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Technologies for Mine Action

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Contents

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Executive summary

This WIPO Technology SPARK (Short Pieces of Analysis, Research and Knowledge) report provides an overview of global patenting trends in mine action-related technologies, focusing on detection, clearance and personal protective equipment (PPE). Between 2004 and 2024, 3,548 patent families related to mine action were published, with a steady increase in activity seen over recent years, particularly in 2019 and 2023. Patent trends reveal a significant shift toward the develoment of remote sensing technologies, such as unmanned aerial vehicles (UAVs) and sensor fusion systems, aimed at improving detection efficiency and reducing operator risk. Notably, advancements in ground-penetrating radar, multi-sensor systems and robotics are prominent, reflecting ongoing efforts to enhance efficiency, effectiveness and safety of mine action operations.

Analysis also highlights a growing interest in autonomous systems and AI-driven decision-making, and increasing patent activity in areas such as UAV-based surveys, robotic ground vehicles and sensor fusion. These are expected to play a key role in future developments in the field. Such advancements align with a broader push toward reducing human exposure to hazardous environments, while at the same time improving the operational efficiency of mine action programs.

Introduction and background

Introduction

Landmines, cluster munitions and other explosive ordnance continue to threaten lives and livelihoods in more than 60 countries and territories. Globally, someone is killed or injured by such weapons approximately every two hours. Survivors and their families face lasting physical, psychological, social, and economic consequences.[1] Explosive ordnance blocks access to essential services and humanitarian aid both during a conflict and after it has ended. Even long after hostilities have ceased, these dangerous remnants of war remain present near homes and schools, along roads and on agricultural land, and even under water – in rivers, lakes and irrigation canals, as well as coastal waters – forcing an estimated 75 million people to live at daily risk of harm. Explosive ordnance contamination restricts mobility and access to education, health care and livelihoods, and impairs recovery and development.

Mine action is the name given to the humanitarian response to this challenge. According to the International Mine Action Standards (IMAS) framework, mine action encompasses activities which aim to reduce the social, economic and environmental impact of explosive ordnance. This is not solely about demining, but also about addressing the broader effects on people and societies. Its goal is to reduce explosive ordnance risk to a level where safe living, economic and social development, and victim assistance are possible.[2,3] Despite decades of effort, landmine and unexploded ordnance contamination remains a pressing humanitarian and development challenge.

This WIPO Technology SPARK (Short Pieces of Analysis, Research and Knowledge) *Technologies for Mine Action* report, undertaken in collaboration with the Geneva International Center for Humanitarian Demining (GICHD), aims to provide insights into technological innovation across post-conflict explosive ordnance survey and clearance, including mechanical systems and sensing technologies. By analyzing patenting activity and innovation trends, the report supports a better understanding of innovation pathways: how new technical solutions emerge, evolve and are applied in practice. Detection technologies constitute a central focus of the work, being so critical to safe, effective and efficient mine action through having the ability to determine the location of hazardous areas and explosive ordnance. Ultimately, the challenge for detection technologies is to maximize the probability of detection, while minimizing the

1 GICHD (2024). The GICHD Corporate Brochure 2024. Geneva: Geneva International Centre for Humanitarian Demining. Available at: https://www.gichd.org/publications-resources/publications/the-gichd-corporate-brochure-2024
2 IMAS (2024). IMAS 04.10 – Glossary of Mine Action Terms, Definitions and Abbreviations, Second Edition, Amendment 12, October 25, 2024. International Mine Action Standards. Available at: https://www.mineactionstandards.org/standards/04-10
3 GICHD (2024). Innovative Finance for Mine Action: Needs and Potential Solutions. Geneva: Geneva International Centre for Humanitarian Demining and Symbio Impact Ltd. Available at: https://www.gichd.org/publications-resources/publications/innovative-finance-for-mine-action-needs-and-potential-solutions

number of false alarms – a balance that remains technically demanding and operationally costly.[4,5,6] Moreover, the persistent gap that exists between the technologies available and operational requirements underscores the importance of understanding innovation pathways.

The report provides a unique contribution to this field by systematically mapping patent activity in demining and related technologies. It sheds light on innovation trends, the geographical distribution of intellectual property (IP), and the interplay between civilian, humanitarian and defense-driven research. This perspective is essential for understanding the historical development of demining technologies, identifying opportunities to accelerate innovation, fostering technology transfer, and guiding future investment into research and development. In adopting this perspective, the report aims to inform and provide practical information and solutions relevant to many states, donors, researchers, and practitioners involved in addressing one of the most enduring humanitarian and developmental challenges of our time.

Background

Explosive ordnance (EO) contamination poses serious risks to communities, limiting their access to land, infrastructure and essential services, as well as having long-term social, economic and environmental consequences. Mine action is a set of activities aimed at reducing the impact of EO – a category that includes landmines, cluster munitions, unexploded ordnance (UXO), abandoned ordnance, booby traps, improvised explosive devices, and other hazardous devices.[7]

While mine action is organized around five complementary pillars – explosive ordnance clearance, risk education, stockpile destruction victim assistance, and advocacy – each with a critical role to play, this report focuses primarily on land release, which is central to restoring land to safe and productive use (Figure 1).

4 IEEE (2001). IECON 01 – 27th Annual Conference of the IEEE Industrial Electronics Society 2001 (Cat. No.37243), Denver, CO, November 29–December 2. Institute of Electrical and Electronics Engineers

5 GICHD (2023). Innovation Conference Report 2023, Geneva, November 14–16. Geneva International Centre for Humanitarian Demining. Available at: https://www.gichd.org/fileadmin/uploads/gichd/Photos/Innovation_Conference_2023/GICHD_Innovation_Conference_Report.pdf

6 Evans, R., T. Temple and L. Nelson (2024). The detection problem: An eight-decade challenge – The difficulty of practically detecting and discriminating mines, booby traps, and victim operated improvised explosive devices. CISR Journal, 28(1). Available at: https://commons.lib.jmu.edu/cisr-journal/vol28/iss1/8

7 IMAS (2024). IMAS 04.10 – Glossary of Mine Action Terms, Definitions and Abbreviations, Second Edition, Amendment 12, October 25, 2024. International Mine Action Standards (IMAS). Available at: https://www.mineactionstandards.org/standards/04-10

The five mine action pillars complement each other to reduce the impact of explosive ordnance

Figure 1 Mine action pillars

"Land release" is a term that has been adopted to replace former references to "clearance" and encompasses "survey" as a critical step of the process preceding clearance.

Land release is the process of applying "all reasonable effort" to identify, define and remove all presence or suspicion of EO through non-technical survey (NTS), technical survey and/or clearance.[8]

Survey methods refer to the collection and analysis of information on the presence of EO, leading to the areas surveyed being classified as either safe or else containing suspected or confirmed hazardous areas. This evidence-based approach forms the foundation for all subsequent clearance activities. These entail the detection, removal and/or disposal of EO, as well as post-clearance assessment and quality management, ensuring that land can be reliably declared safe for use.

Technological innovation is central to mine action. Surveying and remote sensing technologies, such as airborne or satellite sensors (e.g., high resolution RGB (red, green, blue) imagery, magnetometry, ground-penetrating radar (GPR), multispectral and hyperspectral imaging) and integrated multimodal data analysis (often assisted with artificial intelligence (AI)

8 IMAS (2019). IMAS 07.11: Mine Action Standards – Survey. International Mine Action Standards (IMAS). Available at: https://www.mineactionstandards.org

computational methods), complement on-the-ground efforts by supporting the collection of evidence as to the presence of EO.

Mechanical demining systems can be categorized as:

- machines designed to destroy hazards
- machines designed to detect hazards
- machines designed to prepare the ground

These systems can support surveying and clearance by speeding up specific processes, such as by providing access to contaminated land; destroying EO; preparing the terrain; removing debris, rubble or tripwires; cutting vegetation; and providing safe platforms for other detection attachments.

Detection technologies, for example, metal detection, GPR and magnetometers, to name but three, are designed to locate EO with a degree of probability, while at the same time minimizing false alarms. Other technologies such as trace explosives detection and nuclear quadrupole resonance (NQR) could vastly minimize false alarms by detecting explosive substances but are still note mature enough to be fielded.[9,10]

Despite decades of research and investment, the adoption of new technologies in mine action has often been slower than anticipated. Operational complexity, environmental variability, a frequent difference in focus between research and development (R&D) and field requirements, limited funding for transitioning prototypes into practical solutions, constraints to scaling due to limited humanitarian funding, and resistance to change are among the key technological challenges.

Finally, no single technology or methodology can address every demining scenario. A deminer's toolbox approach remains essential: understanding the operational realities, key concepts, and technological approaches is essential for interpreting innovation trends and patent activity relevant to mine action, which is the focus of this report.

Methodology

Technologies that support surveying and clearance operations – whether for detecting, removing or neutralizing EO, or for protecting operators in the field – play a critical role in making mine action safer, more effective and efficient. For the purpose of the analysis, these technologies were grouped into three main categories:

1. **Detection technologies**, including sensors for metal, GPR, trace explosives and other methods for locating evidence as to the presence of EO.

9 GICHD (2023). Innovation Conference Report 2023, Geneva, November 14–16. Geneva International Centre for Humanitarian Demining. Available at: https://www.gichd.org/fileadmin/uploads/gichd/Photos/Innovation_Conference_2023/GICHD_Innovation_Conference_Report.pdf

10 Evans, R., T. Temple and L. Nelson (2024). The detection problem: An eight-decade challenge – The difficulty of practically detecting and discriminating mines, booby traps, and victim operated improvised explosive devices. CISR Journal, 28(1). Available at: https://commons.lib.jmu.edu/cisr-journal/vol28/iss1/8.

2. **Clearance technologies**, encompassing mechanical demining systems, vehicles, and tools for the removal or destruction of EO.

3. **Personal protective equipment (PPE)** designed to reduce the risk to operators during survey and clearance activities.

This categorization provides a structured framework for examining patent trends, innovation pathways, and the interplay between different technology types in the area of mine action.

In addition to categorization, the analysis also considers the end-use orientation of the technologies in question. While many inventions for which patents have been filed are potentially dual-use, that is, applicable to both military and humanitarian contexts, others are exclusive to just one domain. For example, mine-clearing charges are designed solely for military operations, whereas most PPE and manual or mechanical clearance tools are primarily humanitarian. This segmentation provides an important layer of interpretation, allowing the report to distinguish between trends driven by military R&D priorities and those more directly relevant to mine action.

Patent families published worldwide between 2004 and 2024 – identified and analyzed using the Patsnap patent database – are included in the analysis. A patent family is a collection of patent applications covering the same or similar technical content (i.e., the same invention). Analysis was conducted using patent families to count inventions and not several patents corresponding to the same subject matter and filed in different jurisdictions (jurisdiction refers to a country or regional office where a patent is filed). All demining technologies, including those not specifically related to mine action, have been included in the analysis.

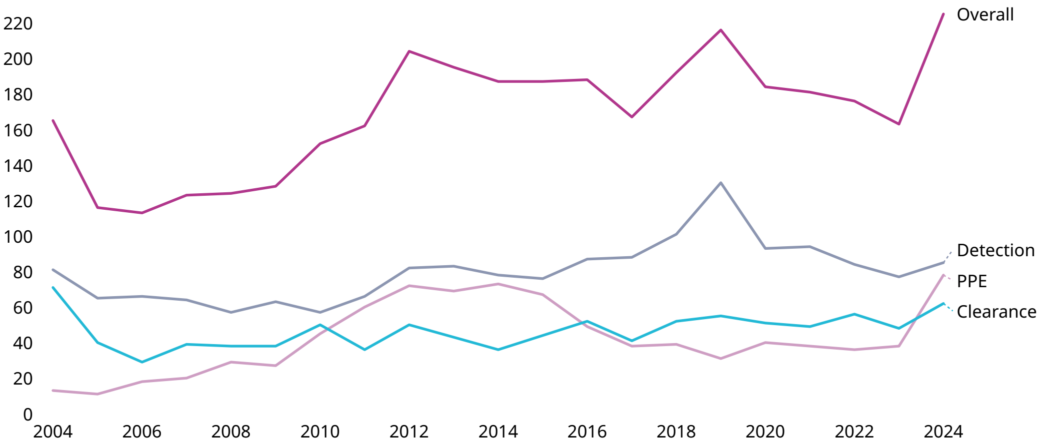
Insights from patent analysis

Global patent overview

This section provides an overview of global patent activity related to mine action. Technologies were categorized into detection and clearance, as well as PPE. The patent search identified 3,548 patents published between 2004 and 2024 (Figure 2). The number of patent families published each year showed a small upward trend, starting from 165 patent families in 2004 and increasing to 225 patent families in 2024, averaging about 169 published patent families annually, with noticeable peaks around 2011, 2018 and in 2023. Patent activity remained steady throughout the 2000s (2004–2008), with around 60–80 inventions being filed annually.

Patent activity in demining technologies peaks in response to several factors including the mine action framework

Figure 2 Patent family publications related to demining by earliest publication year, 2004–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

The earliest peak in 2011–2012 likely reflects the maturation of R&D programs initiated in the mid-2000s, particularly in response to conflict in the Balkans, followed by Afghanistan and Iraq, with a plausible 5–6 year lag between project inception and patent filing. While this first peak was likely to have been driven by mine action, the later peaks in 2019 and again in 2024 had a stronger focus on military applications in the context of the stabilization operations that followed the military campaigns of 2001 (Afghanistan) and 2003 (Iraq). The 2018–2019 increase coincides with the emergence of multi-sensor systems that integrate metal detectors, GPR and trace detection, alongside early applications of AI and advanced signal processing to improve detection capabilities. The sustained high levels of patent activity during 2023–2024 suggest a growing interest in autonomous and AI-assisted detection platforms, including UAV-based surveys and robotic ground vehicles, aimed at enhancing operational efficiency, while reducing risk to humans. Overall, this slow but steady growth in patents reflects the technical complexity of mine action, the historical slow translation of R&D into field-ready solutions, and the combined influence of historical funding cycles, technology maturation and the recent adoption of digital and autonomous technologies.

Detection technologies

Resources for responding to EO contamination are limited and chronically less than what is needed. Therefore, cost efficiency is a very important driver of innovation in the area of mine action. It is to be expected that authorities, agencies, operators and other parties either involved in or associated with EO programs do the utmost to ensure that assets are deployed in such a way as to achieve as much as possible for the least cost in the shortest time. Achieving such efficiency represents a significant challenge when dealing with the complexity of EO contamination.[1]

Practical effort is applied through the process of land release, encompassing non-technical survey, technical survey and clearance. Non-technical survey is the collection and analysis of any information indicating evidence as to the presence, type, distribution and environment withing the vicinity of EO contamination. This is undertaken in order to better define where EO contamination is present and what areas are free of contamination as evidence to support decision-making and clearance prioritization. Non-technical surveys use any method of collection and analysis of information that does not require physical intervention, typically desk research and field assessment leading to the creation of maps, sketches and other documentation, as well as potentially, UAV-based surveys, satellite imagery analysis and remote sensing.

Technical survey builds on non-technical surveying by providing physical, evidence-based confirmation of hazards through the deployment of survey and/or clearance assets. It entails physical intervention at the surveyed site, and relies on assets being deployed, such as detectors, mechanical tools or clearance teams gathering evidence as to the presence of EO. Crucially, technical survey is not only about confirming or dismissing the presence of hazards; it is about collecting and preserving high-quality information that supports confident decision-making about where clearance is necessary, when it can stop, and how resources can be used most efficiently. The choice of survey assets must therefore balance safety, reliability, cost, speed and environmental suitability, ensuring that the information and data generated genuinely strengthens the land release process.

Technical survey is the primary means of defining, with confidence, those areas that require full clearance and of supporting the decision as to when it is appropriate to bring clearance to an end. In this context, accurate detection is essential: technologies must provide sufficient evidence of EO to justify clearance, while also preventing unnecessary effort being made to clear safe areas.

1 IMAS (2019). IMAS 07.11: Mine Action Standards – Survey. International Mine Action Standards (IMAS). Available at: https://www.mineactionstandards.org

During clearance, assets are deployed to ensure that all EO within a specified area is either removed and/or destroyed to the extent required. The type of asset deployed depends mostly on the type of EO present, and also on the information collected during the survey. The extent required is defined by the national authorities responsible for the quality management of the whole process.

The process starts with locating the EO. Technical survey and clearance assets must provide a high probability (near certainty) that the expected presence of hazard items will be detected by the equipment and methodology in use and that the personnel conducting this task can operate safely. Handheld detectors (metal detectors and in some cases dual sensor GPR/metal detector) remain the most commonly used detection asset.

Analysis of how detection technologies have evolved over time shows a steady progression from manual and mechanical methods to sophisticated, autonomous and multimodal systems. Early patents primarily focused on mechanical and chemical approaches to handling and analyzing explosives. Over time, the integration of automation and multimodal sensing technologies began to emerge, expanding the range of potential applications for these detection capabilities.

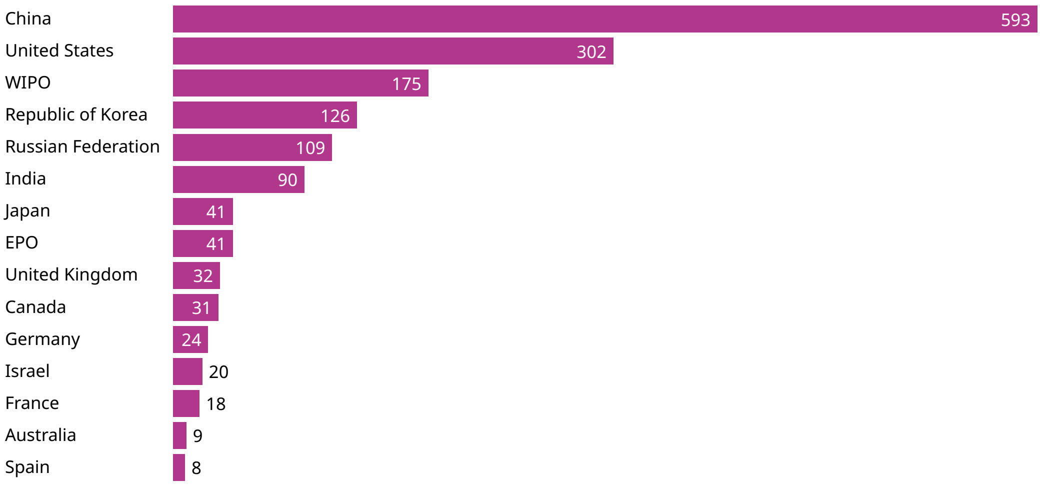
Between 2004 and 2024, 1,677 patent families were published in the field of EO detection-related technologies. Patent family publications reached a peak of 130 in 2019 (Figure 2). This increase in patents can be linked to the growing application of robotics and unmanned aerial vehicle (UAV)-based platforms for mine detection, reflecting broader technological advances in autonomy, remote sensing and AI-driven navigation. Such systems potentially offer the dual advantage of reducing the risk to human deminers, while also improving the efficiency of large-area surveys. The scale of EO contamination arising out of the conflict in Ukraine since 2022, together with the global attention given by the media to the conflict and the openness of the Ukrainian authorities in embracing innovation technologies and methodologies, may be sustaining this trend, as the renewed increase in 2023 and 2024 might suggest. Maturing technologies in unmanned systems, sensor fusion and AI may also support this recent upward trend by opening new avenues for innovation in mine action.

Figure 3 shows patent family publications related to mine detection across the top jurisdictions by earliest publication year. The highest number of patents families were published in China (593), followed by the United States of America (US) (302).

In the United States, a substantial share of patents originated from military research programs, reflecting the historical role of the Department of Defense and defense industry blocks in developing mine detection and clearance technologies. These patents often form the technological basis for later humanitarian applications, illustrating the military-to-humanitarian technology transfer that has shaped the global innovation landscape until very recently. Similarly, China's high patent publication numbers reflect a combination of defense-related research and advancements in geophysical survey technologies that are often adapted for mine detection applications. While some of China’s patents may relate to military defense technologies, a significant portion is also tied to geophysical techniques with dual-use potential, spanning both the commercial and defense sectors.

The high number of patent publications in China may be because of both defense-related research as well as geophysical survey advancements

Figure 3 Top filing jurisdictions for detection technologies, by earliest publication year, 2004–2024

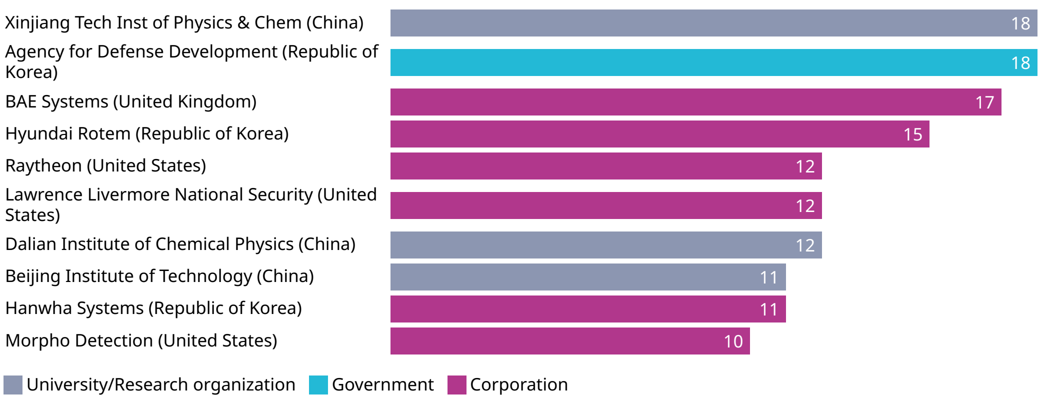


Note: EPO is the European Patent Office and WIPO is the World Intellectual Property Organization.
Source: WIPO, based on patent data from Patsnap, May 2025.

Xinjiang Technical Institute of Physics and Chemistry (China) and the Agency for Defense Development (Republic of Korea) topped the list of top patent owners for mine detection technologies, with 18 patent families each, followed by BAE Systems (United Kingdom), with 17 patent families (Figure 4).

The top patent owners have technologies that are specific for explosive substance detection as well as for detection broadly and for operational support

Figure 4 Top patent owners for mine detection technologies, 2004–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

The Xinjiang Technical Institute of Physics & Chemistry (China) demonstrates a strong focus on explosive substance detection, with patents covering gas sensor arrays, fluorescent nanomaterials, hydrogel-based test kits, colorimetric and optical platforms, and rapid detection methods for both conventional and improvised explosives. These patents suggest a concerted effort to develop sensitive, portable and rapid detection systems, which show promise as both laboratory and field applications in EO detection. Fuel testing appears as a surprisingly prominent domain – likely linked to patents in explosive residue detection – in which techniques developed for fuel or hydrocarbon analysis are adapted to trace explosives.

By contrast, the Republic of Korea’s Agency for Defense Development emphasizes a broader spectrum of detection and operational support technologies, including GPR, adjustable-range metal detectors, vehicle-mounted sensors, and advanced explosive sensing using quantum dots and air-intake detection platforms. While some patents target civilian applications, several clearly retain dual-use or exclusive military applications.

As background to the patent data analyzed from 2004 onwards, earlier developments in EO detection technologies laid the foundation for modern advancements. Between the 1960s and 1980s, patents primarily focused on mechanical and chemical detection methods, such as electromagnetic sensing and acoustic techniques. The 1990s and early 2000s saw the integration of multimodal sensing technologies, including X-ray, chemical and optical methods, as well as the introduction of robotic systems for handling explosives.

By 2004, UAVs had entered the detection landscape, indicating an advance toward remote sensing and the surveying of EO, and opening the door to greater operational reach and safety. Around 2006, GPR technology became more prevalent within detection systems in combination with existing metal detection technologies, leading to an improvement in the ability to distinguish between subsurface EO and the metal clutter responsible for previously extremely high rates of false positive detections in the field. This period also saw the miniaturization of devices, making them more portable and suitable for diverse operational environments.

In 2019, patented technologies in EO detection show a notable spike in the use of AI, marking its growing prominence within detection technologies. The integration of AI computational methods enabled faster sensor data analysis and pattern recognition, while also supporting decision-making through digital systems and information management. This advancement holds significant potential for improving the efficiency and accuracy of detection systems in the future.

The evolution described shows several consistent trends spanning decades: namely, increased automation and robotics; multimodal sensing; portable and UAV-based platforms; advanced material use for high sensitivity; and real-time, AI-assisted detection. The following timeline traces these developments in detail, highlighting key milestones in explosives, mine, and hazardous material detection technologies:

2004–2015: miniaturization, integration and expanded robotics

- Growth of handheld, wearable, and portable detection devices.
- Multimodal integration is explored: optical + chemical + electromagnetic + acoustic sensors.
- Expansion of robotics and UAVs for EO detection, including amphibious and subterranean systems.
- Nuclear quadrupole resonance (NQR) and hyperspectral imaging become mobile and potentially field deployable.

2016–2024: AI, multi-robot systems and advanced materials

- AI and machine learning applied to real-time detection, signal processing and threat classification.
- Multi-robot and UAV platforms enhance mapping, detection and operational safety.
- Nanomaterials, quantum dots and covalent/metal–organic frameworks improve sensitivity and selectivity.
- Multi-environment adaptability introduced: soil, water, vehicle interiors and industrial sites.
- Portable, integrated and autonomous detection platforms dominate patents.
- Autonomous robots with sensor fusion, adaptive control and real-time mapping for landmine and explosive detection.

  - Multimodal sensing: fluorescence, Raman/SERS, X-ray, electromagnetic and acoustic technologies combined.
  - UAV-based surveying and mapping for hazardous terrains.
  - Advanced chemical detection and nanomaterials improve field readiness and selectivity.

Key overarching trends that span decades

1. **Automation and robotics:** attempts to shift from manual and mechanical detection to autonomous robots and UAVs.

2. **Multimodal sensing:** integration of chemical, optical, acoustic, electromagnetic, and nuclear techniques.

3. **Miniaturization and portability:** lab-scale → handheld/wearable → UAV-mounted systems.

4. **Materials innovation:** fluorescent polymers, nanomaterials, quantum dots, and functional surfaces enhance sensitivity.

5. **AI and real-time analysis:** multi-sensor fusion, threat recognition, and assistance to decision-making.

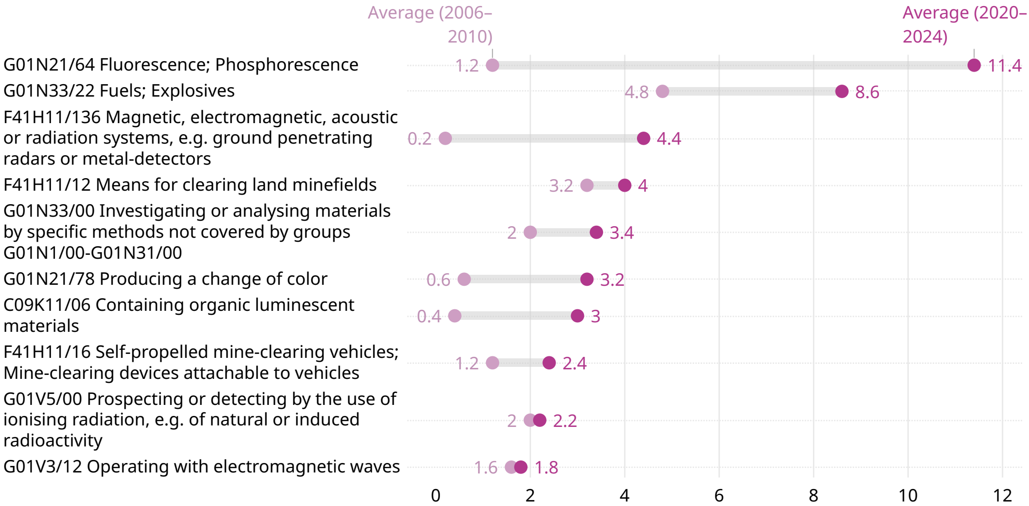
6. **Safety and operational focus:** Remote, standoff, and automated detection reduces risk to operators.

The evolution of mine detection technologies was analyzed through patent classification, a system of language-independent symbols for categorizing patents according to technological area.[2] By comparing the average number of patents in different classification areas between 2006–2010 and 2020–2024 (Figure 5), relatively higher average patent counts were found for specific subgroups in 2020–2024 compared to the time period 2006–2010. There would seem to be a growing interest in the detection of explosives using chemical or physical methods (G01N33/22) such as fluorescence and phosphorescence techniques (G01N21/64) and GPR systems (F41H11/136). There has also been a small trend in the use of optical means in mine detection, for example, using color change and Raman scattering (G01N21/78).

2 See International Patent Classification (IPC) system, available at: https://www.wipo.int/en/web/classification-ipc

Analysis of patents published suggests a growing interest in explosive substance detection using fluorescence and phosphorescence techniques

Figure 5 Patent counts in different patent classifications for mine detection technologies, 2006–2010 and 2020–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

Clearance technologies

The clearance process is an essential component of land release activities, which is preceded by non-technical survey and technical survey. Clearance refers to the tasks or actions required to ensure the removal and/or destruction of all EO within a specified area, to a specified depth or other agreed parameters. These parameters are defined by the National Mine Action Authority (NMAA) or the relevant tasking authority.[3]

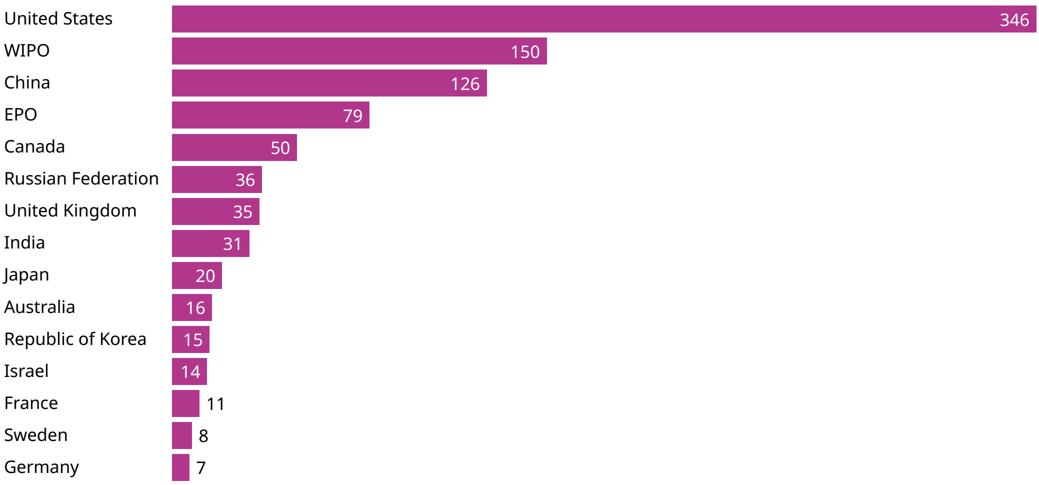
Between 2004 and 2024, 980 patent families were published related to mine clearance technologies, with publications having remained relatively steady since 2005 (Figure 2).

The highest number of patent families were published in the United States (346), followed by Patent Cooperation Treaty (PCT) applications filed at WIPO (150) and then in China (126), as shown in Figure 6. This is in contrast to patent families in detection technologies where the highest number were published in China.

3 IMAS (2024). IMAS 04.10 – Glossary of Mine Action Terms, Definitions and Abbreviations, Second Edition, Amendment 12, October 25, 2024. International Mine Action Standards. Available at:

In contrast to detection technologies, the largest number of patents in clearance technologies were published in the United States

Figure 6 Top filing jurisdictions for clearance technologies, by earliest publication year, 2004–2024

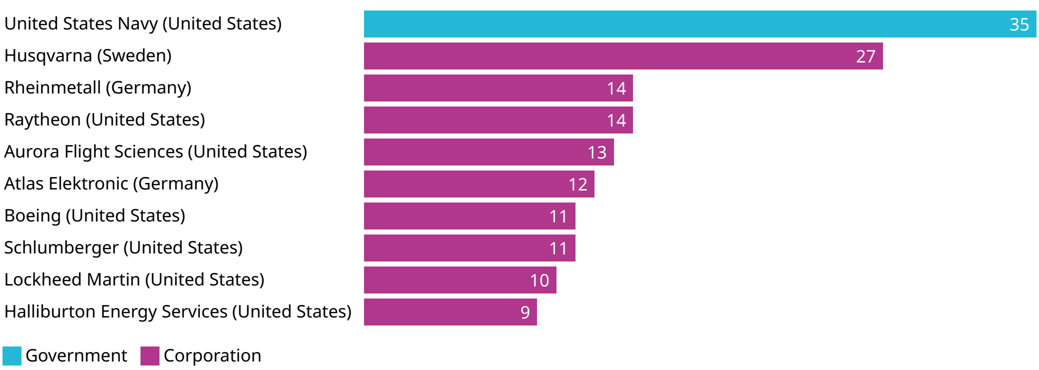


Note: EPO is the European Patent Office and WIPO is the World Intellectual Property Organization.
Source: WIPO, based on patent data from Patsnap, May 2025.

As Figure 7 shows, the top patent owner in clearance technologies is the United States Navy, with 35 published patent families, followed by Husqvarna (Sweden, 27) and Rheinmetall (Germany, 14). Similar to detection technologies, the top patent owners are associated with either the defense or security sectors.

The top patent owners are associated with the defense or security sectors

Figure 7 Top patent owners for mine clearance technologies, 2004–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

Unsurprisingly, the United States, with a dominance in the defense and security sectors, was the location that had the highest inventor concentration in mine clearance technologies, with 359 patent families originating in that country (Table 1). Published inventor addresses were used to determine where the research took place. China had the next highest inventor concentration, with 127 patent families originating in that country.

The United States' dominance in the defense and security sectors makes it the location with the highest inventor concentration in clearance technologies

Table 1 Top inventor locations for clearance technologies, 2004–2024

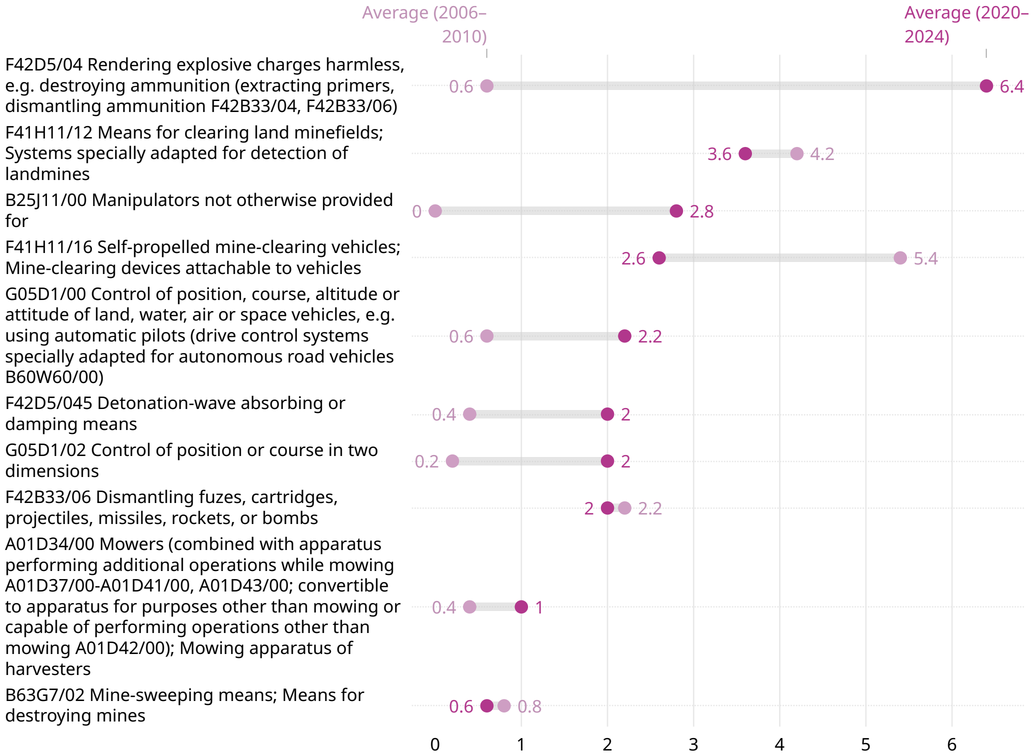
Inventor location	Patent count
United States	359
China	127
Germany	50
Sweden	39
Japan	38
Russian Federation	38
France	34
India	31
Canada	31
United Kingdom	26

Source: WIPO, based on patent data from Patsnap, May 2025.

By comparing the average number of patents in different patent classification areas between 2006–2010 and 2020–2024 in the clearance dataset (Figure 8), an increase in filings for patents related to technologies for rendering explosive charges harmless (F42D5/04) or detonation-wave absorbing means (F42D5/045) was found. Patent filings have also increased in the area of manipulators (B25J11/00) and special use aircrafts (B64C39/02), suggesting advances in applications for manipulators and/or industrial robots and aircrafts/UAVs in clearing EO. At the same time, although it has been a consistent presence, activity in the area of self-propelled mine-clearing vehicles (F41H11/16) has been on the decline.

There is a growing number of patents published in rendering explosives harmless including using robots and UAVs

Figure 8 Patent counts in different patent classifications for clearance, 2006–2010 and 2020–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

Personal protective equipment

Safety is a paramount principle of mine action. Personal protective equipment (PPE) is particularly important when conducting clearance, as deminers work within very close proximity to EO. Protective and blast-protected body suits, helmets, screens, safety gloves and boots are some examples of PPE used by deminers. Blast shields, protective barriers and such like are other examples of safety equipment to be found.

Alongside technological advances in detection and clearance technologies, the safety of personnel has remained a central concern. There were a total of 891 published patents related to PPE. There was a peak in patent publications between 2011 and 2016, with patents dropping off slightly afterward before picking up again in 2024 (Figure 2). Innovations in PPE have maintained steady prominence, with notable activity peaks in 2018, 2020 and again in 2024. This focus complements developments in armored vehicles, protective garments and defensive devices, reflecting a broader application-domain emphasis on safeguarding both deminers and equipment operating in high-risk environments.

The United States has a dominant lead in top jurisdictions for PPE patents, with 538 published patent families, followed by China, the EPO and WIPO, with publication numbers within the 70–80 range (Figure 9).

The United States significantly dominates patent publications in PPE

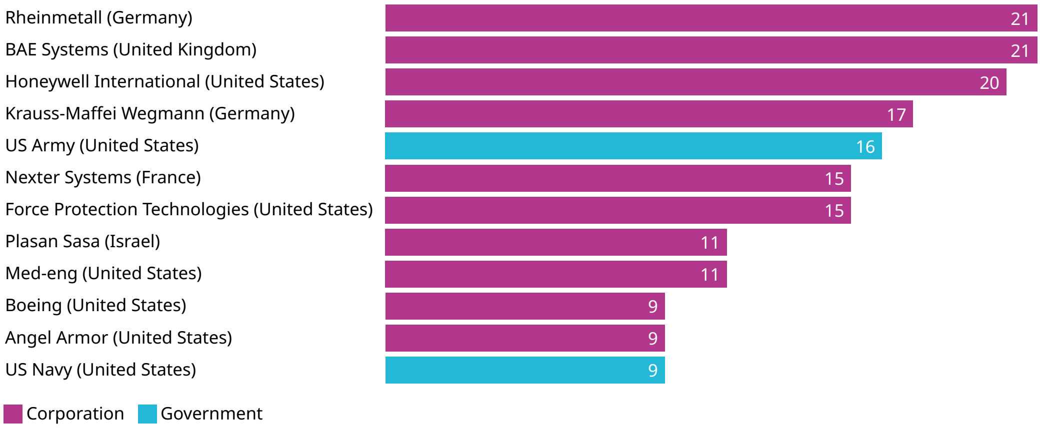
Figure 9 Top filing jurisdictions for PPE, by earliest publication year, 2004–2024

Note: EPO is the European Patent Office and WIPO is the World Intellectual Property Organization.
Source: WIPO, based on patent data from Patsnap, May 2025.

Rheinmetall (Germany) and BAE Systems (United Kingdom) are the top patent owners, with 21 patents each, followed by Honeywell (United States), with 20 patents (Figure 10). However, of the 25 top patent owners, 15 are US-based, consistent with the United States being the top jurisdiction.

The majority of patent owners are based in the United States, consistent with the United States being the top jurisdiction

Figure 10 Top patent owners for PPE, 2004–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

Thus, it also follows that the top inventor location for PPE patents is the United States, followed by Germany and the United Kingdom (Table 2).

Given the dominance of the United States in PPE patents, it is not surprising that it is also the top inventor location

Table 2 Top inventor locations for PPE, 2004–2024

Inventor location	Count
United States	414
Germany	74
United Kingdom	48
France	49
Canada	31
Israel	25
India	22
Netherlands	14
Australia	11
Republic of Korea	10

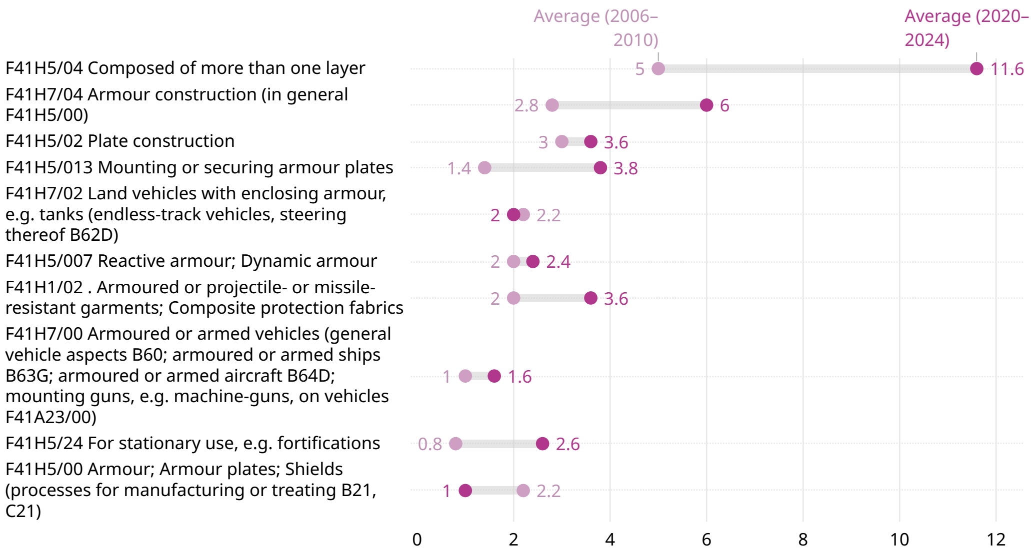
Note: Netherlands is the Kingdom of the Netherlands.
Source: WIPO, based on patent data from Patsnap, May 2025.

By comparing the average number of patents in different patent classification areas between 2006–2010 and 2020–2024 in the PPE dataset, no remarkable changes in patent filings within different technical categories between the two time periods were observed (Figure 11). There has been a growth in the number of patents in the area of multilayer armor plate construction

(F41H5/04), indicating continued and increasing interest in multilayer armor systems likely to be relevant for PPE and vehicle protection. Other categories, such as blast protecting garments, helmets, shields and footwear, have maintained a low but steady presence during both time periods.

Apart from multilayer armor construction, which has shown significant growth recently, other areas show low but steady growth in patent publications

Figure 11 Patent counts in different patent classifications for PPE, 2006–2010 and 2020–2024



Source: WIPO, based on patent data from Patsnap, May 2025.

Summary and looking ahead

Main trends

Analysis of the application domains highlights and confirms two recurring observations in mine action related innovation over the past 20 years: the strong influence of defense-related R&D and a focus on sensors and detection:

- Defense R&D dominates the global innovation landscape, reflecting the strong role played by the military and their much greater defense budgets in shaping technological innovation related to mine action. Although many technological advances and inventions have positively impacted mine action, many are for military purposes and requirements, such as mine clearance linear charges or armored systems that may have limited applicability to mine action.
- Sensors and detection remain the largest category of patenting activity, although it should be noted that only a very few patents have translated into applicable mine action uses, either due to the high cost or a lack of understanding as to the operational requirements for fieldable solutions in mine action.
    - Fluorescence/phosphorescence and chemical indicator-based material analysis point to sustained interest in chemical sensing for explosive detection, where optical or chemical reactions are used to identify explosive residues.
    - Acoustic wave reradiation and radio wave reflection/response highlight the importance of physical wave-based detection, often associated with GPR or acoustic sensing of subsurface objects.
    - Nuclear radiation detection, while less common, indicates attempts to explore niche, but highly sensitive methods for distinguishing explosives underground.Electric/ magnetic analysis and electric/magnetic detection capture patents linked to metal detection and electromagnetic methods, which remain the operational backbone of humanitarian demining.
    - Electric/magnetic analysis and electric/magnetic detection capture patents linked to metal detection and electromagnetic methods, which remain the operational backbone of humanitarian demining.
- Sample withdrawal devices underscore the challenge of obtaining representative soil or air samples for analysis – an enabling technology for many chemical detection systems.

The analysis of global patent trends highlights a sustained effort to leverage advances in other technological domains for mine action purposes, for example, robotics and UAV technologies, AI-assisted systems, geophysical sensing, and detection and chemical detection of explosive substances. However, despite the significant technological momentum, challenges remain in translating R&D into real-world applications that are both cost-effective and scalable in EO affected regions.

Looking ahead

Looking ahead, the mine action sector faces the crucial task of balancing the need for continued innovation with the imperative of providing affordable and widespread access to life-saving technologies. Patents play a vital role in encouraging investment into new technologies, but the IP landscape should evolve, so as to better align with the humanitarian needs of the sector. Findings from the analysis point in the direction of a greater collaboration between mine action organizations, non-military private sector innovators and governments. By fostering cooperative models, not only can the sector better align needs and responses, but also promote shared ownership and transparent licensing mechanisms, ensuring that the benefits of innovation are more widely accessible. Open data frameworks and humanitarian licensing models could be explored in order to facilitate equitable access to critical technologies, particularly in resource-constrained settings where cost barriers are most acute.

The patent dataset reveals a significant variation in patenting activity within the mine action sector. While some organizations actively engage in patenting, many others show little to no activity. This could be due to a range of factors outside the scope of the study.

Another key observation from the analysis is the limited patent activity originating from or protected within those countries affected by EO. Despite the global demand for mine action technologies, these regions contribute very few patents, presenting a significant opportunity to harness the knowledge embedded in patents from other parts of the world. Accessing and utilizing these patents could enable EO-affected countries to adapt existing technologies to the local context and promote the transfer of life-saving innovations.

Moreover, insights from patent data can serve as a strategic tool to guide technology development and deployment. Patent trends provide valuable intelligence on emerging technologies, market dynamics and areas of high innovation potential. By leveraging this information, the sector can identify promising solutions, anticipate future trends and strengthen partnerships with technology providers. Effective technology transfer mechanisms, informed by patent activity, can further ensure that innovations are adapted to the operational realities of mine action, reaching those who need them most. Moving forward, the community should prioritize mechanisms that balance commercial incentives with the urgency of humanitarian goals, ensuring that IP rights facilitate rather than hinder the timely deployment of demining technologies.

Acronyms

AI	artificial intelligence
EO	explosive ordnance
EPO	European Patent Office
GICHD	Geneva International Center for Humanitarian Demining
GPR	ground-penetrating radar
IMAS	International Mine Action Standards
IP	intellectual property
IPC	International Patent Classification
MA	mine action
NMAA	National Mine Action Authority
NQR	nuclear quadrupole resonance
NTS	non-technical survey
PCT	Patent Cooperation Treaty
PPE	personal protective equipment
R&D	research and development
RGB	red green blue
UAV	unmanned aerial vehicle
UK	United Kingdom
US	United States of America
UXO	unexploded ordnance
WIPO	World Intellectual Property Organization

Appendix

Supplementary data

Table A1 Patent family publications related to detection, clearance and PPE by earliest publication year, 2004–2024

Publication year	Detection	Clearance	PPE
2004	81	71	13
2005	65	40	11
2006	66	29	18
2007	64	39	20
2008	57	38	29
2009	63	38	27
2010	57	50	45
2011	66	36	60
2012	82	50	72
2013	83	43	69
2014	78	36	73
2015	76	44	67
2016	87	52	49
2017	88	41	38
2018	101	52	39
2019	130	55	31
2020	93	51	40
2021	94	49	38
2022	84	56	36
2023	77	48	38
2024	85	62	78

Source: WIPO, based on patent data from Patsnap, May 2025.

Search strings

All searches were conducted using the Patsnap patent database in May 2025.

The datasets were reviewed manually to eliminate any irrelevant patents.

Detection

(TAC: ((IDENTIF* OR DETECT* OR SURVEY* OR MAP* OR ANALYZE OR ANALYSE OR ANALYSIS) $W3 (MINE OR LANDMINE OR ORDNANCE OR MUNITION OR BOMB OR EXPLOSIVE OR SUBMUNITION OR EOD OR UXO OR IED OR EO OR ERW)) AND PBD:[20040101 TO 20241231]) NOT (DATA $W5 (MINE OR MINING)) NOT (COAL) NOT IPC: E21

Clearance

((TAC:DEMINING OR ((MINE OR LANDMINE OR ORDNANCE OR MUNITION OR BOMB OR EXPLOSIVE OR SUBMUNITION OR EOD OR UXO OR IED OR EO OR ERW) $W5 (CLEAR* OR NEUTRALI* OR DISPOS* OR DESTRUCT*)) $W5 (VEHICLE* OR MACHINE* OR INSTRUMENT OR TOOL OR APPARATUS OR GADGET OR CONTRAPTION OR EQUIPMENT OR LASER OR BIO* OR FLAIL* OR CUTTER OR TILLER OR SHOVEL OR SIFTER OR ROLLER)) AND PBD:[20040101 TO 20241231]) NOT COAL

Personal Protection Equipment (PPE)

TAC:((LAND_MINE# OR SEA_MINE# OR "NAVAL MINE#" OR "UNDERWATER MINE#" OR "UNDERSEA MINE#" OR "BOUNDING MINE#" OR "BOUNCING BETTY MINE#" OR "DIRECTIONAL MINE#" OR "CLAYMORE MINE#" OR "FRAGMENTATION MINE#" OR "BUTTERFLY MINE#" OR "MINIMUM METAL MINE#" OR "SELF_DESTRUCT* MINE#" OR "COMMAND_DETONATED MINE#" OR "DUMMY MINE#" OR "REMOTE_DETONATED MINE#" OR "ANTI_TANK MINE#" OR "ANTI_VEHICLE MINE#" OR "ANTI_PERSONNEL MINE#" OR "SCATTERABLE MINE#" OR "DISPENSER MINE#" OR "SENSOR_ACTIVATED MINE#" OR UXO OR IEDD OR "UNEXPLODED ORDNANCE" OR "EXPLOSIVE ORDNANCE" OR "EXPLODED ORDNANCE" OR "CLUSTER MUNITION#" OR "IMPROVISED EXPLOSIVE DEVICE" OR "EXPLOSIVE REMNANTS" OR REMNANTS $PRE2 WAR)) AND TAC:(SUIT OR OVERALLS OR APRON# OR HELMET# OR GOGGLES OR "EYE SHIELD" OR BOOTS OR SHOES OR "EAR MUFFS" OR "EAR DEFENDERS" OR GLOVES OR RESPIRATOR# OR MASK#)

This WIPO Technology SPARK Report on *Technologies for Mine Action* provides an overview of global patenting trends in mine action technologies, focusing on detection, clearance, and personal protective equipment.

The analysis reveals a shifting trend toward remote sensing technologies with growing interest in autonomous systems and artificial intelligence-based decision making. These developments support the industry-wide goal of enhancing mine action safety and efficiency by minimizing human exposure to dangerous conditions.