# Dual use security robotics: a demining, resupply and reconnaissance use case

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*Abstract*— **As robots are more and more leaving the protected lab environment, they are also more and more used for civil security and military use cases. Very often, these civil and military robotics development projects share large similarities and there is a substantial potential for dual use. In this paper, we will present and study three practical European projects where security field robots are being developed. The AIDED project focuses on the development of demining robots, whereas within the iMUGS project, a resupply scenario is considered. Finally, the CUGS project builds on the iMUGS developments and explores more in detail the reconnaissance use case.**

## I. INTRODUCTION

The advent of more intelligent and more affordable robotic solutions has sparked the introduction of these robotics tools for multiple security - related applications. In many cases, a clear parallel can be observed between civilian and military use cases for these security robots. As an example, security guard robots that guard the perimeter of an industrial facility could be compared to military force protection robots that protect military encampments. Similarly, civil security search and rescue robots that can assist search & rescue workers in their search for survivors after a major disaster can be compared to military ISTAR (Intelligence, surveillance, target acquisition, and reconnaissance) robots that seek intruders and enemies within an area. Also in the domain of logistics, such an analogy can be observed: while the first commercial delivery robots can nowadays be spotted on the sidewalks, also military end users want to make use of similar tools in order to lift the burden of carrying heavy gear. Furthermore, there are typical dual use applications like demining where similar (robotics) technologies can be used.

All this does not imply that there are no differences between the civilian and military use cases. To come back to the demining example: there is a clear difference between humanitarian demining [1] which happens post-conflict and has as an objective to release the mine-infested land to the civilian population and military demining [2] which has as an objective to breach a passage for the troops to pass. As such, there are very different requirements: humanitarian demining can take some time, but should reach a near-100% clearance ratio, while military demining needs to be quick, but some margin of error is tolerated.

One of the main characteristics of military applications compared to civil security is the requirement for advanced mobility on rough terrain. This poses important mobility constraints on unmanned ground systems (UGS), as navigating rough unstructured terrain requires a careful consideration of the design of the vehicle drivetrain, dynamics and control mechanism [3]. Arguable, one could say that for this reason, military security robots bear high similarities to civil security search and rescue robots [4] that also need to be able to negotiate very rough terrain and also require a fast deployment capability and a capability to operate under difficult outdoor conditions [5].

Another difference between military security robots and their civilian brethren is that military applications often require low observability and high robustness, which implies not only a reduced RF signature sensors, but also that popular sensors like LIDAR (easily visible for enemy forces) and GNSS (can easily be jammed or spoofed) should be avoided.

In a military context, it is often the case that multiple countries partner up in an alliance on the battlefield. In this case, it is essential that the data obtained by one partner can easily flow to the alliance partners, so interoperability is key. While this is also a point of attention in the civilian world, e.g. through the use of ROS(2) as an open-source robotics middleware suite, this goes much further in the military world, as it is a driving force behind the adoption of not only common reference (software & hardware) architectures, but also e.g. standardized approaches towards multi-domain robot control [6].

Obviously, cybersecurity is much more important for military security robots compared to civilian systems, as hacking, spoofing or data theft from these systems could have disastrous consequences, which is why in general targeted cyber-proof solutions are adopted [7].

Finally, military security robots can (depending on their purpose) have either direct or indirect (e.g. if the information they provide is incorrect) lethal consequences. This is why the ethics constraints on military security robotics are invariably much tougher than for their civilian counterparts. Notably, the aspects of meaningful human control in the decision process [8], explainability of choices taken by the autonomous system and the calibration of a correct level of trust [9] between the human operator and the robotics systems are key aspects in the design of the control paradigm of military robotics systems.

This paper will now study three use cases where security robots have been (or are being) developed in the context of several European projects. For each of these use cases, we will discuss the choices in the design process.

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## II. DEMINING ROBOTICS: THE AIDED USE CASE

The use of Explosive Ordnance (EO) like Improvised Explosive Devices (IEDs) and landmines has become more prevalent in recent conflicts like those in Ukraine, Afghanistan, Iraq, and Syria. This leads to increased casualties among EU and NATO member and partner states. To substantiate this, IEDs alone account for around half of all soldier deaths in action. However, also long after the conflict is over, IEDs and landmines wreak havoc on the civilian population (and specifically on children who are less aware of the dangers).

Multi-agent robotic systems have the potential to increase the efficiency and effectiveness of IED detection operations, as they can cover a larger area and share information to make more informed decisions. Furthermore, using robots can reduce the risk of harm to human operators, as robots can be remotely operated or even work autonomously. However, there exists a large gap between demining robotics that are developed in research labs and the reality on the terrain, where true intelligent robotic tools are still scarcely used.

To address this issue, the European Union has decided to funded the AIDED (Artificial Intelligence for the detection of explosive devices) project. AIDED researches and integrates cutting-edge technologies to; i) Identify both unconventional and conventional explosive devices, such as buried mines and IEDs; ii) Efficiently plan robotic demining missions both offline and in real-time.

Demining sensing technologies have to adapt to the evolution of the mines used in conflicts. While the use of Electromagnetic Induction (EMI) arrays (metal detectors) alone was effective for the detection of traditional mines, plastic mines and IEDs that contain no or low levels of metal make it now insufficient. This is why metal detectors need to be coupled with a Ground Penetrating Radar (GPR) [10] for enabling the detection of non-metallic objects and reducing the number of false detections by differentiating any metallic object from a potential IED. The use of a Laser Induced Breakdown Spectroscopy (LIBS) sensor can further enhance the accuracy of detection [11].

In order to achieve a robust and high detection ratio with few false positives, an intelligent data fusion scheme is required in order to incorporate all the sensor measurements. To achieve this, the system uses AI-machine learning techniques, including deep learning, to train on simulated and real datasets from various sensors such as Ground Penetrating Radar (GPR), EMI, infrared and thermal cameras. A major problem is the incompleteness of the data for training, as it is impossible to incorporate in the dataset each imaginable IED in each type of soil. AIDED is as such a case study for dealing with limited resources to train a robust classifier.

The AIDED Multi-Robot System (MRS) consists of two UGVs (a Teodor robot [12] with an array of metal detectors & a LIBS and a Husky robot with a metal detector) and one UAV equipped with a GPR to detect EO that are visible, buried, or hidden. The multi-agent robotic system also uses AI-machine learning techniques for positioning, navigation, and mapping to achieve robustness and independent operation, even in GNSS-denied environments.

AIDED proposes a cooperation strategy between centralized and decentralized mission planning algorithms, which have been developed based on different AI architectures. This strategy aims to provide a conflict-free distribution of tasks among the agents, along with optimal path planning. The AIDED mission planning tool allows to monitor the state of the UxVs (Online or Offline), visualize and analyze all the data received from the different robots and configure missions with their goals. A human-friendly graphical user interface (GUI) is presented to the EO operators to configure a mission with all the assets at hand. The offline planner enables the operator ro choose an optimal plan for deploying the robots, as the offline planner optimizes the use of the robots based on their position and the time.

In many aspects, the military demining project AIDED is a further development of components of the humanitarian demining project TIRAMISU [1], where adaptations are made in order to fit the military use case, mainly by rendering the operations faster. Specifically, where TIRAMISU followed a serialized approach towards area reduction and close-in detection, AIDED follows a much more parallel approach where multiple agents with heterogeneous sensing abilities are deployed simultaneously, thereby greatly increasing the speed of the demining operation.

Fig. 1. Three AIDED robots simultaneously at work while scanning a minefield

## III. Resupply Robotics: The iMUGS Use Case

An often-neglected, but very important use case for security robotics is logistics. Indeed, whether it are search and rescue workers, firefighters or military units, all these end users have to deal with the problem of carrying around often very heavy gear, which hinders them in their own mobility and reduces their ability to work. Mobile robotic tools can provide an answer to this question, provided that they do not slow down the human operators, as this is the prime requirement in almost all terrain logistics applications.

In the framework of the European project iMUGS, a modular multi-robot solution was developed, enabling a seamless collaboration between military operators and robotic assets. iMUGS focused specifically on the development of standard architectures and interfaces enabling multi-robot collaboration and this for multiple use case scenarios: casualty evacuation, intelligence, surveillance, target acquisition, and reconnaissance and also resupply. In this paper, we will concentrate specifically on the outputs of the project related to the logistics scenario of performing a resupply operation.

However, in order to explain the iMUGS concept [13], first the developed iMUGS architecture is explained briefly. This architecture incorporates a mobile C2 center that enables manned-unmanned field squads to work together. A human-multi-robot architecture can use a data-centric approach, where the C2 vehicle collects and analyzes data from all agents on a single node. However, this depends on communication quality and security. The iMUGS architecture distributes the system functions over the network fog and edge layers. The C2 vehicle has the main computing power in the fog layer, while the manned-unmanned vehicles have less computing power in the edge layer. The iMUGS MRS module takes high-level mission information from the operators and assigns tasks to each robot in the team. The MRS module can handle different mission types, such as resupply. The operator can give information about the mission, the team, and the strategy through a map interface. The MRS module then computes a high-level trajectory with waypoints for the Autonomy module in each robot. A hybrid architecture is developed, using both a centralized and a decentralized approach. The centralized approach uses the fog layer to make decisions based on the whole team's data. However, it needs good communication between the robots and the command post. Communication problems in hostile fields can affect the centralized approach, so a second approach is developed and integrated into each edge device. This approach can use local communication with nearby team members or their own perceptions to estimate the team's state and the environment's changes. The two approaches must be compatible and exchange information with other modules. The centralized approach is the default mode, using the network data to optimize the MRS resources. The decentralized approach is activated when communication is lost or degraded, computing the trajectory to complete or continue the mission until the C2 link is restored. Both approaches must be updated for a smooth control switch.

In order to validate the iMUGS architecture, a resupply scenario was defined where robots and humans work together in urban warfare. The paper describes a scenario where robots help to resupply friendly troops with ammunition during a battle. The robots include:

- 1 Boxer vehicle for controlling the mission
- 3 Themis UGS for scouting
- 5 Summit UGS for delivering supplies

The different vehicles are equipped with heterogeneous sensor kits, such that each one of them brings extra information towards the mission controller installed in the Boxer control vehicle.

A human – centred design approach [14] was followed within the iMUGS project in order to take into consideration the needs and requirements of the military end users during each step of the design process.

The trial involved the Belgian Land component as actors, users and evaluators of the UGS tools. They had to adapt their procedures and tactics to use the new tools. This shows that using robots in military operations is not easy or simple, but needs planning and training. Nevertheless, the team worked well with the robots and met all the technical requirements.

In many aspects, the military project iMUGS on MRS for resupply builds further on earlier work in the EU project ICARUS [15], where MRS were developed for a search and rescue scenario. Also in ICARUS, as standardized architecture enabling interoperability and collaboration was developed [16] and the iMUGS architecture can be regarded as a further evolution of this, which stresses again the links between civil and military security robotics developments.

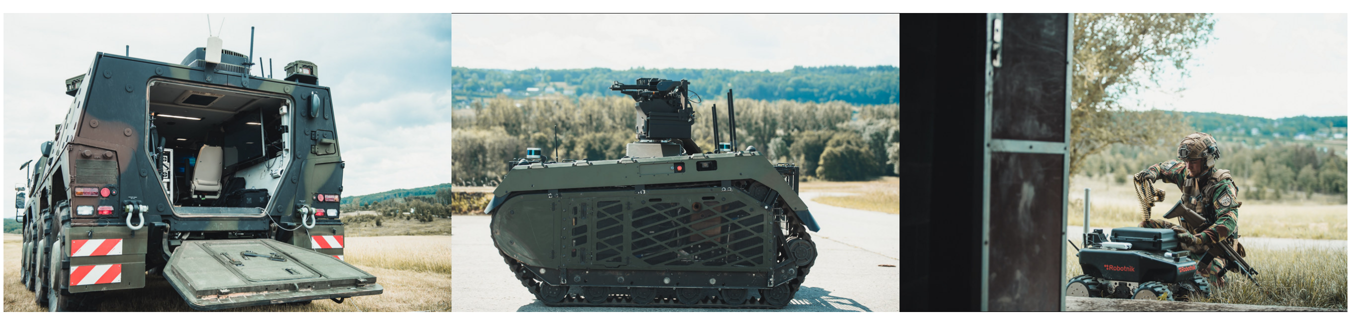

Fig. 2. From left to right: The Boxer mobile control vehicle; The Themis scouting robot; One of the Robotnik resupply robots providing ammunition

## IV. RECONNAISSANCE ROBOTICS: THE CUGS USE CASE

Combat Unmanned Ground Systems can enhance the safety, robustness and resilience of ground forces. To achieve this vision, the European Defence Agency has decided to fund the CUGS project, which focuses on four key aspects of UGS: 1) Platforms; 2) Navigation; 3) C3 and cooperation; 4) Effector management. In comparison tu iMUGS, much larger platforms are also considered (see Fig. 3) and effectors are also incorporated in the study.

This paper focuses on the Belgian contribution to this project which deals with the second aspect: autonomy & navigation. Autonomy and navigation of UGS are challenging because they need to work in any environment and weather conditions. This study will develop a way for UGS to estimate how traversable the terrain is, based on their sensors, and use this information for autonomous navigation and situational awareness. Another development in this study will be a method for UGS to access and interpret maps from drones or satellites and use them for autonomous navigation and situational awareness. This is a crucial feature that is lacking in current UGS, which often rely on unrealistic assumptions about the terrain knowledge, which do not match the reality. Finally, this study will develop local swarming capabilities, enabling multiple combat UGS to work together as a coordinated team in a distributed manner, without relying on a central command and control station. This development builds upon the research performed within the iMUGs project, where the focus is more on global swarming (which implies centrally coordinated swarm behaviour). In realistic military operations a centralised command cannot always be ensured (or is unwanted due to radio silence requirements), which means that a decentralised, distributed swarming approach is highly required for combat UGS.

The CUGS project is still in its early phases and while its application is quite military-oriented, also for this project there are important parallels to be found with developments in the domain of civil security robotics.

As an example, the research work performed within CUGS on terrain traversability analysis is based on the work on traversability in the civil security robotics projects ViewFinder (on crisis management robotics) [17] and ICARUS (on search and rescue robotics) [18]. CUGS will develop a novel hybrid methodology towards terrain traversability analysis. This approach will apply AI & machine learning on the full 3D data stream (such that no information is lost), in order to derive terrain features that will be employed to build up a terrain model. This terrain model will be used as a basis for autonomous navigation behaviors such as route following & obstacle avoidance and will also be fed as input to the situational awareness.

Also in the domain of mapping, CUGS will build further of earlier work performed in the domain of search and rescue robotics [19], with a focus on developing and streamlining an air-to-ground map portability workflow, enabling combat UGS to seamlessly interpret and directly use data that has been captured (before) by airborne and / or spaceborne assets.

Finally, CUGS will bridge existing practical gaps between theory and implementation of scalable multi-agent collaboration and optimization, which should ensure operations in mission-critical unstructured outdoor environments. Building on the developments in iMUGS (where the focus is on global swarming approaches), CUGS concentrates more on developing local optimization approaches, relying also upon local (edge) information and dealing with the constraints of limited computational power.


Fig. 3. Robotic vehicles used in the CUGS project

## V. CONCLUSIONS

Military and civil security robotics are both fields that use robots to perform tasks that are dangerous, difficult or dull for humans. There are multiple similarities between them, opening the door for dual use applications. Indeed, both use robots for surveillance, inspection and detection of threats, such as explosives, chemical agents, intruders or terrorists. Moreover, both use robots for remote operation and communication, such as telepresence, video conferencing or data transmission. Furthermore, both face cybersecurity challenges and need to protect their robots from hacking, spoofing, jamming or denial-of-service attacks. However, there are also important differences. Military robots may be equipped with effectors / weapons and used for combat. As a result, ethics, human oversight and accountability are very important in the control process of military security robots. Military robots also may have higher requirements for autonomy, lethality, manoeuvrability, survivability and sustainability, while civil security robots may have higher requirements for safety. Finally, military security robots may operate in more diverse and hostile environments, such as deserts, jungles, mountains or urban areas, while civil security robots may operate in more controlled and regulated environments, such as airports, stadiums, malls or hospitals13.

In this paper, we prepared three use cases of military security robotics research projects that are strongly connected to civil security robotics projects. We have shown how developments from one domain influence the developments in the other domain, thereby making a case for dual use applications.

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## REFERENCES

[1] Y. Yvinec, Y. Baudoin, G. De Cubber, M. Armada, L. Marques, J.-M. Desaulniers, and M. Bajic, "Tiramisu: Fp7-project for an integrated toolbox in humanitarian demining," in *GICHD Technology Workshop*, 2012.

[2] M. Prem, M. E. Purroy, and J. F. Vargas, "Landmines: The local effects of demining," 2022.

[3] J. Suthakorn, S. S. H. Shah, S. Jantarajit, W. Onprasert, W. Saensupo, S. Saeung, S. Nakdhamabhorn, V. Sa-Ing, and S. Reaungamornrat, "On the design and development of a rough terrain robot for rescue missions," in *2008 IEEE International Conference on Robotics and Biomimetics*, pp. 1830–1835, IEEE, 2009.

[4] K. Berns, A. Nezhadfard, M. Tosa, H. Balta, and G. De Cubber, "Chapter unmanned ground robots for rescue tasks," 2017.

[5] G. De Cubber, D. Doroftei, H. Balta, A. Matos, E. Silva, D. Serrano, S. Govindaraj, R. Roda, V. Lobo, M. Marques, *et al.*, "Operational validation of search and rescue robots," in *Search and Rescue Robotics-From Theory to Practice*, InTech Rijeka, 2017.

[6] W. Müller, F. Segor, D. Mühlenberg, B. Driessen, V. De Geus, Z. Papp, P. Svenmarck, A. Kalis, and A. Amditis, "Interoperability of armed forces unmanned systems: the interact project," in *Open Architecture/Open Business Model Net-Centric Systems and Defense Transformation 2023*, vol. 12544, pp. 206–217, SPIE, 2023.

[7] V. Mayoral-Vilches, "Robot cybersecurity, a review," *International Journal of Cyber Forensics and Advanced Threat Investigations*, 2022.

[8] J. van Diggelen, K. v. d. Bosch, M. Neerincx, and M. Steen, "Designing for meaningful human control in military human-machine teams," *arXiv preprint arXiv:2305.11892*, 2023.

[9] D. Doroftei, T. De Vleeschauwer, S. L. Bue, M. Dewyn, F. Vanderstraeten, and G. De Cubber, "Human-agent trust evaluation in a digital twin context," in *2021 30th IEEE International Conference on Robot Human Interactive Communication (RO-MAN)*, (Vancouver, BC, Canada), pp. 203–207, IEEE, Aug. 2021.

[10] D. Ambruš, D. Vasić, V. Bilas, L. Marsh, J. Davidson, and A. Peyton, "Embedding target discrimination capabilities into commercial handheld metal detectors for humanitarian demining," pp. 167–172, 2016.

[11] L. Cardona, J. Jiménez, and N. Vanegas, "Landmine detection technologies to face the demining problem in antioquia," *Dyna*, vol. 81, pp. 115–125, 2014.

[12] G. De Cubber, H. Balta, and C. Lietart, "Teodor: A semi-autonomous search and rescue and demining robot," in *Advanced Concepts on Mechanical Engineering (ACME)*, 2014.

[13] E. Le Flecher, A. La Grappe, and G. De Cubber, *iMUGS - A ground multi-robot architecture for military Manned-Unmanned Teaming*. IEEE, 2022.

[14] D. Doroftei, G. De Cubber, R. Wagemans, A. Matos, E. Silva, V. Lobo, K. C. Guerreiro Cardoso, S. Govindaraj, J. Gancet, and D. Serrano, *User-centered design*, ch. Chapter 2, pp. 19–36. InTech, 2017.

[15] G. De Cubber, D. Doroftei, D. Serrano, K. Chintamani, R. Sabino, and S. Ourevitch, "The eu-icarus project: Developing assistive robotic tools for search and rescue operations," in *2013 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, pp. 1–4, 2013.

[16] D. S. López, G. Moreno, J. Cordero, J. Sanchez, S. Govindaraj, M. M. Marques, V. Lobo, S. Fioravanti, A. Grati, K. Rudin, *et al.*, "Interoperability in a heterogeneous team of search and rescue robots," *Search and Rescue Robotics-From Theory to Practice*, pp. 93–125, 2017.

[17] Y. Baudoin, D. Doroftei, G. De Cubber, S. A. Berrabah, C. Pinzon, F. Warlet, J. Gancet, E. Motard, M. Ilzkovitz, L. Nalpantidis, and A. Gasteratos, "View-finder : Robotics assistance to fire-fighting services and crisis management," in *2009 IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR 2009)*, pp. 1–6, 2009.

[18] G. De Cubber, D. Doroftei, H. Sahli, and Y. Baudoin, "Outdoor terrain traversability analysis for robot navigation using a time-of-flight camera," in *RGB-D Workshop on 3D Perception in Robotics*, 2011.

[19] H. Balta, J. Velagic, H. Beglerovic, G. De Cubber, and B. Siciliano, "3d registration and integrated segmentation framework for heterogeneous unmanned robotic systems," *Remote Sensing*, vol. 12, p. 1608, May 2020.