depicts a drone survey conducted over a CHA and illustrates how difficult it is to manually identify an anti-personnel mine in a single drone image out of the 1150 images that comprise the survey. SpotlightAI employs a custom-trained AI detection model which, in a matter of seconds, detects, classifies, and locates visible surface EO in a drone image. Assuming drone imagery was collected of all of Ukraine's suspected contaminated land (174,000 km^2), it would take (17,400,000 ha * 600 imgs per ha * 3 min per img / 20 person team ≈) approximately 500 million man-hours or 3,000 years for a team of 20 to manually search this imagery for EO. With SpotlightAI, the task of analyzing this imagery and locating all visible EO in Ukraine's suspected contaminated land will still be a massive endeavor but will be within reason.

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Figure 1. Example of real-world drone survey processed by SpotlightAI, with detection of a PFM-1.

Usage

SpotlightAI is designed to fit within the existing framework of a non-technical survey (NTS). It is designed to be user-friendly, scalable, secure, and require no prior Geographic Information System (GIS) experience. The software is compatible with most commercial-off-the-shelf UAVs and requires no additional hardware components, deriving all information from the drone's built-in visual camera. In conjunction with desk assessments and community interviews, SpotlightAI provides essential direct evidence points that can be used to more accurately determine the classification of a surveyed area (candidate for cancellation, SHA, or CHA), the perimeter of that area, priority for clearance, and appropriate assets for clearance. This information will also increase the safety and situational awareness for deminers on the ground. Actionable intelligence is created from each drone survey in the following forms:

1. An orthomosaic: sub-cm resolution georeferenced map of the surveyed area created from drone images.
2. Interactive hazard map with orthomosaic, detected items, drone images with detections, vegetation height map, detection rate heat map based on vegetation height, and 25m buffer polygon around confirmed detections (Figure 2).
3. GIS-compatible CSV and KML files with coordinates of detected items.
4. Automatically generated PDF report structured in accordance with National Mine Action Authority and based on NTS reports from HMA non-profits.

How do you use SpotlightAI?

A user must have an account to access SpotlightAI. Anybody can login to safepro.ai and request an account, which, once approved, will give them full access to the system. Once logged in, the user can upload a drone survey and SpotlightAI will begin the analysis.

The workflow is as follows:

1. A drone operator collects a grid-style UAV survey over an SHA.
2. A user with access to the internet will upload the collected images to SpotlightAI.
3. SpotlightAI's machine learning model will immediately begin scanning the drone imagery and marking the suspected hazardous items in the drone images.
4. Once the operator finishes uploading the images and the initial predictions are made (available within minutes), the imagery can be processed using structure-from-motion photogrammetry into sub-cm resolution, georeferenced maps.
5. After the maps are generated (usually 20 min - 4 hours depending on size of survey), suspect items and their coordinate locations are plotted on the maps. A user can quickly refine the results by viewing all the predictions in our Prediction Reviewer.

The final result is a map of the suspected hazardous area with the images of the detected surface contamination and their precise coordinates.

Methods

SpotlightAI's computer vision engine has been trained on 150+ specific types of EO, with over 100,000 real-world samples. The labeled samples are grouped into 23 general categories enabling us to produce models that can extrapolate to detect new EO beyond the 150 specific types it has been trained on. These categories include but are not limited to: submunition, projectile, munition casing, anti-personnel landmine, anti-tank landmine, and rocket propelled grenade (RPG). The EO items used to train are predominantly Russian and US-manufactured ordnance. The AI detection models are constantly updated to adapt to the evolving situation on the ground. SpotlightAI's custom-built algorithms are optimized for small object detection and automatically reduce the number of false positives.

SpotlightAI uses structure-from-motion (SfM) photogrammetry tailored for drone mapping missions to process the drone imagery into orthomosaics. The orthomosaic generation software is built-in (requiring no additional software licenses), using powerful cloud computing to process many surveys simultaneously, which is not possible on a desktop or laptop. The resolution of the orthomosaic is dependent on the input drone imagery but is usually 0.25 - 0.35 cm/pix for SpotlightAI surveys. It takes on average two hours to process one hectare of land. The system applies custom algorithms that build off the 3D mesh produced from the photogrammetry to extract vegetation height and uncertainty maps shown in Figure 2.

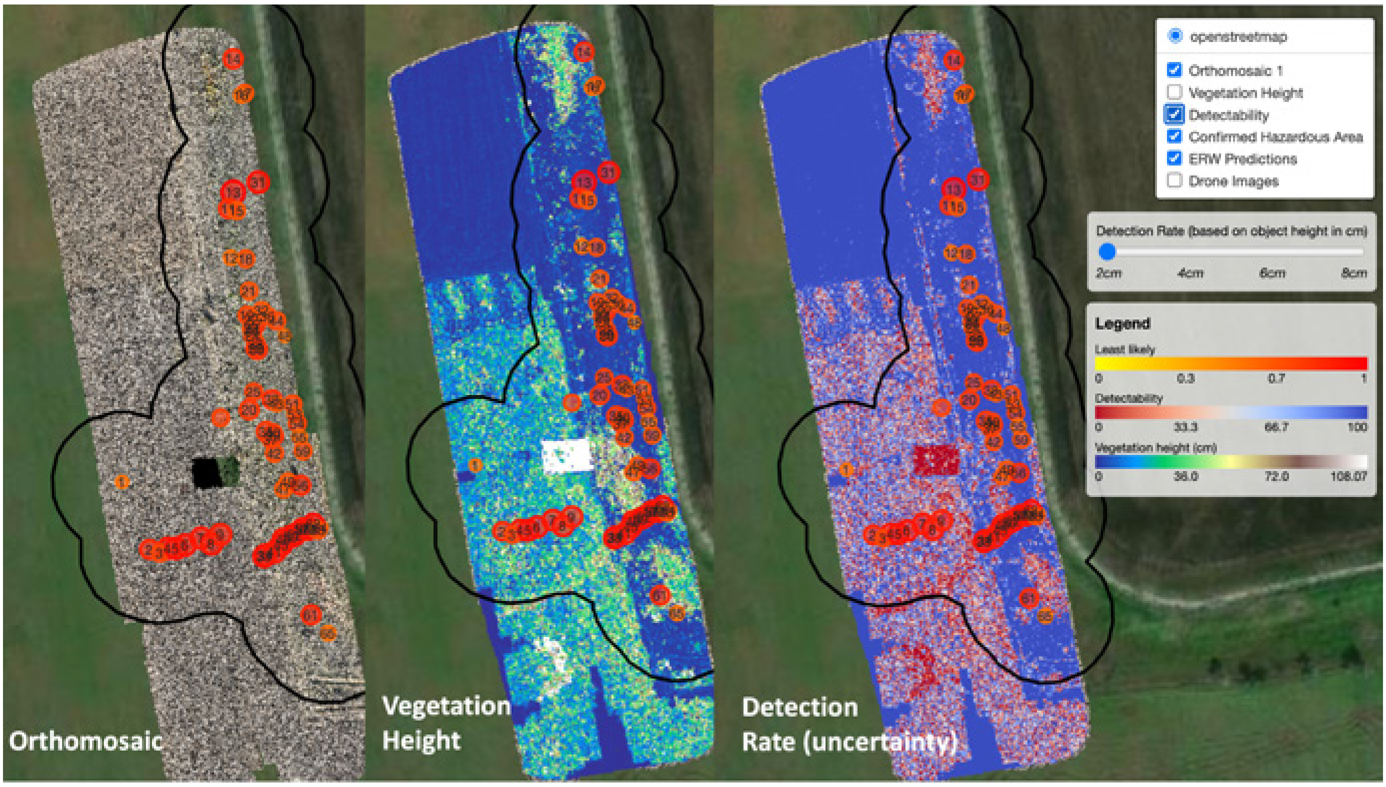

Figure 2. Hazard map with different layers selected. The red dots are EO, the black outline is the 25m buffer for a CHA polygon, the middle panel shows the vegetation height map, and the right panel shows the detection rate map.

Field Results

SpotlightAI is actively being used in Ukraine by non-profit organizations such as The HALO Trust and Norwegian People's Aid and Ukrainian government entities such as the State Special Transport Service to augment non-technical surveys. It has processed surveys from multiple oblasts including Chernihiv, Kharkiv, Kherson, and Mykolaiv in environments such as agricultural fields, roads, suburban streets, and former battlefields. Over 150 drone surveys have been processed as of February 2024, with more being processed every day. These surveys range in size from less than 100 to over 6000 drone images, corresponding to ~0.25 hectares to 10 hectares of land mapped and scanned for EO in each survey. From these surveys, thousands of real-world EO and EO indicators have been detected. Figures 3 and 4 show examples of some real-world detections.

Figure 3. Example of an anti-tank mine line detected using SpotlightAI.

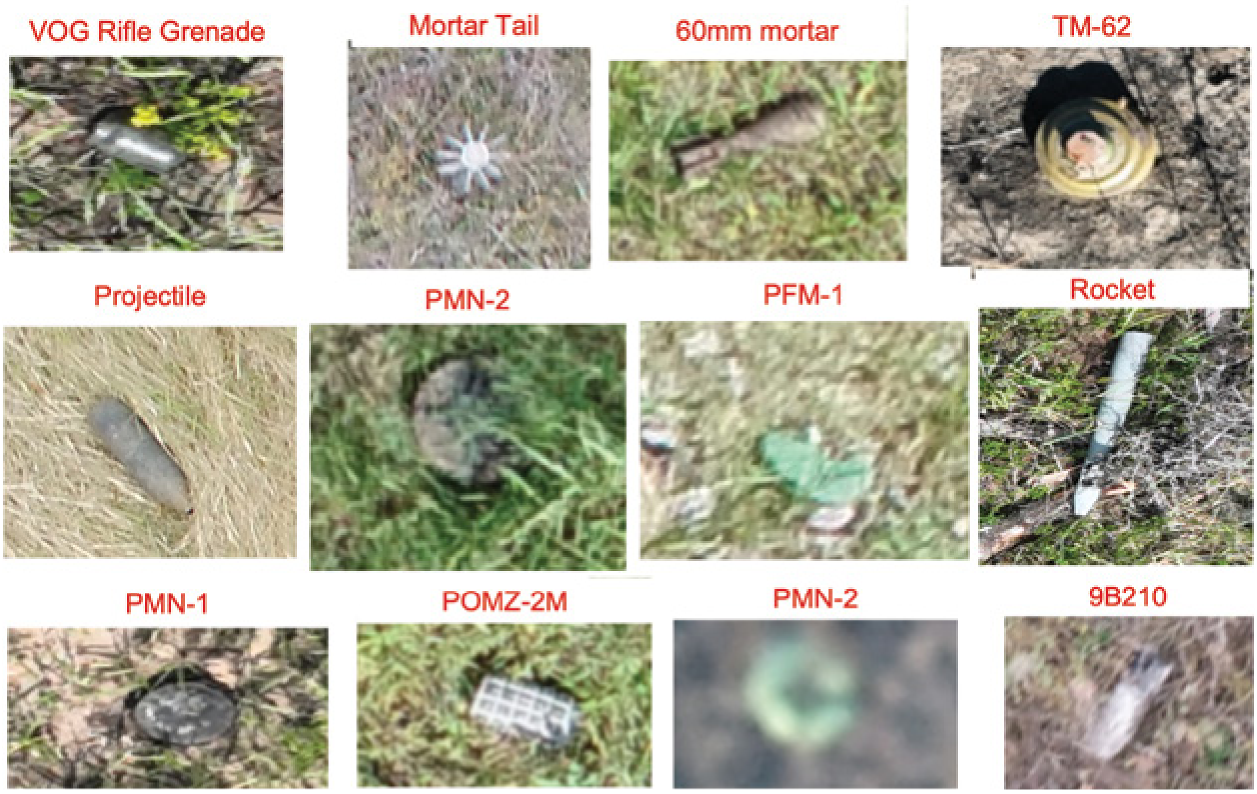

Figure 4. Example of some real-world explosive ordnance detected using SpotlightAI machine learning model. There are a variety of items in different environments and varying image quality that have been located.

Table 1 provides an objective side-by-side comparison between a manual approach and the SpotlightAI approach for analyzing drone imagery from a real-world 2-hectare CHA in Ukraine. The timing and accuracy to map out surface contamination for a NTS are documented for each method. The manual approach consisted of processing the drone imagery into an orthomosaic locally using Pix4DMapper, then analyzing the orthomosaic in QGIS, marking any visible contamination. The computer for the manual method was a powerful gaming laptop with the following specifications: Intel Core i7-10750 CPU @2.60GHz, 16GB RAM, NVIDIA GeForce RTX 2060 GPU. The SpotlightAI approach consisted of uploading the drone images to SpotlightAI, reviewing AI predictions and analyzing the automatically generated orthomosaic.

Table 1. Comparison of SpotlightAI versus manual analysis of an orthomosaic in a CHA.

	Manual process	**SpotlightAI**
Time for upload	00h:00m (Not applicable)	00h:47m (upload speed ~8mb/s)
Time for orthomosaic generation	08h:23m	01h:46m
Time for analysis	05h:42m	00h:24m
Total time Total Time per hectare	14h:05m 06h:49m / hectare	02h:57m 01h:26m / hectare
Accuracy for AP mines	50% (5/10)	80% (8/10)
Accuracy for AV mines	84% (16/19)	100% (19/19)
Total Accuracy	72% (21/29)	93% (27/29)

The results show that SpotlightAI outperformed the manual analysis and processing in both time and accuracy for this test case. These metrics are useful for comparison, but the results from this test are subjective to the type of environment (half-plowed agricultural field) and type of EO present. It is important to note that accuracy is largely a function of occlusion due to vegetation. In unoccluded (low-vegetation) environments, SpotlightAI achieves up to a 95% accuracy, but as vegetation obscures the view from above, the accuracy decreases. To quantify the detection rate, detectability maps are generated based on vegetation height and density (shown in Figure 2). These maps put the detection rate of surface contamination into environmental context.

Conclusion

SpotlightAI is designed to assist HMA organizations by providing a scalable method to map and analyze thousands of drone images and extract direct evidence points of explosive ordnance. Based on feedback from HMA operators, SpotlightAI is constantly being updated and improved by our dedicated team of scientists, developers, and mine action experts based in New York, Washington DC, Kyiv, Zaporizhzhia, and Mykolaiv. Combining the ability of commercial off-the-shelf drones to survey wide areas and the accuracy and speed of a highly trained AI recognition model, SpotlightAI can systematically detect explosive ordnance at scale, providing HMA organizations a powerful new tool to combat explosive remnants of war. If interested in a license to use SpotlightAI, please reach out to us via email.

Affordable geo-localisation of humanitarian demining tools (mountable on K9, robot, hand-held device, etc.) in GNSS-denied environment

Janusz Będkowski[1], Tresya Yuliana Fitri[2], Michał Pełka[3]

Abstract

This paper addresses affordable geo-localization technology supporting demining action (especially surveying, mapping, and marking) in GNSS-denied environments and GNSS-challenged terrains. Thus, roads, footpaths, forests, houses, schools, and other indoor/outdoor scenarios are within the scope of an investigated localization technology. Obviously, such functionality is provided by GPS/GNSS receivers, but not always sufficient in all scenarios. The goal was to reach a centimetric localization and the capability to reconstruct surroundings (as a dense 3D point cloud). For this reason, an affordable LiDAR-based mobile mapping system was chosen for performing experiments including hand-held, K9, 4x4 wheeled robot, and 4-legged robot. Experiments show satisfactory results in providing accurate trajectories and 3D maps that can be used for Humanitarian Mine Action (HMA) – improving survey and assessment, mapping, marking, training, quantitative grading, and risk education by supporting digital twinning. Hence, the application should imply the Quality Management System (QMS) in terms of the process approach, improvement, evidence, and data-based decision-making.

Introduction

Landmines and explosive remnants of war (ERW) are threats to civilians. These dangerous weapons can be found on roads, footpaths, farmers' fields, forests, deserts, along borders, houses, schools, and many other places of daily activities [2]. This paper concerns the idea of accurate tracking of clearance tools: mine detection dogs K-9 (canine), manual deminers, mechanical demining equipment, and robots, that are working especially in GNSS-denied conditions. This can improve the process of area reduction, thus gathered information locates the perimeter of a suspected hazardous area (SHA), moreover it is possible to annotate hazardous objects with centimetric precision in the 3D map that is built thanks to accurate reconstruction of the LiDAR attached to the clearance tools. We are optimistic that the proposed technology can improve technical survey (TS), especially within the context of clearance tool tracking, and reconstruction of the surrounding environment of ERW contamination. This work is dedicated to supporting land release prioritization, decision process, and land release.

Accurate tracking of clearance tools is challenging in GNSS-denied conditions (indoor, forest, tunnels, etc.). Moreover, tracking K-9 (canine) in such conditions is still an open challenge, but there are some promising results for the search and rescue domain [3][4]. According to our best knowledge, K-9 LiDAR-based tracking and 3D mapping for humanitarian demining in GNSS-denied environments has not yet been elaborated in literature [5]. Moreover, the proposed technology [6] can be applied to other clearance tools since it is lightweight and does not require any other integration than mechanical mounting (figure 5 shows examples elaborated in this paper). We hope this work will have a positive impact on e.g. Route Overwatch Search Dogs (ROSD) and Explosive Detector Dogs (EDD) cyber enhancement, thus search action can be done at a greater distance from their handlers. The tracking and 3D mapping technology is based on Livox Mid-360 (range up to 70m, precision around 3cm, weight approx. 265g) composed of an Inertial Measurement Unit (IMU) and Light Detection and Ranging (LiDAR) with nonrepetitive scanning pattern[7] measurements. Our software recovers the trajectory and the 3D map with LiDAR odometry [8] and Pose Graph SLAM [9] algorithms. It is available as open hardware **https://github.com/JanuszBedkowski/mandeye_controller** and open source **https://github.com/MapsHD/HDMapping**. The methodology is elaborated in [10].

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Problem statement

It is difficult to obtain accurate localization using a GNSS receiver when a large noise is evident. It is caused by phenomena like multi-path interference and buildings obscuring the almanac or when the signal is lost. Moreover, GNSS provides only 3DOF (three degrees of freedom - position) instead of the required 6DOF (position and orientation), which is essential for 3D reconstruction. Figure 1 shows such a scenario. Figure 2 shows plenty of noisy GNSS measurements that do not help in device tracking. The goal is accurate tracking of the device. Hence, an accurate 3D reconstruction can deliver meaningful information.

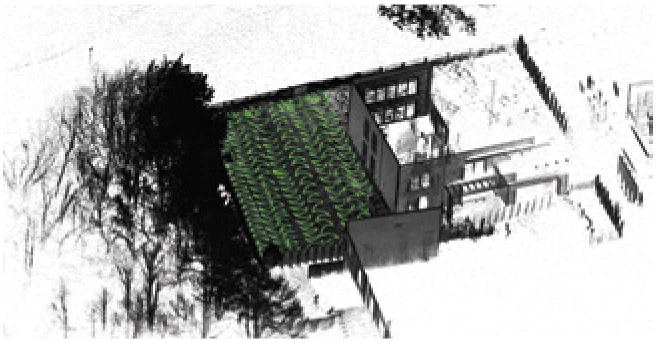

Figure 1: Example survey results with handheld device equipped with LiDAR. Gray-scale: 3D map, green: the trajectory of the handheld device.

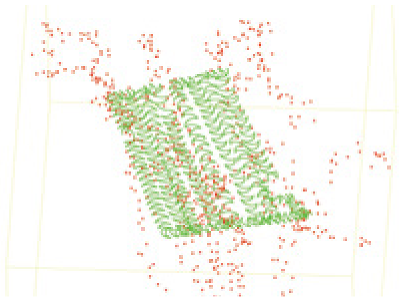

Figure 2: Green lines: the trajectory of the hand-held device, red dots: GNSS positions (large noise is evident and caused by phenomenons like multi-path interference and buildings obscuring almanac).

Approach

We incorporated a wide field of view LiDAR Livox Mid-360 (figure 3) with a nonrepetitive scanning pattern (figure 4) [11] that enables covering up to 99% of the surroundings within seconds.

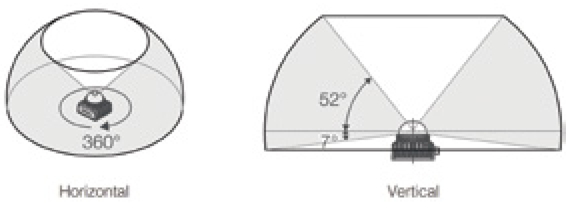

Figure 3: Effective field of view of the Livox Mid-360 [1].

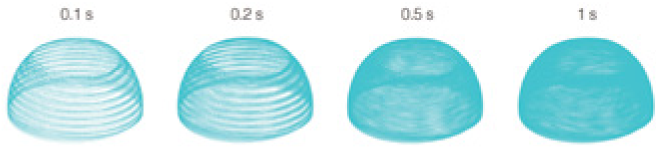

Figure 4: Point cloud patterns of Livox Mid-360 accumulated over different integration times [1].

It is equipped with IMU, which is used for initial orientation calculation with the Magdwick filter [12]. The first step is LiDAR odometry which creates the initial trajectory. The second step is to refine this trajectory by manual loop closure [6]. This is a postprocessing approach, thus we record data and process them afterward. Obviously, such an approach is chosen for research purposes. Our target is a fully automated application in the future.

Tested clearance tools

Figure 5 shows tested clearance tools: hand-held device, K-9, 4x4 wheeled robot, and four-legged robot. The goal was to verify if the attached IMU/LiDAR-based navigation system is capable of trajectory tracking and 3D mapping in realistic conditions.

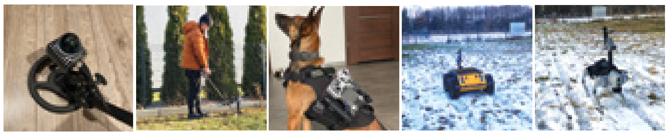

Figure 5: From left, LiDAR mounted onto the hand-held device, hand-held device, K-9 with LiDARs, 4x4 wheeled robot, four-legged robot.

Mobile mapping and trajectory tracking of different systems (hand-held, wheeled robot, legged robot)

In this experiment we obtained the trajectories (Figures 7-9) and the 3D maps (Figure 6) for each of the tested systems. The goal was to cover the area by parallel paths. It can be seen that it is possible to obtain centimetric precision. This statement is based on the accuracy of the obtained 3D model. The thickness of the reconstructed walls does not exceed several centimeters, thus we claim that the precision of the trajectory is also on the centimetric level. The experiment is done in GNSS-challenging environment (GNSS positions are shown in Figure 2). Moreover, the software enables georeferencing using external sources of information (georeferenced point cloud or GNSS data). Thus, it is possible to reach global accuracy limited to the accuracy of the provided georeferenced data.

Figure 6: 3D maps of the testing area.

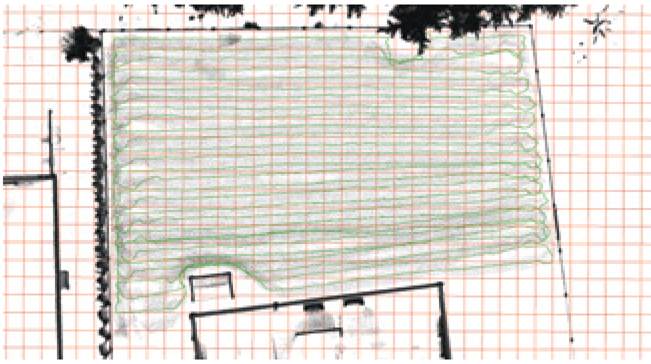

Figure 7: Trajectory of 4x4 wheeled robot and reconstructed 3D map (top view).

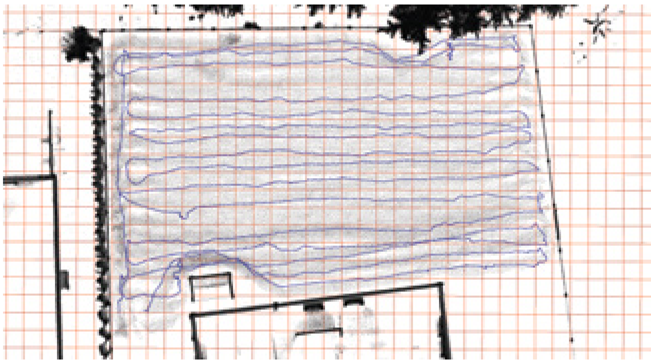

Figure 8: Trajectory of the four-legged robot and reconstructed 3D map (top view).

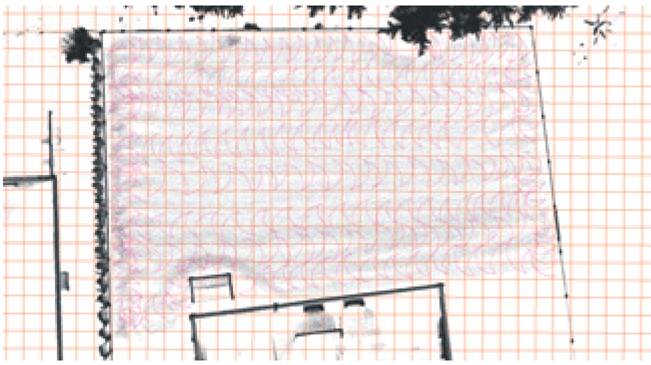

Figure 9: Trajectory of handheld device and reconstructed 3D map (top view).

Mobile mapping with K9

The goal of this experiment was to verify that K-9 equipped with 2x Livox Mid-360 is capable of providing precise and accurate trajectories with reconstructed point clouds. Figure 10 shows the entire experimental path from START to FINISH points. Two control points are marked as CP1 and CP2 for which we calculated deviations from ground truth. Ground truth is taken from aerial mapping available in Geoportal **https://mapy.geoportal.gov.pl/**. This service is a central node of the Polish Spatial Information Infrastructure with access to spatial data and related services. Figure 11 shows the top view with trajectory and point cloud. Figure 12 shows a perspective view of the zoomed region with K-9 trajectory and the 3D point cloud. Most of the details can be easily interpreted. Figures 13 and 14 show measured deviations compared to ground truth CP1: $\Delta xy < 3m$, CP2: $\Delta xy < 1.4m$.

Figure 10: Top view of the K-9 trajectory.

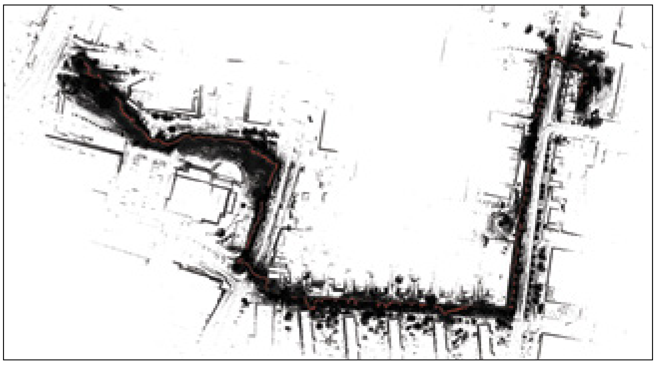

Figure 11: Top view of the 3D point cloud reconstructed with K-9 trajectory and 2xLivox Mid-360 LiDARs.

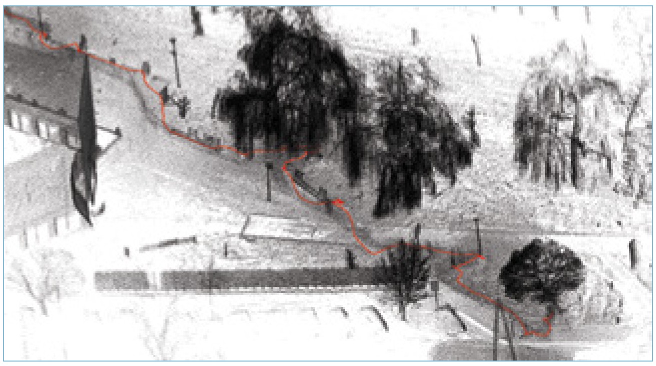

Figure 12: Perspective view of the zoomed region with K-9 trajectory and the 3D point cloud.

Figure 13: Measured error (Δxy > 3m) to ground truth (CP1 – see figure 10).

Figure 14: Measured error (Δxy > 1.4m) to ground truth (CP2 – see figure 10).

Conclusion

This paper proposed affordable geo-localization technology supporting demining action (especially surveying, mapping, and marking) in GNSS-denied and GNSS-challenging environments. Obviously, additional information concerning ground truth is necessary for geo-localization. It can be derived from geodetic surveys such as ground or aerial mobile mapping that do not have to be performed during this time of humanitarian demining action. It can be integrated later e.g. during humanitarian demining action. The tracking and 3D mapping technology is based on Livox Mid-360 (range up to 70m, precision around 3cm, weight approx. 265g) – an affordable LiDAR with a nonrepetitive scanning pattern and embedded IMU. Experiments including hand-held, K9, 4x4 wheeled robot, and 4-legged robot show potential positive impact into e.g. Route Overwatch Search Dogs (ROSD) and Explosive Detector Dogs (EDD) cyber enhancement, precise (centimetric) and accurate (metric) tracking of other humanitarian demining tools such as handheld, robotic, etc. This work is supported by the open source projects **https://github.com/JanuszBedkowski/mandeye_controller**, **https://github.com/MapsHD/HDMapping**.

Future work will be related to full automation of the tracking and mobile mapping functionalities that are supposed to be performed online.

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Multi-robot AI based Explosive Detection Demonstration

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Abstract

Artificial Intelligence for the detection of explosive devices (AIDED) is a European defense research project aiming to design, develop and integrate AI-ML techniques to detect IEDs and UxOs, navigation of robots and cooperative planning multi-agent unmanned systems. These cutting-edge technologies to; i) Identify both unconventional and conventional explosive devices, such as buried mines and IEDs; ii) Plan missions both offline and in real time (iii) perceive and navigate in the environment using classical and AI techniques. The Multi-Robot System of AIDED is composed of two UGVs of different sizes and a single UAV to detect threats that are visible, buried, or hidden. The system also uses AI-machine learning techniques for positioning, navigation, and mapping to achieve robustness and independent operation in GNSS denied environments. The AIDED project was demonstrated at an EOD base in Belgium to stakeholders in defense. The project overview and results are described in this paper.

Introduction

In recent conflicts like those in Ukraine, Afghanistan, Iraq, and Syria, the use of Explosive Ordnance (EO) like Improvised Explosive Devices (IEDs) and landmines has become more prevalent, leading to increased casualties among EU and NATO member and partner states. IEDs alone account for around half of all soldier deaths in action. To address this issue, the European Defense project AIDED project developed an AI based systems aiming at the detection and classification of explosive devices by means of heterogeneous robotic platforms (UAVs and UGVs).

Multi-agent systems have the potential to increase the efficiency and effectiveness of IED detection operations, as they can cover a larger area and share information to make more informed decisions. The use of multi-agent systems for demining has already been assessed on a previous NATO project [1].

The methods and technologies applied in demining had to adapt to the evolution of the mines used in conflicts. For the detection of traditional industrial mines, plastic mines and IEDs that contain no or low levels of metal made it insufficient. Most recent applications have proposed to couple the use of the metal detector with a Ground Penetrating Radar (GPR) [2]. This not only allows the detection of non-metallic objects, but also reduces the number of false detections [3] by differentiating any metallic object from a potential IED.

Fig. 1: AIDED multi-robot C-IED/EOD team

The use of Laser Induced Breakdown Spectroscopy (LIBS) has also proven its efficiency to detect EOD [4] [5]. The AIDED system [9] demonstrated the potential of multi-agent robot systems for IED detection with insights into the challenges and opportunities of using robotics for counter-IED operations (Fig.1). Furthermore, it explores the development of artificial intelligence (AI) solutions based on advanced machine learning (ML) techniques, such as deep learning (DL), able to detect and classify explosive devices in a deployment scenario.

1 Space Applications Services, Belgium

Systems and architecture

A. Platforms

The Large Unmanned Ground Vehicle (LUGV) Fig. 2, has been modified [6] to use the middleware ROS [7] and be more modular than the original robot. The purpose of the LUGV is to embed all the sensors used in the project for EOD detection in order to provide the most accurate and reliable detection possible while limiting false positives by fusing all sensors with an AI.

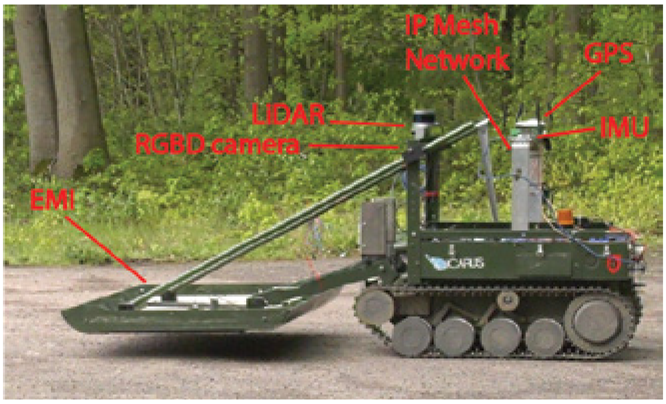

Fig. 2: LUGV with EMI, GPR and LIBS

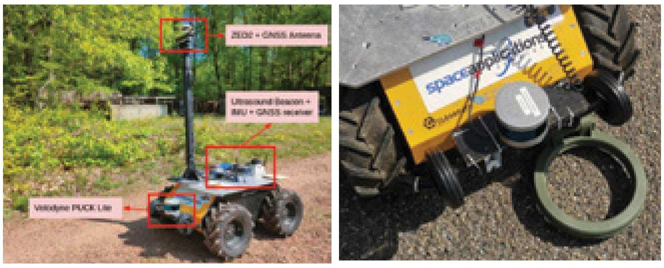

Fig. 3: SUGV with sensors and EMI

A Small Unmanned Ground Vehicle (SUGV) Fig. 3, is exploited for fast recognition and maneuverability. The SUGV is equipped with an electromagnetic induction (EMI) sensor. Considering the reduced dimensions, the choice of the sensor fell on a single coil of 25 cm of diameter as in Figure 2. The UAV for AIDED, shown in Figure 1 contains perception and navigation systems for a fixed height scan of the terrain using a RadSys Zond GPR. The UAV also has onboard processing similar to the UGVs such as the Zed stereo camera, IMUs, GNSS and a laser altimeter.

B. Control Center and Offline Planner

The Supervisory Control Center (SCC) is a technological ecosystem with the objective to connect a group of unmanned Vehicles to perform super-vision tasks, such as; Monitor the state of the UxVs (Online or Offline); Visualize and analyze data received from robots; An offline planneroptimizes the use of the robots based on time and positions of the robots, and their cooperation.

C. Explosive Ordnance Detection

Advanced ML techniques such as Bayesian optimization [8] were adopted for this model calibration step. The training and validation of models were achieved with datasets collected during the project, featuring measurements of actual improvised explosive device (IED) mock-ups acquired with real sensors [9].

D. GPR data processing

GPR B-scan data can be represented as a single channel image, making the basis for the GPR-based EO detection prototypes a CNN. CNNs have had immense success in practical applications dealing with them [10]. Existing works employing CNNs for buried object detection using B-scan data [11] [12] employ similar style architectures.

E. EMI data processing

The project explored the applicability of long-short term memory (LSTM, [13]) cells to capturing the temporal correlations between EMI signals, and compare them to traditional feedforward architectures, namely the multi-layer perceptron (MLP).

F. LIBS data processing

AIDED explored the usage of small scale MLP networks [14]., to avoid overfitting on reduced sample LIBS datasets, coupled with feature extraction techniques such as principal component analysis (PCA) to deal with the wide spectra typically imaged by this sensor.

Demo outcomes analysis

A. Perception & Navigation

Perception and navigation modules were extensively tested during the field demonstration. All three UxVs performed autonomous operations in two different scenarios as a result of the perception and navigation stack. On the sensors side, all the UxVs were equipped with a camera for positioning and mapping purposes, IMU and GNSS receiver. On top of the camera, the UGVs were equipped with a Lidar sensor for both mapping and obstacle avoidance. The sensor inputs are filtered using a Kalman Filter technique. Different inputs to the filter are used according to the scenario and to the UxV. The UxVs used a mix of SLAM algorithms based on images and 3D data, combined with GNSS data for robustness. In the Figure 7is possible to appreciate a detailed 3D map, representing DOVO facilities, produced by the SUGV with the LiDAR Slam algorithm, with the path highlighted in cyan. The color code of the map is related to the elevation of points, from dark red as lowest to dark blue for highest (Fig 4.).

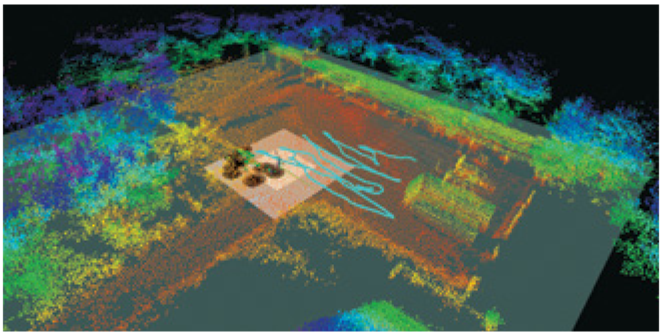

Fig. 4: 3D Map generated during field trials

Regarding the navigation aspects, a combination of techniques have been used. In particular two path planners, one global, based on Dijkstra algorithm, and one local, based on Time Elastic Band algorithm, have been successfully deployed. Together with the construction of a global and a local map using the LIDAR sensor, the UGVs were capable of navigating the environment safely. The UAV was using Ardupilot stack for navigating between waypoints, without active obstacle avoidance. An elevation map (Fig. 5) of the environment was created using pointcloud from stereo camera.

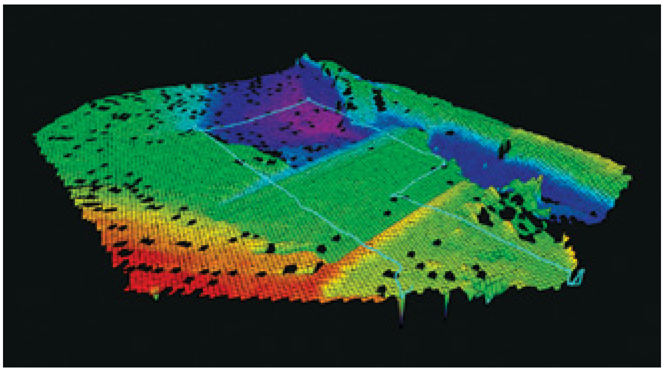

Fig. 5: 2.5D Map during field trials by UAV

The solution developed considered the possibility of degraded GNSS signals, which can easily be jammed. Some limitations were observed in the case of highly unstructured environments, where limited features could be used localization through SLAM techniques.

B. Mission Planning and monitoring

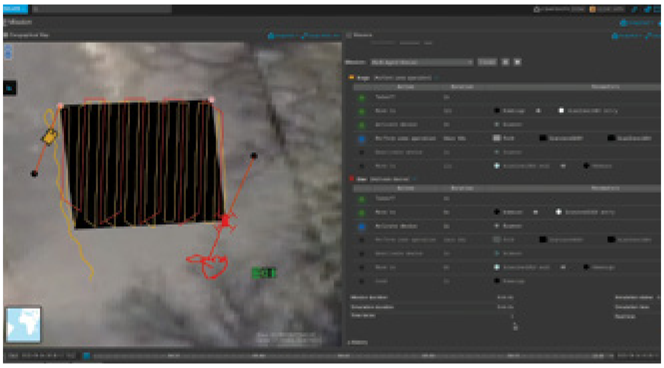

Fig. 6: Scanning of a defined area for IED's.

The MOSAIC application is utilized for the strategic orchestration, real time surveillance, and deployment of UxVs. Mission parameters were provided as prerequisites for a mission planner, facilitating the formulation and execution of both singular and multi agent missions. Two fundamental scenarios were conceptualized and rigorously assessed: the systematic scanning of areas and the post verification of detected IED locations. These scenarios were evaluated across two distinct environmental settings: open fields and marketplaces. Each area imposed distinct requisites and limitations, e.g., marketplaces presented diminished GPS signals. Following the completion of scans, IED locations were relayed and stored in the local data base (Fig. 6). These detected IED locations were used for the verification of these previously detected IED's using a larger robotic platform equipped with enhanced precision sensors (Fig. 7).

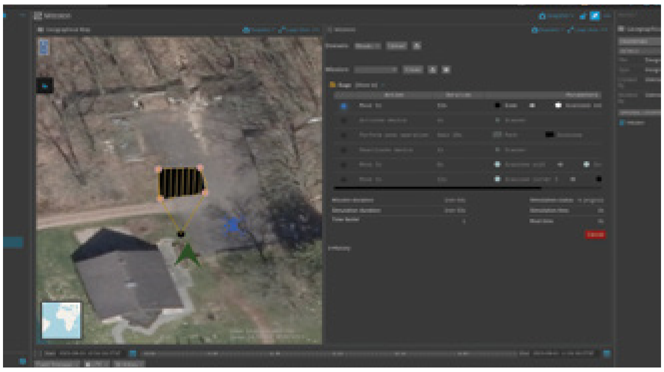

Fig. 7: Verification of detected IED's.

C. IED and UxO detection

The detection of IEDs using the EMI sensors on the UGVs proved to be accurate enough to be used on the field, while the LIBS tests proved that it was possible to classify IEDs composition during missions. Challenges to detecting IEDs via the UAV-GPR system consistently was observed due the sensitivity of the GPR scans being distorted due to altitude changes in the UAV. The results of the project showed that AI techniques were successful for some sensor data like EMI and LIBS, while it was challenging in case of other sensors such as the GPR. The perception, localisation and navigation was also a highlight of the integrated multi-robot system.

D. Robot Demonstrated capabilities

Along the final demonstration of the AIDED project, several capabilities have been demonstrated. In particular, a full multi-robot and integrated system was capable of performing autonomous operations in an unknown environment, while detecting threats. The C-IED operation has been developed and demonstrated on the field as follows:

- The UxVs have been brought to their initial position and the AIDED software solution for autonomous operations and detections has been initialised;
- A mission has been computed offline on-the-fly for all the agents available, using the MOSAIC tool;
- The mission has been deployed and the agents started moving autonomously. In a first phase, the SUGV and the UAV performed a first recognition of the area, while in a second moment the LUGV went to the suspected IEDs detection for confirmation using its larger sensor suite;
- The UxVs mission was updated online according to the threats detected

Conclusion

The demo was conducted successfully with a majority of the expected outcomes as per the system and operational requirements. The feedback received from military observers and visitors was good and useful having developed this complex system. Overall the project was a high-risk high-reward, disruptive technologies research solution, which indeed stayed focused on this core approach. The novel use of classical AI and Machine Learning across IED detection, classification, navigation, cooperation and planning indicates a step change of using AI in defense for counter IED application technologies. These technologies will next be matured from the current TRL3-4 to TRL5-6 for evaluation in operation conditions in the AIDEDex follow up project.

Acknowledgement

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Stand-off landmine detection using (hyperspectral) infrared imaging

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Abstract

This paper outlines the objectives of four Belgian Defence projects, which focus on developing stand-off detection of surface-laid and buried landmine using panchromatic or hyperspectral infrared imagers.

A first study will focus on detecting anomalies using hyperspectral imaging in the Short Wave Infrared (SWIR), and more in particular detection of water absorption features, variations in reflectance due to soil disturbance from the burying process and variations in the chlorophyll red edge of plants on top of the mine.

A second study will focus on detecting traces of explosives using hyperspectral imaging in the SWIR, as most explosives have absorption features around 1.6µm.

A third study will focus on detecting anomalies using hyperspectral imaging in the Long Wave Infrared (LWIR), and more in particular on detecting the Reststrahlen effect, disturbances in the Quartz-Index and heat flow anomalies.

A fourth study will investigate if some bands in the thermal infrared have a higher impact on discriminatory performance than others. If narrow bands can be identified, then appropriate filters can be placed on panchromatic imagers, turning them into cheap, though very rudimentary, multi-spectral imagers.

What is HSI?

Hyperspectral imaging (HSI) is a technique used to capture and process information across the electromagnetic spectrum. Unlike traditional imaging systems that capture data within a few discrete bands (such as RGB for visible light cameras), hyperspectral imaging collects data across hundreds or even thousands of contiguous bands, covering a wide range of wavelengths.

Each pixel in a hyperspectral image contains a complete spectrum of information, allowing for detailed analysis of the material properties, composition, and conditions of the objects or scenes being imaged. The process involves scanning a scene using specialized sensors that detect the intensity of electromagnetic radiation across the spectrum. The resulting hyperspectral data cube consists of two spatial dimensions and one spectral dimension (wavelength or frequency), creating a three-dimensional dataset. Advanced algorithms are then used to analyze and interpret the data, extracting valuable information for different applications.

Applications of HSI

Hyperspectral imaging finds applications across various fields due to its ability to provide detailed spectral information about objects or scenes.

In agriculture, for instance, HSI can be used for crop monitoring, disease detection, and assessing plant health. By analyzing the spectral signatures of plants, farmers can identify stress factors such as nutrient deficiencies, pests, or diseases, allowing for targeted interventions and optimized crop management.

HSI can also be employed in environmental studies to monitor water quality, detect pollution, and assess ecosystem health. It can identify contaminants, algae blooms, and other indicators of environmental degradation in bodies of water and terrestrial environments.

HSI sensors, often mounted on satellites, are regularly used to identify minerals and map geological formations. By analyzing the unique spectral signatures of minerals, geologists can locate ore deposits and assess the potential for mineral extraction. These sensors can also be used to provide detailed information about land use, vegetation types, and surface materials, facilitating resource management and urban development planning.

HSI is also used in food inspection and quality control processes. It can detect contaminants, assess freshness, identify foreign objects, and classify food products based on their spectral characteristics, ensuring food safety and quality standards are met.

In biomedical applications, HSI is used for tissue analysis, disease diagnosis, and monitoring treatment responses. It can identify biomarkers, distinguish between healthy and diseased tissues, and provide insights into physiological processes at a cellular level.

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HSI is also applied for military reconnaissance, surveillance, and target detection. It can identify camouflage, detect chemical and biological threats, and analyze terrain features for military planning and operations.

At the Royal Military Academy of Belgium, the Hyperspectral Research Unit has been working in various fields of applications over more than two decades. Projects have been funded by the Belgian Defence, but also by other funding agencies (EDA, EDF, BELSPO, …). Specific examples include measuring chemical pollutant gasses in the port of Antwerp, detection of various objects in urban scenarios using airborne sensors, measurement of industrial spills and other hazardous materials, detection of explosive traces and chemical warfare agents, analysis of combustion plumes of jet and rocket engines, et al. The research unit is also very active in a NATO context, participating in various Exploratory Teams and Research Task Groups (SET-190, SET-240, SET-313, SET-ET-135, AVT-376, SCI-ET-066).

Use of HSI for demining

SWIR

Our research unit has several research actions regarding detection of landmines. The first study will focus on detecting anomalies using hyperspectral imaging in the SWIR (0.8µm-2.5µm)[3]. This part of the EM spectrum provides feature-rich images without relying on the thermal emission of the objects and can be operated under degraded visual environments (DVE) such as rain, snow, fog, dust, sand and smoke.

SWIR imagery can detect disturbances in soil characteristics due to the action of burying the mine, as reflectance in the SWIR is sensitive to variations in grain size and composition because many minerals have spectral properties in the SWIR [Mak17, McF05, McF07], while increased surface roughness can create microshadows, thus reducing reflectance [Ken03]. Both these effects are ephemeral, though, due to attenuation over time by wind and rain.

The presence of water (soil moisture, rain, fog) is the main challenge when using SWIR HSI, as it has strong absorption features in the SWIR [Lie09]. However, depressions occur due to the settling of the soil after the burial process. SWIR HSI can detect differences in the water absorption features (at 1.4 and 1.9µm) caused bythis depression and by reduced percolation in the presence of the mine [McF07].

'While mines might be painted in colors that closely match the background on average, they rarely exactly match the spectral response entirely and can thus be detected if the spectral and spatial resolution of the HSI sensor is high enough [Kho13, McF05]. This is already so in the visible part of the spectrum, but becomes more pronounced in the SWIR, as is the case for most anthropogenic objects [McF05]. One of the main reasons is the fact that most paints are hydrophobic, while rocks and soils are mostly hydrophilic. The latter thus absorb more radiation in the 1.4µm and 1.9µm water vapor bands.

Plants are known to exhibits variations in their chlorophyll red edge (0.710µm - 0.805µm) due to disturbance by the burial process, presence or absence of certain minerals, moisture levels etc. [McF05, McF07]. Explosive traces taken up by the roots can have similar effects.

In a parallel study will focus on detecting traces of explosives using hyperspectral imaging in the SWIR, as most explosives have absorption features around 1.6µm.

LWIR

In the thermal infrared, a third study will focus on detecting anomalies using hyperspectral imaging in the LWIR.

Indeed, when infrared radiation passes through a crystal lattice, it interacts with the lattice vibrations. An effect, called Reststrahlen, occurs when the frequency of the infrared light matches the resonant frequency of these lattice vibrations. At this specific frequency, the crystal lattice strongly absorbs the infrared radiation, leading to reduced reflectance and transmission of light in that particular band. For common quartz-bearing soils, for instance, the Reststrahlen effect occurs in the 8.0µm-9.5µm region. Often, disturbed soil has lower spectral contrast than undisturbed soil in the Reststrahlen region due to the presence of smaller particles [Hib07, Joh98, Koh06, McF07, Win97].

The presence of a mine will create heat flow anomalies [Ten23]. These anomalies might not always be detectable on average (i.e. with panchromatic sensors), but when a detailed thermal spectral signature is included, the difference caused by thermal transport physics allows for better discrimination [Ach07].

A last study will try to identify if some bands in the thermal infrared have a higher impact on discriminatory performance than others. If narrow bands can be identified, then appropriate filters can be placed on panchromatic imagers, turning them into cheap, though very rudimentary, multi-spectral imagers.

Drawbacks of HSI

Even though HSI is a potentially powerful method to detect landmines, there are important drawbacks to consider. One of them is the huge amount of data it generates

3 Sometimes the [0.8-1.0]µm part of the spectrum is called Near Infrared (NIR).

and its complexity. Indeed, HSI images typically consist of hundreds to thousands of spectral bands, resulting in large data volumes. Processing and analyzing such high-dimensional data can be computationally intensive and require specialized algorithms and resources. Interpreting hyperspectral data and extracting meaningful information requires expertise in spectral analysis, data processing, and domain-specific knowledge. Identifying relevant spectral signatures and distinguishing between different materials or conditions can be complex and subjective. Atmospheric effects such as scattering and absorption can distort hyperspectral data, particularly in remote sensing applications. Correcting for these atmospheric effects requires additional processing and calibration steps.

Furthermore, acquiring hyperspectral imaging data often requires specialized sensors and equipment, which can be costly to purchase and maintain. Additionally, the need for controlled lighting conditions and calibration further adds to the expenses. It also has to be noted that achieving high spatial resolution in hyperspectral imaging may require compromises in spectral resolution, and vice versa. Balancing spatial and spectral resolution to meet specific application requirements can be challenging. HSI systems may also have a limited field of view compared to traditional imaging systems. This limitation can restrict the coverage area or necessitate multiple scans to capture a large scene, increasing acquisition time and complexity.

For mine detection, perhaps the most important drawback, at least for buried mines is the limited penetration depth restricting the detection of subsurface features or objects, unless indirect methods are used, as mentioned earlier.

Despite these drawbacks, ongoing research and advancements in hyperspectral imaging technology aim to address many of these challenges, making it a valuable tool for various scientific, humanitarian, military, industrial, and commercial applications.

IR alternatives to HSI

HSI is a unique technology that combines spatial and spectral features, but comes at a cost. Trade-offs can be made. For instance, the use of spectroradiometers allows for a much higher spectral resolution but loses all spatial information, as it only measures at a single point. For stationary objects, this can be compensated by mechanically scanning the area.

Panchromatic infrared sensors, on the other hand, discard the spectral resolution in favor of lower complexity, lower weight, lower cost and possibly higher spatial resolution. This can be applied in the reflective domain (visible to short-wave infrared) or thermal domain (mid- and long-wave infrared). Buried landmines, for instance, can exhibit temperature differences compared to the surrounding soil due to their thermal properties, such as differences in thermal conductivity and heat retention. Infrared thermography can detect these temperature anomalies, aiding in landmine detection.

Conclusion

In this short paper, we have briefly outlined the potential and drawbacks of hyperspectral imaging in the framework of mine detection. The Hyperspectral Research Unit of the Royal Military Academy has been active in this field of research for many years and will be for the foreseeable future, with a renewed emphasis on mine detection, both in a military and a humanitarian context.

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Introducing MRead's advancements in magnetic resonance based sensing

Henry Hamilton[1]

Introduction

This paper introduces MRead's novel magnetic resonance (MR) technology and puts it in the context of humanitarian demining operations. It addresses the challenges that have previously inhibited the use of MR sensing and how these challenges have been overcome.

MRead is an Australian startup, formed to develop a MR sensor that can speed up the landmine clearance processes. Our technology has been developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national science agency, who developed hardware and software solutions to overcome the challenges that have prevented previous attempts at MR sensing. The technology is being developed to meet or exceed the International Mine Action Standards (IMAS) established by the United Nations Mine Action Service.

MRead began operating as a standalone company in early 2023 and has been building our first product to address the challenges of detecting and clearing landmines. We are completing the development of our "Gen 1" prototype and plan on performing laneway trials in Australia and demonstrating our sensors in Cambodia in mid-late 2024. Our product development has been assisted through a research partnership with The HALO Trust and a strategic investment from Minelab.

MR Sensing

MR is a form of radio frequency spectroscopy used for detection of specific molecules. There are several classes of MR that do not require application of an external static magnetic field, which considerably simplifies the practical deployment of a sensor. The major class that MRead will exploit is Nuclear Quadrupole Resonance (NQR) which provides highly discriminating detection of certain solid crystalline substances, specifically explosives and drugs.

The technique relies on the specific chemical environment of selected nuclei to uniquely identify a solid crystalline substance. A pre-requisite for applying the technique is that nuclei must have an intrinsic nuclear electric quadrupole moment. Nitrogen, chlorine and potassium isotopes satisfy this criteria, and NQR is particularly sensitive to nitrogen atoms (amongst others), which are well-represented in explosives.

The technology uses relatively low frequency radio waves (~0.5-5 MHz) which are highly penetrative through most substances, making them ideal for stand-off detection. We use rapid pulses of radio waves at the specific frequency that correspond to the resonance frequency of the target substance, inducing transient radio responses called "free induction decays". This signal response is differentiated from background noise to confirm the detection.

MR technology has been researched by several groups since its discovery due to several benefits over current landmine detection methods.

- Simple to operate
- Highly discriminating technique; unique resonance frequencies of explosives
- Radio waves can penetrate through concealing surfaces (topsoil, plastic cased landmines)
- Does not detect harmless clutter (shrapnel, rocks, roots etc.)
- Not affected by soil type or conditions.

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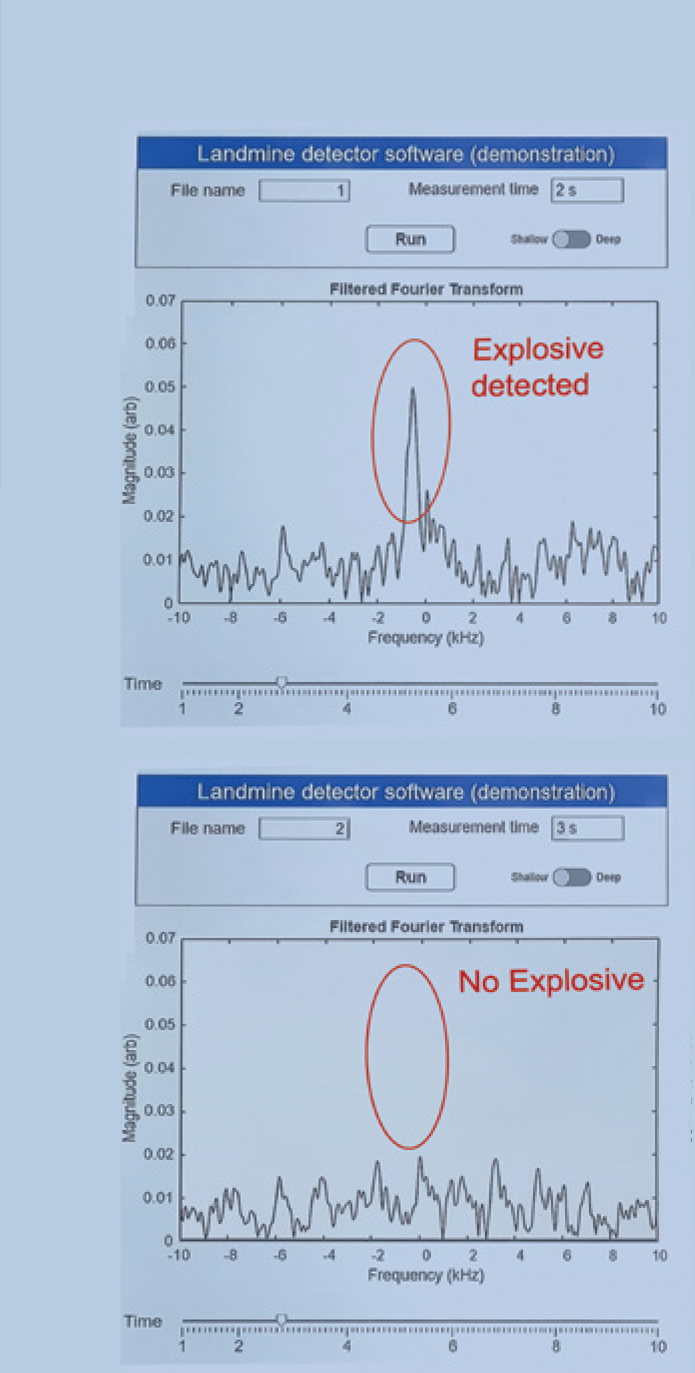


a)

b)

Figure 1:
A peak at the resonance frequency shows the presence of the target explosive (a) and no observable peak shows its absence (b)

Unlike many other technologies, the false alarm rate is not driven by ground clutter but rather by its signal-to-noise ratio (SNR). The SNR increases with the square root of the interrogation time and also increases linearly with the mass of the explosive. Thus, with sufficient interrogation time, MR can achieve nearly perfect operating characteristics (probability of detection near one with probability of false alarm near zero)[2]. Reducing the amount of interrogation time required to achieve this near perfect operating characteristic has been a key focus of international MR research programs.

2 Alternatives for Landmine Detection, J MacDonald et. al., 2003

Receiver operating characteristics

MRead's approach for setting detection thresholds is to ensure that no landmines are missed (zero false negatives). For conventional metal detection this typically results in excessive number of false positives, each of which can take 30 minutes or more to manually excavate. By minimising false positives MR detection can significantly improve the speed of clearance, despite taking longer to make a detection than metal detectors.

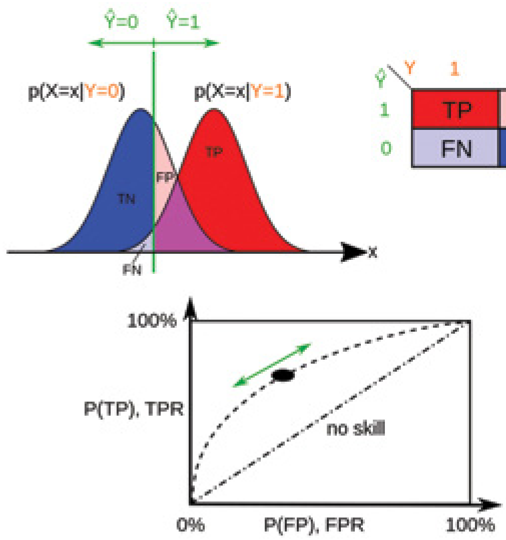


Figure 2
Receiver operating characteristics, Wikipedia (Kakau)

Measurement Approach

CSIRO approached the challenge of minimising interrogation time by addressing the amount of noise that is captured by the antenna. The electromagnetic spectrum that we operate in is extremely noisy, and differentiating the resonance signal from background noise is critical to achieving sensors that can effectively operate outside of the laboratory.

CSIRO tackled this problem by designing a sensor that actively cancels out electromagnetic noise at the sensor head. This proprietary design shields against far field radiation whilst still detecting the signal that resonates from the explosive target. Approaching this problem through hardware solutions has enabled a rapid improvement in detection times for the MR method.

CSIRO built upon the MR technique for the minerals industry, forming NextOre Limited who have successfully commercialised their sensors. Certain sub-components of MRead's sensors are common to the application in the minerals industry and the learnings gained from this process are being applied to our sensors. The specialised computing boards, MR control board and signal processing have been adapted to suit our smaller sensor.

The impact of changing temperatures causing the resonance frequency to drift has historically caused issues for MR sensing. However, the relationship between temperature and resonance frequency is known and predictable. CSIRO addressed this issue through bespoke algorithms and modelling the changing soil temperatures throughout the top-soil profile.

Limitations

MR sensing has a few inherent limitations, which require our sensors to operate in conjunction with existing systems. Radio waves are unable to penetrate through faraday cages, so complete metal encasement (full metal landmines, UXO) will not be detected by our sensors. However, less sensitive metal detectors can be used to find these large metal targets, with our MR sensors accurately detecting low-metal mines.

Our sensors are optimised for the detection of specific explosives such as TNT or RDX, so minefields that contain landmines with both pure RDX and pure TNT mines would require two sensors. These can be used together as part of a systematic clearance method that integrates with current processes that are widely used by the humanitarian demining community. Future developments may enable 'broad-band' sensing capabilities.

Finally, our first MR detection product is expected to have dwell times around 30s – 1 minute for deeper anti-personnel landmines. It is envisioned that this product would operate as a confirmation sensor on already identified targets, necessitating a metal and/or GPR sensor or other method identifying the targets of interest for subsequent testing.

The next phase in our development path is characterising the performance of our sensor through trials in real-world environments, which will allow us to refine our detection speed estimates.

Detection characteristics

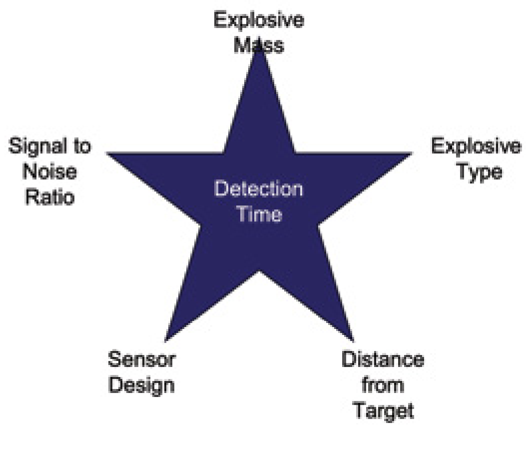
MRead's design approach for our first product is to strike a balance between detection depth, speed and functionality of our sensor. We have optimised our sensor to detect anti-personnel landmines at typical clearance depths. It will also be capable of detecting anti-tank mines and surface mines.

Detection time is a trade-off between explosive type, target mass, distance from the sensor, sensor design and desired signal to noise ratio.

Each explosive molecule has different MR frequencies, which enables detection without false positives. Molecules with low MR frequencies have a smaller signal and longer relaxation times that inhibit signal averaging, therefore take longer to confirm detection.

Larger masses of explosives result in faster detection. More molecules that 'resonate' produce a more powerful signal that can be detected by our sensor. Anti-tank mines will be detected faster than anti-personnel mines. Minimising the distance between the detection target and sensor head is critical for minimising the detection time. Shallow targets will yield faster detections than deeper targets. This necessitates placing our sensor close to the ground, similar to metal detectors.

Background noise from electromagnetic interference stems from multiple sources such as motors, telecommunications, and lightning. Remote areas may have less noise. The amount of background noise influences the signal to noise ratio (SNR), which will be the key metric used to determine when a detection can be made. MRead plans on engaging with demining operators to set suitable SNR thresholds that strike a balance between minimising false alarms and rapid detection. Reducing the SNR will allow faster detection, however, increase the chance that an 'indeterminate detection' occurs. An indeterminate detection would arise when a signal cannot be adequately distinguished from background noise. Increasing the resonance time reduces the chance that a false alarm or indeterminate detection occurs. This means that false alarms or indeterminate detections can be 'self-investigated' with our sensors.



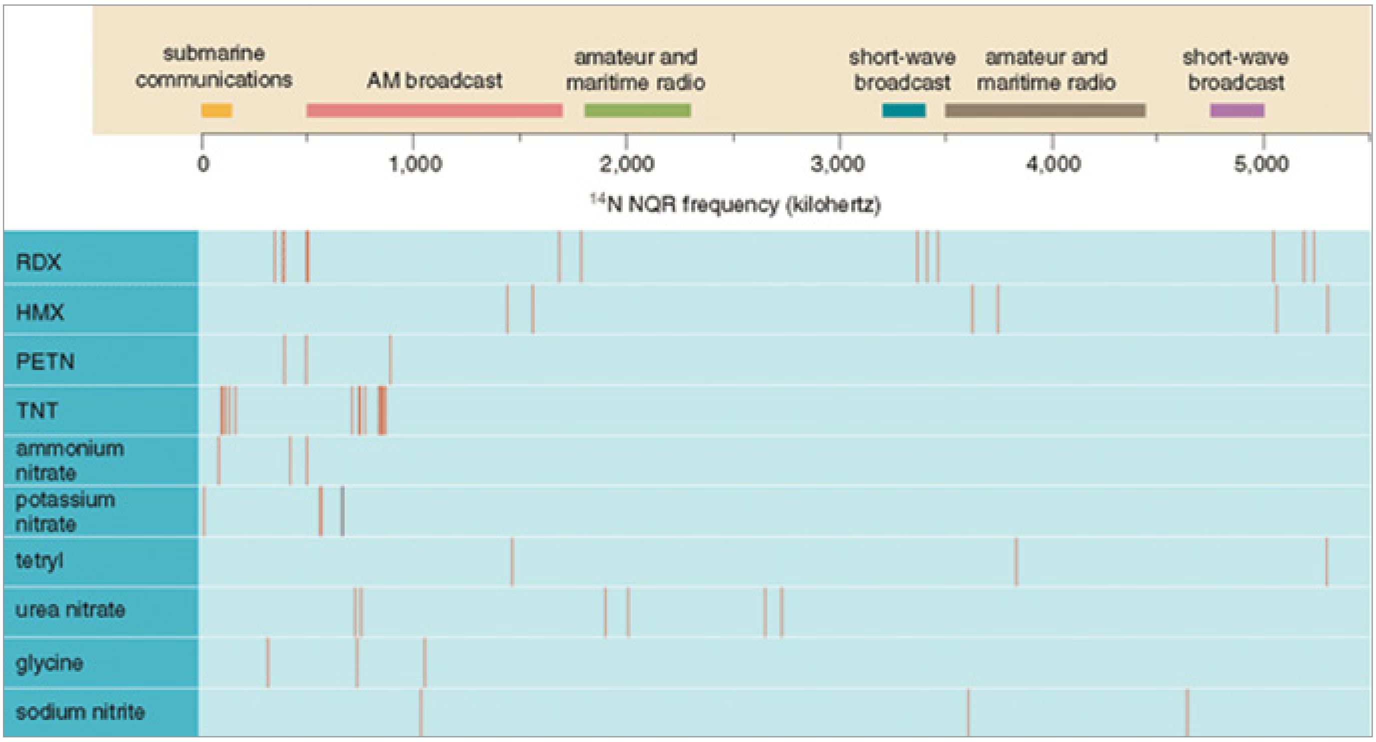


Figure 3 Major components impacting detection time for MR sensing, MRead

MRead's Prototype

Our prototype sensor is nearing completion and will be trialled in settings that resemble humanitarian demining operations in 2024. Following trials we will review our product design with feedback from operators informing product improvements.

Our first prototype is expected to consist of a ~5kg hand carried sensor and shaft, with an additional ~3kg of additional electronics carried in a satchel form. We expect battery life to be sufficient for ~2 hours of operations. Our power system consists of lithium-ion batteries that are easily exchanged, allowing full-day use of our sensor.

Our sensor will be simple to operate in the field, with a single button used to initiate the detection process and lights and audio prompts alerting the operator of the presence or absence of an explosive.

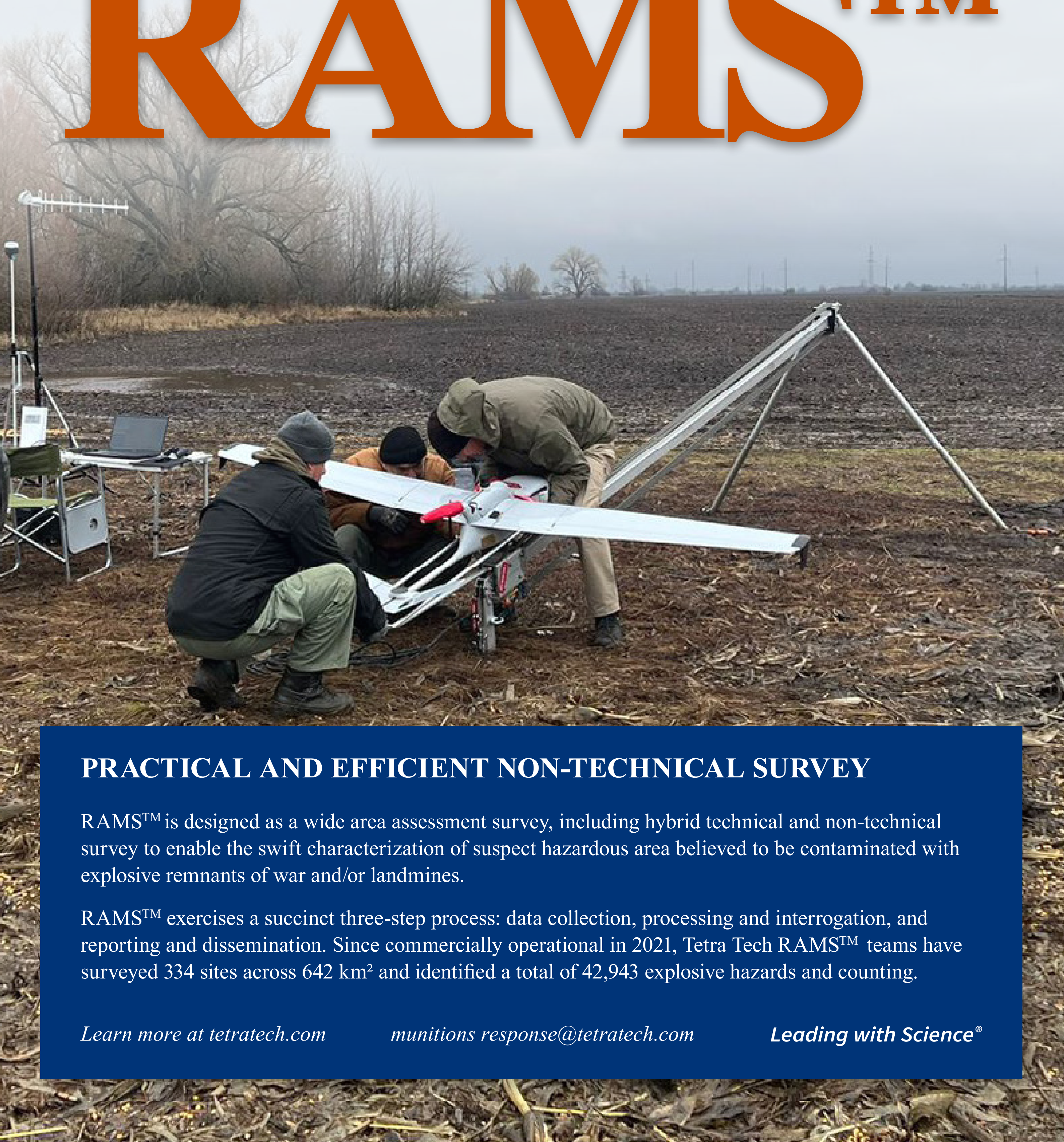
We expect our first product to be ready for use in 2025, and welcome product feedback from the humanitarian demining community.

Figure 5 Snapshot of MRead's product under development, MRead 2023

TETRA TECH

REMOTE AERIAL MINEFIELD SURVEY

RAMS™



PRACTICAL AND EFFICIENT NON-TECHNICAL SURVEY

RAMS™ is designed as a wide area assessment survey, including hybrid technical and non-technical survey to enable the swift characterization of suspect hazardous area believed to be contaminated with explosive remnants of war and/or landmines.

RAMS™ exercises a succinct three-step process: data collection, processing and interrogation, and reporting and dissemination. Since commercially operational in 2021, Tetra Tech RAMS™ teams have surveyed 334 sites across 642 km^2 and identified a total of 42,943 explosive hazards and counting.

Learn more at tetratech.com *munitions response@tetratech.com* ***Leading with Science®***

Remote Aerial Minefield Survey (RAMS™)

David Houghton[1], David Denman[2], and Steve Priestley[3]

Introduction

Through *Leading with Science*® Tetra Tech puts science and innovation at the forefront of our projects.
This paper looks at the Remote Aerial Minefield Survey (RAMS™) deployed operationally by Tetra Tech since 2021.

Background

Since 2015 Tetra Tech has been involved with the development of unmanned aircraft (UA or drones) and their associated payloads to support demining operations.

Initially, the project employed a geophysical-based system, developed in partnership with Foerster GmbH. However, it was quickly established that these systems exhibit a very low level of productivity due to the necessity of operating at low altitudes and slow speeds. As a result, they were only suitable for environments with minimal or no vegetative cover and limited topographical variation.

At this point, a re-evaluation exercise was conducted to establish what drone systems could do to actively assist demining rather than force-fit technology into a UA system for the sake of it.

The study explored how drones are successfully employed in industries such as agriculture, archaeology, and geodesy to identify processes that could be adapted for the demining sector.

The exercise concluded with the identification of the following key findings:

- Drones eliminate the need for personnel to enter hazardous areas.
- Drones by their design are best suited for the collection of data over a wide area.
- The collected data enables informed decisions based on facts rather than judgments based on assumptions.
- Successful drone systems collect data from multiple sources, rather than relying on a single source.

The above confirmed that drone systems are best suited to support non-technical surveys (NTS) or an explosives remnants of war (ERW)-based Wide Area Assessment (WAA) rather than to replace deminers tasks and activities.

As such between 2018 and 2021 RAMS™ was developed through pilot projects in the UK, Iraq, and Libya to update the NTS process, which was largely unchanged since the late 1940s.

How it Works

RAMS™ collects various remote-sensing datasets that are individually interrogated with the results being combined. The generated results highlight confirmed hazardous areas and land suitable for release or cancellation after verification.

RGB Dataset

The survey area is systematically flown over and mapped using a high-resolution conventional camera. As the human eye can only view red, green, and blue, these are referred to as RGB images. For the identification of landmines and ERW, the dataset is collected with a Ground Sampling Distance (GSD), i.e., pixel size of < 1cm/px.

The collected images are stitched together using photogrammetry software to generate a Georeferenced Tagged Image File Format (GeoTIFF). This has a positional accuracy of ≤ 250 millimetres (mm) on the X, Y, and Z axes.

The RGB GeoTIFF forms the baseline map for all RAMS™ findings.

Multispectral Dataset

The survey area is flown over again, this time with a multispectral (MS) camera. RGB and MS datasets are collected separately due to the varying GSD of the payloads.

MS cameras work by capturing reflectance levels at different wavelengths along the electromagnetic (EM) spectrum. Currently, we collect data from the Red 668 nanometer (nm) (R), Green 560nm (G), Blue 475nm (B), Red Edge 717nm (RE), Near Infrared 840nm (NIR), and panchromatic (Pano) range (380-900nm).

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Each set of images and the Pano are run through photogrammetry software to generate individual R, G, B, RE, and NIR reflectance maps. The Pano layer is used to increase the GSD of the reflectance maps, an approach widely used in applications like Google Earth.

Specialist software, proprietary formulas, and reflectance maps are used to generate MS indices. These can highlight variations in soil, moisture levels, or vegetation health that cannot be viewed with the human eye. Several indices developed by the RAMS™ team can highlight the reflectance of landmines and ERW even if covered by soil or vegetation. Others can discriminate between natural and man-made objects.

Once edited the indices are turned into GeoTIFF files. It should be noted that RAMS™ has a database of approximately fifteen indices. However, the numbers used will vary depending on local conditions before work begins.

Colour-Corrected Dataset

This is a relatively new dataset developed since deploying RAMS™ to Ukraine in 2023 and allows for increased levels of vegetation and battlefield debris.

A standard RGB image contains a colour palette of approximately 16.5 million colours, while a Colour-Corrected (CC) image palette is reduced to approximately one hundred.

The reduced colour palette highlights any variations in colour, shadow, shine, and outline. While the CC index cannot identify completely buried items, it is of particular use in vegetated and complex environments. Another benefit is that due to its increased GSD compared to MS datasets, anti-personnel (AP) mines can be discriminated from similar-sized stones or debris.

Thermal Infrared Dataset

The survey area can be mapped or inspected in real time using Thermal Infrared (TIR) cameras that operate between 7,500 and 13,500nm on the EM spectrum.

When climatic conditions permit, this approach can identify surface landmines and ERW. In some instances, it can also identify shallowly buried items but only to a depth of approximately 3-5mm.

The use of this payload is predominantly limited to an internal quality control (QC) role used in the early morning and late afternoon when thermal variations are at their greatest.

However, TIR datasets can be incorporated into RAMS™ when it is requested by the client or stakeholder.

LiDAR Dataset

Light Detection and Ranging (LiDAR) is similar to radar but uses light instead of radio waves. Lasers used by LiDAR operate between 900 and 1,550nm in the EM spectrum, so they are safe for human health.

LiDAR cannot be used to identify landmines or ERW directly but can identify indicators of their presence, e.g., craters and defensive positions.

Other advantages of LiDAR are its ability to penetrate most types of vegetation and identify buried features, e.g., deposition sites and caches/dumps.

Although it is not a standard RAMS™ dataset in rural and semi-rural environs, LiDAR can be requested when RAMS™ data is combined with another service such as topographic survey or damage assessment.

Interrogation

The standard size threshold for interrogation is set to identify a PMN AP landmine. This has been selected as it is the most encountered AP landmine to date.

Once each of the datasets has been generated, they undergo artificial intelligence software and manual interrogation. The results of each dataset are collated into a central finds database.

A minimum of 20% of the survey area is subject to blind internal QC checks. Additionally, all identified findings are verified as part of the QC process.

Deliverables

Upon completion of data processing and interrogation, the findings of the survey are presented to the client or stakeholder in a two-tier system of information.

The first tier is intended for geospatial professionals and consists of the shape files, MS Excel database, and the RGB GeoTIFF.

The second tier of information is aimed at project management or personnel without access to GIS software and/or higher specification computers. This user-friendly package consists of a technical report supported by a Google Earth KML file and an interactive PDF map.

Productivity and Data Protection

Typically, a single RAMS™ team can survey two square kilometres per working day. Data is processed at the same rate with a 24 to 36-hour delay allowing for the transfer of data from the field to the processing office. Productivity can be increased by simply adjusting the numbers of flight crews and analysts.

Due to the sensitive nature of the information collected, all RAMS™ data is held on solid state drives (SSD) that are protected by 256-bit AES encryption. As an additional layer of security, all projects are subject to a social media blackout unless requested by the client.

Processing of data is conducted on a closed IT network at a secured office and never processed or stored on a cloud server.

Deliverables are issued to client and/or stakeholder(s) as per contract requirements and are not released to third parties unless written instruction is given. Data is held for five years after completion of the project at a secure office facility.

Summary of Operations 2021-2023

Since becoming commercially operational in 2021 RAMS™ has surveyed 334 individual sites totalling 642km². A total of 42,943 finds have been identified:

- 8,002 Anti-Vehicular Landmines
- 6,692 AP Landmines
- 14,664 Items of Ordnance (UXO/AO)

Of the total survey area, approximately 553km² (86%) is classed as being suitable for land release/cancellation after verification has been conducted following the host's national mine action authority (NMAA) procedures.

System Accuracy

Two separate exercises have been conducted where the initial RAMS™ findings have been compared to the final ones of the clearance program.

In 2022, the findings of three sites were compared post-clearance. This established that RAMS™ had an accuracy level of 60.61 to 80.00%. Since this exercise, RAMS™ has used these figures as its operating range.

The three sites had also undergone an early conventional NTS, which achieved an accuracy level of only 0.00 to 1.82%.

A separate exercise was conducted comparing the productivity rates of RAMS™ to a conventional NTS. This demonstrated that RAMS™ was, on average, 24.2 times faster at assessing the given area.

Based on the information from 2022, additional control measures were implemented in both field and processing procedures to enhance the accuracy of RAMS™.

A larger assessment of the findings of 142 sites (42.51% of all task sites) totalling 54,243 hectares was conducted in 2023. This proved that 98% of the reviewed sites had met and, in most cases, far exceeded the 2022 Operating Range.

Urban Environments – Digital Twins

RAMS™ is predominantly designed for use in rural and semi-rural environments. As demand for its use in urban environments has increased, new processes and technologies have been adopted by Tetra Tech to meet this demand.

Building on the success of the Raqqa and Mosul clearance programs funded by the United States (U.S.) Department of State's Political-Military Bureau, Office of Weapons Removal and Abatement (PM/WRA)4, the previously generated photogrammetry-based 3D models are being enhanced with LiDAR and laser scanning to create "digital twins".

A digital twin is a digital representation of something that exists in the physical world and is dynamically linked with remote sensing and physical data. Digital twins can be linked to national databases for multiple stakeholder coordination.

As well as being used to plan and coordinate demining/clearance operations, the digital twin can be used to plan humanitarian assistance to the civilian population and infrastructure stabilisation in advance of reconstruction programs.

Conclusion

The Tetra Tech team was given the objective of finding a 21st-century solution to a process developed half a century earlier.

The result is the RAMS™ system. This was achieved by adopting already proven processes from other sectors and the continuous enhancement from the ongoing drone industry revolution.

Although not seen as a direct replacement, RAMS™ offers a modern-day solution with productivity and accuracy levels that far exceed conventional methods.

4 Reviving Old Mosul: 3D Modeling Aids Safe Clearance in Iraq By Erin Atkinson, Marc Dennehy, and Craig Locke [Tetra Tech] - https://www.jmu.edu/news/cisr/2023/10/273/08-273-atkinson.shtml#atkinson

From Enigma to Essential: Long-term User Testing of Seaterra's DMAG UAS

Authors: Branislav Jovanovic EOKHUB

Abstract:

Unmanned Aerial Systems (UAS) have emerged as a critical tool in mine action, offering the potential to revolutionise road surveying and explosive hazard detection. In this in-depth analysis, we delve into the multifaceted role of Seaterra's DMAG UAS in advancing road safety and humanitarian efforts in conflict-affected regions. Through extensive field testing and meticulous evaluation, we explore DMAG's technical capabilities, operational effectiveness, limitations, and opportunities for optimisation. By providing a nuanced understanding of DMAG's performance and its implications for mine action, this analysis aims to inform decision-makers, practitioners, and researchers on leveraging UAS technology for enhanced humanitarian impact.

Special gratitude is extended to Edgar Schwab, CEO of Seaterra, and Dieter Guldin, COO of Seaterra, for their permission to conduct independent testing and share information transparently without any interference.

Key words: UAS, mine action, road surveying, Seaterra DMAG, independent testing, humanitarian efforts, conflict-affected regions, technical specifications, operational effectiveness, limitations, recommendations.

Introduction

The proliferation of landmines and improvised explosive devices (IEDs) on roads presents a significant threat to civilian safety and hampers humanitarian aid delivery in conflict zones. Traditional survey methods are often cumbersome, resource-intensive, and pose risks to surveyors. The advent of UAS technology offers a promising solution for overcoming these challenges, enabling rapid and accurate detection of explosive hazards. This analysis examines the role of Seaterra's DMAG UAS in mitigating road safety risks and supporting mine action efforts through comprehensive surveying and data collection.

Explosive Ordnance UAV Survey System DMAG

Seaterra's DMAG represents a sophisticated integration of UAS technology, sensor arrays and specialised software tailored for explosive ordnance detection. The system comprises a DJI 210v2 RTK drone equipped with four 3-axis magnetometers, DJI and Trimble base stations, radio communications, and proprietary in-the-house software solutions. Through rigorous development, testing, and operational use starting in 20219, DMAG has evolved into a versatile tool capable of precise and efficient road surveys in challenging environments.

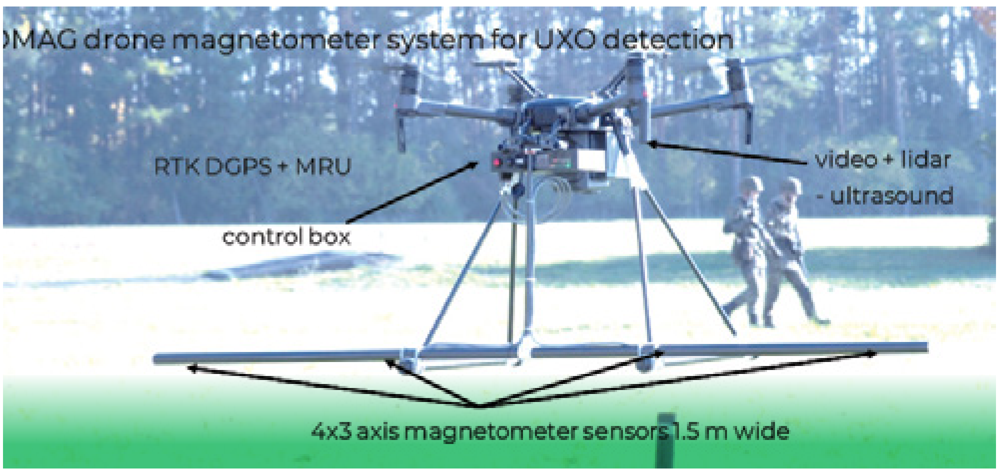


Photo 1. Explosive Ordnance UAV Survey System DMAG

Technical Specifications and Performance Evaluation

The technical specifications of DMAG align closely with its real-world performance, as validated through extensive field testing. The system demonstrates commendable accuracy and reliability in distance detection capabilities, meeting or exceeding manufacturer claims. The user-friendly interface facilitates seamless setup, operation, and data interpretation, ensuring accessibility for field operators with varying levels of expertise.

Independent user testing

Field tests were meticulously planned to encompass various scenarios encountered during road surveys. Until now, due to the limited time, we were writing this article, the testing focus has been European theatre.

The survey of predetermined routes

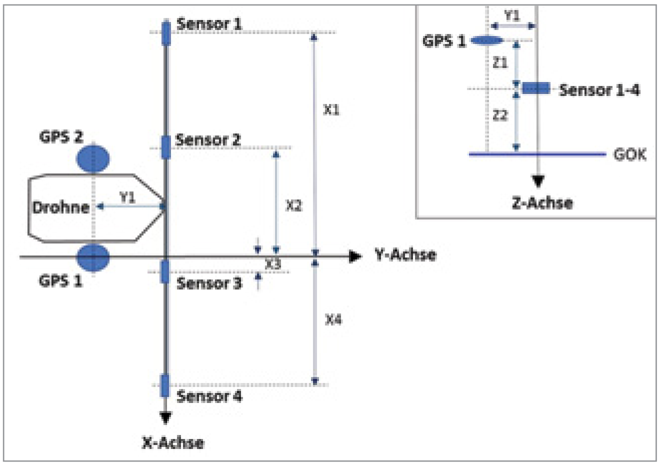
The survey of predetermined routes began with an initial assessment using standard UAS survey methodology. Data collected during this phase served as a reference layer for subsequent testing. Leveraging pre-collected data enabled seamless execution of surveys in automatic mode, minimising complications. The objective was to compare real-time data with existing records to detect any changes in magnetic readings along the road, which Seaterra software AGSpro did.

▲ Photo2: Preparations for survey

The survey of "new" routes

The survey of "new" routes was done in semi-automatic mode. Navigation was facilitated during the surveys using SeaTerra's proprietary AGSDrone navigation software. This mode allowed for automatic maintenance of speed and altitude above ground while the drone pilot focused on directing the flight path from a moving vehicle. Positional data was displayed in real-time on an external monitor (tablet) for the drone pilot, facilitating prompt corrections for any deviations or gaps in measurement. Additionally, the entire flight was recorded via the drone's camera, ensuring comprehensive documentation of the survey process. This simultaneous control of parameters in real-time enabled efficient data collection and ensure accuracy during the survey missions.

During the recording of the measured values, the four sensors below the drone were rigidly fixed, and the axis of the sensor array was guided parallel to the top of the terrain (GOK). The arrangement of the two GPS antennas and the sensor positions resulted in a precisely defined geometry stored in each measurement file within the evaluation software to enable high-quality data processing and interpretation. Since the penetration depth of the sensors depends on the distance of the sensors above the terrain (the magnetic field decreases with the depth r in a ratio of $1/r^3$), SeaTerra made sure that the sensors were directly above the terrain during the measurement.



▲ Photo 3. DMAG geometry

All sensor and position information came together in the data recording software, which was stored continuously. The data was stored as raw data without any editing. The real-time processing integrated the mapping of the sensor data to calculate position information. Here, the position information such as altitude above ground, flight altitude, direction information, movement data and positions of the drone and the measuring platform were linked and graphically displayed based on the system geometry. Linked to the drone system geometry, these parameters were used for survey control and navigation during the measurement as well as for precise data processing. The data recording made it possible to control and display all exploratory information in real-time.

Photo 3. Operator perspective

Data Processing and Interpretation:

Position and sensor data were processed in real time using the AGSDrone software, specifically designed for explosive ordnance detection. The software integrated mapping of sensor data to calculated position information, facilitating precise data processing and interpretation. All sensor and position information was continuously recorded as raw data without editing, enabling real-time control and display of exploratory information. The communications between the system and the leading vehicle were maintained with radio communications.

This feature allows the operator to detect possible threats on the road.

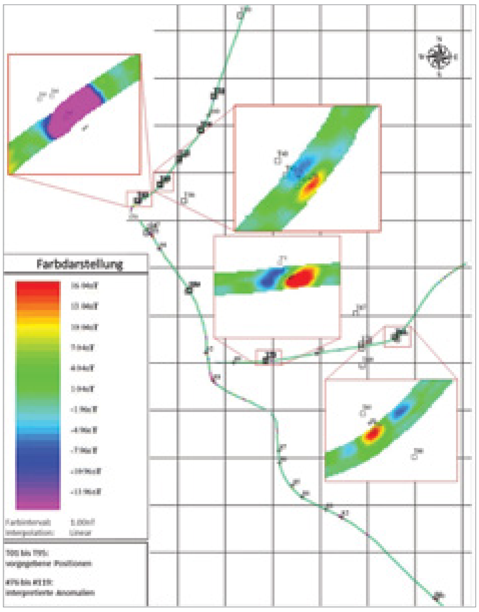


Photo 5: Data interpretations

Post-Mission Data Processing

Following survey missions, the acquired data underwent meticulous processing using the in-house developed software "AGSProc." This software played a crucial role in transforming raw survey data into actionable insights. AGSProc enabled informed decision-making and comprehensive reporting on magnetometer data collected during road survey missions. Additionally, the software marked every change in the path, ensuring accuracy in data analysis.

Navigation During Test Field Measurement

SeaTerra's AGSDrone software was used for navigation during the field test measurements. The drone autonomously flew over the measuring field, following a pre-defined DXF overlay. Parameters such as height above the ground, line spacing, sampling rate, and airspeed were set in advance. An existing GPS waypoint map was used to interpret the data, with all position data displayed in real time on an external monitor. This allowed the drone pilot to correct any measurement gaps or deviations promptly. The system operator had the option to switch to manual mode at any time during the testing.

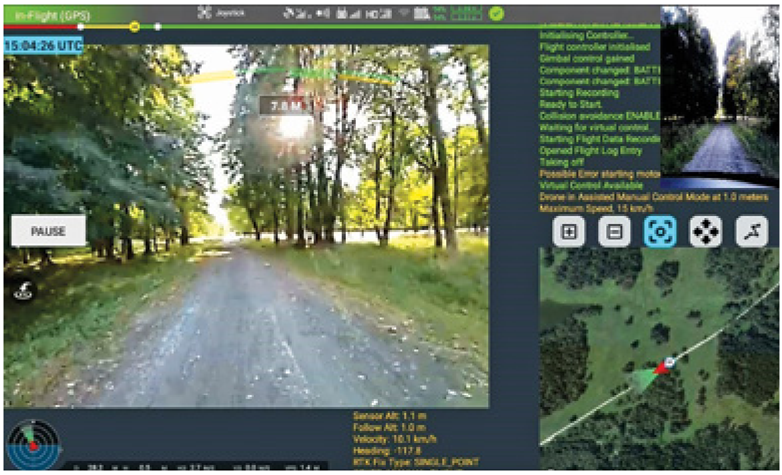


Photo 6. AGSDrone display during testing

Results

The distance between the leading vehicle and the system can be set differently depending on the route and risk assessment. During this test, we did not test more than 30 meters. The test demonstrates that stable flight at a height of 0.5 meters is possible with a speed of no more than 15 km/h. AGSpro can detect all that standard survey mode can detect. The sensor on this application can detect and collect data in real time. AGSpro can perform data analysis and transfer data to a remote screen (tablet). The resolution is not ideal, but it can provide enough information to the operator about incoming threats. The survey can detect a path 2 meters wide, sufficient for the safe navigation of a possible convoy. All the tests show that DMAG is a useful tool for road surveys in specific scenarios.

Limitations

Using old DJI 210v2 RTK UAVs has several limitations that need to be addressed. For instance, their flight durations are limited and susceptible to wind, snow, and rain. On average, these UAVs can only fly for a maximum of 20 minutes. Moreover, the magnetometer sensor has its limitations in detecting low-metal content threats (as depicted in the table).

Additionally, the built-in radio communication system has limited capacity to transfer real-time data, with speeds ranging to 10Hz. Due to these limitations, the current system is unsuitable for urban or high-traffic environments.

To address these issues, we recommend replacing the DJI 210v2 RTK with a newer version of UAV or, even better, a hybrid UAV. A hybrid drone with a greater weight payload provides the opportunity to integrate other payloads and possibly overcome issues with low-metal content objects.

Furthermore, replacing the radio communications with a MESH or 5G local network will give new possibilities in transferring data and navigating the entire system. This will result in better control and monitoring of the UAVs, allowing them to fly for more extended periods and operate in more challenging environments.

Table 1: Sensor detection range

	distance to sensor*																							
UXO/mine	0.5	0.6	0.7	0.8	1.1	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2.0	2.1	2.1	2.2	2.3	2.5	2.6	2.7	2.8	3.0	3.2	3.5
A mine PMR-2a	x	x	x	x																				
B mine PROM	x	x	x	x	x																			
C Mine M3	x	x	x	x	x																			
20mm / SprGr 38	x	x	x																					
37mm / PzGr 38	x	x	x	x																				
T1 60mm / GrW	x	x	x	x	x	x	x	x	x															
T2 81mm / UEBGRKPR 56A1 mit ZERS 83	x	x	x	x	x	x	x	x	x															
T3 81mm / EXGR 70/80	x	x	x	x	x	x	x	x	x	x	x													
T4 85mm / PzG BR-365	x	x	x	x	x	x	x	x	x	x	x	x												
T5 105mm / L-HILUEBG	x	x	x	x	x	x	x	x	x	x	x	x	x	x										
T6 120mm / UEBGR 78/EXAZ 66	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							
T7 155mm / EXGR 88 M 185 w ZERS/AZ6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
T8 155mm / UEBGR 94 w ZERS	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
round steel / Ø100mm, l = 450mm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
pipe/ Ø100mm, l = 450mm, s = 20mm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
pipe / Ø100mm, l = 450mm, s = 10mm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

	distance to sensor*									
UXO/mine	1	2	3	4	5	6	7	8	9	10
100 lbs bomb	x	x	x	x						
200 lbs bomb	x	x	x	x	x					
500 lbs bomb	x	x	x	x	x	x	x			
1000 lbs bomb	x	x	x	x	x	x	x	x	x	
depth charge	x	x	x	x	x					
anchor mine	x	x	x	x	x	x				
ground mine	x	x	x	x	x	x	x	x		

* detection depht below ground = distance to sensor - flight hight

x 100% detected

80% detected

<80% or no detection

Conclusions

Seaterra's DMAG UAS has demonstrated significant potential as a valuable tool for road surveying and explosive hazard detection in conflict-affected regions. Through a comprehensive analysis of its technical specifications, operational effectiveness, and limitations, several key conclusions can be drawn:

Effectiveness in Road Surveying: DMAG excels in conducting road surveys and accurately detecting changes in magnetic readings along predetermined routes. Its seamless integration with AGSpro software allows for real-time data collection and analysis, providing critical insights for route safety assessment.

Operational Efficiency: The system's semi-automatic mode, facilitated by SeaTerra's AGSDrone navigation software, enables efficient data collection while ensuring the drone pilot's focus on directing flight paths. Real-time positional data display and continuous recording of sensor information enhance operational control and data quality.

Limitations and Challenges: Despite its effectiveness, DMAG faces limitations such as the restricted flight duration of older UAV models like the DJI 210v2 RTK, susceptibility to weather conditions, and constraints in urban or high-traffic environments. Additionally, the limitations of magnetometer sensors in detecting low-metal content threats pose challenges to comprehensive threat identification.

Recommendations for Enhancement: To address these limitations and enhance system performance, recommendations include upgrading to newer UAV models or hybrid drones with increased payload capacity and integrating advanced communication technologies such as MESH networks or 5G local networks. These enhancements would not only improve data transfer capabilities but also expand operational capabilities, especially in challenging environments.

In conclusion, while Seaterra's DMAG UAS represents a significant advancement in mine action and road safety efforts, further technological advancements and adaptations are necessary to realize its full potential. By addressing existing limitations and leveraging emerging technologies, DMAG can continue to evolve as an indispensable tool for humanitarian efforts in conflict-affected regions, ultimately saving lives and facilitating the delivery of essential aid.

Assisted Explosive Ordnance Disposal:
Teleoperated Robotic Systems with AI, Virtual Reality, and Semi-Autonomous Manipulation for Safer Demining Operations

Mario Malizia[1], Ana María Casado Faulí[1], Ken Hasselmann[1], Emile Le Flécher[1], Geert De Cubber[1], Rob Haelterman[2]

Abstract

This paper outlines the objectives of BELGIAN, a Belgian Defence project that focuses on developing mobile manipulation tools for demining, Explosive Ordnance Disposal (EOD) &Improvised Explosive Device (IED) operations. The goal of the project is to improve the safety of demining operations through the use of robotic systems, specifically addressing therisks associated with traditional landmine removal methods that endanger operators during manual extraction. Focusing on the challenge of intensified IED usage in armed conflicts, BELGIAN aims to integrate technologies such as artificial intelligence (AI), virtual reality (VR), and semi-autonomous manipulation. On the one hand, AI will play an important role in providing a solution to the complex landmine removal problem, including the localisationand the classification of explosive devices in remote exploration. The use of VR in real-time applications, on the other hand, aims to simplify on-the-ground decision-making for removaloperations, providing immediate and immersive insights for increased situational awareness.Semi-autonomous manipulation capabilities will assist robotic arms in demining, employing techniques such as motion correction and coordinated platform movement to monitor the procedure. Through a co-creation methodology involving end users, particularly EOD units, BELGIAN ensures that its technological solutions align with operational needs and gain user acceptance.

Introduction

In the context of contemporary armed conflicts, the prevalence of Explosive Ordnance (EO) threats, specifically Improvised Explosive Devices (IEDs) and landmines, has become a growing concern. These hidden dangers pose significant risks to the safety of troops, seeking innovative approaches to assist demining operations. In the domain of contemporary armed conflicts, the Belgian Defence has funded a project, known under the acronym BELGIAN, that focuses on developing assisted mobile manipulation tools tailored for demining and countering the dangers of IEDs. Drawing from insights gained in previous collaborations with the Belgian EOD Group [1], [2] and incorporating directfeedback from the end user, BELGIAN has been proposed to enhance the safety of demining operations. By deploying robotic systems, it actively mitigates the risks posed byconventional landmine removal methods thatjeopardise human operators during manual extraction. In recent years, several alternatives to address land demining problems have been proposed [3], [4]. While robotic platforms that mimic human walking behaviour have been suggested in the past [5], [6], the primary focus of this project is on enhancing the Human Machine Interface and maintaining a man-in-the-loop rather than emphasizing the demining platform itself. Motivated by this objective, the deployment of a robotic platform based on a rover UnmannedGround Vehicle (UGV) as outlined in [7] will be adopted. BELGIAN will primarily rely on artificial intelligence (AI), virtual reality (VR), and semiautonomous manipulation toassist the demining operation. The use of AI and VR will assist the operator by providing guidance in localising and categorising explosive devices during remote exploration, aswell as offering distance-from-target statistics. By integrating new technologies and novel algorithms, it envisions a future wheredemining operations are not only safer but also more efficient, contributing to the safeguarding of personnel.

This article delves into the system and architecture of the project, introducing the UGV platform, network architecture, sensors layout, and software architecture. A comprehensive methodology is presented, outlining the approach and procedures, including feature-based and AI-based sensor processing, real-time virtual reality

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streaming, assisted robotic manipulation, and multi-robot fleet management.

System and Architecture

In this section, we introduce the robotic system involved in BELGIAN and its architecture.

Figure 1: The Husky UGV Platform. The manipulator arm will be mounted on top of the roboticplatform.

UGV Platform

The UGV involved in the development of the project is a Clearpath Robotics Husky platform by Rockwell Automation [8]. The Husky's adaptability extends to various devices, allowing customisation to meet specific research needs due to its payload capacity and robust power systems. The UGV platform is represented in Figure 1. Leveraging the adaptability of the platform, a UR5 robotic arm from Universal Robots [9] will be integrated into the UGV to safely perform the demining operation.

Network Architecture

The UGV platform will be fitted with a processing unit and various sensors to acquire data for subsequent processing. For what concerns the network communication, an antenna is positioned on the robot, whereas an additional antenna serves as a range extender on the base station. The integration of a network extension facilitates uninterrupted communication between the robot and the end user, ensuring a robust final interface. Figure 2 gives a general overview of communication constraints.

Sensors Layout

The platform will primarily involve two types of sensors: proprioceptive and exteroceptivesensors. Proprioceptive sensors, such as Inertial Measurement Units (IMUs), will offer the operator feedback on the robot's position and velocity. This information is essential for demining tasks, as it allows operators to make real-time adjustments and ensures the robot's accurate and safe movement. On the other hand, exteroceptive sensors, such as cameras and LiDARs, will provide near real-time feedback to the operator about the surrounding environment. Furthermore, cooperative efforts through field test organisation will contribute to a deeper understanding of the sensor suite,especially in the context of deploying furtherequipment such as a thermal camera or an infrared camera on the platform.

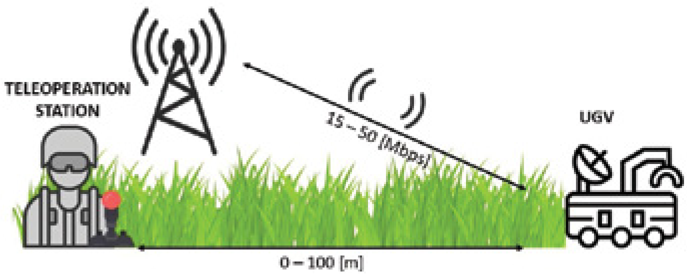

Figure 2: Communication constraints. Bi- directional communication with the Navigation module allows the operator to control platform motion and receive feedback in real-time.

Software Architecture

The software architecture will be built using the Robot Operating System 2 (ROS 2) [10]. ROS 2 enables communication across various software distributions, ensuring compatibility between different robotic systems [11]. This approach is favoured for its versatility and scalability. This design choice enables expansion and adaptability to several (and varying) operational requirements. Meanwhile, each UGV platform relies on a CPU to handle tasks like controlling wheel motors and overseeing fundamental sensor operations, while a GPU is dedicated to managing more complex algorithms, specifically in image processing.

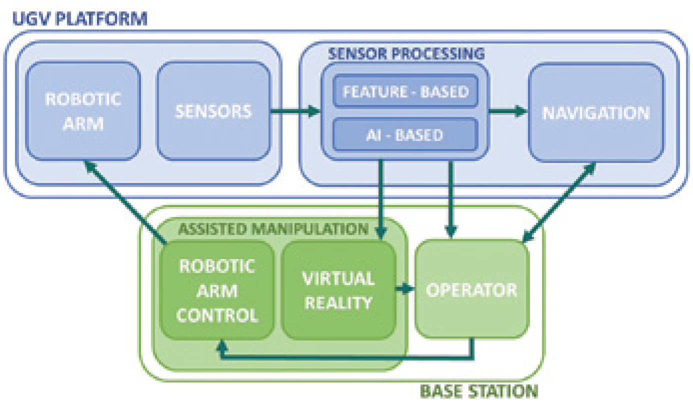

Figure 3: Architecture of the robotic system. The system is composed of a UGV platform (in blue) and a base station (in green)

Methodology

In this section, we present the methodology employed in the BELGIAN project, outlining the approach and procedures that will be applied. Figure 3 illustrates the robotic system architecture. The system allows for operator interaction for navigation and manipulation tasks. The operator will be able to choose between direct sensors feedback: either Feature-based (see Section 3.1) or AI-based (see Section 3.2) or VR feedback (see Section 3.3) provided by the Assisted Manipulation module (see Section 3.4).

Feature-Based Sensor Processing

Feature-based sensor processing will significantly enhance the capabilities of demining applications [3]. This can be achieved by employing LiDARs and cameras. In particular, correlating depth information from the LiDAR point cloud with individual pixels in the 2D camera image will provide the operator with a general overview of the surrounding scene and environment. Building upon the same principle, the implementation of Simultaneous Localisation and Mapping algorithms (SLAM) [12] offers another dimension to the operator's understanding of the terrain surrounding the robot. This process enables the generation of a 2D or 3D map while simul taneously tracking the robot's position. This additional layer of information contributes to raise awareness during the operation.

AI-Based Sensor Processing

The use of AI will provide the operator with relevant feedback, such as terrain traversability, to smooth the control of the robotic platform. A potential processing method could involve semantic segmentation techniques, as in [13], where the output consists of assigning a specific label to different elements in a raw image such as objects, structures and terrains. Moreover, LiDAR point clouds can be substituted by applying depth estimation techniques to images [14]. This approach is particularly favoured due to its cost-effectiveness, both economically and computationally. Furthermore, depth images will contribute to estimating explosive quantities based on the dimensions of the detected explosive device.

Real-Time Virtual Reality Streaming

The incorporation of VR is seen as a potentially valuable asset for operators engaged in mine removal processes. Beyond providing video feedback to the operator, VR may offer a new experience by reconstructing the 3D map discussed in the previous sections. This will improve the perception of the end user, contributing to further understanding of the task at hand. However, the transmission of data for this application poses a challenge in terms of bandwidth constraints.

Assisted Robotic Manipulation

While various control interfaces exist for robotic manipulation, such as joysticks or foot pedals, each with its own advantages and constraints [15], the inherent challenge of coordinating platform movement and manipulator tasks persists. Specialised algorithms can help address these challenges, optimising synchronisation and mitigating overly aggressive arm motion. However, research continues to explore alternative control methods that could improve the precision and efficiency of robotic manipulation in specific applications, such as demining.

Multi-Robot Fleet Management

Coordination among robots in a fleet will involve the collaborative efforts of several units advancing to inspect the terrain, identify potential hazards, and real-time mapping of the environment efficiently. Due to the different nature of the IEDs [16], a variety of sensors must be deployed in these robots, such as metal detectors, ground penetrating radars, or thermal cameras. In the event of a positive IED detection, the manipulator robot takes charge of extracting the explosive.

Conclusion

The primary objective of BELGIAN is to showcase the potential advantages derived from the application of AI in demining activities, particularly in supporting operators during the demining operation. The project's evolution is characterised by field trials conducted in collaboration with end-users, specifically the Belgian Explosive Ordnance Disposal (EOD) Group within the Belgian Army. These trials serve to understand the specific requirements of the final user and improve the outcome of the project in the coming years.

Acknowledgements

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Enhancing and Expanding EOD Operations Through EOD NOW: A New Approach to Addressing Global Challenges

Tobias de Taillez[1], Alexander F. Wüst[2], Ken La-Ramée[3], Davor Petek[4]

Introduction

The task of Explosive Ordnance Disposal (EOD) globally faces significant challenges, exacerbated by the increase in armed conflicts across various regions and the resulting spread of Explosive Remnants of War (ERW) and Improvised Explosive Devices (IEDs). In 2022, statistics indicate that Unexploded Ordnance (UXO) and ERW were responsible for an estimated 17,000 casualties worldwide, with civilians making up over 80% of these victims. This statistic underlines the significant risk posed by these explosive hazards and highlights the need for improved efficiency and effectiveness in EOD operations. Consequently, the adoption of innovative approaches and technologies to advance EOD clearance operations is both necessary and urgent.

The need to address these challenges is particularly acute in Ukraine, where ERW significantly impacts civilian populations and hampers economic recovery and development. This situation is not unique to Ukraine; similar issues affect other conflict-affected regions globally, where the remnants of war pose a continuous threat to lives, even after the cessation of hostilities. The EOD NOW initiative is introduced in this context as a strategic response, aiming to incorporate innovative solutions.

EOD NOW takes a comprehensive approach by integrating technological innovations across various applications. This includes the deployment of autonomous systems and robots for the safe detection and neutralization of ERW and IEDs, as well as the use of advanced artificial intelligence (AI) and machine learning algorithms to enhance the accuracy of detection and classification tasks. Additionally, the initiative emphasizes the development of integrated data management and communication systems to improve coordination among all participants in EOD operations, including the engagement of public communities, to achieve a more effective and efficient clearance process.

Challenges and Necessities

Current EOD operations are characterized by numerous challenges, including limited resources, high risks to clearance personnel, and slow clearance rates, endangering civilian safety and delaying socio-economic development in affected areas. However, technological advancements offer new opportunities to overcome these challenges. The EOD NOW initiative represents one such opportunity, proposing innovative solutions for detection, identification, neutralization, documentation, and handover in EOD operations.

Vision and Objectives of EOD NOW

EOD NOW aims to improve EOD clearance by integrating and optimizing existing and newly developed technologies. The main objectives include:

1. **Increasing efficiency and safety** through the use of autonomous systems and AI-powered detection technologies that minimize risks to clearance personnel and accelerate the pace of EOD operations.
2. **Sustainability and capacity building** by training and equipping local teams with the necessary technical skills and knowledge to establish long-term EOD capabilities in affected countries.
3. **Enhanced documentation and reporting** through the development of integrated software solutions that enable transparent and efficient documentation and analysis of clearance data.

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Technological Innovations and Integration

The EOD NOW initiative encompasses a range of technological innovations and integrations:

- **Autonomous Systems and Robots:** Use of drones and robots for the safe detection and neutralization of ERW and IEDs. These systems can efficiently survey hazardous areas with minimal risk exposure to clearance personnel.
- **Artificial Intelligence (AI) and Machine Learning:** Development and deployment of AI algorithms to improve the detection and classification of ERW and IEDs. These technologies can increase the accuracy of detection and reduce false positives.
- **Integrated Data Management and Communication Systems:** Creation of a centralized data management system that facilitates seamless communication and coordination between various actors involved in EOD operations including the public community.

Case Study: The PEREGRINE EOD Drone

The PEREGRINE EOD Drone, developed by WARG-drones GmbH, represents a technological advancement in Explosive Ordnance Disposal (EOD). It is engineered specifically for the identification, analysis, and neutralization of explosive threats, utilizing a high-precision two-axis gimbal system equipped with a LANCE disruptor for accurate ordnance neutralization. This integration enables safe, remote operations while maintaining necessary precision for EOD missions.

Figure 1: PEREGRINE drone ready for take-off.

Operating on the Robot Operating System (ROS), PEREGRINE provides responsive control through real-time data processing. Its user interface is designed for operational efficiency, reducing cognitive load with clear, intuitive navigation. Safety protocols include continuous monitoring and emergency responses to connection or system failures, ensuring reliability during EOD operations.

The UAV is designed to accommodate the recoil of a disruptor, allowing for vertical effector deployment without destabilizing flight, enhancing its operational flexibility across EOD scenarios. The gimbal's adaptation for the LANCE Disruptor from Canadian Technology Systems enables precise targeting, with recoil compensation allowing for stable engagement of targets. The system supports a variety of projectiles, offering versatility in neutralization methods.

Figure 2: Neutralization of an inert C4 explosive charge by precise destruction of the detonator using a gel-water shot. 4 m stand-off distance, 2 cm accuracy, 4 min total operation time.

The software backbone, based on ROS, facilitates high-frequency, low-latency data processing, critical for real-time operational demands. The user interface integrates live video streams and satellite mapping for comprehensive situational awareness, essential for precise targeting and control.

Advanced safety systems include ADS-B for automatic aircraft detection, protocols for data link loss or GPS failure, and continuous mechanical integrity monitoring, ensuring operational and bystander safety. These features position the PEREGRINE as a significant contribution to modern EOD operations, merging advanced technology with tactical efficiency.

Results and Outlook

Through the integration of the proposed technologies and methods, EOD NOW can significantly contribute to enhancing EOD clearance. Preliminary analyses suggest that EOD NOW can increase clearance speed while significantly improve the safety of clearance personnel. In the long term, EOD NOW has the potential to accelerate socio-economic development in former conflict areas and improve the quality of life for the local population.

Conclusion

The EOD NOW initiative offers a visionary and comprehensive approach to improving global EOD clearance. By integrating state-of-the-art technologies and methodologies into EOD operations, efficiency, safety, and sustainability can be significantly enhanced. While EOD NOW is currently still in the conceptual phase, its potential underscores the importance of innovation and international collaboration in combating the threat posed by explosive remnants of war.

Evaluating PPP-RTK Technology for Precision Real-Time Tracking of Mine Clearance Operations

Patrick Truong[1], Jacqueline Brownhill[2]

Abstract

This study presents the novel application of Precise Point Positioning – Real Time Kinematics (PPP-RTK) technology in detector-assisted manual mine clearance operations. PPP-RTK is widely known for its precision in sectors such as autonomous navigation and geospatial mapping, utilising satellite-based corrections to achieve 3-6 cm accuracy without the need for a base station on the ground. The MiFi Maps detector tracker prototype integrates PPP-RTK technology into a lightweight, compact design which attaches directly to any metal detector, tracking every sweep in real-time with centimetre accuracy. Field tests involved a controlled grid where the metal detector's actual path was compared against the tracker-recorded trajectory displayed on a map overlay. Initial results demonstrate the prototype's efficacy, with data points confirming the anticipated accuracy range. This validation underscores the MiFi Maps detector tracker's potential to revolutionise mine clearance operations through vastly improved accuracy in mapping, quality assurance, and quality control with further applications in accountability and training.

Introduction

MiFi Maps has developed a functional prototype for precision, real-time tracking of mine clearance operations, using Precise Point Positioning – Real Time Kinematics (PPP-RTK) technology in a lightweight, compact design which attaches directly to any metal detector, tracking every sweep as it occurs with centimetre accuracy.

Precise Point Positioning (PPP) works by using a single receiver device to process Global Navigation Satellite System (GNSS) signals, correcting for satellite clock errors, atmospheric delays, and other systematic biases to achieve high-level accuracy on a global scale [1].

Real-Time Kinematics (RTK) technology enhances positioning accuracy by utilising a fixed base station to correct errors in the GNSS signals received by mobile rovers, achieving precise measurements to within centimetres, but with the system operating range limited by the transmission range of the base station [2].

PPP-RTK combines the global coverage and systematic error correction of PPP with the real-time, high-precision capabilities of RTK, offering centimetre-level accuracy without the need for a nearby base station, virtually eliminating range limitations [3].

This combination of precision and mobility is uniquely suited for accurately tracking mine clearance operations in real-time and has the potential to set new industry standards in mapping, quality assurance, and quality control.

This study aims to evaluate the performance of PPP-RTK technology in real-world environments to further understand its capabilities compared to standard GPS devices currently in widespread use in the mine action sector, and assess its potential for precision, real-time tracking of mine clearance operations.

Materials and Methods

The Control consists of:

- Android smartphone GPS (internal)
- generic Android GIS application

This type of device is very commonly used for reporting daily operations in mine action programmes throughout the world.

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The Independent Variable is the MiFi Maps prototype which consists of:

- PPP-RTK receiver (internal)
- Bluetooth module (internal)
- rechargeable battery (internal)
- weatherproof electronics enclosure
- GNSS antenna (external)
- universal clamp to attach to detector
- Android smartphone
- generic Android GIS application

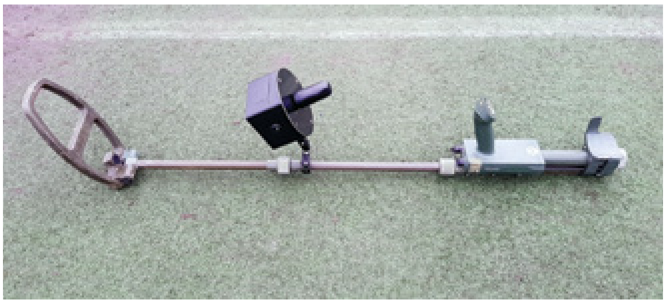

Figure 1. Tracker attached to metal detector.

The GNSS antenna receives signals and corrections which are processed by the PPP-RTK receiver, generating accurate position data which is then sent by the Bluetooth module to the GIS app on the Android smartphone.

The Android GIS app receives the position data and displays it in list form. The relevant data for this evaluation are:

- Easting/Northing Coordinates
- Fix Type
- Horizontal Accuracy

The Easting/Northing Coordinates are only used to plot the real-time position of the tracker on a satellite image overlay from Google.

There are four Fix Types listed here from worst to best level of accuracy:

- Single (Worst)
- DGPS
- RTK Float
- RTK Fix (Best)

The source code and documentation for this GIS app is not readily available. However, Horizontal Accuracy is typically calculated using Root Mean Square (RMS) error.

The RMS is a statistical measure that quantifies the magnitude of a varying quantity and is commonly used in GNSS to express the accuracy of position estimates.

The formula for the RMS error of a single component (e.g., easting or northing) is given by:

$$\mathrm{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where:

- n is the number of observations,
- x_i is the ith observation, and
- $\bar{x}$ is the mean of observations [4].

The combined Horizontal Position Error (HPE) at 95% confidence level can be calculated as:

$$\mathrm{HPE}_{95\%} = 1.96 \times \sqrt{\mathrm{RMS}^2_{\mathrm{easting}} + \mathrm{RMS}^2_{\mathrm{northing}}}$$

where:

- 1.96 is the factor for the standard deviations from the mean in a normal distribution, and
- RMS is the Root Mean Square error which in this formula, the easting and northing components are combined to provide one single measure of Horizontal Accuracy [5].

The GIS app can also provide Vertical Accuracy. However, the Control (Android smartphone internal GPS) does not generate any data for this variable to compare to the MiFi Maps prototype, and therefore it is not included as relevant for this study.

The field tests were conducted in two different environments:

- Suburban: a “No Parking” grid in a car park with some buildings nearby
- Semi-Rural: a cricket pitch in a large nature park with trees in the distance

At both locations, the MiFi Maps prototype was tested first. This was done by:

- connecting the prototype to the smartphone via Bluetooth
- enabling track recording in the GIS application
- sweeping the detector horizontally between the lines of the car park or cricket pitch, proceeding forward approximately 10 cm (the width of the prototype enclosure) after each horizontal sweep
- observing the track line and relevant data on the smartphone screen
- taking screenshots of notable events

Then the Control was tested by:

- attaching the smartphone to the clamp with an adapter
- enabling track recording in the GIS application
- sweeping the detector horizontally between the lines of the car park or cricket pitch, proceeding forward approximately 10 cm (the width of the prototype enclosure) after each horizontal sweep
- observing the track line and relevant data on the smartphone screen
- taking screenshots of notable events

Figure 2. Prototype testing at car park.

Figure 3. Prototype testing at cricket pitch.

Results

The primary performance metrics evaluated were the Fix Type and Horizontal Accuracy. Additionally, the track recordings of the prototype and the Control were visually compared with each other and with the actual path on the ground.

Suburban Environment:

- MiFi Maps prototype performance:
  - Fix Type: RTK Fix throughout
  - Horizontal Accuracy: 14-32mm
- Control performance:
  - Fix Type: Single throughout
  - Horizontal Accuracy: 3 metres

Semi-Rural Environment:

- MiFi Maps prototype performance:
  - Fix Type: RTK Fix throughout
  - Horizontal Accuracy: 14-28mm
- Control performance:
  - Fix Type: Single throughout
  - Horizontal Accuracy: 3 metres

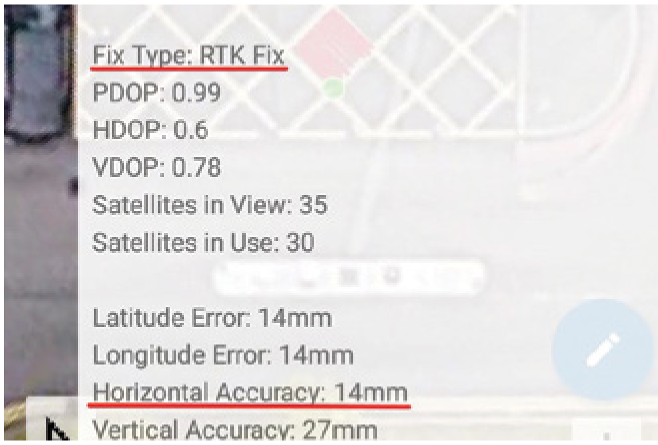

Figure 4. Prototype performance metrics for Suburban Environment.

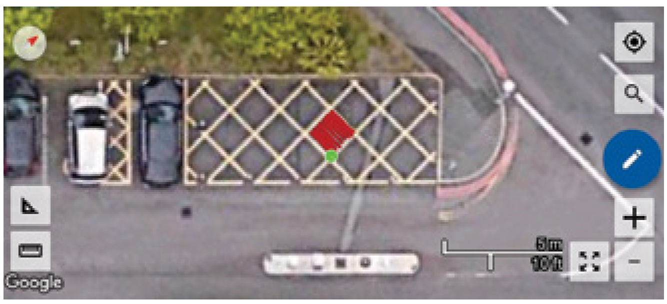

Figure 5. Prototype track recording in Suburban Environment.

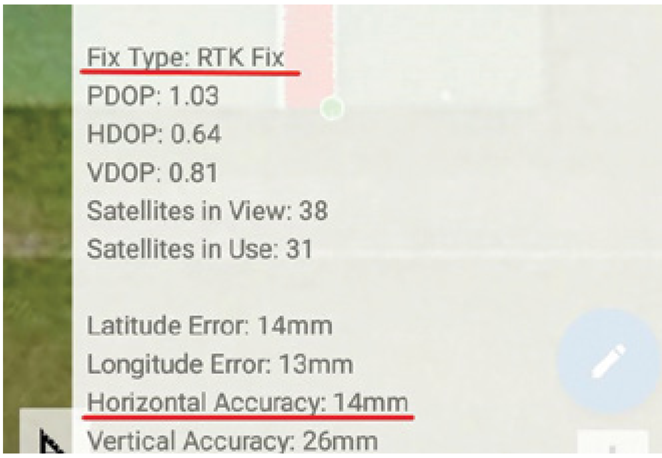

Figure 6. Prototype performance metrics for Semi-Rural Environment.

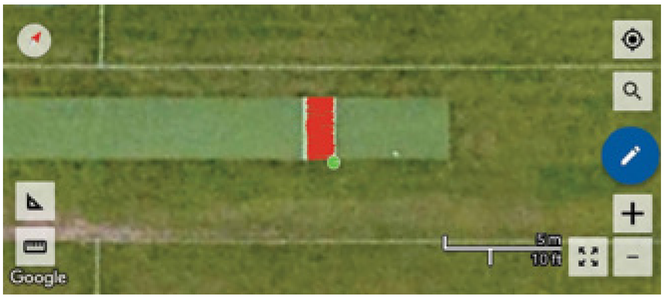

Figure 7. Prototype track recording in Semi-Rural Environment.

Conclusions

The MiFi Maps detector tracker prototype with PPP-RTK technology performed significantly better than expected (with a Horizontal Accuracy of 14mm at best and 32mm at worst) compared to the 3-6cm industry standard for this type of system.

These results underscore the efficacy of PPP-RTK technology as a viable solution for precision, real-time tracking of mine clearance operations without the need for a base station on the ground. This would make the overall system faster and easier to deploy in minefields in various challenging environments around the world.

MiFi Maps will continue to develop the detector tracker system to be smaller, lighter, and more robust, conducting further research into increasing the range of connectivity between the trackers and the monitoring device using supplementary systems such as mesh networking, with the aim of delivering a reliable product which will revolutionise how mapping, quality assurance, and quality control is conducted throughout the mine action sector.

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Innovation in Mine Action Remote Reporting and Analysis

Rory Collins

Introduction

UNOPS plays a pivotal role in advancing innovation within the field of mine action, particularly in the domain of remote reporting and analysis.

Through strategic partnerships and dedicated Research & Development initiatives, UNOPS supports the exploration and implementation of innovative tools, equipment, and procedures for mine action.

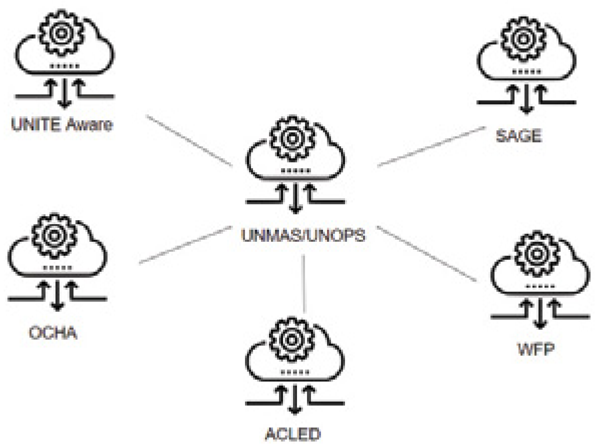
UNOPS has piloted significant contributions to mine action programmes through its R&D based innovations in three primary areas:

Data Sharing

UNOPS views information management systems as hubs within a network of partners, not a collection of siloed systems.

Using advanced Esri technology, UNOPS has been able to automate data sharing with partners such as the UN's Peacekeeping incident reporting platform, UNITE Aware.

This approach simplifies planning and prioritization for Non-Technical Survey (NTS) operations, primarily by removing resource-heavy and time consuming data processing. This approach has significantly changed the landscape of how partners can collaborate within the sector.

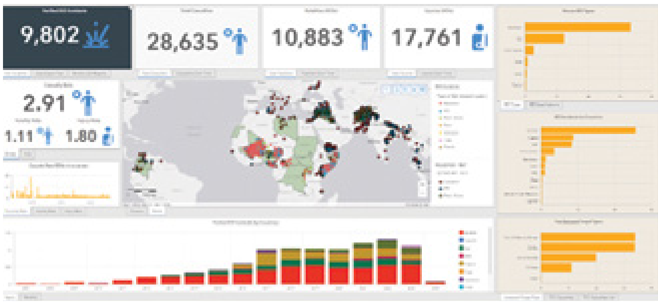


Source: *Global IMS Data Governance Framework*

Data Management

Providing a comprehensive and accurate threat assessment is crucial to operational planning. A growing success factor is being able to process large amounts of data from multiple sources in a timely manner. In response to this growing need, UNOPS is now using Natural Language Processing (NLP) scripts to automatically detect, clean and catalog reports from multiple data sources into highly accurate datasets.

One example of this is global Improvised Explosive Device (IED) Reporting, where reports from multiple external sources are merged with internal reporting, providing decision makers with a more comprehensive assessment of the current threat, and its emerging trends.

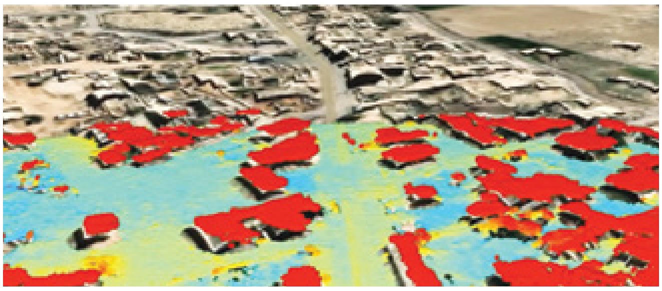


Source: *Global IMS IED Dashboard*

Remote Sensing

The need for accurate Geographic Information System (GIS) based threat assessments has given rise to the use of advanced remote sensing technologies. UNOPS has adopted these new technologies, such as Artificial Intelligence (AI) generated satellite imagery analysis, to better inform advocacy and operational planning.

One innovative approach UNOPS has adopted is using off-nadir views and shadows from stereo images to create 3d models of damaged buildings. This provides an accurate assessment of the volume of rubble from damaged buildings, such as in Syria.

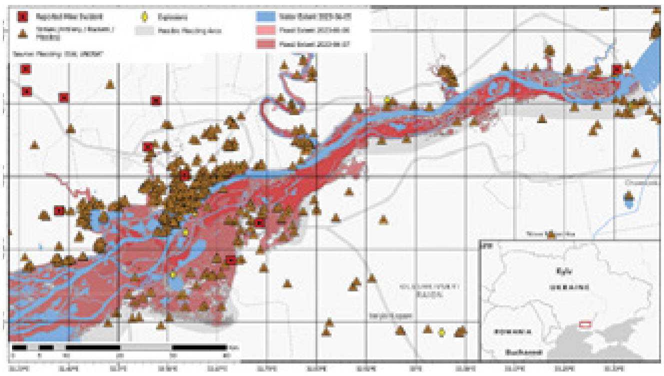


Source: *Global IMS Syria NTS Desk Assessment*

Another innovative approach is building AI models to detect and measure positive socio-economic changes as a result of Mine Action activities. In Kandahar, Afghanistan this approach has provided visual evidence of the long term impacts of thirty years of Mine Action, mapping direct contributions to the UN SDG.

Source: *Global IMS Afghanistan Impact Assessment*

Furthermore, using similar remote analysis and satellite imagery based techniques in Ukraine, UNOPS has developed forecasting models to predict the impact of flooding on Explosive Ordnance contamination; this was a crucial requirement in the wake of the Khakovka dam disaster.



Source: UNOPS Ukraine Flooding Impact Assessment

Additionally, UNDP partnering with Croatia, engaged UNOPS Ukraine to procure three high powered computers with AI software, and a team of three IM specialists in support of the State Emergency Service Ukraine (SESU). This contribution allowed SESU to confirm 5,000 sq. m. as free of contamination in just six weeks.

Conclusion

As UNOPS continues to navigate the evolving landscape of research and development, its commitment to fostering innovation underscores its dedication to creating a safer world, free from the threats posed by EO.

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MINE DETECTION DOGS AND THEIR ROLE IN HUMANITARIAN DEMINING

Optimising Performance: Managing Quality and Efficiency of Mine Detection Dogs Across Varied Contamination and Environmental Settings

Kenan Muftić[1], Darvin Lisica[2]

Abstract:

Since 1995, the Norwegian People's Aid (NPA) has been utilizing Mine Detection Dogs (MDDs) with evolving strategies, culminating in the establishment of the Global Training Centre in 2004 to standardize methodologies worldwide. This article investigates the transformative journey of MDD deployment techniques, focusing on operational experiences across different operational contexts in five countries.

Key findings reveal the adaptability and efficacy of MDDs, particularly in investigations within technical surveys and landmine cluster detection. Technical Survey dogs (TSD) have optimized hot spot exploration, expediting target localization and subsequent manual clearance. Operational success stories from Zimbabwe, Thailand, Cambodia, Iraq, and Bosnia and Herzegovina underscore the critical role of MDDs in diverse contexts, from minefields to cluster munition and IED-contaminated zones.

The article also delves into quality management aspects, emphasizing the importance of ongoing training and testing protocols tailored to specific operational environments. Moreover, an analysis of operational efficiency highlights productivity growth trends and cost-effectiveness considerations, guiding strategic decision-making for NPA programs globally.

Overall, the study underscores the importance of strategic integration and competent operational management in maximizing the efficiency and effectiveness of MDD deployment, ensuring sustainable progress in mine action and disarmament efforts worldwide.

Keywords: mine detection dogs, land release, efficiency, NPA, MDD

Background

NPA has been using MDDs since 1995, initially encountering modest results. However, the early 2000s marked a pivotal moment when NPA intensified efforts to refine both the training of their MDDs and operational protocols. This dedication culminated in the establishment of the Global Training Centre in 2004, fostering the implementation of standardized methodologies across mine action programs worldwide. Consequently, MDDs seamlessly integrated into NPA's arsenal, yielding remarkable contributions to land release efforts.

As land release methodologies advanced, particularly through targeted and systematic investigations within technical surveys, the role of MDDs underwent significant transformation. Working techniques were tailored to meet evolving demands, ensuring adaptability and effectiveness in various operational contexts. Presently, NPA deploys MDDs across several countries and operational contexts, demonstrating their versatility and efficacy. For the purpose of this article, insights and experiences from four distinct operational scenarios in Zimbabwe, Thailand, Cambodia, Iraq, and Bosnia and Herzegovina will be examined and elucidated.

MDD Deployment Techniques

MDDs are deployed utilizing a variety of working techniques and search patterns. The International Mine Action Standards (IMAS) delineate clearance standards in the context of landmine removal, stipulating that the area must be searched by two separate MDDs (a double search). However, in Technical Surveys and clearance of areas contaminated with cluster munition remnants (CMRs) and with other explosive remnants of war, a single dog search is deemed acceptable.

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The predominant search pattern involves searching in straight lanes perpendicular to the base lane, extending approximately 10 meters ahead of the handler. These lanes are parallel, with varying distances between them, sometimes less than 50 cm in clearance activities and up to several meters in systematic investigations within technical surveys. The length of the leash—and consequently, the searching lane—may extend to over 30 meters, or even more when dogs are unleashed in technical surveys. This technique has recently gained recognition as a distinct animal detection method termed Technical Survey dogs[3] (TSD).

TSD techniques facilitate targeted investigations, particularly in exploring hot spots, where handlers can direct dogs in multiple directions from a single point until targets (landmines) are confirmed or all potential hot spots are thoroughly checked. This approach optimizes the exploration of hot spots, expedites target localization, and allows for quicker subsequent manual clearance.

In scenarios where hot spots are difficult to determine, systematic investigations are carried out through parallel lane searches. The spacing between these lanes depends on contamination contexts, obstacles, and terrain configurations. This method also serves to bolster confidence in area reduction within the technical survey process or in locating mines that may have been missed based on established patterns derived from available minefield records or non-technical survey information (missing mine drills).

Photo 1. Technical Survey Dog (TSD)

NPA MDDs in minefields of Zimbabwe and Thailand

The minefields along the Zimbabwean-Mozambiquan border from Sheba forest to Leacon Hill usually consisted of ploughshare mines attached to the metal posts protruding about one meter above the ground. They were often "protected" by two to four antipersonnel landmines forming clusters with distances of 20 to 50 meters in between. Visually locating ploughshare mines on the posts, and therefore identifying the mine belt seems easy, however, after decades, almost none of the posts is erect anymore and most of the ploughshare mines are removed or exploded leaving only antipersonnel mines waiting for local civilians.

Initially, only manual deminers were deployed along the mine belt clearing the width of at least 50 meters. MDDs were used to search and confirm the fadeout areas outside of mine belts, and searched often for thousands of square meters before finding mines that were for some reasons dislocated from their original place within the mine belt. Such approach was changed, and MDDs were effectively employed within actual mine belt with the aim to locate landmine clusters. This new approach limited the processed area in technical survey and significantly enhanced program efficiency. By utilizing dogs to pinpoint each mine position/cluster and transitioning swiftly between clusters with minimal fadeout, the program has developed a markedly more efficient approach.

Similarly, in Thailand, the NPA utilized MDDs to conduct searches within designated boxes, while manual teams cleared lanes around these boxes. However, following a comprehensive analysis of operational outcomes and MDD performance, the program underwent a strategic shift. MDDs were subsequently employed for targeted technical surveys, tasked with breaching lanes into suspected hazardous areas to identify minefields and facilitate access for subsequent manual clearance efforts. Once mines were detected, the MDDs were relocated to new locations, while deminers were deployed to clear the identified mine rows.

This strategic realignment yielded highly positive results. Each MDD achieved significantly higher release rates compared to deminers, whether in technical survey or clearance roles. Concurrently, the overall number of devices removed by the entire team saw a significant increase.

3 According to IMAS Test and Evaluation Protocol 07.31 the term 'Technical Survey Dog' (TSD) refers to a dog specifically trained to detect and correctly indicate vapour from EO, normally in the minefield environment /setting, and is used with or without leash to distances greater than 10-meter and without any prior ground preparation.

Photo 2. Breaching lanes, Muzite, Zimbabwe

IEDs in Landmine Context – Iraq

MDDs deployed in IED-contaminated areas in Ramadi and Haditha play a crucial role in the Technical Survey activities, while manual deminers focus on clearing mine/IED rows. The IEDs encountered in these areas typically range in size, with explosive charges varying from 5 to 25 kg. These devices are often positioned in shallow sub-surface locations, triggered by pressure plates or sensitive crush wires, sometimes found in proximity to the main charge. Special attention is given to identifying different types of sensitive crush wires. At each location, the discovered targets generally belong to the same type, although variations occur between sites. While there is typically a discernible pattern to the placement of these items, predicting it can be challenging in certain instances. Scenarios involving scattered IEDs across an area, as well as combinations of different IED types and other Explosive Remnants of War (ERW) contamination, are also encountered.

Photo 3. MDD team in Ramadi, Iraq

The search for deeply buried items is a task assigned to MDDs, either through systematic investigation or during Quality Control (QC) searches in areas reduced through technical surveys. In Iraq, MDDs are integral assets within the NPA's program, capable of detecting standard ammunition, various types of improvised explosive devices (IEDs), and improvised landmines. Notably, MDDs are specially trained to detect crush wire—a particularly challenging task given the specific conditions encountered in Iraq.

CMR Survey– Cambodia

Photo 4. Short leash search pattern in CMR context

Cluster munition remnants (CMRs) contamination in Cambodia and Southeast Asia is a lingering consequence of the Vietnam War. However, the type of cluster munitions used during this period does not present a direct hazard to personnel traversing cluster-contaminated areas. Consequently, manual searchers often operate without personal protective equipment, simplifying operational deployment considerably compared to scenarios in areas contaminated by landmines. Deploying explosive detection dogs (EDDs)[4]

4 The official term used in Cambodia for all detection dogs deployed in CMR survey or battle area clearance is 'Explosive Detection Dog' (EDD).

for cluster munition survey in this context does not necessitate prior arrangements such as clearance and the establishment of access lanes. All EDDs operate on a short leash according to the revised standard operating procedure, conducting searches in both directions with the handler maintaining control on either side. This approach enables the handler to make real-time corrections during the search and allows the EDD to deviate in either direction if it detects the scent of explosives. Although this differs from the traditional short-leash procedure, it is technically sound and notably more efficient as the foregoing walking breaks between each searched lane is deemed unnecessary.

Operations in Northern Bosnia and Herzegovina

One of the most noteworthy examples showcasing the seamless integration of various demining assets is found in the northern regions of Bosnia and Herzegovina. Here, the NPA operates within dense, youthful forests and frequently flooded plains that become inaccessible for several months each year. While mechanical assets effectively clear vegetation, remnants of bushes and roots still pose obstacles that must be addressed before metal detectors can be employed. The introduction of MDDs has markedly expedited this process.

MDDs are strategically deployed to either confirm and clear mechanically prepared access lanes during targeted or to complement manual assets in systematic investigations. In the latter scenario, MDDs are dispatched from different directions or used interchangeably with manual deminers to search access lanes, providing them with the flexibility to concentrate on confirmed mine rows, areas with lower metal contamination, or regions with fewer vegetation remnants obstructing progress. This coordinated approach optimizes efficiency and ensures comprehensive coverage of demining efforts in challenging terrains.

Quality

Quality Management of MDD assets is a multifaceted endeavor, encompassing several critical aspects. At its core, monitoring comprises three primary dimensions: the dogs' work and detection performance, their overall health and fitness, and the efficacy of operational procedures along with the quality control of the surveyed land.

Ensuring optimal detection performance is achieved through a structured regimen of regular testing and maintenance training. This includes daily, monthly, and

Table 1. Area proceed by MDDs in 2021-2023

Area processed by MDDs in 2021-2023	Contamination context							
	Landmines (including improvised mines)				CMRs			
	2021	2022	2023	Annual growth	2021	2022	2023	Annual growth
	m^2			%	m^2			%
MDD 2-search	296,348	355,38	715,64	55,4%	8,16	18,607	-	-100,0%
MDD 1-search	327,121	547,114	453,899	17,8%	327,121	679,79	706,131	46,9%
Total	623,469	902,494	1.169.539	37,0%	335,281	698,397	706,131	45,1%
Share of MDD 2-search	47,5%	39,4%	61,2%		2,4%	2,7%	0,0%	

accreditation testing routines. Notably, training persists as an ongoing activity, irrespective of the operational status of the MDDs or any seasonal or annual breaks. Paramount to this process is the alignment of testing and training protocols with the specific operational contexts they will encounter. This necessitates consideration not only of the expected explosive items or target substances but also the terrain configuration, soil composition, vegetation density, and other environmental factors likely to be encountered during operational deployments.

Managing MDD testing to comprehensively cover these parameters can pose significant challenges, particularly in dynamic operational scenarios where returning to established testing fields may be impractical and time-consuming. Additional obstacles, such as security concerns and regulatory restrictions on handling explosives or acquiring testing materials, further complicate matters. In response, the development of alternative testing and training methodologies becomes imperative, ensuring their continued relevance to real-world operational contexts.

Regrettably, this critical aspect of quality management often receives inadequate attention from both mine action operators and national mine action authorities. Addressing these shortcomings demands heightened vigilance and proactive measures to uphold the integrity and effectiveness of MDD operations.

Operational efficiency

An analysis of MDD operational efficiency in all NPA programmes from 2021 to 2023 focused on three key parameters: dogs' search output and trends, monthly productivity changes, and cost-effectiveness. Over this period, the average annual growth in the area searched by dogs was 39.9%. The utilization of double search techniques increased from 31.8% in 2021 to 38% in 2023, particularly notable in landmine contamination scenarios, including improvised mines. Conversely, single search techniques predominated in CMR contexts. Overall, the area searched with dogs doubled across both contamination contexts.

Productivity growth over the three years averaged 6.6%, with dogs demonstrating varying efficiency across different contamination contexts: 2,500 - 4,500 m^2 in landmine contexts, 11,000 - 12,000 m^2 in CMR contexts, and 10,000 - 20,000 m^2 in improvised explosive device (IED) contexts. Operational management significantly influences productivity fluctuations, particularly concerning dog maintenance, operational planning, and resource integration.

Performance varied across different NPA programs. While NPA Angola[5] experienced a decline in productivity in 2023 due to health care and operational issues, stable productivity was observed in NPA Bosnia and Herzegovina, NPA Cambodia, and NPA Iraq, with improvements noted in the latter due to enhanced procedures and management. NPA Thailand's introduction of dogs into its operational toolkit was facilitated by NPA Cambodia, with operational planning improvements at a global level.

NPA MDD average monthly productivity	All contamination contexts			Contamination context
	2021	2022	2023	
	m^2/MDD			
Angola		4.542	2.530	Landmines
Bosnia and Herzegovina	2.767	3.191	3.193	Landmines
Cambodia	12.243	11.006	12.081	CMRs (85% of outputs)
Iraq	9.813	9.657	22.464	IED of landmine nature
Thailand		4.407	3.250	Landmines
Zimbabwe	6.902	4.954	3.953	Landmines
Average	8.745	5.720	9.934	
All figures are for the monthly productivity of MDD single search				

Table 2: Monthly productivity of NPA dogs in different contamination contexts

5 The MDD team in Angola was operational only for a short period and it was not subjected to concept examination. However, results from all NPA MDD programmes were considered for the analysis of operational efficiency.

Conversely, NPA Zimbabwe faced productivity challenges attributed to operational leadership weaknesses, though organizational changes in late 2023 aimed to address these issues.

Cost-effectiveness analysis compared the cost per square meter of single and double dog searches with manual clearance costs. Notably, double dog searches incurred approximately 20% higher costs than single searches. In landmine contamination contexts, the cost per square meter of single dog searches ranged from 16% to 74% of manual clearance costs, averaging 38%. In CMR contexts, the cost was approximately 60% of that in landmine contexts due to higher manual clearance productivity.

Costs related to detection dogs represented about 4.5% of NPA's global turnover in 2022, covering dog production, operational use, salaries, facilities, and medical support. In terms of operational contribution, MDDs processed 18.5% of the total area in landmine contamination contexts and 1% in CMR contexts in 2022, increasing to 24% in landmine contexts in 2023, indicating positive efficiency trends for NPA dogs.

Table 3: Ratio between the cost price of MDD single search and manual clearance for 2022

Index of the cost of MDD single search compared with the cost of manual clearance (MCl=1) in 2022	Landmines incl. IED	CMRs
Angola	0,48	
Bosnia and Herzegovina	0,16	1,64
Cambodia		3,73
Iraq	0,61	
Thailand	0,74	
Zimbabwe	0,53	
Average for NPA	0,38	2,78

Conclusions

The efficient utilization of dogs in NPA programmes relies heavily on their seamless integration into operational strategies. Lessons learned emphasize the heightened productivity achieved when combining dogs with manual teams for technical survey and clearance tasks. It's imperative for NPA programmes to determine the optimal ratio of deminers, dogs, and machinery, as this significantly impacts strategic outcomes, especially regarding equipment.

Operational management within NPA programs must possess the requisite competencies in planning and deploying detection dogs, considering them as vital assets for land release. Failure to do so risks inefficient, unsafe, and lower-quality utilization of dogs, leading to scepticism about their operational value, as observed in the past.

Despite challenges, positive trends indicate the potential for sustained dog detection capabilities within NPA programs. However, further efforts are necessary to expand the utilization of dogs across various contamination contexts in a cost-effective and qualitative manner, ensuring long-term operational capacity and effectiveness.

Photo credits: Giovanni Diffidenti, Search Mapossa, NPA Iraq, NPA Cambodia.

MINE ACTION AND ENVIRONMENTAL IMPACT

Lightwater Sensors - Environmental Monitoring for Explosives

Sagarika Mishra, Edward B Ogugu, Graham A Turnbull, Ross N Gillanders[1]

Abstract

Chemical contamination arising from the storage, manufacture, or deployment of explosives poses enduring toxicological threats to human life, livestock, wildlife, and ecosystems. Soil and water contamination resulting from these sources can often go untracked and remain unaddressed for extended periods. The Lightwater Sensors project aims to address this challenge via real-time detection using light-emitting polymer-based sensors. It makes use of an innovative portable sensor to detect explosives in air and water in-situ, transmitting data to a smart device immediately upon detection. This paper explores the origins of explosives contamination, its environmental impacts, highlights the urgency of environmental monitoring, and presents cutting-edge optical sensors for instantaneous detection of explosives like DNT in real water systems.

Introduction

The study of explosives detection has traditionally focused on homeland security and counter-terrorism efforts. However, in recent years, there has been a significant shift in global awareness towards the environmental impact of explosives. With increasing concerns about the presence of explosive residues in ecosystems, there is a pressing need for advanced detection technologies to monitor and mitigate their effects on various environmental elements such as rivers, water basins, treatment plants, and wastewater systems along security fronts. This growing demand underscores the necessity for sensors that are not only easy to use and cost-effective but also offer fast response times enabling real-time, in-situ analysis to effectively safeguard environmental quality and public health.

Understanding the urgency of this global concern over the proliferation of explosives and their detrimental impact on ecosystems continues to grow, and developing reliable and sensitive detection technologies is paramount. Lightwater Sensors, leveraging cutting-edge optical and sensing technologies, has emerged as a promising solution for real-time monitoring of explosives in air, water, and soil. This article explores various sources of explosives and their pathways into the environment, as well as their resulting impacts, and a novel method for environmental monitoring of explosives.

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Origins and sources of explosives contamination

Explosives are highly energetic materials, synthesized to meet the specific requirements of diverse civil and military applications [1]. These applications range from essential tasks like mining, rock blasting, and excavation to more complex undertakings such as tunnel and road construction, underwater excavation, and scientific research, apart from their pivotal roles in military operations, serving as propellants for rockets and missiles, among other uses.

However, the widespread use of explosives, whether in constructive, warfare, or terrorist activities, poses significant environmental challenges. The detonation of explosives releases contaminants into the surrounding air, water, and soil, contributing to pollution that persists over extended periods. This environmental contamination stems from various sources like munition factories, transportation routes, military sites, training facilities, ammunition testing areas, demilitarization activities, and even improvised explosive device (IED) production sites, sometimes makeshift areas like kitchens [2]. One particularly concerning aspect of explosive-related pollution is its impact on water systems. Chemical compounds from explosives can tightly bind with soil particles, leading to contamination that affects both surface water and groundwater. During periods of heavy rainfall or soil disturbance, these pollutants can leach into nearby water sources, exacerbating the environmental impact and posing risks to ecosystems and public health [3].

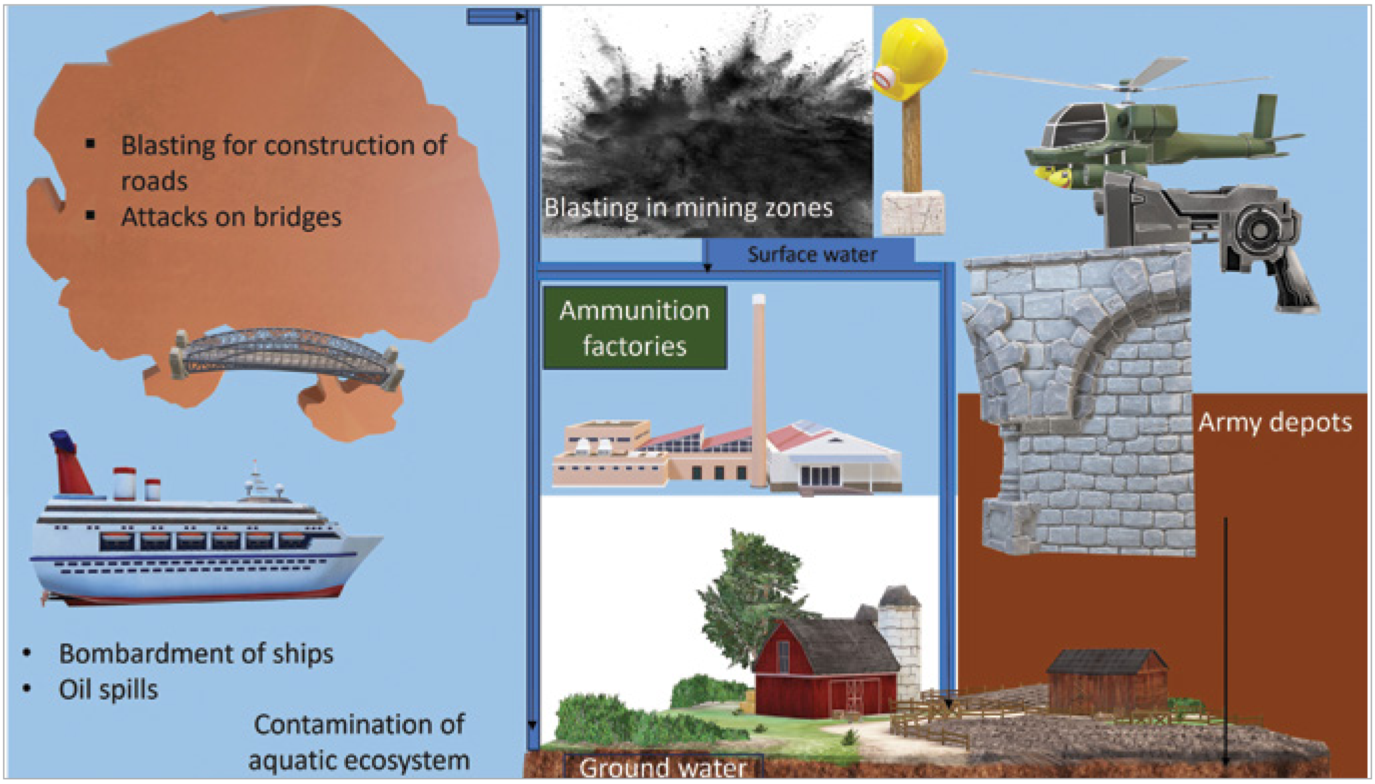

Figure 1 Various pathways of explosive contaminants into water bodies.

Environmental & Health Impacts

Commonly used military energetic compounds encompass explosives such as 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX). In addition, nitroglycerin (NG), nitroguanidine (NQ), nitrocellulose (NC), 2,4-dinitrotoluene (DNT), and various perchlorates find application in missile, rocket, and gun propellants[4, 5]. The toxicity levels of these chemicals vary depending on the species they affect. The chemical characteristics of the soil also play a deterministic role on the effects of a particular explosive on its flora and fauna.

The toxicity concerns of TNT start from its manufacturing, wherein the step of purification generates red-coloured effluent which is highly toxic to the soil and water biota. TNT and its breakdown products have a negative impact on aquatic life. It adversely affects plant growth, germination, and biomass. TNT is linked to liver dysfunction and anaemia in humans. RDX is known to cause teratogenicity, stunted shoots, roots and leaves in plants and convulsions in mammals. Studies have shown acute toxicity effects of TNT on earthworm *Eisenia andrei* and found that TNT resulted in a decrease in fertility rate and biomass production [6]. The USEPA has set lifetime exposure drinking water health advisory limits for TNT, RDX, and HMX at 2.0, 2.0, and 400 μg/L, respectively.

In Europe and the United States, occupational exposure of explosives has been reported to be a cause of vomiting, unconsciousness, convulsions, and vertigo in factory workers.

Africa, Eastern Europe, Australia, and the Middle East are facing substantial environmental challenges due to explosive contamination. In the current Ukraine-Russia war, destruction of bridges to inhibit the opponent army forces continuously releases contaminants through debris into rivers and disturb the aquatic eco-systems [7]. Therefore, addressing the environmental consequences of explosive usage requires comprehensive strategies to identify and mitigate contamination. The initial scientific intervention mandates effective environmental monitoring using sensing tools. This is vital for assessing baseline contaminant levels, understanding contaminant movement and distribution, and evaluating the effectiveness of remediation systems.

Needs for modern detection technology & Lightwater Sensors

Various techniques employed for detecting explosives include mass spectrometry, ion mobility spectrometry, gas chromatography, surface-enhanced Raman scattering, infrared spectrometry, fluorescence spectrometry, colorimetric assay, electrochemical assay, and electrophoresis. While each method offers advantages, most instruments are costly, bulky, and require extensive handling time. The pursuit of user-friendly detection methods with minimal training, low cost, and low sample consumption is ongoing. Chemical sensors, particularly simple visual or optical sensors, represent a promising avenue. Biological or bio-mimetic recognition components like antibodies, aptamers, polymers, and biosensors are being explored to render specificity to sensors. Alternative methods such as employing sniffing dogs and bees also show promise in this field [8]. However, these methods are cost intensive as well as dependent on environmental factors such as weather, terrain, and distractions.

The Lightwater Sensors project was launched with a comprehensive understanding of various challenges. We have developed a portable torch-like optical sensing platform. The newly developed portable device boasts a groundbreaking detection method and holds promise for online deployment worldwide. It uses thin polymer-films for optical detection of analytes. These are fit into a torch-like head which pairs with a smart device and streams data for real-time monitoring. It can be used for spot-checking or be integrated with legacy infrastructure for long-term monitoring.

It can assist Humanitarian Mine Action (HMA) in mapping the landmines, and Explosive Remnants of War (ERW) contamination data in affected areas. This will fast-track the environmental remediation projects as well as reveal potential zones of threats which need to be dealt with care. They have been tested and show high level of confidence for screening of chemical contaminants like explosives, pharmaceuticals, and pesticides. This will also be aided in long-term and/or remote deployments by making use of 5G communications. Here, we discuss a use-case example where it was effectively used to detect DNT.

Detection of DNT

DNT is a primary component in the synthesis of TNT and used in various industries including the manufacturing of polyurethanes, dyes, plastics, and herbicides. It is frequently found in surface water, groundwater, and soil at sites linked to ammunition facilities or other industries which use it in their processes. The laboratory verification of the method was conducted under normal conditions. Using Wi-Fi, the platform was connected to a mobile phone and immersed in de-ionized water. A stock solution of DNT was prepared in acetonitrile and added to the water. Different concentrations of this solution were added gradually to the vessel. Throughout this process, the sensor head of the platform remained exposed to the increasing concentrations of DNT solution, and readings were continuously monitored on the mobile phone screen. These readings were then translated into a concentration versus counts plot to analyse the sensor's response to increasing concentrations of DNT, as shown in Figure 2. The plot indicates a quenching response in the presence of DNT.

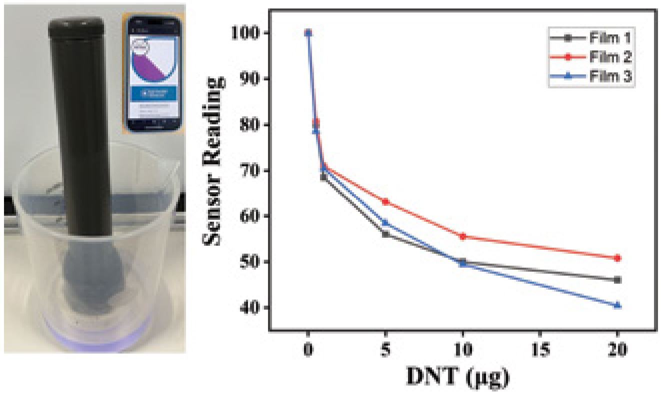

Figure 2: (Left) Sensor unit in water, real-time visualisation on smart phone (inset); (Right) sensor response to DNT.

Conclusion

In conclusion, the study of explosives detection has evolved from a focus on homeland security and counterterrorism to a broader consideration of their environmental impact. As the Lightwater Sensors project demonstrates, the development of reliable and sensitive detection technologies is paramount and offers a promising solution for real-time monitoring of explosives in air, water, and soil. By effectively detecting compounds like DNT, these sensors can aid in environmental remediation projects and reveal potential threat zones requiring careful attention. Moreover, their potential applications in humanitarian mine action and the detection of explosive remnants of war highlight their significance in addressing environmental and security challenges. Through continued innovation and deployment, these technologies hold the key to safeguarding our environment and communities from the detrimental effects of explosives contamination.

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Bringing into Focus the Relationship between Underwater Munitions and Their Environment

Nicole Nietzey[1] and Colin King[2]

Introduction

Starting in 2022, the Center for International Stabilization and Recovery (CISR) at James Madison University (JMU) partnered with explosives experts from Fenix Insight Ltd. to observe and characterize the visual and structural changes that occur to munitions as a result of aging in an underwater environment. JMU faculty with scientific backgrounds in chemistry, physics, geology, biology, and environmental and materials sciences lent their expertise to the project in the form of a research advisory board to help the team better understand the scientific explanations behind the physical and chemical effects being observed, as well as their potential implications. The U.S. Department of Defense's Strategic Environmental Research and Development Program (SERDP) is funding this work and thus it is focused on the implications for cleanup of U.S. military testing and training facilities, but its findings can also inform the work of the humanitarian sector involved in explosives remediation[3].

The team consolidated and reviewed existing data on the aging of land-based ammunition to make logical predictions for their application to underwater munitions. Patterns of deterioration in casing materials, mechanisms, and explosive compositions were investigated to make educated predictions for future comparisons. The team also relied on its own prior work studying the effects of time and environment on land-based munitions.[4] Some of those previous studies involved the complete disassembly and analysis of live ammunition,[5] along with preliminary studies and risk assessment.

The ability to visualize, examine, and test internal structures proved invaluable, with some of the observed effects being undoubtedly transferrable to the underwater environment. Thus, imagery and data from those studies have informed this investigation.

The Nature of the Problem

This study predominantly focuses on ammunition used during testing or training that has failed to function as designed, which is categorized as unexploded explosive ordnance (UXO). Alternatively, other explosive ordnance (EO), whether derived from stockpiles, sunken cargo vessels, or historic disposal programs like sea dumping, are classified as abandoned explosive ordnance (AXO). UXO and AXO exhibit critical differences in their conditions and associated risks. UXO, typically being fully fuzed, frequently armed, and often subjected to impact, contains a high level of uncertainty due to the generally unknown reasons for its failure and the type and degree of damage sustained. In contrast, AXO, mostly being unfuzed, unarmed, and not subjected to impact, has the greatest level of uncertainty related to the effects of aging on casings and main fillings, rather than delicate mechanisms and sensitive explosives.

Ammunition failure can result from numerous factors, but even well-manufactured, tried and tested designs can have surprisingly high dud rates, even more so where they impact water. This has resulted in vast quantities of UXO being scattered across current and former ranges and test areas, with a substantial proportion being underwater. Much of the ammunition has been immersed for years, subject not only to the effects of water, but also to a variety of other influences present in the underwater environment. The condition of this ammunition, already uncertain due to the unknown reasons for its failure during deployment, is further complicated by the effects of aging.

Additionally, ammunition comes in all shapes and sizes, incorporating a wide variety of inert and energetic materials, many of which respond differently to the vari-

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3 The full report is expected to be published in the first half of 2024 and will be available on the CISR website at https://www.jmu.edu/cisr/programs/aging.shtml.

4 See for example: *Scoping Study of the Effects of Aging on Landmines*; *Study of the Effects of Aging on Landmines*; *Guide to the Ageing of Explosive Ordnance in the Environment*

5 A process known as "exploitation".

ous influences in the underwater environment. Together, these represent a vast number of permutations within a subject where there has been very little research. While this project seeks to understand as many of these factors as possible, it would be unrealistic to expect to explore every issue or to reach definitive conclusions. Instead, the work aims to provide a foundation of knowledge in the area of ammunition aging underwater, identify key issues, and suggest more focused follow-on work.

For decades, various types of ammunition (from small-scale devices like cannon projectiles and grenades to large-scale ordnances such as missiles and bombs), have been developed, tested and deployed within and around U.S. territories. Not only does this inventory incorporate a multitude of ex-plosive types and construction materials, but it also features a wide array of fuzing types, each with varying levels of complexity, which sets the stage for our study of the interaction between diverse aging munitions and underwater environments.

Predisposition to Aging

Before examining the influences involved in deterioration and their effect on ammunition components, it is important to consider the factors that may either promote or inhibit the aging process. The combination of these "predisposition influences" explains why similar types of ammunition, in comparable environments, can exhibit varied behaviors during aging. These influences include inherent characteristics, such as:

- **Materials.** The properties of the materials themselves, and how they are combined.
- **Design.** Features of the components or assemblies and production quality.

Additional influences are present before a munition's prolonged exposure to the underwater environments, such as:

- **Pre-deployment.** The time and conditions under which the ordnance has been stored, including any maintenance it has received.
- **Deployment.** The manner in which it was deployed, including damage sustained before or during impact.

Factors Involved in Aging

Many factors can influence how munition deteriorates over time, affecting external casings, internal components, and energetic materials in different ways and at varied rates. For example, water may have virtually no long-term effect on a plastic but instantly neutralize a partially soluble explosive mixture, such as black powder (gunpowder). For most munitions, the predominant factors leading to deterioration are the basic environmental elements, such as water and oxygen, though these may be augmented by a wide variety of other natural and human influences. Figure 1 illustrates the relationships among common aging influences, though it is by no means comprehensive.

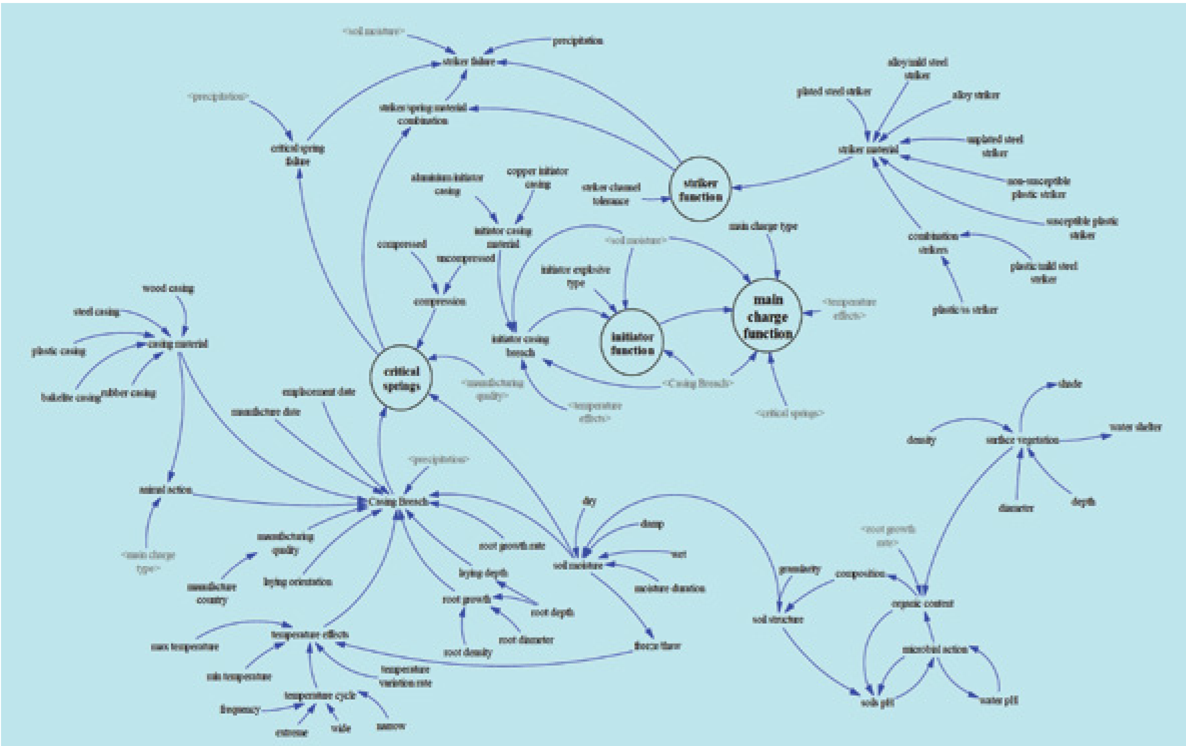

Figure 1: A representation of the relationships between some of the typical influences involved in the aging of simple munitions. In reality, there are often many more influences and relationships, creating a huge number of permutations[i]

Factors explored in the study, that are already well-documented include the influences of water, rusting, soil, mobility, and sunlight. A notable phenomenon unique to the underwater environment is that of concretion on munitions (i.e., the buildup of marine encrustation on items submerged for long periods). This buildup can significantly alter the ordnance's appearance, which hinders visual detection and recognition, and may also degrade the performance of sensor-based detection technology trained to look for particular signatures. Additionally, it may provide a layer of insulation from the surrounding environment that – counterintuitively, based on the munition's appearance – could actually slow any aging effects (see Figure 2).

Figure 2: (Upper photo) A munition experiencing the effects of concretion before cleaning. (Down) The same munition after cleaning

Changes Due to Aging

The effects of aging mean that all ammunition will eventually cease to function, typically beginning with the failure of the initiation mechanism as designed and culminating with all energetic material being lost or becoming inert. However, the time scale may be protracted and unpredictable, and the degradation process may involve several phases.

Even when the intended method of initiation fails (in UXO) or is absent (in AXO), the likely presence of the main charge means it cannot be considered "safe." Aging-related changes can potentially increase the munition's volatility and danger, either by sensitizing the existing fuze system or creating unforeseen initiation methods. This is an area of great uncertainty and therefore, by definition,[6] an area of great risk.

Changes due to aging, which compromise the ability of the ammunition to function as designed, can affect one or more of the following ammunition sub-assemblies:

- Warhead casing
- Fuzing mechanism
- Explosive train

UXO may include all three of these assemblies, while AXO often lacks the fuzing system and usually has an incomplete explosive train. Other inert components, such as fins, are generally not important. In UXO, rocket motors are likely to be expended and inert, while relatively few AXO items are likely to incorporate rocket motors.

Creation of New Hazards

Various new hazards can develop as munitions age underwater; many are the same as those on land, but some are unique to the subsurface conditions. For example, although corrosion will occur due to contact with water in both environments, underwater munitions at depth will experience hydrostatic pressure that surface and shallow subsurface munitions on land will not, potentially affecting the external casing, internal components and explosive fillings. These new hazards can be categorized as follows:

- **Physical hazards** include failure of casings, components, and other safety-critical elements.
- **Chemical hazards** relate primarily to either the energetic compositions or degradation of batteries.
- **Environmental hazards** primarily involve the leakage of energetic materials, with a smaller concern of leaking corrosion products.

An additional consideration is the potential hazards created when munitions are intentionally brought to the surface, or unintentionally wash ashore.

6 ISO 45001 defines "risk" as "an effect of uncertainty."

Conclusions

This study has reached the following key conclusions:

- **Limited information.** Relatively little is known about the effects of aging on munitions spending prolonged periods underwater, largely due to policies of either leaving these munitions undisturbed in place or destroying in situ.
- **Predictability.** The many influences in the underwater environment, with their potential interactions creating a vast number of permutations, make it extremely difficult to predict effects and outcomes with any accuracy.
- **Problematic research.** One reason so little information exists is that practical research in this area is considered hazardous. This perception is probably accurate but, ironically, is a self-reinforcing barrier to gaining greater clarity.
- **AXO and UXO.** AXO is usually unfuzed, unarmed, and undamaged when it is abandoned. It therefore involves far less uncertainty than UXO, which is often armed, damaged, and may have been subjected to extreme forces during deployment and impact.
- **Trend toward failure.** Munitions inevitably progress from fully functional to being incapable of functioning as designed, starting with the failure of one or more key components until they eventually become fully inert.
- **Non-functional does not equal safe.** The fact that a munition may be incapable of functioning as designed does not necessarily make it "safe". So long as explosive material is present, it continues to retain some potential risk.
- **External impetus.** In most cases, the net effect of fuze failure is to increase the energy threshold for initiation. While this threshold may no longer be available from, or exceeded by, the fuzing system, it could be provided by an external source, such as violent impact or intense heat.
- **Unintended mechanisms.** Deterioration can lead to unintended initiation mechanisms through chemical reactions, physical changes, or both, temporarily increasing the risk of accidental or spontaneous detonation.
- **Climate change.** Changing environmental factors, such as the acidification of seawater, increased water temperature, and increases in storm intensity, may become significant. In particular, the chances of ammunition suddenly becoming exposed to air appear to be increasing.
- **Exposure to air.** When ammunition is washed up on land or otherwise exposed to air, the substantial change of environment could exacerbate the creation of unintended mechanisms. This includes the possible reversal of effects that had resulted in non-functionality.

Other Considerations

The report focuses mainly on the risk of accidental initiation, as people or equipment interact with submerged munitions during activities like clearance, construction, and leisure pursuits. Yet other risks, such as environmental contamination, clearly co-exist.

Aging effects on munitions' appearance and physical characteristics of munitions may have important implications for visual recognition, as well as for emerging detection and identification technologies. In many cases, the deterioration of ammunition will degrade these capabilities and hamper clearance efforts. A better understanding of aging effects is therefore important to the preliminary stages of ordnance location, as well as its eventual disposal.

Recommendations

This report has confirmed that there is relatively little awareness or understanding surrounding the effects of aging on ammunition underwater. This can be addressed by focusing greater attention on the subject, which can be done through communication of these issues to key stakeholders (such as funders, clearance operators, affected populations, researchers, and equipment developers), as well as their coordination and cooperation on these issues; systematic collection of further data by those encountering underwater ordnance; investigation of accidents and incidents involving underwater munitions; and further targeted research, including detection trials using aging inert ammunition. Particular knowledge gaps recommended for further exploration include developing predictive models for the effects of water on primary explosives, an examination of the effects of prolonged submersion on fuze mechanisms, and prediction of ordnance aging underwater for different ammunition types based on existing knowledge and data on corrosion, concretion, and other underwater aging effects.

i C King, "The Effects of Ageing on Colombian 'Shoe Polish' Mines" Fenix Insight (2020): 11. https://commons.lib.jmu.edu/cisr-globalcwd/1564/.

Green-label Armenian Programme of "Nannasystem" Socio-economic Impact Analysis

Karine Shamiryan[1]

The "Center for Humanitarian Demining and Expertise" State Non-Commercial Organization (CHDE SNCO) was established by the Government of the Republic of Armenia in 2011 and it is functioning as the National Mine Action Authority since 2014.

Mine Action problem in Armenia arose as a result of conflict over Nagorno Karabakh. According to non-technical surveys, there are 4 regions in Armenia contaminated with mines/explosive ordnances. The total amount of contaminated areas is currently 42 165 966m^2.

To define the priorities correctly and to support international structures and national donor organizations in implementation of programs in mine impacted regions of Armenia, the CHDE developed a new project called "Green-label – Armenian programme of "nannasystem". In the framework of the programme, during the first stage the CHDE gathers information from both international and local organizations (UN Development Programme, UN World Food Programme, UNICEF, ICRC, local self governing authorities, population, state bodies, NGOs etc.) about the planned projects to be carried out in mine affected communities as well as the lands prioritized by the community and analyze them. During the second stage, in the planning process, the following is implemented in parallel with professional humanitarian mine action evaluation:

- Assessment of mine contamination impact on socio-economic development of the communities,
- Defining clearance priorities based on the assessments as a result of analysis
- Planning programmes aimed at socio-economic development of affected communities
- Effective introduction of joint humanitarian efforts as a result of network cooperation
- Start of clearance operations in the prioritized area

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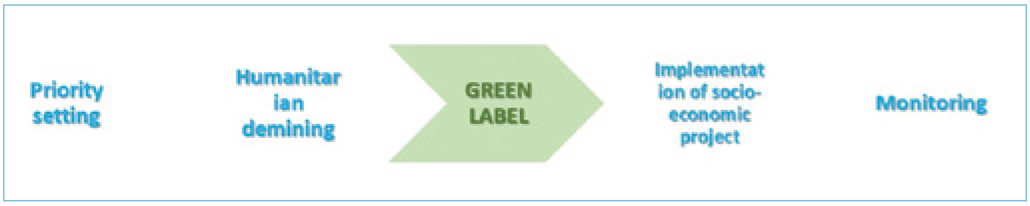
After defining the priorities, the CHDE implements its main functions i.e. non-technical and technical surveys, risk education, humanitarian demining. After the completion, the cleared areas are provided with **GREEN LABEL.** It is considered the announcement of the safe start of socio-economic projects. During the project implementation and after their completion, CHDE carries out their impact analysis from the perspective of humanitarian mine action safety, investments and savings. We aim at ensuring that clearance operations are not only carried out in a safe, effective and efficient manner, but also in a manner that leaved the environment in a state that is – at a minimum - similar to the one before demining operations commenced, as well as not leading to vulnerability and threats to the environment and livelihoods.

The sequence of the activities is below:



In 2023, in the frame of such programme, humanitarian demining operations were carried out in Vayots dzor region, Armenia. 214 192 m^2 area of agricultural and community significance were cleared from explosive remnants of war. UN World Food Programme started its socio-economic programme in already cleared area constructing a reservoir.

It is worth mentioning that most part of CHDE activities (clearance operations, EORE etc.) in 2023 were carried out with the support of UNDP in Armenia funded by EU in the framework of the project "Strengthening National Mine Action Capacities in Armenia".

For the implementation of humanitarian mine action the following is prioritized:

- Supporting the prospective socio-economic programmes,
- Long-term impact of the programmes,
- Increasing access to sustainable livelihoods,
- Forming safe behavior of the population.

Thus, the results of network cooperation are the areas cleared from mines and EOs, where different development projects are carried out, safe behavior formed among the population, adoption of "not harming the environment" policy during the clearance operations, restored or newly established infrastructure, increased level of food security and general standard of population livelihood through the implementation of socio-economic programs in the bordering communities.

In 2024 CHDE expands the "Green Label" into a more comprehensive programme called "Greenning Mine Action" that includes the following aspects:

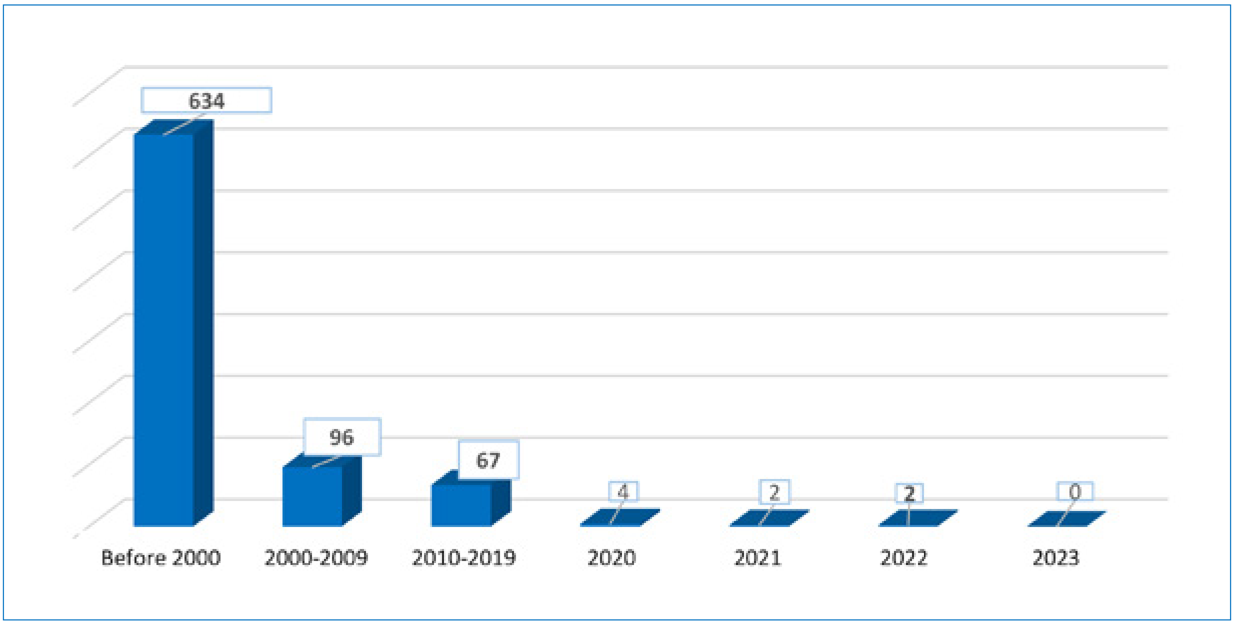
1. Introduction of EORE in school curriculum,
2. Organizing performances and puppet shows in the framework of EORE,
3. Cooperation with private sector, higher education institutions and diaspora,
4. Implementation of socio-economic projects,
5. Community liaison through SMSs,
6. Involvement of victims in EORE activities,
7. Introduction of Victim Information System (VIS).

As for the latter, Armenia adopts cross-sectoral approach to VA. We work jointly with agencies responsible for health, social affairs, education, labor, human rights and social protection. Thus, CHDE leads design of a new victim database system - digital solution with advanced tools for need-based support for victims diversified by gender and age, easy-to-use reporting and analytical system, user friendly interface and improved accessibility, shared platform with respective national and local agencies.

This database helps CHDE to improve data gathering and sharing, cooperation and coordination.

As of 2024, currently there are 805 victims in Armenia. Due to the coordinated work, last year there was no accident accordingly no mine victim in Armenia.

See the cart below:



We move forward with establishing an International Advisory Group to bring together a diverse group of representatives from national and international organization, UN agencies, GICHD, ICRC, etc., with interests and influence in the mine action sector, who can support the core team of CHDE with non-binding strategic advice, professional experience, knowledge and contacts not readily available elsewhere. The Advisory Group will add value by widening the networks of professional contacts and opportunities available to CHDE as well as by challenging our assumptions and serving as a "learning forum".

At the end of 2023 the CHDE organized "National Mine Action Coordination Platform" where it was decided to found a "Board of Priority Coordination for the Clearance of Areas Contaminated with Explosive Ordnances" that includes representatives from the Office of Human Rights Defender of RA, RA ministries, regions, UNDP, UN WFP, UNICEF, Delegation of European Union, Armenian Red Cross Society and CHDE holding managerial positions in the Board. Working groups were formed under the Board with the following directions:

- "Explosive ordnance risk education and risk awareness".
- "Coordination of victim assistance".
- "Socio-economic analysis and classification of priorities for the clearance of areas contaminated with explosive ordnances".

CHDE highly emphasizes the role of network cooperation that enables to have faster and easier information collection, correctly defined priorities, as well as obvious results. The complete overcoming of challenges and obstacles will allow to reform humanitarian mine action in Armenia and to coordinate close cooperation among stakeholders in mine safety sector in national and international levels through introduction of new management approaches. It will promote the safe movement of people and transportation means contributing trade development and sustainable economic growth, ensuring safe environment relevant to international standards.

NATIONAL ACHIEVEMENTS IN MINE ACTION

Investing in People, Organizations, and Institutions: A Holistic Approach for Supporting National Achievements in Mine Action

Kelly McAulay

Introduction

Mine action, a complex and challenging undertaking that demands unwavering commitment and strategic collaboration between national and international actors, plays a pivotal role in securing a safer future for conflict affected nations. As we bear witness to the remarkable strides in the management and advancement of national mine action responses, it becomes evident that fostering and sustaining progress requires a paradigm shift and a deeper understanding of the ubiquitous term 'capacity building'.

The United Nations Office for Project Services (UNOPS) Peace and Security Cluster (PSC) has nearly 30 years experience of delivering explosive hazard management projects in complex environments across more than 25 countries and territories, delivering over $252m of operations, annualy, on behalf of UNMAS and other partners. UNOPS has always understood that in order to sustain impact in any context, it is critical to invest in national structures and capabilities.

The process of mine action is inherently unique to each affected country, resulting in diverse national approaches and thus, approaches to support national achievements. Over the years, our understanding and approach to supporting national achievements has evolved. A foundational lesson from UNOPS experience is that capacity development cannot be a process that happens to someone, to a team or to an organization. Capacity development is a nuanced process that cannot be imposed by external actors onto national entities. Rather, the vision has to be generated, and driven by the national actors themselves. This intrinsic motivation is crucial for the acceptance, sustainability and effectiveness of capacity development initiatives, ensuring that they are tailored to the unique needs, priorities, and contexts of the nation in question. Further, there's no right or wrong model, no one size fits all, for this developmental journey, a combination of methods, resources, timeframes are required. What's critical is that the national entity has choice and voice in the design, delivery and monitoring of this process, which they have ownership of.

This paper explores some of the ways UNOPS has worked in partnership with national actors to support their efforts to eradicate explosive risk, emphasizing the necessity for support at three critical levels: individual skills building, organizational strengthening, and bolstering institutional maturity.

Individual skills building

It is imperative to recognize the importance of individual skills building. Front line workers deserve to have access to the latest knowledge on best practice, coupled with a sound understanding of and access to, equipment that best suits the task at hand.

In Sudan, mine actors faced challenges hiring adequately skilled female deminers. At the request of the National Mine Action Centre (NMAC) UNOPS delivered multiple training courses aimed at training women in Explosive Ordnance Disposal (EOD) and then supporting those women to enter the workforce where they were mentored.

In Mali, UNOPS conducted training for national trainers, enabling them to subsequently instruct their peers. The project collaborated with the Malian Armed Forces' *Direction du Génie militaire* (DGM)/national authorities to identify two individuals suitable for becoming trainers. Over the course of a year, these individuals shadowed the project's instructors, acquiring both theoretical knowledge and practical experience. By the end, they had gained the confidence to independently conduct lessons on diverse topics related to explosive disposal. This approach helped the Malian Defence and Security Force take ownership of their training and build their own capacity in a sustainable way.

In South Sudan, operational staff of the National Mine Action Authority (NMAA) underwent on-the-job training and received mentoring from the UNOPS Quality Assurance team. This initiative provided them with valuable exposure to a dynamic working environment, fostering numerous learning opportunities. They subsequently leveraged this experience upon returning to their national offices, catalyzing positive change within their respective roles.

In Afghanistan, UNOPS seconded gender specialists to embed full time into several National Non-Governmental Organisations (NGOs), resulting in sustained transformation of their internal policies and gender responsive operations, later leading to the appointment of gender focal points in these NGOs who are still today mainstreaming gender and diversity needs in planning and operations despite the changes in government.

Organizational strengthening

Organizational strengthening forms the second pillar of support, where national NGOs and other actors strengthen their capabilities to emerge as vital players in the mine action landscape, who will continue to act long after the international organizations have departed. UNOPS has tried different models of supporting national organizations to achieve their organizational strengthening needs.

Humaniceimos DH in Columbia

In Colombia, a multi-year, benchmarked workplan was developed between UNOPS and HUMANICEMOS DH, a national NGO led and staffed by former combatants, arose from the Peace Agreement between the Colombian Government and the Revolutionary Armed Forces of Colombia–People's Army (FARC-EP). The organizational strengthening process used a combination of targeted training, experts consultants embedded to accompany specific processes and staff secondments. This process supported a fledgling civil society organization to grow into a formidable clearance capacity, which is independently funded and delivering high quality clearance operations across the country, while supporting the reintegration processes of its members.

In Iraq, UNOPS funded developmental partnerships, where national NGOs and international NGOs worked together to exchange knowledge and approaches, resulting in benefits to both entities. In this model, INGOs were partnered with Iraqi national NNGOs to provide training, and transfer skills and experience for a period of three years. The process culminated in 2023 with the NNGOs fully accredited and funded through other sources to implement explosive ordnance (EO) clearance operations.

In Ukraine, following an extensive joint assessment conducted with the national police in late 2022 and early 2023 to identify their needs and priorities, UNOPS is working to augment the national police EOD capabilities including training in advanced EOD techniques in support of frontline operations. Also, in Ukraine, UNOPS, with UNDP, is supporting the State Emergency Service of Ukraine (SESU) efforts to build an improved information management system, through the provision of technical Information Management (IM) staff and equipment. This system will be used to enhance the Ukrainian Government's efforts to reduce suspected contaminated land through the use of artificial intelligence.

Pictures 1 and 2: EOD training for the National Police of Ukraine in Chernihiv /photo: UNOPS

In Mali, UNOPS collaborated with the DGM/national authorities to establish an operations coordination centre (Centre de Coordination des Opérations, CCO). The project approach involved providing equipment and training, furnishing the CCO with essential tools and educating staff in information management, analysis, and coordination. Additionally, ongoing support and guidance was provided by assigning a project advisor to work closely with CCO leadership, fostering trust and ensuring operational continuity through leadership changes. Resultantly, the CCO evolved into the central point for managing information and coordinating explosive device disposal efforts, contributing to improved decision-making capabilities for the military leadership and enhancing the CCO's capacity to manage specialized resources and personnel effectively.

In these examples plans were developed and national entities were supported to achieve maturity milestones set across multiple pillars, including, information management, finance, procurement and human resource systems, governance frameworks and resource mobilization. UNOPS has learned that working with national entities holistically and beyond the technical level, fosters resilience and sustainability.

Bolstering institutional maturity

The third level of support focuses on institutional strengthening at the governance level, when UNOPS has been invited to support national institutions to enhance their coordination and governance of mine action programs. Continuing from previous themes, integral to UNOPS approach is to listen to the vision, plan and needs of the institution and decide in partnership, how to support and where UNOPS can add value. Support packages are always bespoke.

In Somalia, filling a critical gap in provision of support to the Somali Explosive Management Authority over an 8-year period, providing training and mentoring and covering core staff salaries in the absence of sufficient national support.

In Burkina Faso, after supporting the NMAA to complete a capacity assessment, UNOPS facilitated the development of a highly innovative six-years National Counter-Improvised Explosive Devices (IED) Strategy, first in Africa and will provide a package of support to the roll out. With the support of technical experts, the IM capacity of the national authority has been strengthened and regional offices equipped with Information technology (IT) assets for more effective data collection and analysis of the IED threat with its subsequent victims.

In South Sudan, and several other countries, UNOPS teams co-locate with the NMAA to share information and skills, overtime, transferring responsibilities to the national counterparts, as in Afghanistan with the Afghan Directorate for Mine Action obtaining ownership in 2018, after progressive transition, when Directorate of Mine Action Coordination (DMAC) absorbed all Afghan technical mine action personnel previously employed by UNOPS.

In Togo, UNOPS is supporting the United Nations Office of Counter-Terrorism (UNOCT)'s plan to support the national C-IED center to mitigate the impact of IEDs. Following a series of consultations, UNOPS has deployed technical expertise in IED risk mitigation, Information Management and Explosive Ordnance Risk Education (EORE) to support the authoritie's development of a governance framework and operational plan.

UNOPS, committed to catalyzing positive change, by embracing a holistic perspective on mine action, to support national actors to lead the nation and contribute to the global effort to eliminate the risks posed by landmines and unexploded ordnance. Together, through individual empowerment, organizational resilience, and institutional maturity, we can forge a path towards a mine-free world, leaving a lasting legacy of peace and security for generations to come.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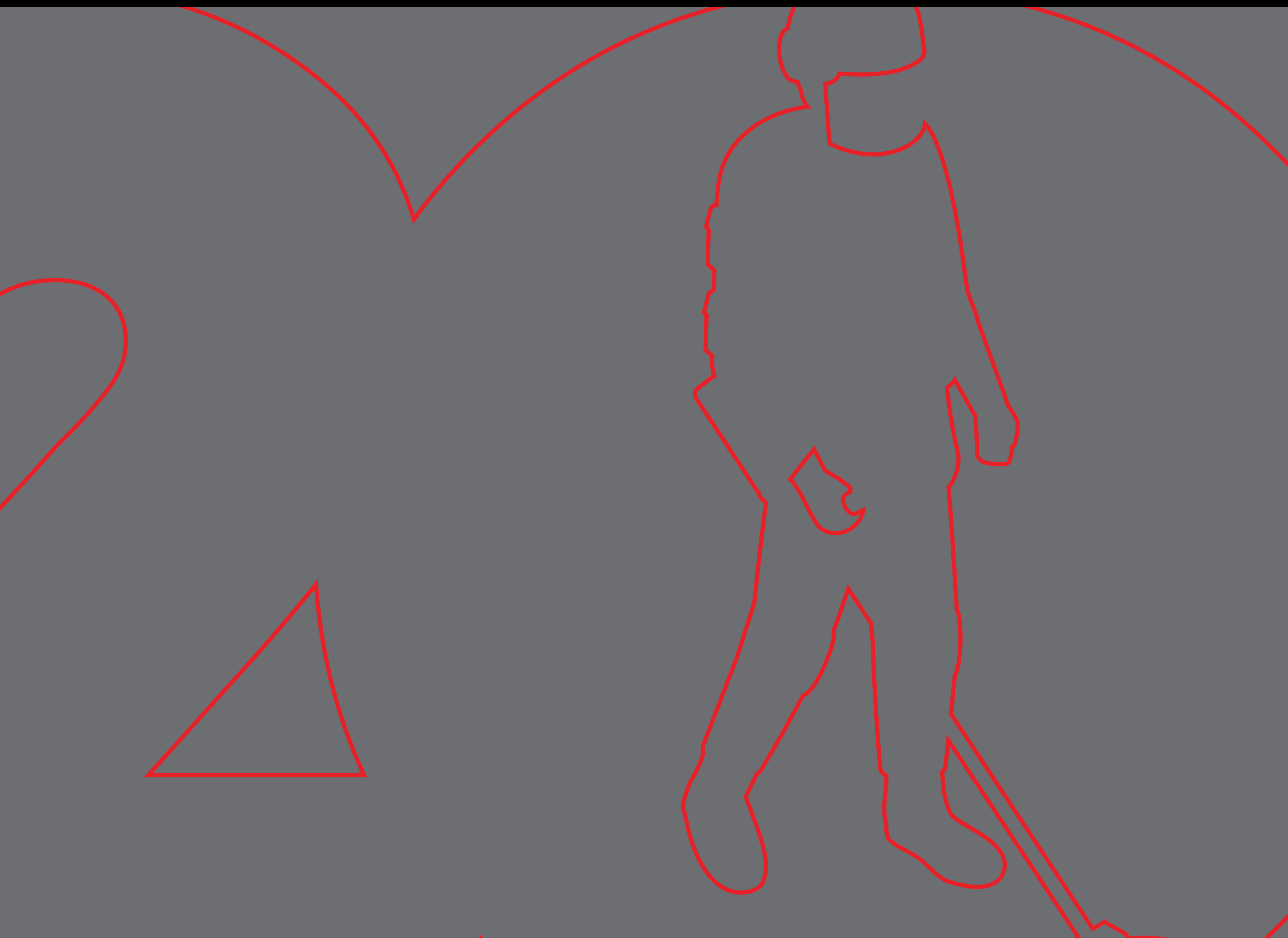

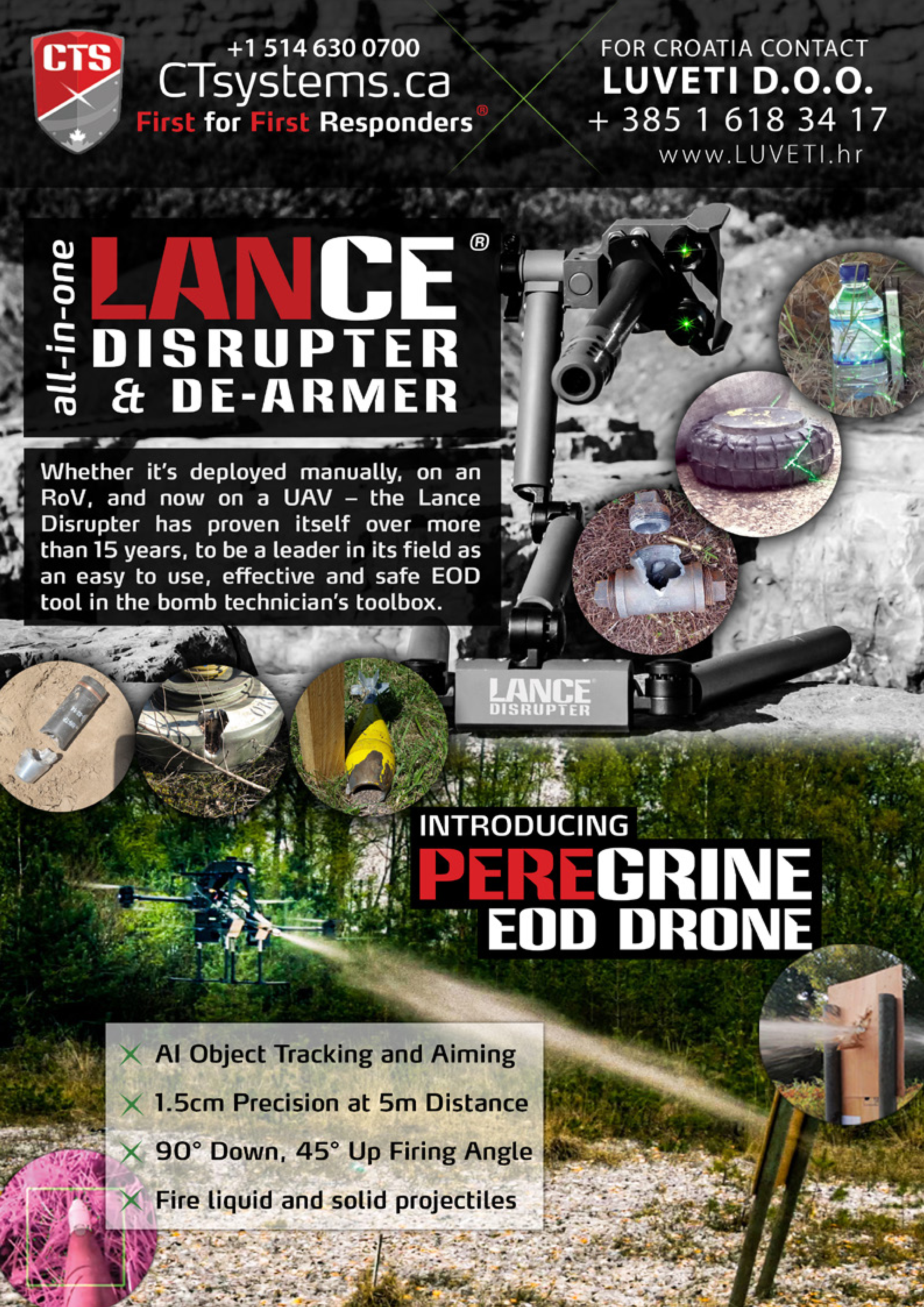
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