SPS SPARKS

NATO Science for Peace and Security Magazine

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Content

Welcome to SPARKS

The first magazine from NATO's Science for Peace and Security (SPS) Programme

A Word from the Editor...

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"SPARKS is the example on how scientific cooperation can promote stability, resilience, and peace."

This magazine is the spark of an idea from the SPS team to share and amplify the hundreds of remarkable stories of scientific cooperation between researchers from all over the world that the Programme supports and their impact on our shared security.

SPARKS is the example of how scientific cooperation can promote stability, resilience, and peace. With SPARKS, we aim to shine a light on these principles in action.

This magazine marks the beginning of a new journey for the Programme, aiming to bring scientists, researchers, students, policy makers and the wider public closer to NATO science diplomacy, and to showcase cutting-edge research activities supported by the SPS Programme.

Whether you are a researcher seeking collaboration, a policymaker exploring the interconnection between science and security, or simply someone who believes in the value of dialogue through knowledge, we hope you will find in these pages a spark—an idea, a project, a story—that speaks to you.

In this inaugural edition, we look at how SPS has contributed to demining over the years, supporting projects that have not only brought about significant scientific advancements in this area, but that have also been verified and applied in practice, contributing to the demining efforts and public safety in several countries facing this security challenge.

Introducing new approaches, developing new technologies, building up partnership networks and sharing of knowledge have been at the core of the SPS success stories that are featured in this magazine.

We hope these examples of clearing the path to sustainable peace will serve for inspiration and encouragement for further scientific excellence and collaboration, which the SPS Programme is standing ready to support.

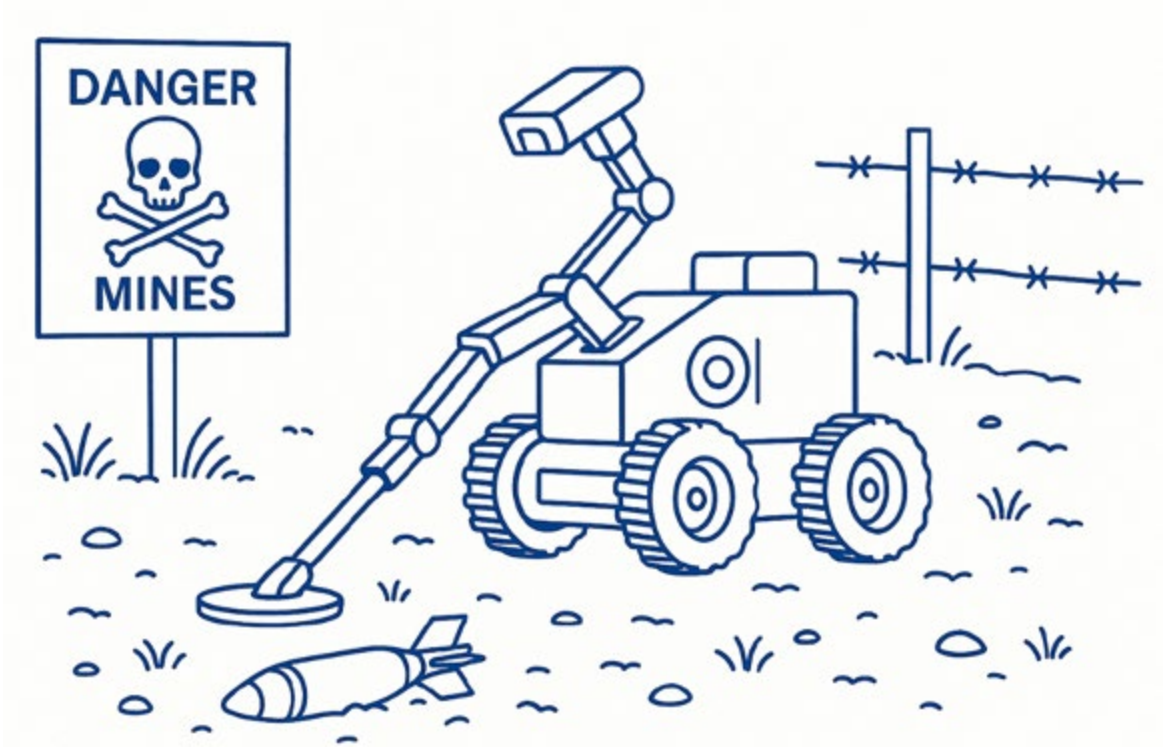
We, as the SPS Team, are proud to bring this magazine from concept to reality and as a platform to showcase the Programme's vital work in support of NATO's strategic objectives. We hope you enjoy reading this new magazine!

OPENING LETTER

The Invisible Battlefield:

The Crisis Hiding in Plain Sight

BY: EYÜP KUNTAY TURMUŞ



Mines, unexploded ordnance (UXO), improvised explosive devices (IEDs) and other explosive remnants of war (ERW) pose a direct threat to the security of the citizens of NATO members, NATO partner countries, and to regional development. Mines and UXO are a persistent global threat, particularly in war-torn countries. International cooperation is crucial to effectively address this challenge.

In modern times, IEDs have been the weapon of choice for terrorists around the world, and as such there is a growing need for methods to quickly and effectively detect explosives in both military and civilian environments. Explosive detection and removal are extremely challenging as devices become more sophisticated and deadly due to advancements in materials, shapes, sizes and varieties. The high cost and general inaccessibility of state-of-the-art explosives detection devices, high risk and inefficiency of classic demining activities, and a lack of information and education on detection and clearance in danger zones present considerable challenges to peace and security.

NATO 2030, the Alliance's agenda to be strong, ready, and united for the future, seeks to invest

in critical technologies and boost training and capacity building in NATO partner countries, particularly in areas that promote stability within their respective regions. Building upon NATO's Defence Against Terrorism Programme of Work, the Science for Peace and Security (SPS) Programme continues to support capabilities and technologies to address human, scientific and technological advancements in the field of Mine and UXO Detection and Clearance. Among others, SPS supports the development of new capabilities and technologies to tackle the significant threat posed by mines, UXO and IEDs, and has made it a key thematic priority. SPS seeks to manage the consequences of the proliferation of mines, UXO, and IEDs by cooperating with partners and international organizations to leverage the full potential of each stakeholder engaged in the global effort to manage explosive devices. In sum, the Programme funds projects, awareness-raising activities and the development of capabilities for long-term solutions.

What is the SPS Programme?

The SPS Programme is a well established NATO programme that is based on the three pillars of science, partnership and security. In the spirit of cooperative security, SPS provides concrete, practical

opportunities for cooperation for scientists and experts within NATO's wide network of partner countries based on security-related civil science, technology and innovation. All activities funded under the SPS Programme address one or more of the programme's key priorities, and have a link to security. According to these priorities, the Programme promotes cooperation, scientific research and innovation to address contemporary security challenges, enhance support for NATO-led operations and missions, increase awareness of security development including though early warning (e.g., Mine and UXO Detection and Clearance) and is open to any other cooperation clearly linked to the field of security.

The SPS Programme has been contributing to the core goals of the Alliance for six decades. The origins of the Programme date back to the 1950s, and its outlook has been successfully adapted to the changing security environment over the years. For 67 years, the SPS Programme, including in all its previous forms, has been fundamental to building bridges and fostering partnerships amongst NATO members and partner countries through tailored and targeted activities that promote capacity building and technological innovation through practical cooperation.

It speaks volumes that specialists from well over half of NATO's partner countries have been directors or co-directors of SPS funded activities under the priority of counter-terrorism. Many of these activities focused on explosives management in a variety of fields, including data analysis, developing new and advanced technologies; as well as training, preparation, dissemination and capacity building, to name a few. These tailored SPS activities often build links between technological research and development of new capabilities, and the human and social aspects of explosives management.

The Programme provides funding and expert advice for security-relevant activities in the form of workshops, training courses, or multi-year research projects, which foster practical cooperation by developing networks between academia, think tanks, civil society and government representatives. One of the specific objectives of the SPS Programme is to encourage applications that bring a lasting impact, and have a thematic and geographical perspective. To this end, applications that promote long-term research in hard sciences, as well as in social disciplines are encouraged. Social sciences applications may be in the form of long-term studies, case studies with practical applications, and field studies. By connecting scientists, experts, government representatives and civil society on key issues of security, the SPS Programme makes a significant, positive impact upon society, and achieves tangible and more immediate results.

About the Author

Eyup Kuntay Turmuş is the Head of the Science for Peace and Security Programme Section in the NATO Operations Division. His main responsibility is the development and management of research and capacity-building activities for practical cooperation with Allies and NATO's partners countries under the SPS Programme. These activities address key priorities including counter terrorism, explosives hazards management and defence against CBRN agents.

He joined NATO following a career in the defence sector involving academia, industry, and government where he took part in the management of major national and international armament programs. In this capacity, he managed major national and international armaments programmes, involving industry, universities and research organizations. Eyup holds a PhD in technology management. ■

SPS PROJECTS OVER THE YEARS

A brief history of completed and ongoing demining focused projects in the SPS Programme

G5208 'Ground Penetrating Radar Attached to a Hexacopter for Automatic Mine Detection'

Slovenia and the Republic of North Macedonia 2016-2019

A multi-year project led by experts from Slovenia and the Republic of North Macedonia to develop a low-cost ground penetrating radar and graphical user interface attached to a drone, which can detect landmines from the air.

G5423 'Portable Sensors for Unmanned Explosive Detection'

Italy and Azerbaijan 2018-2021

A multi-year project led by experts from Italy and Azerbaijan to prepare sensors for the detection of explosives, particularly nitroaromatic explosives like TNT, to be used in unmanned drones for the exploration of hazardous environments.

G6063 - 'Multisensor Drone Technique for Different Types of Mine Detection'

Türkiye and Ukraine 2023-Ongoing

This ongoing project will develop a multi-sensor detection system installed on a drone and use Magnetic Anomaly (MA) detection and broadband MultiSpectral ReFlectometry (MSRF) to detect landmines and different types of IEDs buried underground.

G5607 'Accelerating Mine Clearance by Introducing a User-Friendly and Cost-Effective Dual-Sensor Detector in Humanitarian Demining Operations'

The Netherlands and Japan 2020-2023

The Advanced Landmine Imaging System (ALIS) can visualize buried landmines for deminers to easily understand their shape, differentiating between mines and metal fragments. This project developed by the Netherlands and Japan has supported humanitarian demining efforts in Bosnia and Herzegovina.

G5711 'Virtual Evidence Capture Tool for Ordnance Recovery (VECTOR)'

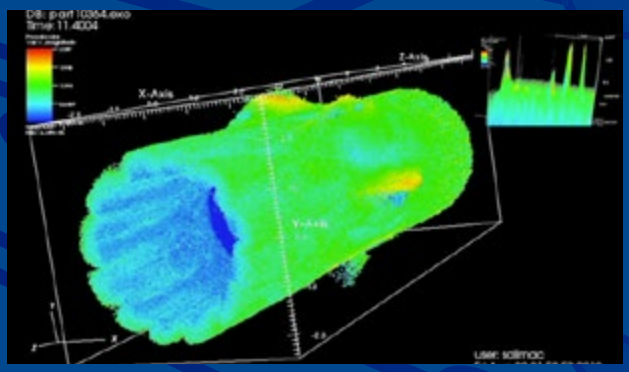
UK, Bosnia and Herzegovina, Greece, and the Republic of North Macedonia 2020-2022

This multi-year project developed by experts in the UK, Bosnia and Herzegovina, Greece, and the Republic of North Macedonia filled a critical gap in current EOD and Law Enforcement Agency operations by enabling detailed, remote analysis and communication between off-site experts and units on the ground. It provides smart solutions for the identification classification and assessment through a digital Command and Control platform.

G5195 - 'Advanced Microwave Sources'

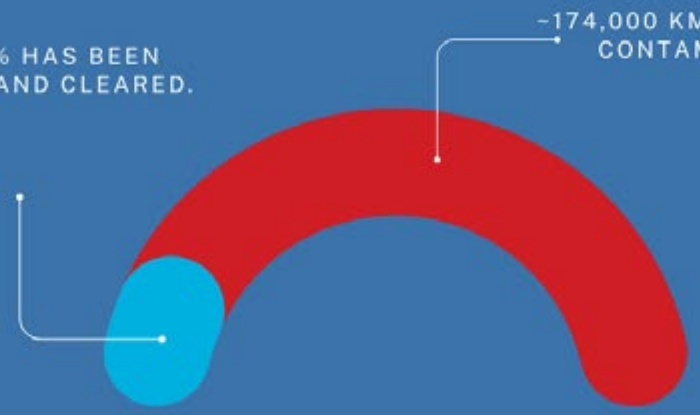
USA, Ukraine, Türkiye and Italy 2017-2021

The research from this project resulted in a high power microwave source that could generate electromagnetic energy, propagate this through space and deposit it on a mine or unexploded ordnance neutralising it by damaging electronic circuitry and other detonating mechanisms.



Clearing the Path to Safety

WHY THE FIGHT AGAINST LANDMINE, ERW, AND UXO CONTAMINATION IN UKRAINE IS IMPORTANT



IN 2023, UNMAS ESTIMATED ROUGHLY 174,000 KM² WERE CONTAMINATED WITH MINES IN UKRAINE.

AS OF JUNE 2025, ABOUT 35,000 KM² HAVE BEEN DECLARED SAFE.

UN MINE ACTION SERVICE (UNMAS), JUNE 2025

~25%

OF UKRAINE IS MINE CONTAMINATED LARGER THAN **2,500 FOOTBALL FIELDS!**

UNDP, SEPTEMBER 2024

Total recovery and reconstruction needs for explosive hazards management are estimated at US$27.6 billion for the 10-year period 2026–2035

WORLD BANK REPORT, 25 MARCH 2026

OVER 6 MILLION PEOPLE IN UKRAINE LIVE IN OR AROUND LANDMINE CONTAMINATED AREAS.

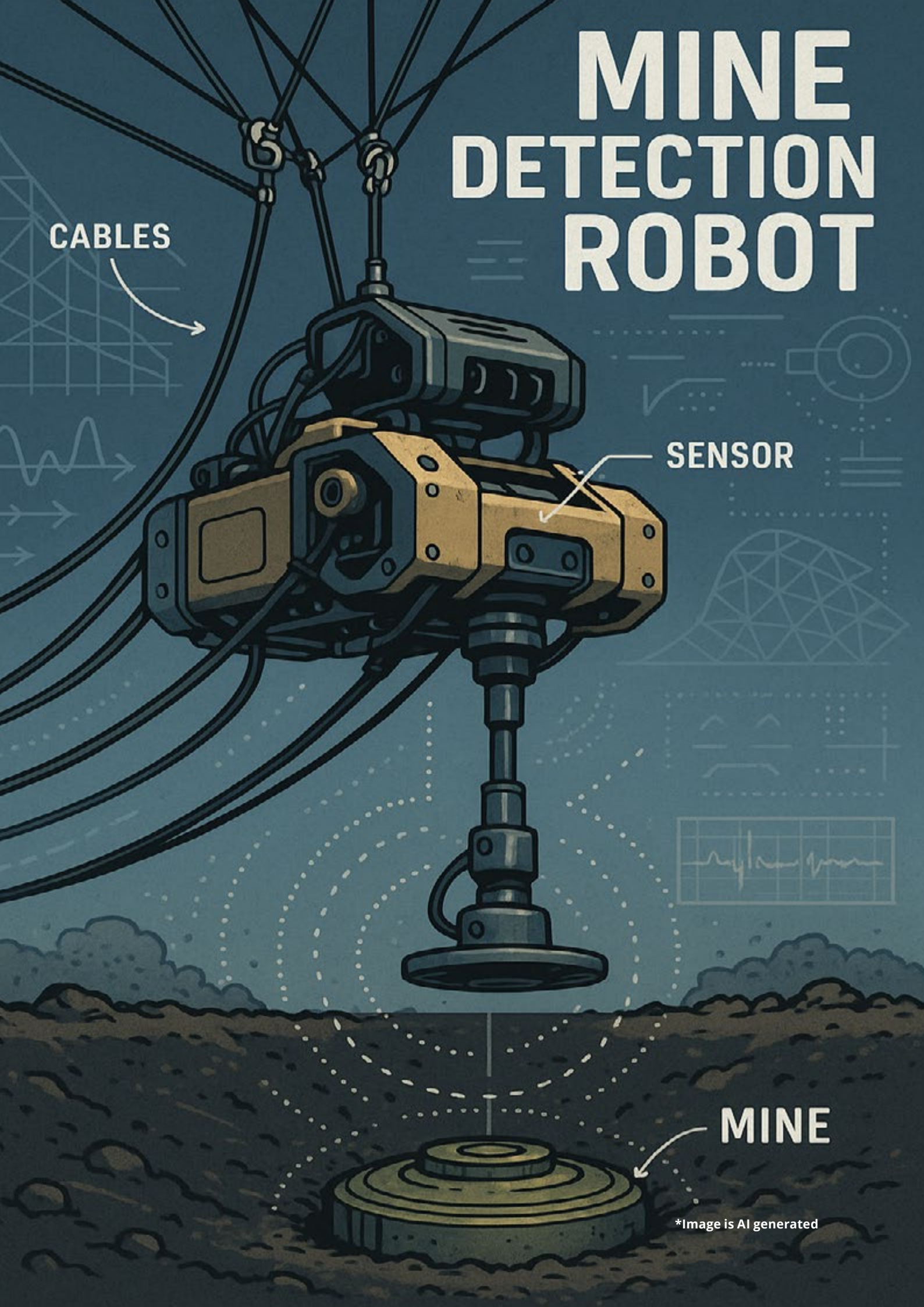
UNMAS, JUNE 2025

IN UKRAINE, AN ESTIMATED 9,000 ACCIDENTS RELATED TO LANDMINE, ERW AND UXO CONTAMINATION ARE EXPECTED TO OCCUR BY 2030.

WORLD BANK REPORT, FEBRUARY 2025

SINCE FEBRUARY 2022, EXPLOSIVE ORDNANCE DISPOSAL TEAMS FROM UKRAINE'S STATE EMERGENCY SERVICE HAVE DETECTED AND DISPOSED OF OVER 533,200 EXPLOSIVE ORDNANCE AS OF OCTOBER 2024.

WORLD BANK REPORT, FEBRUARY 2025

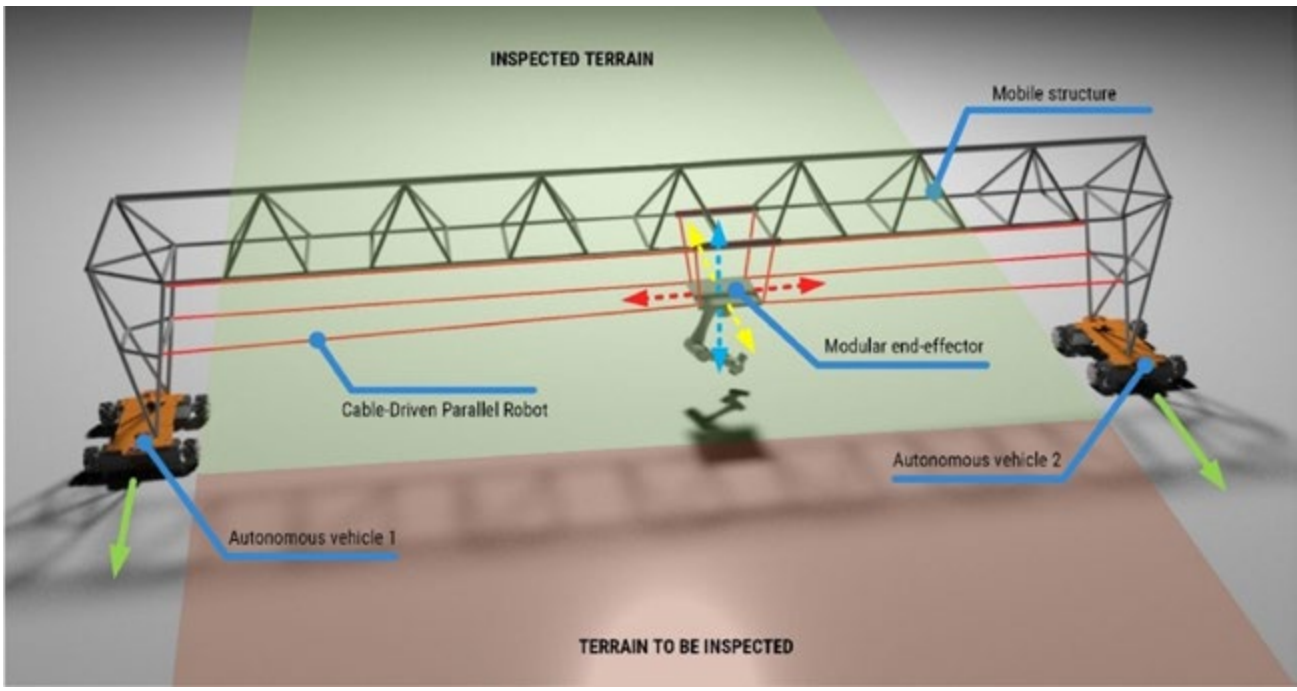

MINE DETECTION ROBOT
CABLES
SENSOR
MINE
*Image is AI generated

SPS PROJECT SPOTLIGHT

MUCADE:
Swinging Mine Detection

ARTICLE BY RESEARCHERS LEADING PROJECT G6001 “A MULTI-CABLE DRIVEN ROBOT FOR SAFE MINE DETECTION AND DETONATION”.

COLLABORATION BETWEEN SPAIN, COLOMBIA, ITALY, AND SLOVAKIA



Conceptual illustration of the MUCADE system showing the mobile cable-driven structure and end-effector.

Instead of sending people into minefields with metal detectors, MUCADE uses two mobile robots that position themselves at safe distances and stretch cables between them. A specialized scanning device travels along these cables, floating above the dangerous ground below. This system keeps humans completely out of harm’s way while the robot searches for buried explosives, destroys them safely, and learns to recognize new threats – turning one of the world’s most dangerous jobs into a remote operation.

Despite decades of international efforts, anti-personnel mines and UXO continue to pose lethal threats to civilians in post-conflict zones, particularly in regions like Colombia, the Western Balkans, and Ukraine. Mines hinder safe resettlement, agriculture, and development, transforming once fertile and vibrant areas into hazardous no-go zones.

An international consortium of researchers and engineers is advancing a novel robotic solution aimed at accelerating the detection and neutralization of landmines and unexploded ordnance (UXO) in conflict-affected regions. The NATO Science for Peace and Security (SPS) Programme project *Multi Cable-Driven Robot for Detecting/Detonating Unexploded Mines and Ordnance (MUCADE)* is developing an innovative cable-driven robotic system designed to sweep large areas with precision and safety.

A New Approach to a Persistent Threat

Even after the cessation of hostilities and the definition of peace agreements, landmines continue to represent a substantial threat to civilian populations and post-conflict recovery. High financial costs limited operational efficiency, and elevated risk to personnel typically characterize mine clearance operations. While humanitarian demining protocols have seen recent improvements and standardization, the underlying technologies have remained unchanged since the Second World War. The financial burden associated with demining is often comparable to the national budgets of some of the most severely affected countries. This is primarily due to the continued reliance on manual, frequently rudimentary methods, which involve basic tools for ground scanning. Such procedures are inherently slow and hazardous, with progress measured in square meters per day.

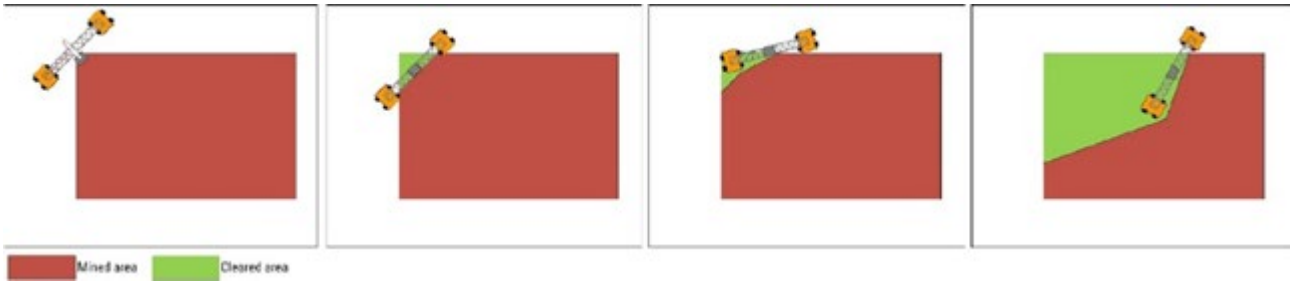
Traditional demining methods rely heavily on highly trained personnel, often working under dangerous and slow conditions. Although many innovative demining approaches have been explored—including deploying trained animals, drones and autonomous robotic systems—the number of practically effective and widely implemented solutions remains limited.

MUCADE introduces a paradigm shift using a **Multi-Cable Driven Parallel Robot (CDPR)** – a robotic platform suspended and moved via cables attached to mobile vehicles. This unique and novel configuration allows the robot's end-effector tool to operate safely above the ground, reducing the risk to human life.

The robot's end-effector is modular, integrating:

- **Detection tools** for identifying buried mines and UXO.
- **Controlled detonation systems** for safe neutralization.
- **Vision systems** for image capture and data logging.

These visual records are used to train an artificial intelligence system capable of recognizing threats through computer vision, enhancing the system's autonomy and reliability.



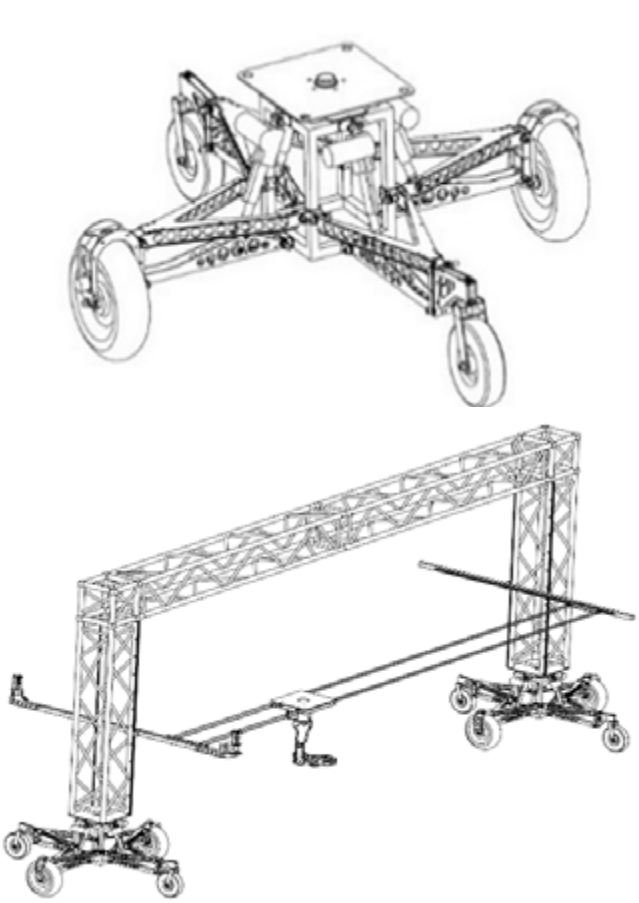
Manoeuvres strategy of the MUCADE system for clearing mined areas.

Since its launch in June 2023, the MUCADE team has successfully completed two technical milestones:

- **Milestone 1** focused on the analysis of mine/UXO types and detection/explosion technologies and defining system requirements.
- **Milestone 2** involved completing the design and building a full prototype, including mobile robots, cable systems, and software components.

The system comprises two mobile robots carrying a cable-driven structure that deploys the inspection tool. The structure is made from commercial parts, ensuring ease of integration and maintenance. Its onboard sensors support navigation, object detection, and geolocation.

The upcoming phase involves full system integration and experimental field tests, validating MUCADE's performance in real-world conditions. The project team is already exploring complementary applications



Design and prototype of the structure for the Cable-driven robot

for the system in areas such as in-situ 3D printing and precision agriculture.

MUCADE's ambition is to enhance humanitarian demining capabilities and promote peace, safety, and technological collaboration across NATO and NATO partner countries.

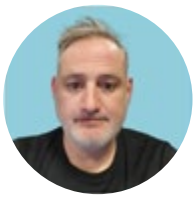
The project also emphasizes training and international mobility for young researchers, including joint PhD theses, postdoctoral stays, and undergraduate thesis work. ■

To follow the progress of the MUCADE project, visit: https://mucadeproject.com

Programming of the robot's manoeuvres for mine detection and extraction

MUCADE is the result of interdisciplinary cooperation between 5 NATO Ally academic institutions and one NATO partner country institution:

- **University of Castilla-La Mancha (Spain)** – Project coordinators and mechatronics experts are responsible for the final system design and prototyping the complete system for validation testing.
- **University of Ibagué (Colombia)** – Experts in the design of mechatronic systems, with extensive knowledge of anti-personnel mines. Their role in the project focuses on the design of the robot end-effector for mine detection and detonation using cable robots.
- **University of Cagliari (Italy)** – Experts in mechatronics contribute to the design of various robotic system components. In particular, they are responsible for mine detection and extraction using a robotic arm mounted on the robot's end-effector.
- **University of Cassino and Southern Lazio (Italy)** – Responsible for the conceptual design of the cable-driven robot, which enables the controlled movement of the various tools integrated into the robotic system.
- **University of Žilina (Slovakia)** – Experts in UXO and blast effects, they are in charge of defining the design specifications for the tools integrated into the robot and designing the field validation tests.
- **Polytechnic University of Valencia (Spain)** – Experts in mechatronics, they are responsible for the coordinated navigation of the mobile robots, in sync with the movement of the cable-driven robot and the system's end-effector for detection and detonation.



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DEFENCE CAPACITY BUILDING

SPS Support for Humanitarian Demining in Ukraine

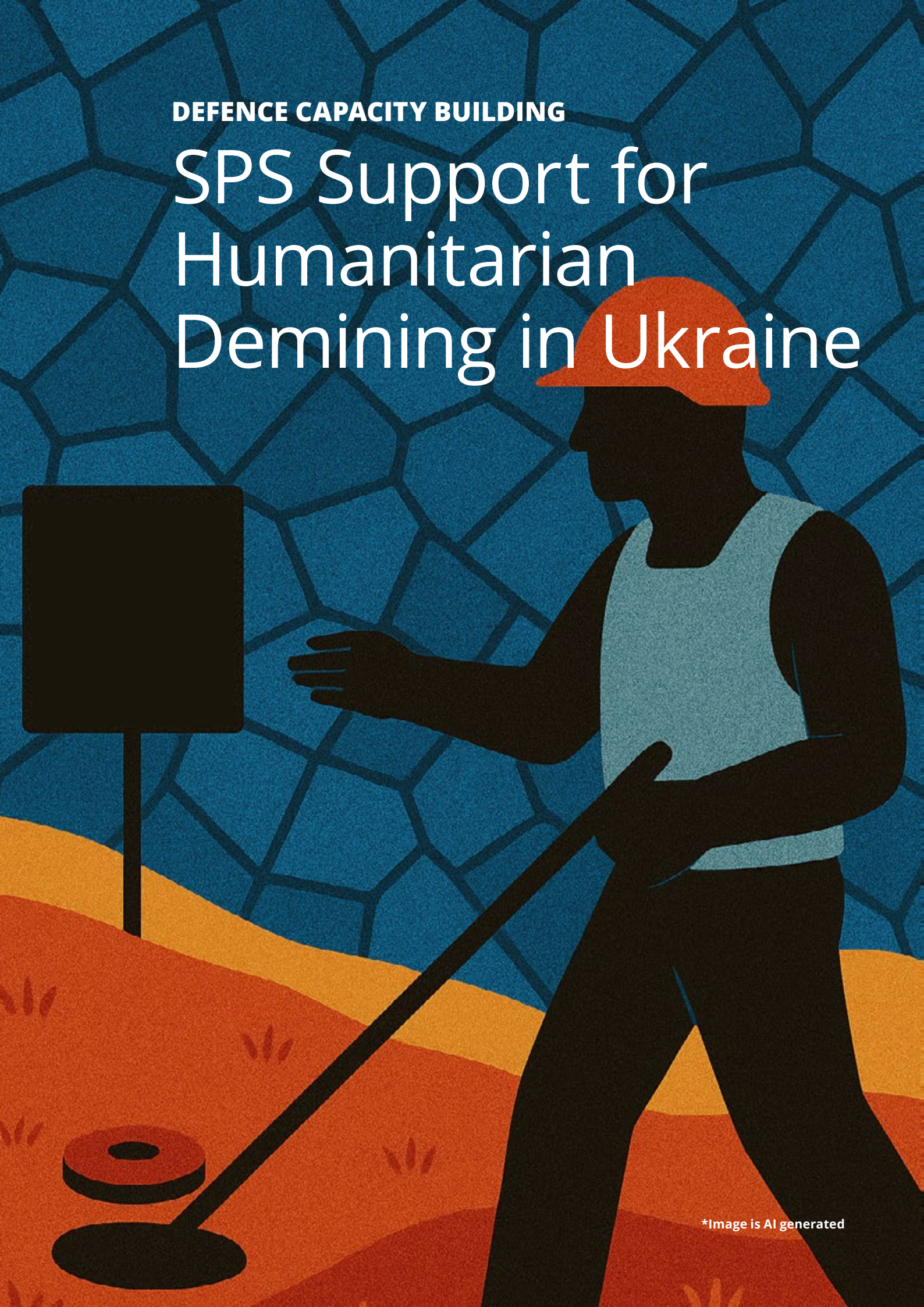


*Image is AI generated

Ukraine is arguably the most heavily landmine contaminated country in the world. The country, has seen widespread and almost indiscriminate use of both anti-personnel and anti-tank mines laid and randomly distributed along its eastern and southern borders. Compounding this challenge is unexploded ordnance resulting from the heavy use of artillery and mortars. These must all be detected and removed if the "breadbasket" of eastern Europe is ever to return to previous levels of agricultural productivity, let alone civilian habitation. Currently, the World Bank estimates $55 billion USD will be needed for reconstruction and recovery needs in the agriculture sector.

There are two types of demining processes needed: **immediate**, which permits the tactical use of ground by combatant forces and **longer-term** for the return of the land for safe use by the populace at large. The NATO Science for Peace and Security (SPS) Programme has been funding research projects aimed at addressing the longer-term challenge. A number of project proposals have been received, evaluated and funded to examine and develop the application of novel technologies that address this challenge. It is hoped that scientists and researchers from both Allies and NATO partner countries will continue to submit proposals for evaluation and eventual funding in this area.

The methods of laying mines have changed from the traditional hand and mechanical approaches to the use of drones, aircraft and artillery for dissemination. The use of sensitive anti-personnel mines greatly increases the danger not only for deminers, but also to any inhabitants of the affected areas. This has indeed developed into a very severe humanitarian crisis.

The mines used include anti-personnel mines. Booby traps and Russian landmines, designed to attack helicopters and low-flying aircraft, have also been detected. Booby traps remain a complicating factor, along with improvised explosive devices (IEDs) for demining initiatives.

Comprehensive Assistance Package (CAP) for Ukraine

The Comprehensive Assistance Package (CAP) for Ukraine has systematically integrated EOD and demining support as critical components of NATO's non-lethal military assistance. Since 2022, CAP initiatives have specifically targeted the enhancement of Ukraine's EOD capabilities through both immediate equipment provision and strategic capacity building programs. Analysis of NATO's assistance framework reveals that demining capabilities constitute a

principal line of effort within the recovery and reconstruction strategy, acknowledging the extensive contamination of Ukrainian territory with explosive remnants of war. This dual approach—addressing immediate EOD needs while simultaneously developing sustainable, on the ground demining infrastructure—reflects NATO's commitment to both short-term security stabilization and long-term reconstruction efforts in Ukraine.

Ukraine and SPS

Ukraine has also been a part of many SPS projects. The Ukrainian scientific community has demonstrated steady interest in the SPS Programme and between 2014-2025, with one in four SPS activities have involved Ukraine. These projects are especially imperative as the scale of contamination by ERWs and landmines in Ukraine is one of the largest since the Second World War. According to the World Bank Report, it is estimated that at least 135,503 km² of land and 14,000 km² of water are at risk of contamination and in need of survey as of December 2024.

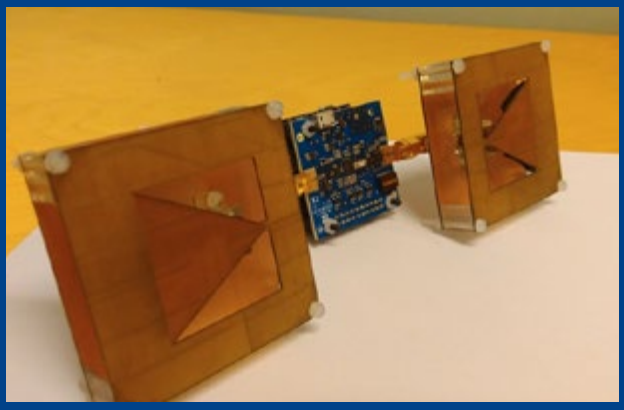
As noted, the NATO SPS Programme has already received, examined, and in some cases funded novel approaches to addressing the challenge of demining in NATO partner countries, and in particular, Ukraine. ■

SPS Demining Projects with Ukraine

G5217 - Development of Mine and IED Recognition System Based on Ultrawideband Technology

Norway and Ukraine 2016-2018

A multi-year project led by Norway in partnership with Ukraine that augmented the capabilities of existing mine-detection and recognition technology, making it smarter and able to "sniff" all existing types of mines, ERWs, and IEDs as well as see their shape in 3D.



G5014 - U-GO 1st Holographic and Impulse Subsurface Radar for Landmine and IED Detection

Italy, Ukraine and USA 2015-2018

Italian, Ukrainian, and US experts cooperated on a multi-year project to develop a multi-sensor system on a semi-autonomous vehicle for detection and disposal of explosive devices in order to reduce direct human-to-mine and animal-to-mine contact.

G5024 - Support to Humanitarian Demining in Ukraine

NATO and Ukraine 2015-2018

SPS provided the State Emergency Service of Ukraine ERW teams with modern technologies of detection and clearance and associated specialist training so that they can cope with the additional challenges brought about in a higher threat environment.

SPS PROJECT SPOTLIGHT

Seeing Through Soil:

Robots Mapping Buried Dangers in Ukraine

ARTICLE BY RESEARCHERS LEADING PROJECT G7563 “INNOVATIVE SENSOR INTEGRATION FOR REMOTE LANDMINE DETECTION “.

COLLABORATION BETWEEN ITALY, UKRAINE, THE USA, AND JORDAN.

After two successful phases of development, an international interdisciplinary team from Ukraine, Italy, and the USA has launched the third phase of an ambitious project to speed up humanitarian demining in Ukraine.

The problem with finding landmines is surprisingly similar to looking for a needle in a haystack, except the haystack is full of old bottle caps, shell casings, and scrap metal that all look suspicious to a metal detector. A continuation of two previous SPS projects, aims to tackle that challenge by using multiple detection technologies working as a team: ground-penetrating radar that can “see” plastic mines, metal detectors for traditional threats, and 3D imaging systems that can tell the difference between a dangerous explosive and harmless metal objects. By combining all these sensors on cooperating robots, the system dramatically reduces false alarms while catching nearly every real threat, making the whole process far more efficient and reliable.

NATO Science for Peace and Security (SPS) Programme project **G7563 “Innovative Sensor Integration for Remote Landmine Detection”** follows **G5014 “Holographic and Impulse Subsurface Radar for Landmine and IED Detection”** and its successor **G5731 “Multi-Sensor Cooperative Robots for Shallow-Buried Explosive Threat Detection”**.

A July 2024 report from Reuters indicates that Ukrainian investigators have documented up to 300 civilian deaths from mines planted by Russia. In 2024, Yuliia Svyrydenko, Ukrainian First Deputy Prime Minister of the Ministry of Economy has stated “Humanitarian demining is the zero stage of Ukraine’s recovery. At present, 156,000 square kilometers of land are potentially

Robot with cm-accuracy GPS (white) and 1TX-4Rcv impulse GPR (gold).

contaminated, and more than 6 million Ukrainians are at risk." According to the United Nations Human Rights Monitoring Mission (HRMMU), farmers are among those most at-risk, transforming an acute local threat into a chronic global threat of food insecurity. Ukraine is one of the most fertile places on Earth, holding as much as 30 percent of the world's most productive black soil (chernozem) reserves among its 100 million acres of agricultural land. The UN World Food Program (WFP) estimates that over 400 million people around the globe rely on Ukraine for their food supplies. In August of 2023, the State Emergency Services of Ukraine (SESU) estimated that clearing all of the mine-contaminated land at that time would take over 700 years. Now, the demining initiatives in the country are likely to change the speed, efficiency, and safety of clearing war zones in the aftermath of the conflict.

Demining is typically slow for two main reasons – first, it is exceedingly dangerous and thus must be done deliberately by highly trained and skilled personnel. And the second and bigger factor, is the presence in post-conflict zones of ubiquitous clutter; shrapnel, empty tins, vehicle and machine parts, shell casings, and other bits of metal. This can lead to the detection (and time-consuming careful exposure) of dozens to hundreds of bits of harmless pieces of rubbish for every dangerous mine found by a metal detector or magnetometer. What's more, in the last fifty years, many mines have been developed with plastic casings with minimal metal parts – making them difficult to find with a metal detector. The threat of tripwire-activated booby traps in minefields and other post-conflict also make the task of humanitarian demining even more difficult and dangerous. Serhii Reva, Director of the Mine Action Department at the State Emergency Service in Ukraine (SESU) recently said:

"We find 'explosive gifts' in the most unexpected places, from front doors to personal belongings, closets, beds, even beehives. The most dangerous are grenades on tripwires."

Safe and effective humanitarian demining includes the following elements:

1. A high level of detection for explosive threats (approaching 100% for protection of civilians).
2. A low rate of false alarms to reduce clearance delays.

Sapper with lost ammunition found during demining operations
(Photo: From project participants)

3. Protection of the demining personnel from mines and booby traps set to prevent demining or simply out of spite.

Elements 1 and 2 can be achieved by deploying multiple sensor types – a challenge that has driven this project's evolution across its three phases.

Phase 1 breakthroughs established that ground penetrating radars (GPRs) are capable of detecting buried non-metal objects with holographic subsurface radar (HSR) proving especially powerful for making 3-dimensional images of buried targets whose shape may determine whether it is a mine requiring removal or destruction, or simply harmless clutter that can be dealt with more easily.

Phase 2 innovations demonstrated that mounting these sensors on autonomous vehicles could greatly enhance deminer protection, satisfying Element 3. To keep the autonomous vehicles light, the sensors are mounted on separate, but cooperating four-wheel robots that share positioning and sensor data and are deployed sequentially. Both Phase 1 and 2 proved that swarms of cooperating robots could be built on the same platform with easily interchangeable sensors which ultimately simplifies repairs and allows for customization for specific tasks and environments. The current Phase 3 centers on perfecting fusion of data from different sensors (impulse GPR, HSR, metal detector, etc.). Early results have shown this integration could lower false alarm rates from hundreds per actual mine to less than ten.

Robot with holographic radar scanning system and shared GPS/ communications base station in background.

Screenshot showing PFM-1 "butterfly" scatter-able mine detected with 72.8% confidence by AI app.

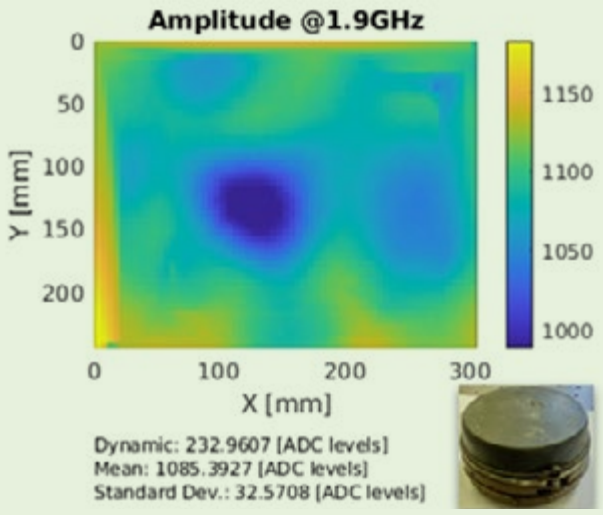
In the current Phase 3 configuration, the team has developed a sophisticated four-robot system that demonstrates how AI-powered sensor fusion operates in real world conditions.

The **first scout robot** carries a camera which feeds video to an algorithm that detects disconnected but co-linear sub-horizontal line segments that could represent concealed tripwires. It also uses a smartphone with LiDAR and photogrammetric 3-D imaging to construct a digital elevation model (DEM) for identification of navigation hazards. The smartphone feed can be sent to an AI system trained to recognize surficial threats – particularly the scatterable PFM-1 antipersonnel mine.

The **second robot** has a sweeping arm with an induction metal detector coil that produces georeferenced heat maps of metallic targets. The **third robot** carries a one-transmitter and four-receiver impulse GPR that detects and calculates precise positions of buried metal or non-metal targets. Finally, the **fourth robot** deploys an HSR scanner that quickly produces a 3-D image of buried targets detected by the metal detector or impulse radar. This robot does not sweep the entire minefield, but instead investigates targets for geometric data that is used in discriminating mines from clutter. Development of receiver operating characteristic (ROC) curves for HSR and landmines indicates that HSR alone has a true detection to false alarm ratio comparable to any existing mine detection system.

All robots are built and equipped using commercial off-the-shelf (COTS) or 3-D printed parts and their programming uses and produces open-source code. The idea is to develop and test a prototype team of cooperating robots, and distribute plans widely. Other groups are then able to develop their own robot teams; and with enough teams of cooperating de-mining robots, clearance of mined areas in Ukraine can be accelerated to make life and agriculture safe and productive again.

All sensor data collected by this four-robot team



Plastic PMN-4 Mine (lower left), and its holographic radar image after being buried for four years.

will be continuously analyzed to refine AI algorithms to aid in improving the system's ability to distinguish real threats from false alarms.

Beyond technological advancement, Phase 1, 2, and 3 have also demonstrated the power of scientific collaboration between young scientists and engineers in Ally and NATO partners countries. Each institution has involved undergraduate students, Masters, PhD students, and early career PhDs. Moreover, the project has also fostered participation of a diverse group of researchers having a variety of backgrounds and a wide range of expertise that can further Ukrainian demining efforts in addressing this critical humanitarian challenge while developing valuable skills that can be applied to similar operations globally. ■

The Project G5014 (Phase 1) team collects terrain and soils data for design of subsurface radars.

Project 5731(Phase 2) participants at the August 29, 2023 final field demonstration

SPS PROJECT SPOTLIGHT

MineSensa:
Sniffing Out Landmines

ARTICLE BY RESEARCHERS LEADING PROJECT G7614 "STAND-OFF CHEMICAL DETECTION OF LANDMINES FOR UKRAINE AND AZERBAIJAN (MINESENSA)".

COLLABORATION BETWEEN THE UK, UKRAINE, AND AZERBAIJAN.

Most explosives are sealed tight inside their containers, but they still release tiny amounts of chemical traces into the air around them. MineSensa works like a robotic bloodhound, using specially designed materials that can detect these microscopic chemical signatures with incredible sensitivity. The system combines two breakthrough technologies: synthetic materials that act like biological receptors (think artificial antibodies that lock onto specific explosive molecules) and brain-inspired computer processors that learn to recognize patterns the way living organisms do. This approach could revolutionize mine detection by literally sniffing out buried threats from a safe distance, much like the trained rats and dogs already used in demining operations, but with the durability and consistency that only technology can provide.

Imagine stepping onto your farmland, your livelihood dependent on the rich soil, only to hear an earth-shattering blast. This fear hangs heavy in the air across vast swaths of Ukraine and Azerbaijan, which are contaminated by the insidious legacy of landmines and unexploded ordnance (UXO). Globally, over 100 million active landmines threaten the safety and recovery of communities, causing around 6,500 casualties annually, with more than half being children.

Despite many technological innovations over the past decades, the humanitarian landmine clearance process has not changed significantly since the Second World War. Demining remains a laborious, time-consuming, and dangerous task that must be completed under stringent quality control processes to achieve final land release back to communities. Historically, the vast majority of cleared hectares and subsequent land release has relied on coordinated teams of human sappers armed with little more than sharp eyesight and a metal detector. Yet, metal detection is a poor strategy for finding landmines, as modern landmines increasingly have plastic bodies with minimal metal components.

Foundations of MineSensa: KrNU visiting delegation exploring drones during 2023 UoL-KrNU Summer School.

Image credit: KrNU

Spectroscopic assessment of gold nanoparticle molecularly imprinted polymer explosives optic fiber detector.

Image Credit: Project Participants

A portable technology that could achieve rapid stand-off detection of traces of explosives in the field is likely to provide a step-change in our ability to locate and clear landmines efficiently. This is the key objective for project MineSensa, supported by the NATO SPS Programme, which combines exquisitely sensitive molecular sensors with AI processors and robots to create a self-contained chemical sensing module targeted at classifying explosives for accurate stand-off chemical detection of landmines.

Trace explosives detection is a hugely challenging sensing problem, as most explosive compounds are sealed in the solid phase inside the device, exhibiting extremely low rates of evaporation and vapor pressure at ambient temperatures. Advanced sensor developments and signal processing strategies are necessary to reliably detect such minute quantities that can leach into the environment over long periods.

MineSensa builds upon existing sensor technology advances at the University of Leicester made during a previous NATO SPS project led by Professor Piletsky and Dr. Chris Zaleski. They developed Molecularly Imprinted Polymers (MIPs) based on composite nanoparticles. MIPs are usually classified as polymer analogues of the biological antibody–antigen systems. Likewise, they use a “lock and key” mechanism to selectively bind the molecule that was used as a template during the MIP synthesis phase. MIPs are biomimetic, potentially offering the specificity and selectivity of the biological receptors with notable advantage of durability to environmental conditions, while also being a relatively low-cost material. They are very robust and can be exposed to and survive extreme environmental conditions with no special storage requirements, unlike biological antibodies often used in biosensor solutions.

These novel materials exhibit highly specific responses with exquisite (femtomolar) sensitivity to explosives that has been previously demonstrated in laboratory testing. To get a sense of the extreme levels of sensitivity demonstrated by these advanced sensor devices, femtomolar concentration translates to approximately one teaspoon (about 5 grams) of target material diluted by 100 million Olympic-sized swimming pools.

Translating this laboratory result to a portable instrument validated for reliable detection across various conditions and adverse environments presents several challenges. MineSensa will make

use of biologically inspired signal processing strategies to build a dedicated neuromorphic AI MIPs processor, developed by Dr. Tim Pearce, a world-leading expert on olfactory neuromorphic systems. This builds upon previous neuromorphic processor developments that suppress drift and noise in chemical sensors while simultaneously predicting chemical identity from early transient phases of sensory input.

By combining these biomimetic technologies to address the demining challenge, MineSensa sets out to revolutionize landmine detection, making it faster, safer, and more efficient, ultimately saving lives and aiding in the recovery of war-torn communities.

MineSensa is a direct result of "The UK-Ukraine Twinning Initiative" ("Yednannia") that was established in 2022 in partnership with the Cormack Consultancy Group and the Association of Universities of the United Kingdom, supported by the UK Government and the President of Ukraine's Fund for Education, Science, and Sports. As part of this international project "The UK-Ukraine Twinning Initiative" ("Yednannia"), Kremenchuk Mykhailo Ostrohradskyi National University (KrNU) and University of Leicester (UoL) twinned by Memorandum of Understanding in September 2022. The twinned universities developed a 5-year roadmap of aerospace, bioengineering, and artificial intelligence, supported by a £88.5k 2023 award from Universities UK International, which is part of UK Research and Innovation.

This funded an International Summer School organized and led by Dr. Aldo Rona at the School of Engineering at the University of Leicester and by Dr. Andrii Gladyr, Director for the Center for International Activity at KrNU. A group of KrNU scientists presented in person at UoL and many more attended and presented by videoconferencing from KrNU. Three thematic days on Aerospace, Bioengineering, and Artificial Intelligence exposed mutual competences and a will to exploit them to address urgent problems arising from the military operations in Ukraine. A hybrid face to face and web conference round table facilitated by Rona and led by Pearce identified de-mining as an impactful and synergic opportunity for aerospace, bioengineers, and AI scientists to all work together for the greater good. A number of mini-projects ensued using UoL and KrNU research expertise aimed to strengthen the cooperation between two universities.

One of the mini-projects selected for high-priority exploration was employing automated robotic and sensing platforms, including drone copters to various practical tasks, including agriculture, environmental monitoring and humanitarian demining.

A Biomimetic Approach to Demining Technology

The project researcher's approach to the landmine detection challenge is biomimetic, modelled after the exceptional olfactory abilities of mine detection rats and dogs (MDDs) used operationally in humanitarian demining. These animals are highly effective due to their ability to sniff out minuscule trace amounts of explosives, achieving over 95% accuracy under favorable conditions.

Training these animals is a rigorous and expensive process. For rats, training begins at infancy and involves associating the smell of explosives with a food reward using a clicker, a process that can take up to nine months. Once trained, the rats are equipped with harnesses and taught to walk on a rope grid in the field. When they detect a landmine, they scratch at the ground to signal the presence of explosives, which is then verified and safely detonated by human de-miners. The lifespan of commonly used Giant African Pouched Rats is 6-8 years, necessitating a continual and expensive training process. Interestingly, like its biological counterparts, MineSensa is likely to need regular training and calibration, yet this will be developed as an automated online process that does not require significant MineSensa system downtime nor additional effort and training of its operator.

Olfactory experts such as demining rats and dogs achieve their impressive explosives detection performance through the evolution of dedicated olfactory receptors and neural pathways optimized for air sampling, olfactory object detection, learning, and memory. By leveraging biomimetic chemosensor strategies, sniffing-based sampling, neuromorphic signal processing/AI processors, and quadruped robotics, MineSensa aims to achieve comparable detection performance that will be validated against MDDs at the end of the project in Azerbaijan under the supervision of ANAMA.

KrNU and UoL hope to further develop this concept within their 5-year roadmap of twinned research, through activities complementary to MineSensa. The AI MIPs light-weight processor core and femtomolar detection enable its airborne use on small drones. The UoL team will engage the expertise in the installation and operation of sensors on aerial drones and in aerial survey from the Drones Laboratory of Space Park Leicester to enhance the spatial resolution and accuracy of mined areas currently observed through satellite imagery. Small and affordable drones, like quadcopters, provide not only affordability and ease of operation, but also have potential for greater spatial accuracy of mine detection. The downdraught from rotors produces an air 'self-mixing' environment around the drone that limits the ability of flying towards the explosive by tracing the gradient / intensity of the chemical trace of the explosive. The combination of a small drone as well as Computational Fluid Dynamic modelling of the downdraught by Dr Aldo Rona (University of Leicester School of Engineering) will provide enhanced olfactory directivity capabilities to the airborne system.

By combining biomimetic technologies and principles in the MineSensa project, the project aims to build landmine localization technology that approaches the performance of animals, enabling faster clearance and lowering the danger they pose. A direct impact of such projects should be more effective and affordable autonomous explosives detectors tested in the field, with the potential to transform the de-mining process in NATO partner countries and beyond.■

MineSensa project partners:

University of Leicester (UoL), UK. The project consortium is led by Dr. Tim Pearce (Project Director, School of Chemistry) who has spent a lifetime building neuromorphic processors for chemical detection (School of Engineering) and Professor Sergey Piletsky and Dr. Chris Zaleski (University of Leicester, School of Chemistry) who have world leading expertise in developing molecularly imprinted polymer materials as molecular sensors. The UoL team will further develop the MIPs to optimize their responses to explosives and develop a dedicated AI MIPs processor core for efficient low-power target detection and identification.

Kremenchuk Mykhailo Ostrohradskyi National University (KrNU), Ukraine. Dr. Dmytro Mamchur (Project Partner Director) brings wide experience with autonomous control and field robotics and with the KrNU team will work closely with the Interregional Humanitarian Demining and Rapid Response Center (IHDRRC) of the State Emergency Service of Ukraine who are responsible for civil demining on a national level. Together they will prepare a dedicated test field with all necessary infrastructure, simulating main types of landmines laying typical for Ukrainian conditions (agricultural fields, forests, public roads, etc.) ready for MineSensa validation tests. The Ukrainian KrNU team will be responsible for collecting and pre-processing test results and providing feedback on tests success, aiming to mitigate identified technical obstacles and shortcomings across iterations of the MineSensa instrument.

Mine Action Agency of the Republic of Azerbaijan (ANAMA), Azerbaijan. Mr. Elnur Gasimov (NATO partner country Co-director and Head of the Monitoring and Quality Control department at ANAMA) brings a wealth of experience and expertise to the project on meeting operational QA processes during humanitarian demining. Extensive testing of MineSensa in the field will be carried out under the direct supervision of ANAMA that is responsible for demining operations in Azerbaijan. During test evaluation the Interregional Humanitarian Demining and Rapid Response Center (IHDRRC) in Ukraine and ANAMA will provide guidance on the major types of explosives, landscapes and environmental conditions relevant to civil demining in real-life scenarios. They will also share their requirements for the robotic platforms and their experience with potential obstacles in the demining process, helping the project team to achieve the best results for real-life implementation of the device. ANAMA also have drone capabilities for land survey that will be used to mount MineSensa for air-based sector detection. ANAMA extensive capabilities in Mine Detection Dogs (MDDs) will be key for comparative animal vs. technology detection tests in the last six months of the project.

SPS PROJECT SPOTLIGHT

MinesEye In the Sky

ARTICLE BY RESEARCHERS LEADING PROJECT G6261 "UXO IDENTIFICATION AND CLASSIFICATION FOR UKRAINE (MINESEYE) ".

COLLABORATION BETWEEN POLAND AND UKRAINE.

MinesEye is a collaborative demining technology developed by researchers in Poland and Ukraine. The project uses drones equipped with ultra-sensitive magnetic sensors to detect the tiny magnetic disturbances that buried metal objects create underground. When explosives are buried, they leave invisible magnetic fingerprints that specialized equipment can read, much like how medical imaging reveals what's inside the human body without opening it up. The system doesn't rely on magnetic detection alone though. It combines magnetic sensors with high-resolution cameras and artificial intelligence that processes all this data together, creating a comprehensive picture of what lies beneath the surface. This multi-sensor approach helps distinguish between dangerous explosives and harmless scrap metal, making the detection process both more accurate and more efficient. This article presents the views of the NATO country project director of the project. You can read about their Ukrainian counterpart's perspective in *Clearing the Deadly Legacy* later in this magazine.

According to Vlad Kozak, Founder and Managing director of Postup Foundation, "Ukraine needs innovations to aid the humanitarian demining process to make it safer and faster. The SPS framework should help us introduce a more scientific approach for product development and base next milestones on objective criteria - crucial for a solution to be accepted by end users. Ukraine is one of the most UXO-contaminated countries and it has historically been one of the largest producers of crops. Solving the landmine contamination problem will bring us closer to world food safety."

The problem of landmine and unexploded ordnance contamination in Ukraine is staggering. At least 30% of the country's territory is estimated to have landmine and UXO contamination. The estimated cost of clearing those territories is around 40 billion USD based on a World bank assessment. The scale of potential contamination is roughly 180,000 km2 of land in Ukraine. With currently available de-mining methodologies, Ukraine is estimated to need more than ten years to achieve the Government's target of 80% mine decontamination. From 2015 to 2021, the slow pace of demining via conventional methods accounted for only 2.5% of potentially contaminated land being cleared in Ukrainian-controlled and non-controlled areas. It's estimated that 350,000 sappers are needed to clear 80% of UXO-contaminated territory if no technical advancements are introduced.

Testing bench

According to the latest statistics (July 2024), there were 672 incidents recorded that took the lives of 300 people and left 679 people injured. Nearly half of incidents occur on open territories, such as agricultural fields and non-paved roads connecting them or in shallow waters. Each of these use cases could be potentially scanned by remote sensing systems which will help to speed up the process significantly. The central question is whether such systems can demonstrate sufficient reliability and detection performance to justify the cost and effort of integrating them into the process.

To answer this question, Postup's team is executing several research activities that include assembly of experimental hardware, along with testing rounds in diversely challenging environments. The result of this project will include system validation against various critical metrics including UXO detection and identification rate, as well as overall system productivity. Aerial measuring systems are increasingly used for various commercial applications; however, UXO search remains one of the most complex due to their small size and wide variety of targets.

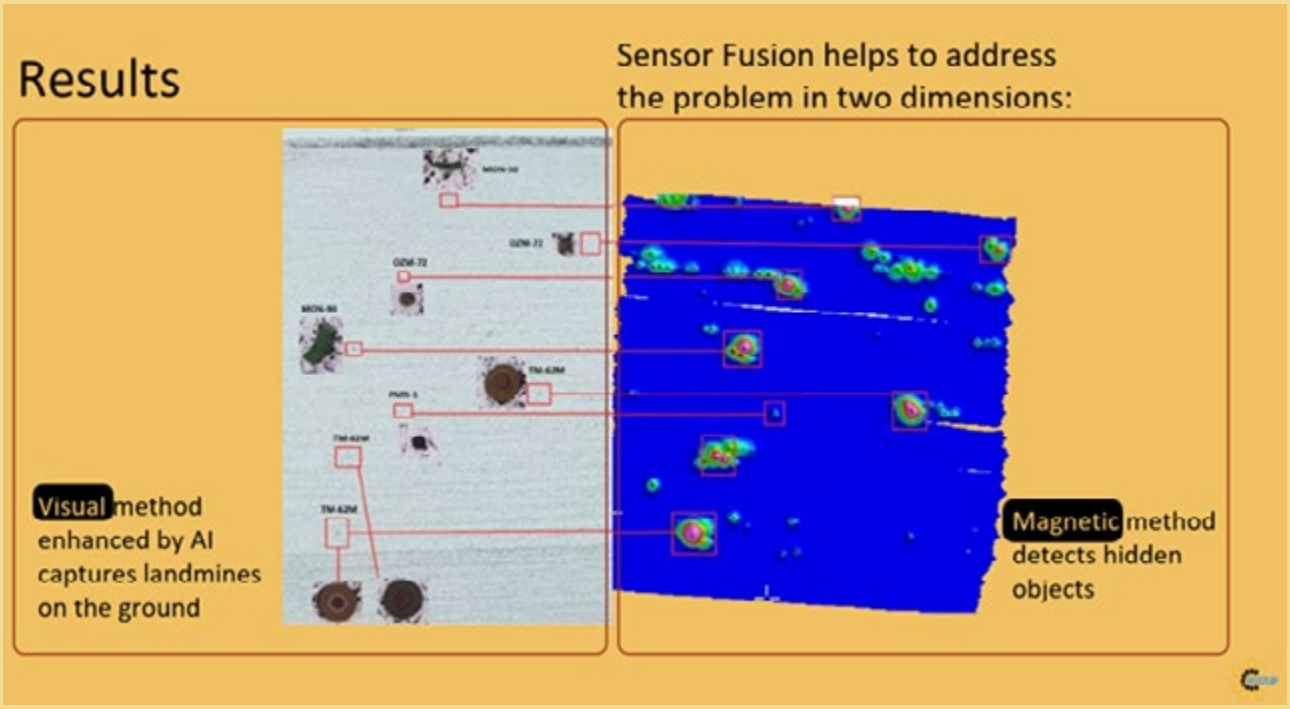
Among the many solutions currently in testing phase, visual inspection is the only method being used on a large scale by demining operators.

The MinesEye system operates with hardware and software elements for its research. On the hardware side the team leverages a multi sensor approach with simultaneous data collection by magnetic and optical sensors. The concept lays in simultaneous data collection joining datasets from different sensors with timestamps. This helps to cross reference data with very high precision and makes the system less dependent on GPS signal, which doesn't always provide accurate precision and can be jammed by electronic warfare systems. However, in order for this approach to work, it's required to align data collection altitude which can vary between optical and magnetic sensors.

In order to address this issue, Postup's team dedicates a part of their research on mechanical engineering of non-ferrous foldable extenders. This not only helps to modulate survey altitude for different sensors, but also - to diminish electromagnetic parasite signals from the drone which is one of the more pressing issues in aerial magnetometry. For example, current aerial systems based on copter with fixed suspension have as high magnetic system noise as 38 nT, while systems on fluctuating suspension imply non-systematic fluctuations of magnetometer that produce random anomalies that are difficult to filter. The idea is to push the boundaries and have semi fixed suspension that will not introduce fluctuations of magnetometer but diminish magnetic system noise to less than 2 nT. For reference, residual magnetic anomalies from the most common search object, a TM-62 landmine, is as high as 15-50 nT from a survey altitude of 1.5 meters. Thus, there is a risk of not detecting it during magnetic survey, especially in case the object is hidden underground.

On the software side, the challenge is to apply relevant data processing methods for each type of sensor. For example, magnetic data processing requires significant expertise in geophysics in order to understand data filtering methods for capturing anomalies of interest and understand the dependency of object residual anomalies from different factors, such as distance, shape, magnetic susceptibility and other factors. In case of visual data, the problem comes from the huge amount of data that has to be processed by automated AI algorithms. Data processing of other types of sensors brings additional detection and identification potential but requires additional research.

To address the challenge of anomaly classification and hazardous object recognition, Postup is working on the development of a UXO and replicas library. The data is being collected on a magnetic and visual spectrum with additional sensor data to be included at a later stage of the project. When sufficient datasets have been collected, it will be possible to validate the individual detection rate of each method, how much it varies depending on external conditions, and what is possible to achieve by combining the methods. From initial research, the magnetic method should allow the detection of 50-70% of hazardous objects, including those placed on the sub surface. For this reason, combining it with other methods will help better



address other types of objects.
The final objective of the project is to measure the capabilities of the multi sensor system in landmine detection and classification and validate both the detection rate, classification and identification rates on large data sets of unknown data.

The MinesEye system is being developed in cooperation with end users, including the State Emergency Service of Ukraine (SESU). Postup Foundation signed the cooperation agreement with SESU in February 2023. “It’s crucial to spend most of the time close to the end user and be ready to operate in a real-world environment. This way we are able to develop a system that would really help demining operators to do their job safer and faster,” Vlad Kozak stated.

Since the start of the MinesEye project in January 2024, the Postup team has attracted interest from humanitarian demining operators exploring new drone technologies. A demo has also been provided for 10 operators, including HALO Trust, FSD (Fondation Suisse de Déminage), and Ukrainian government services like SESU and the State Transport Special Service (DSST). Additionally, automated data processing and AI have the potential to transform survey methods

and disrupt the demining market. These technologies can reduce the manual components of the demining process, allowing sappers to operate from safer distances away from dangerous areas. By embracing these technological advancements, Allies and NATO partners can accelerate critical demining efforts; taking meaningful steps to create safer communities where civilians can return and rebuild without the threat of unexploded ordnance. ■

MinesEye systems prepared to work in cooperation with SESU demining reconnaissance team

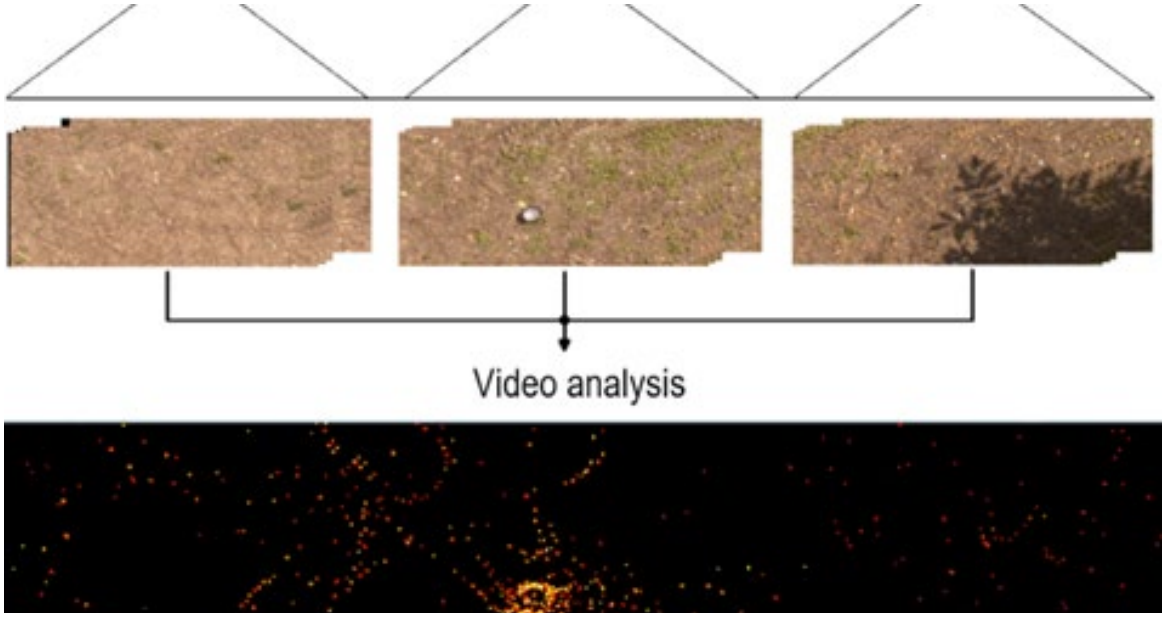
The Buzzing Bomb Squad:

Training Bees to Find Landmines

ARTICLE BY RENÉE STOUTE

Landmines are still present in post-conflict areas in many countries around the world, where they take a heavy toll in terms of civilian casualties, unfarmed land and loss of trade and communication. Humanitarian demining is time consuming, expensive, and poses a high risk for deminers. Landmines are also a potential security threat as explosive materials can be scavenged by terrorist organisations for home-made explosive devices. Consequently, biological methods, including the use of honeybees, represent a promising avenue for innovation in demining efforts. Honeybees are widespread in almost all inhabited areas and can be utilized as an inexpensive tool for landmine detection available in any location.

Biological Method (Bees) for Explosive Detection (Bee4Exp) is an SPS supported project developed by researchers in Croatia, Bosnia and Herzegovina, and the UK. Field tested in Croatia, this innovative approach uses trained bee colonies to detect landmines through two distinct phases, each leveraging different aspects of bee behavior. In Phase One, the passive phase, bees inadvertently become living samplers as they forage across mined areas. The bees collect explosive particles on their fuzzy bodies and bring chemical signatures back to their hive for analysis. Phase Two, the active phase, takes a completely different approach by training the bees to actively seek out and congregate at locations where they detect explosive vapors, essentially turning them into tiny, flying mine detectors. The project combines these biological methods with cutting-edge technology including organic semiconductor-based vapor sensing films, UAVs with thermal imaging, and specialized image processing software.



A combination of traditional video processing algorithms, such as video stabilization and background subtraction, and deep learning are used for honeybee detection. Flying honeybee detections are accumulated into spatial density maps.

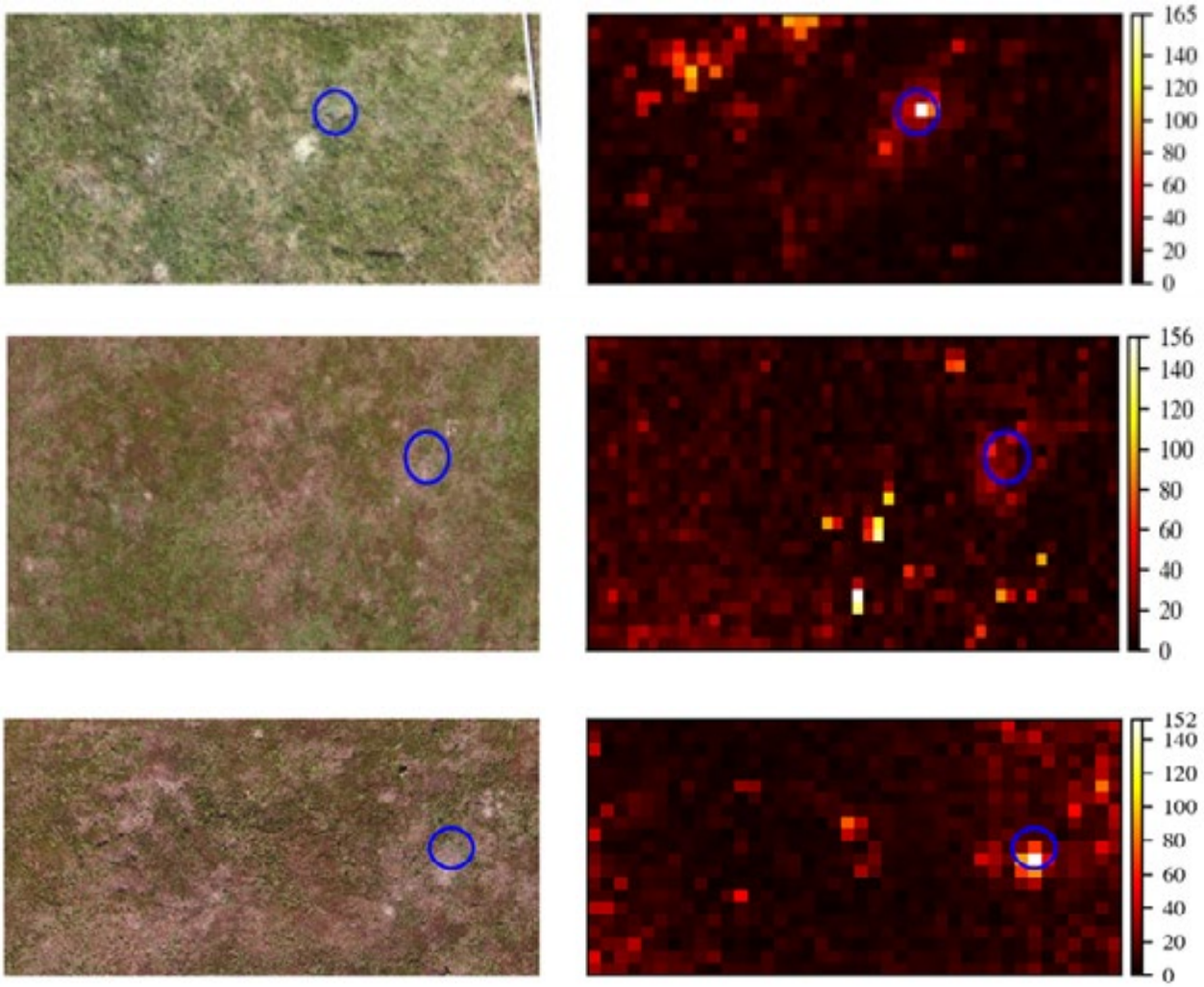
The Collection Phase

What's the Buzz?

The main task of the passive method is to detect the presence or lack of explosives in a wide area of interest. As honeybees collect water and forage for nectar and pollen, the electrostatic charge on their body hair attracts dust, pollen, soil, and other particles, including chemicals from their flight area. Thousands of honeybees from a single colony accumulate these particles in flight and bring it back to their closed environment of the hive. Honeybees can be directed to fly in specific areas by placing artificial food sources in different positions. On their return, they bring back to their hives particles of chemicals as well as biological agents and other materials collected during flight. The particles of TNT collected in the beehive can be measured and analyzed using equipment for the specific detection of nitro-aromatic vapors.

The sensors work by a change in light emission (fluorescence or laser light) when minute quantities of TNT-like molecules come into contact with the polymer film. Preconcentrators allow the build-up of trace chemicals from the environment over time. By adapting these polymer materials into 4-channel cartridges for insertion at the colony entrance, returning bees deposit explosive materials attached to their hair via foraging. Findings show that bees can collect between 5ng and more than 1 mg of explosives per field sample, with the average bee carrying 35ng of explosives per trip!

A light emitting polymer is exposed to the preconcentrator, which releases the built-up explosives when thermally treated. The light emission decreases in real-time on contact with



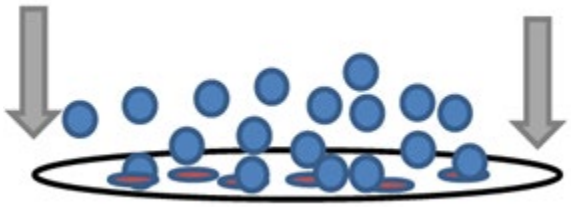
Peaks of Detection

an explosive particle. This indicates the presence of explosives, and hence land mines, in the surveyed area. This data helps researchers identify high-risk areas for further investigation.

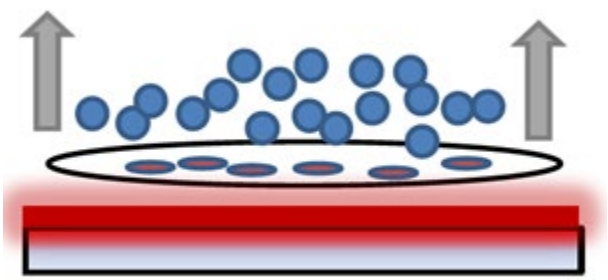
The Detection Phase

Bee-havioral Detection

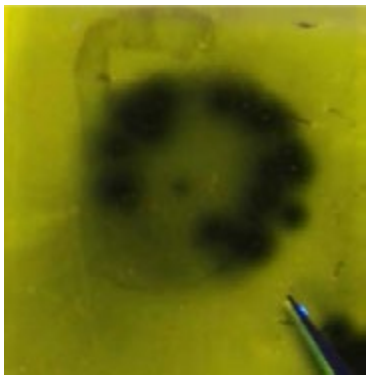
The active method in Bee4Exp is to train honeybees to detect the scent of explosives and track and trace them to their most visited gathering spots. As honeybees are trained to search explosive scents, areas with a concentration of bees are most likely to have unexploded ordnance. However, tracking and tracing honeybees in the open field is a challenging task, which



Air is drawn through the filter and explosive vapors adsorb to polymer surface then heating desorbs the vapors where the sensor film can be used for detection.



Clean Polymer



Exposed Polymer to DNT

is achieved by using UAVs equipped with video capturing devices and cutting-edge video processing algorithms. In general, the active method relies on UAV technology and ultra-high-resolution cameras in order to pinpoint the exact places where honeybees are gathered.

Bee-yond Traditional Detection

This innovative biological approach to humanitarian demining offers significant advantages over traditional methods. The Bee4Exp project demonstrates a multifaceted solution to the complex challenge of demining. The combination of passive sampling for explosives detection over wide areas with active pinpointing of specific landmine locations creates a complementary system than increases both safety and efficiency. As field trials expand beyond Croatian test sites, new developments could substantially reduce the risks faced by human deminers while accelerating clearance operations in post-conflict regions for Allies and NATO partners. The successful implementation of such biologically oriented approaches may ultimately usher in a paradigm shift in humanitarian demining practices, offering a sustainable, scalable solution to one of the most persistent dangers threatening civilian populations in former conflict zones. ■

The incoming bees and outgoing bees are separated into four channels each.

FUTURE VISION

Clearing the Deadly Legacy:

Experts Perspective on the Future of Demining

As this special issue has explored, the landscape of demining operations stands at a pivotal moment. Technological breakthroughs are reshaping possibilities in the field. The previous articles presented highlight cutting-edge detection systems, the complexities of partnerships and defence capacity building, and paint a picture of a field in transition.

But where does this all lead? What does the future actually hold for demining operations, and how can NATO build on current momentum to address the deadly legacy of explosive contamination more effectively?

To answer these questions, the SPS Team asked practitioners working directly within NATO's strategic framework and the SPS Programme with firsthand knowledge of both the promise of emerging technologies and the persistent obstacles that prevent faster progress. Their perspectives reveal that the next decade will not only concern deploying better technology, it will also require a total overhaul on how to coordinate demining efforts and build sustainable capacity.

AI and autonomous systems show genuine potential to transform how demining operations work, but realizing that potential means addressing gaps in training, standardization, and resource allocation that have plagued the field for years. Similarly, while NATO's mechanisms offer a strong foundation for international cooperation, maximizing their impact requires agile approaches to policy development and more effective integration of civilian and military capabilities.

The expert analysis that follows provides insights into how these dynamics unfold in reality, drawing on both frontline experience and strategic oversight to highlight pathways forward. These expert's answers reveal both the complexity of current challenges and genuine reasons for optimism about the field's trajectory.

Expert Profile: Leading Innovation in Real-World Conditions

Dr. Ievgen Polianchenko brings a unique perspective to contemporary demining challenges as a Senior Researcher at the Institute of Geophysics of the National Academy of Sciences of Ukraine. His work extends far beyond theoretical research—operating within Ukraine's current conflict environment, he contributes directly to developing technologies that address one of the world's most pressing humanitarian crises.

As a key participant in a NATO Science for Peace and Security Programme project, Dr. Polianchenko plays a central role in the groundbreaking MinesEye initiative. This project represents a collaboration between Polish and Ukrainian institutions to develop advanced detection systems specifically designed for the massive scale of contamination facing Ukraine today.

The context surrounding his work underscores both its urgency and complexity. With an estimated 30% of Ukraine's territory affected by landmine and unexploded ordnance contamination—roughly 180,000 square kilometers—the country confronts a humanitarian and economic challenge of staggering proportions. Current demining

methodologies would require decades to address even 80% of the contamination, while the World Bank estimates cleanup costs at approximately 40 billion USD.

Dr. Polianchenko's research directly addresses these realities through the MinesEye project's innovative multi-sensor approach, which combines magnetic and optical detection systems with artificial intelligence for automated data processing. The project has already conducted over 100 aeromagnetic surveys in both controlled and real-world conditions, working closely with Ukraine's State Emergency Service to ensure practical applicability.

His position offers rare insights into how cutting-edge detection technologies perform under actual conflict conditions—experience that proves invaluable for understanding both the potential and limitations of emerging demining capabilities. Through this work, Dr. Polianchenko contributes not only to Ukraine's immediate needs but to broader international understanding of how technology can accelerate humanitarian demining efforts globally.

Strategic Assessment: Technology Innovation in Crisis Response

The following analysis examines current technological developments and operational challenges through the lens of direct implementation experience, offering perspectives shaped by both scientific research and urgent humanitarian necessity.

SPS: Why did you choose this field? What interests you the most about it?

Dr. Ievgen Polianchenk: I am drawn to this field because of its importance for safety and people's lives. Landmine clearance helps reduce risks from remnants of war, saves thousands of lives, and restores land for use. I am inspired by the opportunity to apply technology to solve global problems.

SPS: What technological breakthroughs do you believe will fundamentally change mine clearance operations over the next decade?

IP: Artificial intelligence and autonomous systems will undoubtedly play a key role, enhancing efficiency and safety. Additionally, advancements in sensor technology, improved methods for detecting mines, and new materials for neutralization also have great potential.

SPS: What unique contributions does Ukraine bring to international mine clearance efforts that other NATO partner countries cannot?

IP: Ukraine has significant resources and experience in combat conditions, as well as geographical features that allow testing and implementing new technologies in real-world situations. This offers valuable experience and opportunities for international collaboration.

SPS: What are the main obstacles hindering faster progress in global mine clearance efforts, and how can they be overcome?

IP: Major obstacles include insufficient funding, technological underdevelopment, and limited access to marked and controlled zones. These can be addressed through international cooperation, adoption of innovative technologies, and stable financial support.

SPS: What approaches to training and developing doctrines in the field of mine clearance do you see as most effective?

IP: There should be an emphasis on multidisciplinary training: technical knowledge, tactical skills, and legal aspects. It's also important to address gaps in testing tools and simulation trainers to enhance professionals' competence.

SPS: How do CBRN threats affect your approach to mine clearance?

IP: Threats from weapons of mass destruction and the uncertainty in conflict zones lead to a more cautious approach, utilizing advanced technologies to minimize risks for personnel and local populations.

Expert Profile: From Frontline Operations to Strategic Advisory

Kim Hughes GC represents a unique convergence of operational expertise and strategic insight in the explosive ordnance disposal community. A highly decorated bomb-disposal operator with experience in Afghanistan, Hughes was awarded the George Cross in 2010 for what military officials characterized as "the single most outstanding act of Explosive Ordnance Disposal ever recorded in Afghanistan."

Hughes' career trajectory exemplifies the evolution of modern EOD operations. Beginning as a driver in the Royal Logistics Corps in 1997, his career led him to become one of Britain's most experienced ammunition technicians. Prior to leaving military service in 2022, he served as Group Senior Ammunition Technician and Senior Counter-Improvised Explosive Device Warrant Officer, positions that placed him at the forefront of developing UK counter-explosive ordnance capabilities.

Hughes bridges operational experience with strategic policy development. His role encompasses generating technical requirements, evaluating supplier capabilities, and ensuring delivery assurance across international partnership frameworks.

His transition from frontline operations to strategic advisory roles provides Hughes with comprehensive understanding of both tactical challenges and institutional coordination requirements. As a renowned international author and representative of the UK Ministry of Defence in global defence engagement activities, he continues to influence Counter-IED training and NATO partner nation engagement initiatives worldwide.

Strategic Assessment: Current Challenges and Emerging Opportunities

NATO Science for Peace and Security (SPS) Programme: Why did you choose this field? What interested you the most about it?

Kim Hughes: I joined the British Army in 1997 as a Driver within the Royal Logistics Corps. In 1999, during my first deployment to Northern Ireland I was attached to an Explosive Ordnance Disposal (EOD) Unit. I was intrigued by the role of the EOD Operator and the operating dynamic of the EOD team. The inner workings of Improvised Explosive Devices (IEDs) and Conventional Munitions fascinated me. In 2001, I retrained as an Ammunition Technician and became an EOD Operator

SPS: What technological breakthroughs do you anticipate will fundamentally change demining operations over the next decade? For example, do you see artificial intelligence (AI) and autonomous systems playing a significant role, or are there other technologies that show more promise?

KH: AI is the key component in any future development in the demining capability. Its ability to evolve through algorithmic learning will revolutionise future demining operations by

enhancing the speed, accuracy and safety during the detection and neutralization of Explosive Ordnance (EO) be that IEDs or Conventional Munitions. By leveraging AI's ability to analyse complex patterns, vast datasets and make real-time decisions, demining efforts can become significantly more efficient and less hazardous for the EOD Operator. When integrated with practical, field-based technologies – such as Ground-Penetrating Radar (GPR), Unmanned Aerial Vehicles (UAV), and Robotic Platforms, AI can dramatically improve overall effectiveness. The combination of AI and practical based technologies holds the potential to change the face of demining operations, making them faster, safer, and more scalable in post-conflict regions around the world.

SPS: What are the most significant obstacles preventing faster progress in global demining efforts, and how can they be overcome?

KH: There are several obstacles including, international stakeholder prioritization, high-cost vs. limited funding, conflict area accessibility, lack of or inaccurate historical data, international/local capacity, limitations in practical field-based technologies. This is not an exhaustive list, but these challenges can be overcome by a coordinated, international stakeholder approach, aligning international priorities, governance, policy and doctrine, and engagement with key industry leaders, NGOs and local communities. A shift in reactive to proactive tech-enabled strategies is key to accelerating progress.

SPS: How can Allies and NATO partners better coordinate their demining resources and expertise for maximum impact?

KH: NATO Allies and NATO partners can significantly enhance the effectiveness of their demining efforts by adopting a unified approach that leverages centralized coordination and information sharing. Establishing interoperable platforms and standardized reporting systems enables real-time data exchange and operational transparency, minimizing duplication and maximising impact. Joint training and harmonized certification will ensure EOD Teams from different NATO partner countries can operate seamlessly together, while pooled resources and specialised capabilities reduce cost, eliminate redundancies, and increase flexibility. Strategic prioritisation – based on humanitarian need, military relevance, and socio-economic impact, ensures that resources are directed where they are most needed. By integrating civilian expertise – 'Government Assured, Contractor Delivered' and military capacity, NATO can foster a versatile workforce that supports both immediate clearance and long-term stabilisation. Finally, embracing cutting-edge technologies, such as AI-driven detection tools and unmanned systems, alongside internationally aligned, multi-year funding models, will ensure sustained, adaptive, and high-impact demining operations across conflict-affected regions.

SPS: What do you see as the most effective approaches to training and doctrine development in demining? Where do you observe the biggest capacity gaps that need addressing?

KH: The most effective approach to training and doctrine development in demining must prioritise practical, scenario-based learning integrated with robust feedback from field operations. Training should be standardized across regions but adaptable to local threat environments, ensuring personnel are equipped with both foundational skills and context-specific knowledge. Where NATO partner country training capacity is lacking, contracted solutions should be considered. I observe the biggest capability gaps in standardised training across different organisations and countries, leading to inconsistent skill levels, incorrect Threat Assessment (TA) and procedural adherence. Doctrine often lags behind evolving threats of IEDs – particularly in asymmetric conflict zones, which highlights the need for a more agile doctrine development process that incorporates lessons learned and After-Action Reviews (AAR) feedback in near real-time. Additionally, there is a critical need to enhance the integration of evolving technologies – such as unmanned systems, GPR and data analytics, into both training and doctrine. Addressing these gaps requires investment not just in tools and technology but in human capital and institutional flexibility.

SPS: How are EOD/UXO threats shaping how you approach demining efforts?

KH: EOD activity and UXO threats significantly influence how demining operations are planned and executed, necessitating a careful balance between safety, efficiency, and adaptability. These threats determine the selection and deployment of personnel and equipment, shape procedures and often require a multi-layered approach to mitigate risk. EOD Operators must anticipate a wide range of EO from IEDs to remnants of war items, each presenting a unique challenge and hazard. As a result, Training, Techniques, and Procedures (TTPs) are continually adapted to account for evolving threats, incorporating intelligence analysis, remote detection technology and manual cleaning methods - including Render Safe Procedures (RSPs). These adaptations include enhanced training for identifying EO, deployment of robotic systems into high-risk areas, dynamic risk assessments, and real-time procedural changes to adjust for terrain, conflict history and local civilian activity. Ultimately, a flexible threat-informed approach is essential to ensure the safety for not only the EOD Operator but civilians while maintaining progress in the demining effort. ■

What is the ISEG?

Following initial screening by the SPS Programme, each application is reviewed by members of the Independent Scientific Evaluation Group (ISEG). The ISEG includes scientists and experts nominated by NATO member countries, who are selected on the basis of their expertise in specific areas of SPS Key Priorities, as well as their experience and potential to contribute to the Group's work. Once appointed by the Partnerships and Cooperative Security Committee (PCSC), ISEG members do not represent their individual nations. Their main role is to evaluate the scientific and technical merit of all applications through peer-review. ISEG assessments can be carried out during in-person meetings, as well as online.

Starting in May 2025, there are two phases to the application process for Multi-Year Projects. During the first phase, applicants submit a

short-form proposal including limited information about their project goals and setup. Only applicants whose proposals have been recommended by the ISEG after phase one will be invited to participate in phase two of the application process and submit full proposals for further review by the SPS Office and the ISEG. Proposals for Events are reviewed by the SPS Office and the ISEG only once.The direct involvement of ISEG members in SPS initiatives is instrumental to maintaining the integrity and high scientific standard of the SPS Programme. Following activities' approval, ISEG members follow and evaluate ongoing SPS projects and events in their areas of expertise, to ensure that all activities meet the SPS criteria for success, are well managed, and reach the end of their lifecycle with concrete deliverables.

Defence Capacity Building That Lasts:

Success Stories from NATO partner countries

G5387 - Comprehensive Package for Strengthening Jordanian Counter-IED Capabilities

NATO Counter-IED Center of Excellence, Jordan, and Ireland 2017-2019

This multi-year project (MYP) aimed to bolster Jordan Defence and Security Forces' C-IED capabilities and assist in the development of a more robust national program capable of addressing current and anticipated IED threats. This project provided opportunity to foster partnerships between the NATO C-IED COE and NATO partners, Jordan and Ireland.

The Middle East and North Africa region faces complex explosive contamination challenges. Decades of conflict have left a deadly legacy across vast territories. These hazards threaten civilian populations, prevent economic development, and hinder post-conflict recovery. Recognizing that regional security directly impacts the Alliance, the SPS Programme has supported efforts to build sustainable counter-explosive capabilities across NATO partner nations, particularly related to Counter Improvised Explosive Devices (C-IED) and Explosive Remnants of War (ERW). Through tailored training programs, technology transfer, and capacity building initiatives, SPS has worked with Jordan, Egypt, Tunisia, and Iraq to develop expertise that addresses each nation's unique operational challenges, while contributing to broader regional security objectives.

Strengthening Jordanian C-IED Defence Capabilities

In 2014, the North Atlantic Council approved a Defence Capacity Building (DCB) Package for Jordan to support the development of Jordan's capabilities in key priority areas, most notably in countering improvised explosive devices (C-IED). As part of the DCB Package, the SPS Programme has supported tailored and sustainable efforts that meet Jordanian needs. In 2015, the Programme supported an Advanced Training Course (ATC) led by the NATO C-IED Centre of Excellence (C-IED COE) 24 Jordanian Armed Forces (JAF) personnel. The lessons learned from this ATC were used to identify critical capability gaps and to further develop a second SPS ATC in 2017, directly responding to C-IED deliverables identified in the DCB Package. This basic IED Field Exploitation Course (BIFEC) contributed to training 15 JAF personnel and was the first stage of a two-phased approach to further enhance the defence capacities of Jordan.

The 2017-2019 SPS multi-year project (MYP), 'Comprehensive Package for Strengthening Jordanian C-IED Capabilities' served as the second stage and sought to directly respond to the C-IED deliverables in the revised DCB package. The three-year project, led by the NATO C-IED COE in Spain and NATO partners Jordan and Ireland attracted strong support from Allies and contributed to NATO's overall efforts in projecting stability through practical cooperation with NATO partners. There were four main categories of project deliverables including, on the strategic level, on the tactical level, regarding Train-the-Trainer, and public diplomacy. On the strategic level, the deliverables included the development of common standardized IED reporting and lessons learned processes. On the tactical level, officer training programs were reviewed with the intent to incorporate C-IED related content, including awareness, disposal training, and leader

G4899 - Netherlands and Egypt (2015-2020)

Enhanced Explosive Remnant of War (EWR) Detection and Access Capability in Egypt

NATO and Egypt completed a two-year project to introduce advanced detection systems suitable for demining in the Egyptian desert. The majority of landmines in Egypt are remnants of military action during World War II.

engagement courses. The training component, via a Train-the-Trainer format, was led by the C-IED COE and tailored to ensure Jordanian self-sustainment so that trained personnel can educate others in existing Jordanian training centers. Finally, the public diplomacy element amplified the project's outcomes through NATO and the SPS Programme channels, highlighting its contribution to NATO DCB efforts. Altogether, 136 Jordanian military and law enforcement personnel participated in the various training events.

Increasing Egypt's ERW detection capabilities

Regional cooperation is central to SPS's engagements, particularly with Mediterranean Dialogue (MD) partner countries. SPS is able to support Allied priorities by building NATO partners' capacity, like for example helping to boost capabilities and increase the safety of Egyptian deminers. From 2015 to 2020, a five-year SPS supported multi-year project 'Enhanced Explosive Remnants of War Detection and Access Capability in Egypt' led by the Netherlands and Egypt provided enhanced operational detection and clearance capabilities that could overcome challenges specific to the Egyptian Corps of Engineers.

Large areas of Egypt are contaminated with ERW, a legacy of conflicts within the area. The natural wind-blown movement of sand and dunes may cover ERW up to 6 meters. Additionally, salt and minerals can erode the thin metal casings of mines creating an especially challenging clearance environment. Traditional detection methods were limited to surface or shallow buried ERW using hand-held detectors and mechanical mine clearance machines. However, this project identified and incorporated an enhanced Ground Penetrating Radar (GPR) detection and location system and an excavation device able to safely access and expose anomalies in soft sand identified by demining personnel. By enhancing detection and excavation capabilities, this project had an immediate positive impact on the safety and security, not only for the Egyptian deminers, but also for the local population, agricultural land, and industrial and natural resource development.

Enhancing Capacity to C-IEDs in Tunisia

Tunisia has faced significant security challenges due to the proliferation of improvised explosive devices (IEDs), which pose threats to both civilian populations and military personnel. To address this issue, a currently ongoing project, launched in 2024, 'Enhancing Tunisian Counter-IED Capabilities' led by the UK and Tunisia aims to bolster Tunisian C-IED capabilities and assist in developing a more robust national and operational level program that can effectively address IED threats. The project is similar to the SPS Programme's DCB efforts in Jordan with a comprehensive training package, Train-the -Trainer programs, and assistance in the implementation of national interagency C-IED policy and programs developed using existing C-IED COE training programs and Mobile Advisory Teams. The DCB programme also includes support for Tunisian Armed Forces to procure C-IED equipment and progress towards self-sustainment.

Through the SPS Programme, Allies are well positioned to support NATO partners like Tunisia to better protect their citizens and infrastructure from the dangers associated with improvised explosive devices. Furthermore, the collaborative nature of these initiatives not only foster stronger ties between NATO partner countries and Allies, but also promotes regional stability and security. The SPS Programme plays a pivotal role in enhancing Tunisia's capacity to counter the threat of improvised explosive devices. Through targeted training, international collaboration, and the development of specialized skills, Tunisia is making significant strides in safeguarding its national security and contributing to broader regional stability.

Rebuilding Iraq's Post-Conflict Clearance Capacity

Following the 2016 NATO Summit in Warsaw, Allies agreed to conduct DCB training in Iraq, including providing equipment and expert training in the country. SPS coordinated with the C-IED COE to develop a tailored C-IED training course for the Iraqi Army Bomb Disposal School (IABDS). In 2017, the MYP 'Improvise Explosive Devises Disposal Search and Capacity Building for Iraq' provided training to Iraqi personnel from the Iraqi Ministry of Defence, Ministry of Interior, and the Counter-Terrorism Service. The project had two major components. The first was

G5185 - NSPA and Iraq (Sept – Nov 2016)

IED Disposal and Search Capacity Building for Iraq

This training program filled a critical capability gap and an immediate Iraqi priority to implement the post-conflict search and clearance requirements allowing the return of displaced populations. 100 Iraqi explosive ordnance disposal (EOD) personnel were trained, and 154 kits of light-scale EOD equipment were delivered through the project.

to train Iraqi security forces in search and clearance capabilities and to apply train-the-trainer programme to further their capabilities. The second, focused on providing the necessary equipment to safely conduct humanitarian demining clearance. 100 Iraqi explosive ordnance disposal (EOD) personnel were trained and 154 kits of light-scale EOD equipment were delivered through the project. This training program supported Iraq in conducting post-conflict search and clearance, thus facilitating the return of displaced populations. Ultimately, this project promoted security in the region and helps to contribute towards the Alliance's core goals by generating a dedicated team of experts, trainers, instructors for C-IED.

These capacity building efforts represent more than isolated training events or equipment deliveries, but also demonstrates NATO's commitment to sustainable security partnerships and improved security and safety for people. By training personnel across NATO partner nations and supporting DCB Packages, SPS has created a knowledge and capacity multiplier effect that will continue long after individual projects conclude. The evolution from basic detection training to comprehensive national C-IED strategies shows how targeted investment in partners' capacity can positively impact regional security landscapes. As threats continue to evolve and new contamination emerges from ongoing conflicts, these established partnerships and proven frameworks provide the foundation for rapid response and continued cooperation, contributing to the stability and prosperity that benefits both the region and the Alliance. ■

Inside NATO's SPS Programme:

How Science Shapes Security Solutions

History of SPS

Since 1958, science has been integral to NATO's mission and core values. The NATO Science Programme was launched to promote scientific projects and collaboration among scientist from NATO Allies in order to facilitate exchange and maximize return on research investments. In 2004, the NATO Programme for Security through Science focused primarily on security in line with NATO objectives. This included Reintegration Grants for partner country scientists as a support mechanism, priority research areas selected by NATO partner nations, and stipends for laboratory assistant services through Security through Science projects. In its current form, the NATO Science for Peace and Security (SPS) Programme, established in 2006, saw the merging of the NATO Science Committee (SCOM), whose member country representatives were qualified to speak on and recommend scientific policy to the North Atlantic Council; and the Committee on the Challenges of Modern Society (CCMS) dedicated to tackle problems at the national level using expertise and technologies to make recommendations for action to benefit all. Now, SPS provides funding and expert advice for security relevant activities in the form of four established grant mechanisms including Multi-Year Projects (MYPs), Advanced Research Workshops (ARWs), Advanced Training Courses (ATCs), and Advanced Study Institutes (ASIs).

Over the years, SPS has been restructured to evolve with ever changing global challenges that affect Allies and NATO partner countries and to continue to contribute to the Alliance's Strategic Objectives. While SPS primarily supports scientific cooperation, its scope also aims to promote large scale and more strategic activities such as scientific research, technological innovation, and knowledge exchange to enhance the political and public diplomacy impact of NATO's partnerships. Its work with universities, research institutes, government entities, and non-profit institutions in Ally and NATO partner countries is based on practical, mutually beneficial cooperation in security related civil science and technology. This includes providing funding, expert advice, and support to address emerging and disruptive security challenges and their impact on international security.

As many countries continue to face the challenges of explosive ordnance disposal (EOD) and demining requirements as a result of previous conflict, the focus on the required skills to address these challenges has evolved significantly due to changes in technology, tactics, and the nature of global conflicts. In turn, the topics of SPS research project proposals for fundings have also evolved. SPS projects generally address detection technologies against the terrorist threat from explosive devices and illicit activities, expansion of solutions to counter improvised explosive devices (IEDs), and the development and provision of advanced technologies, methodologies, and best practices on mine and UXO detection and clearance. Projects selected are typically more interdisciplinary - connecting different areas based on new advanced technologies. ■

NATO Science for Peace and Security Programme

The NATO **Science for Peace and Security (SPS) Programme** is one of the Alliance's longest-running initiatives, focusing on civil science and innovation to address emerging security challenges. Established in 1958, it has evolved from a scientific exchange program into a major partnership tool connecting scientists from NATO and partner countries to tackle security threats through practical, non-military cooperation.

1. Origins and Early Years (1950s–1960s)

Establishment (1958): Founded to foster ties among civilian communities and promote the training of scientists.

The "Three Wise Men": The programme was rooted in the 1956 report by Foreign Ministers Halvard Lange (Norway), Gaetano Martino (Italy), and Lester Pearson (Canada), which argued that scientific development was vital to national security.

Initial Focus: The programme initially focused on strengthening scientific expertise within the Alliance, with more than 20 Nobel Laureates having been associated with its activities over the years.

Emerging Security Challenges (1969): The scope widened to include environmental challenges with the creation of the Committee on the Challenges of Modern Society (CCMS).

2. Cold War and Post-Cold War Adaptation (1970s–2000s)

Outreach (1990s): Following the end of the Cold War, the programme began, for the first time, to include scientists from partner countries.

"Science for Peace" (1999): The programme was restructured into four sub-programmes to strengthen cooperation with the Euro-Atlantic Partnership Council (EAPC) countries.

Mediterranean & Gulf Partners: In 1999, it opened to Mediterranean Dialogue countries, and by 2010, it included partners from the Istanbul Cooperation Initiative (ICI).

3. Modern Era: SPS Programme (2006–Present)

Merger (2006): The Science Committee and the Committee on the Challenges of Modern Society (CCMS) merged to form the Science for Peace and Security (SPS) Committee, to enhance cooperation with all NATO partners based on security-related civil science and innovation.

2013 Reorientation: The programme was revamped to focus on larger-scale, strategic activities linked directly to NATO's core tasks, such as cyber defence, counter-terrorism, and energy security.

2014 Shift (Ukraine Focus): Following Russia's illegal annexation of Crimea, the programme significantly increased cooperation with Ukraine, making it the largest beneficiary of the SPS Programme.

Key Priorities (2024): Allies agreed to a revised list of priorities to address the current strategic environment, focusing on emerging and disruptive technologies (AI, quantum), defence against hybrid threats, and resilience.

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