2025 IEEE International Conference on
Autonomous Robot Systems and Competitions (ICARSC)
Funchal, Portugal – April 2-3, 2025

Uncrewed Ground Vehicles in Military Operations: Lessons Learned from Experimental Exercises

Bruno Cândido*, Nuno Pessanha Santos†‡§, Alexandra Moutinho*, and João-Vitor Zacchi¶
*IDMEC, Instituto Superior Técnico (IST), Universidade de Lisboa, Lisbon, 1049-001, Portugal
†Portuguese Military Research Center (CINAMIL), Portuguese Military Academy, Lisbon, 1169-203, Portugal
‡Institute for Systems and Robotics (ISR), Instituto Superior Técnico (IST), Lisbon, 1049-001, Portugal
§Portuguese Navy Research Center (CINAV), Portuguese Naval Academy, Almada, 2810-001, Portugal
¶Fraunhofer IKS, Munich, 80686, Germany
E-mails: {bruno.candido, nuno.pessanha.santos, alexandra.moutinho}@tecnico.ulisboa.pt, joao-vitor.zacchi@iks.fraunhofer.de

***Abstract*—The ongoing evolution of modern warfare demands innovative solutions to enhance operational effectiveness and gain a competitive edge on the battlefield. Integrating Uncrewed Ground Vehicles (UGVs) transforms military operations by efficiently performing various tasks while minimizing risks to human life. Developing a UGV architecture that adapts to different mission profiles is essential, though accessing military information and conducting tests can pose challenges. Nonetheless, military experimentation exercises are crucial for ensuring optimal system performance and fostering collaboration between academia, industry, and the military, ultimately leading to more effective systems with direct military applications. This article shares lessons learned obtained through participation in the military experimentation exercises conducted by the Portuguese Army (PoA) and the Portuguese Navy (PoN) in 2024, aiming to accelerate future developments in UGV technology and promote their efficient use in military operations. Future work will focus on enhancing the platform by improving the algorithms used to boost its performance on the identified mission profiles and enabling its autonomous execution.**

***Index Terms*—robotics, uncrewed ground vehicles, military robotics, military operations, military.**

I. Introduction

The Armed Forces (AF) have consistently played a vital role in a country's innovation and scientific development [1]. This is driven mainly by the need for nations to maintain a competitive edge in military operations. This advantage typically requires better-trained personnel, quick and precise access to information for enhanced Command and Control (C2), and more advanced and capable equipment.

As mobile robotics advances, particularly in the field of Autonomous Vehicles (AVs) across air, land, and maritime domains in both academia and industry [2], it is reasonable to expect that the military will integrate these technologies into their operations [3], as seen recently in Russia's full-scale invasion of Ukraine. Integrating AVs into operations allows combat missions to be conducted safely, reducing the risk to human lives. Additionally, it has also improved C2 on the battlefield by enabling the collection of more information, which also supports Intelligence, Surveillance, and Reconnaissance (ISR) operations [4], among other essential tasks.

Uncrewed Ground Vehicles (UGVs) can perform various tasks in military operational scenarios with reduced human intervention. These activities include transporting loads, conducting medical evacuations, and engaging in direct combat operations with weaponry, among other mission profiles [5]. One of the most common military scenarios today involves operating in Global Navigation Satellite System (GNSS)-denied environments [6]. UGVs require suitable sensors and processing capabilities to implement Simultaneous Localization and Mapping (SLAM) algorithms [7], enabling navigation and task completion in hostile environments.

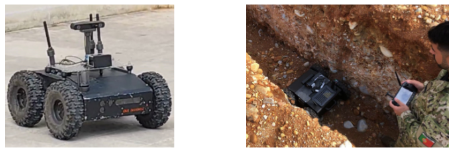

Fig. 1. Used UGV (*left*) and an illustration of a real operation (*right*).

The present study describes a proposed architecture for UGVs designed to meet the unique demands of military operations, as illustrated in Figure 1. Testing developed systems in real-world operations is crucial for gaining insights into future developments and achieving better outcomes, with military experimentation exercises playing a key role.

Military experimentation exercises are crucial for simulating real-world conditions, enabling effective testing and refinement of systems, improving team communication, and building trust among members. An analysis based on the participation in the Portuguese Army (PoA) Technological Experimentation Exercise (ARTEX) and the Portuguese Navy (PoN) Robotic Experimentation and Prototyping with Maritime Unmanned Systems (REPMUS) in 2024 will be conducted, as these exercises provided several opportunities to test personnel and equipment and gather essential knowledge. Whenever possible, field experience should always be documented and shared as lessons learned, especially in military operations.

This work is organized as follows: Section II outlines the proposed UGV intended for use during military operations. Section III details the critical military experimental exercises conducted. The lessons learned and recommendations from these exercises are discussed in Section IV. Finally, Section V presents conclusions and proposes future work directions.

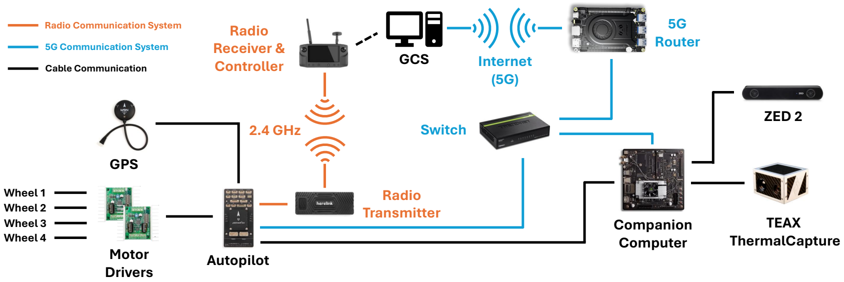

Fig. 2. General schematic of the VIGILANT hardware configuration.

II. System Overview

The proposed architecture for the UGV currently under development is the Versatile Integrated Ground-based Intelligence and Logistics Autonomous Navigation Tool (VIGILANT). This wheeled platform is based on the commercially available *Jaguar-4x4-wheel* mobile robotic platform[1], and it is designed for both military and civilian applications.

The VIGILANT platform is designed to be rugged and compact, water- and weather-resistant. Its lightweight design, weighing approximately 25 kg, allows it to reach speeds up to 11 km/h. Each wheel is powered by its motor, enabling quick maneuverability in indoor and outdoor environments. Additionally, the vehicle's high ground clearance allows it to navigate challenging terrains and low-rise stairs. After modifications to the commercial platform, VIGILANT is currently capable of performing the following tasks:

- **Teleoperation** - It can be done *in situ* or remotely, depending on the communication system, including traditional radiofrequency or advanced 5G technologies for better flexibility and range;
- **Waypoint Navigation** - Autonomous navigation using waypoints in a GNSS-available environment;
- **Detection & Classification** - Detection and classification of individuals as either military or civilian using visible and thermal camera images;
- **Collision Avoidance** - Ability to avoid obstacles based on the depth measurements during teleoperation or waypoint navigation in a GNSS-available environment;
- **Geofencing** - Motion restricted to a virtually defined area during teleoperation or waypoint navigation in a GNSS-available environment.

The following sections explore the hardware configuration and software architecture in detail, allowing for a better understanding of the concepts and their principles of operation.

A. Hardware Configuration

The adopted robotic platform had outdated components, was incompatible with the current software, and lacked sufficient computational power. As a result, the original hardware was removed and replaced, retaining only the chassis, motors, and respective drivers from the original commercial platform. One of the objectives is to utilize the latest open-source technology to enable the performance of both military and civilian missions. Thus, the VIGILANT mobile platform comprises:

- **Sensors & Actuators** - Visible and thermal cameras, Global Positioning System (GPS) with compass, four motors and associated drivers;
- **Autopilot** - Provides fundamental control of the UGV and supervises the operation of the robot wheels to ensure the accurate execution of specified trajectories;
- **Companion Computer** - Responsible for heavy computational tasks, such as high-level control algorithms and computer vision algorithms, among others;
- **Communication Hardware** - Responsible for integrating the previous components and enabling communication with a remote operator or Ground Control Station (GCS).

A general schematic of the hardware configuration of the robot can be seen in Figure 2. The low-level control is performed through a *Pixhawk 6X*, a readily available, low-cost, high-end, widely-used, and thus well-tested independent open-hardware autopilot. It contains three onboard Inertial Measurement Unit (IMU) sensors, which, combined with the externally attached *M9N* GPS, can estimate the robot's position and velocity in a GNSS-available environment.

The autopilot integrates both motor drivers by sending desired control signals via Pulse Width Modulation (PWM). It interfaces with the companion computer through a Serial connection and connects to the robot's Ethernet network. When the robot operates via radiofrequency, it connects to the *Herelink Air Unit* using Serial. Together, the *Herelink Air Unit* and the *Herelink Controller* create a digital transmission system designed for control commands, telemetry, and video transmission, tailored explicitly for use with the *Pixhawk*.

For the companion computer, we use a *Jetson TX2*, which, at its release, was one of the fastest and most power-efficient embedded Artificial Intelligence (AI) computing devices, featuring 8GB of memory. This makes it ideal for running algorithms that demand significant Graphics Processing Unit (GPU) computational power. As mentioned, it connects to the autopilot via Serial and to the robot's network through Ethernet. Moreover, the *Jetson TX2* is connected to two Universal Serial Bus (USB) sensors: the *ZED 2* visible stereo camera from *Stereolabs* and the *TEAX ThermalCapture Fusion Zoom*, combining visible and thermal imaging in one device.

[1] http://jaguar.drrobot.com/specification_4x4w.asp

2025 IEEE International Conference on
Autonomous Robot Systems and Competitions (ICARSC)
Funchal, Portugal – April 2-3, 2025

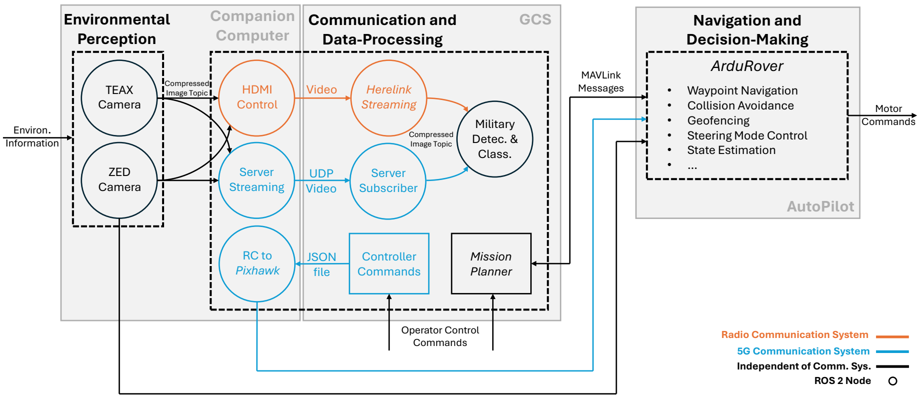

Fig. 3. General schematic of the VIGILANT software architecture.

In terms of communication, the robot can operate using either traditional radiofrequency or 5G connectivity. When using 5G, a *LattePanda Delta 3* acts as a router, connecting to the robot's switch via Ethernet. This setup facilitates the transmission of control commands, telemetry, and video data over the Internet between the robot and the GCS.

B. Software Architecture

Figure 3 illustrates the VIGILANT software architecture. The system is divided into three primary subsystems: Environmental Perception, Communication and Data-Processing, and Navigation and Decision-Making.

1) Environmental Perception: Both cameras perform the perception of the surrounding environment. Their integration algorithms were developed for the Robot Operating System (ROS) 2, a cutting-edge, open-source middleware framework for developing robot software applications. This robotic solution's perception subsystem includes these nodes:

- **ZED Camera** - Captures and publishes the camera's RGB image into a compressed topic. It also calculates the depth and publishes it in a Micro Air Vehicle Link (MAVLink) message for the autopilot;
- **TEAX Camera** - Captures and publishes RGB and thermal images together in a compressed format topic.

2) Communication and Data-Processing: To allow communication between the operator/GCS and the robot, both must run the necessary software to facilitate data exchange. On the robot's side, the following ROS 2 nodes have been developed:

- **HDMI Control** - When the robot operates through the radiofrequency communication system, it subscribes to the ZED or TEAX camera image topic. It outputs it to the High-Definition Multimedia Interface (HDMI) port to transmit it through the *Herelink Air Unit*, therefore allowing the *in situ* teleoperation of the robot;
- **Server Streaming** - When the robot operates through the 5G communication system, it subscribes to the ZED or TEAX camera image topics and streams them through User Datagram Protocol (UDP) to a server;
- **RC to *Pixhawk*** - The robot uses 5G to receive control commands from a server and sends them in an MAVLink message for the autopilot.

As for the GCS, which also runs ROS 2, the implemented software consists of the following nodes:

- ***Herelink Streaming*** - When the robot operates through the radiofrequency communication system, it captures the video stream from the *Herelink Controller*, and it publishes it in a compressed image topic;
- **Server Subscriber** - When the robot operates through the advanced 5G communication system, it captures the UDP video stream from the server and publishes it in a compressed image topic.

The Server Streaming and RC to *Pixhawk* nodes, which run on the companion computer, combined with the server subscriber node and software that transmits control commands from a controller connected to the GCS to the server, allow the platform to be fully remotely teleoperated.

The GCS also runs *Mission Planner*, a software that allows detailed mission planning and real-time UGV monitoring by transmitting and receiving MAVLink messages with the autopilot. *Mission Planner* can also be run on the *Herelink Controller*.

As far as data processing is concerned, the GCS runs the **Military Detection and Classification** node, which subscribes to the compressed image topic and runs the detection and classification algorithm based on the YOLOv8 architecture as described in [8], which relies only on data obtained through the TEAX camera.

3) Navigation and Decision-Making: All the navigation and decision-making algorithms run on the *Pixhawk 6X*. The autopilot operates with *ArduRover*, an advanced open-source firmware designed explicitly for autonomous ground vehicles, including rovers and boats. Built on the *ArduPilot* platform, it offers diverse features that enhance adaptability and robustness for various applications, ranging from research and development to industrial use. In this implementation, the following operational capabilities are utilized:

- **Autonomous Waypoint Navigation** - Based on the autopilot's estimates for the UGV position and velocity and on its navigation algorithms;
- **Collision Avoidance** - Based on the depth measurements obtained for this platform through the *ZED 2* stereo camera and on the *BendyRuler* algorithm[2];
- **Steering Control** - Mode that allows an operator to control the UGV directly;
- **Geofencing** - Based on a defined geographical fence, limits the vehicle movements within this area.

Efficient use of this robotic platform is vital, as advanced software and hardware often fail to meet performance needs in military operations. As discussed in the following sections, conducting experimentation exercises is essential to improving the performance and robustness of these systems and developing solutions for direct field implementation.

III. Military Experimentation Exercises

Collaboration between academia, industry, and the military is crucial for significantly advancing military technology. Strengthening the relationship among system developers allows for the creation of systems directly tailored to existing operational needs.

Exercises like ARTEX and REPMUS are vital for testing and refining emerging technologies in real-world environments. This section will discuss these exercises and VIGILANT's participation in 2024, enabling an analysis of its abilities and gaining valuable knowledge for future military innovations.

A. Army Technological Experimentation Exercise (ARTEX)

ARTEX is a military exercise organized by the PoA[3]. Its primary goal is to test technological systems with potential military applications that are still under development. This exercise aims to identify solutions to address the shortcomings in the Army's land force capabilities, support ongoing modernization efforts, and improve the interoperability between military capabilities and projects presented by the PoA partners.

This year's edition, held at the *Santa Margarida* Military Camp in *Constância*, Portugal, featured the following three different experimentation phases:

- **Phase I** - During this phase, the participants were free to perform their testing, either by themselves or in collaboration with other institutions, to measure the performance of the developed technological solutions and identify possible improvements in their systems in a limitation-free environment;
- **Phase II** - During this phase, the various technological solutions were integrated into tactical test scenarios, contributing to the execution of military operations;
- **Phase III** - Some institutions conducted live fire experiments in this last phase.

VIGILANT participated in the first two phases of experimentation. In the first phase, it was possible to conduct the following tests:

- **Mobility Tests** - These tests took place in various types of terrain, such as dirt, gravel, grass, and rock. Navigation through a trench was also tested (see Fig. 1);
- **Communications and Autonomy** - Maximum communication range and autonomy tests in real operating scenarios;
- **Teleoperation** - *In situ* tests at dawn, during the day, and at night using both the ZED and TEAX cameras;
- **Autonomous Navigation** - Tests were conducted using waypoint navigation in a real-world operating environment;
- **Military Detection and Classification** - Tests were conducted using the actual PoA camouflage and an advanced experimental camouflage developed by a Portuguese textile and clothing technology center named *Centro Tecnológico da Indústria Têxtil e Vestuário* (CITEVE);
- **Jamming** - Tests conducted in collaboration with the Portuguese company *Swatter* were crucial for assessing the platform's robustness and performance in this scenario.

In the second phase of the exercise, VIGILANT integrated the nominated red (enemy) forces during military operations. Its main task was to serve as a scout for troops and to detect opposing soldiers and vehicles in advance without risking human safety. Four realistic operational scenarios were created at different times of the day.

B. Robotic Experimentation and Prototyping with Maritime Unmanned Systems (REPMUS)

REPMUS is an international military exercise conducted by the North Atlantic Treaty Organization (NATO) and led by the PoN. Its purpose is to assess the capabilities of autonomous systems in cooperative operations and to enhance the Alliance's understanding of emerging threats in the maritime environment. This exercise is recognized as the world's premier experimentation event for maritime uncrewed systems. It provides an excellent opportunity for developers and operators in the Alliance to evaluate new technological systems in multidomain experiments.

VIGILANT participated in the REPMUS event at the PoN Operational Experimentation Center (CEOM, in Portuguese) on the Troia Peninsula in Portugal. The event's primary objective was to assess remote harbor protection capabilities from an operations center supported by a private 5G network that covered the area. During this activity, a series of predefined tests suggested by the PoN were conducted to evaluate the robot's performance, as follows:

- **Mobility Tests** - These tests occurred in asphalt, concrete and sandy terrains;
- **Communications and Autonomy** - Maximum communication range and autonomy tests;
- **Teleoperation** - Fully remote teleoperation tests during the day and night using both the ZED and TEAX cameras;

[2]https://ardupilot.org/copter/docs/common-oa-bendyruler.html
[3]https://youtu.be/HrVfG0b8bek

- **Autonomous Navigation** - Tests were conducted using waypoint navigation in a real operating scenario;
- **Collision Avoidance** - Tests during the harbor protection task to ensure personnel, equipment, and robot safety;
- **Geofencing** - Tests during the harbor protection task to ensure limited operation of the robot in a desired geographical area;
- **Intrusion Detection and Classification** - Tests were conducted to identify possible intrusions in military-protected facilities during both day and night;
- **Jamming** - Tests conducted with PoN equipment.

In addition to the standard harbor patrol tasks, two additional real-operation scenarios were tested. The first involved building clearance, in which the robot was required to scout a building to identify an intruder during the day and at night while operating from outside. The second scenario simulated a military amphibious operation in which VIGILANT integrated the red force. Similarly to what happened in ARTEX, this unit was assigned to scout for these forces and detect and identify opposing soldiers and vehicles in advance.

Participation in these exercises provided significant experience and the opportunity to learn valuable lessons. As described in the next section, these lessons will benefit future developments.

IV. Lessons Learned & Recommendations

As described in the previous section, the various tests conducted during ARTEX and REPMUS yielded valuable insights and recommendations. These findings will not only influence the future development of this mobile platform but may also serve as a useful resource for the robotics community. This section will describe the lessons learned and recommendations, divided by mobility type, traction, communication system, autonomy, operational modes, and algorithms.

A. Mobility Type

A critical design decision for a robotic platform such as VIGILANT is its type of mobility. Effective navigation algorithms are useless if the robot lacks suitable mobility for the terrain. Wheeled robots perform well on flat surfaces such as asphalt but face challenges on loose terrain like sand, where they are prone to sinking. While specialized tires can enhance traction on sandy surfaces, they do not fully eliminate this issue. This was a significant challenge for VIGILANT at both events, particularly in the sandy areas during the REPMUS event on the Troia Peninsula.

However, during the harbor protection scenario, which took place on structured terrain, VIGILANT could perform its tasks quickly and efficiently. This highlights the need to choose the right type of mobility for each terrain. A tracked or legged robot is preferable for diverse natural terrains, whereas a wheeled robot is best for flatter and harder surfaces.

B. Traction

During the exercises, VIGILANT encountered some traction issues. Without mechanical suspension and traction control, VIGILANT often became stuck on uneven terrain because the original *ArduRover* firmware only provided skid-steering control for two-wheeled robots. As one or two wheels lost contact with the ground, the remaining wheels could not generate enough power to move the robot. An example of such an issue was when VIGILANT navigated a deep, rocky trench during ARTEX.

C. Communication System

An important design aspect of robotic systems is their communication capability. Effective communication is essential for real-time control and visualization of data, including telemetry and video streams, especially in military operations such as ISR. The robot cannot provide valuable information without real-time updates, which limits its ability to perform C2.

The range is a crucial consideration for communication systems. Ground obstacles can significantly limit radio communication for UGVs. An average maximum ground line-of-sight range of 500 meters, which further decreases with obstacles, was identified for telemetry and video transmission via the *Herelink* radiofrequency system used by VIGILANT while operating with a transmitter power output of 100 mW and on flat terrain. This limitation requires military operators to accompany the robot, risking exposure of their position and military camp, as demonstrated during the ARTEX tactical tests. Additionally, radio communication frequencies widely used in commercial drones are easily susceptible to jamming, as confirmed at ARTEX, where *Swatter* was able to block communication between VIGILANT and the GCS completely.

Mobile broadband, especially 5G, offers a virtually infinite communication range between operators and robots within network coverage. In the REPMUS exercise, VIGILANT utilized this technology by connecting to CEOM's private 5G network, which delivered low latency averaging 150 ms and facilitated real-time communication during harbor patrols. Operations relied on the commercial 5G network, with variable coverage and performance per mission context:

- **Building Clearance** - The mission took place in a well-covered 5G area, allowing the robot to be operated remotely from outside the building with low latency and real-time communication;
- **Amphibious Mission** - The mission occurred in a remote area without mobile coverage, thus nullifying the use of this type of communication. The *Herelink* radio system was also tested but lacked the necessary range for this operation.

It is worth noting that mobile communication is less used to control UGVs remotely, and therefore, commercial jamming equipment is less adapted to disrupt these signals, as confirmed at REPMUS. Nevertheless, while less likely, it is essential to consider that 5G remains vulnerable to jamming, particularly as its adoption in military operations increases.

In conclusion, mobile broadband is the most promising of the two tested communication systems, although its coverage may be limited. A backup radiofrequency system is essential for maintaining the robot's functionality in areas without mobile network access. Additionally, a movable 5G private network, as tested by the company *Capgemini* during ARTEX, could serve areas without commercial mobile networks.

D. Endurance

Robots should ensure long operating hours, as military missions may last hours, days, or weeks. Although VIGILANT has an average of three hours maximum endurance, determined during the more extended scouting missions, a trained operator can swap its batteries in less than 10 minutes, allowing for almost infinite operation time as long as charged batteries are available. Therefore, a simple and reliable battery-swap system is recommended.

E. Operation Modes

Teleoperation was the most relevant operational mode during these two exercises due to the flexibility and control capabilities it offers to military operators. It was conducted with a remote controller and a single ZED or TEAX camera video feed. However, the lack of additional environmental information often hindered the process. Incorporating auditory feedback could help the operator assess and respond to situations quickly. Identifying key sounds like motors, rustling grass, or even voices is crucial for detecting potential threats.

Another improvement would be to replace the static camera with a telescopic pan-tilt-zoom camera. This would provide visibility above tall grass and allow scouting of multiple areas without moving the robot, simplifying the teleoperation task.

F. Algorithms

The *ArduRover* firmware offers basic control and navigation algorithms. As described previously, it only provides kinematics-based skid-steering control suitable for two-wheeled robots. It is insufficient for a four-wheeled robot like VIGILANT to achieve high maneuverability and navigate non-uniform terrain. Additionally, its autonomous navigation and collision avoidance algorithms are basic and not optimized for complex environments, making them limited for UGVs. While useful as a starting point, these algorithms do not provide a robust solution for operational ground robots. More advanced navigation algorithms, such as SLAM, would enable a more effective and robust navigation in this type of environment.

The detection and classification algorithm exhibited promising results. However, tests revealed that distinguishing between military and civilian individuals is insufficient for identifying threats, as civilians can also pose risks. A more effective approach would be incorporating an algorithm that detects suspicious behavior, such as movement in restricted or unauthorized areas and weapon detection.

V. Conclusions

The results from the ARTEX and REPMUS exercises have highlighted several critical considerations for the design and operation of UGVs in military contexts. Mobility is a fundamental design factor. While wheeled platforms perform well on structured terrain, they often struggle on loose or uneven surfaces, such as sand and rocky ground, where tracked or legged designs are more effective. Communication is vital, with 5G technology promising low-latency control in covered areas. However, backup radio communication is essential in remote areas without mobile networks.

Additionally, the operational insights emphasize the need for improved endurance, adaptability, and enhanced situational awareness features. Improving the VIGILANT platform's battery-swapping system could enable extended missions, while better audio and camera feedback would enhance responsiveness during teleoperation. The *ArduRover* firmware limitations show the need for advanced control tailored to UGVs in diverse, challenging terrains.

Refining detection algorithms to include behavioral analysis, not just distinguishing civilians from military personnel, enhances threat identification accuracy and usefulness. In conclusion, these lessons learned will not only guide the future development of the VIGILANT platform but also provide valuable insights into the field of military robotics. Addressing the identified challenges is crucial for deploying UGVs in complex real-world scenarios where adaptive mobility, reliable communication, and high autonomy are essential. Future developments should refine these key areas for the effective and safe integration of UGVs into military operations.

Acknowledgment

The authors acknowledge *Fundação para a Ciência e a Tecnologia* (FCT) for its financial support via project LAETA Base Funding (DOI: 10.54499/UIDB/50022/2020) and via the Ph.D. grant 2024.06034.BDANA, provided by the Portuguese Ministry for Science, Technology and Higher Education, as well as the financial support from the *Aliança para a Transição Energética* (ATE) project (Ref: C644914717-00000023), funded by the PRR Program, NextGeneration EU.

References

[1] W. Chin, "Technology, war and the state: past, present and future," *International Affairs*, vol. 95, no. 4, pp. 765–783, 07 2019.
[2] G. Bathla, K. Bhadane, R. K. Singh, R. Kumar, R. Aluvalu, R. Krishnamurthi, A. Kumar, R. Thakur, and S. Basheer, "Autonomous vehicles and intelligent automation: Applications, challenges, and opportunities," *Mobile Information Systems*, vol. 2022, no. 1, p. 7632892, 2022.
[3] D. Patil, M. Ansari, D. Tendulkar, R. Bhatlekar, V. N. Pawar, and S. Aswale, "A survey on autonomous military service robot," in *2020 International Conference on Emerging Trends in Information Technology and Engineering (ic-ETITE)*. IEEE, 2020, pp. 1–7.
[4] N. Pessanha Santos, V. B. Rodrigues, A. B. Pinto, and B. Damas, "Automatic detection of civilian and military personnel in reconnaissance missions using a UAV," in *2023 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC)*. IEEE, 2023, pp. 157–162.
[5] R. Bogue, "The role of robots in the battlefields of the future," *Industrial Robot: An International Journal*, vol. 43, no. 4, pp. 354–359, 2016.
[6] D. A. Grejner-Brzezinska, C. K. Toth, T. Moore, J. F. Raquet, M. M. Miller, and A. Kealy, "Multisensor navigation systems: A remedy for GNSS vulnerabilities?" *Proceedings of the IEEE*, vol. 104, no. 6, pp. 1339–1353, 2016.
[7] C. Debeunne and D. Vivet, "A review of visual-lidar fusion based simultaneous localization and mapping," vol. 20, no. 7, 2020.
[8] J. P. Matos, A. Machado, R. Ribeiro, and A. Moutinho, "Automatic people detection based on RGB and thermal imagery for military applications," in *Iberian Robotics conference*. Springer, 2023, pp. 201–212.