Challenges and New Approaches regarding Devices, Mechanisms, Robotic Systems, and Sensors Used in Modern Military Technique

PhD student **Aurelian ȘTEFĂNESCU**[1], Researcher II / Lecturer **Iulian Sorin MUNTEANU**[1], PhD student **Viorel NIȚICALĂ**[1], PhD student **Andreea Dana ALIONTE**[1], Prof. **Ana Maria MUNTEANU**[2]

[1] National University of Science and Technology POLITEHNICA Bucharest

[2] Nikola Tesla Technological High School

* iulian.munteanu0306@upb.ro

Abstract: *This article presents a comprehensive overview of the integration of robotic systems and artificial intelligence (AI) in military applications, focusing on land-based robotic platforms. It highlights the mobility mechanisms of military robots, including wheeled, tracked, and biomechanical (legged) systems, as well as the power sources and control technologies that enable their operation. The analysis extends to the leading nations in military robotics development, such as the United States, Japan, South Korea, and key European nations, and emphasizes the importance of emerging players like Singapore, India, and the UAE. The challenges related to AI integration, cybersecurity, and sustainability are discussed, along with the ethical considerations surrounding the future deployment of autonomous robotic systems in military contexts. Finally, the article points to the need for international collaboration and the establishment of regulatory frameworks to ensure the responsible and effective use of military robotics in a rapidly evolving technological landscape.*

Keywords: *Military robotics, artificial intelligence, autonomous systems, biomechanics, tracked mobility, wheeled mobility, military devices and mechanisms, cybersecurity, military innovation, ethical robotics development*

1. Introduction

In the context of continuous advancements in cutting-edge technologies, military robotic systems represent one of the most revolutionary and challenging innovations of the 21st century. The evolution of these systems is closely tied to rapid technological progress, and with the implementation of new innovations, we are opening new pathways to better understanding and utilizing them in the military field. A crucial aspect of the development of these technologies is the integration of artificial intelligence (AI), which promises to transform military operations by enabling autonomous or assisted decision-making processes.

Artificial intelligence (AI) is based on the hypothesis that certain aspects of human thought can be implemented within mechanized systems. Though it has long been a subject of philosophical debates, mathematical models, and computer science research, it has only recently moved to the forefront of public, governmental, and military interest, primarily due to substantial increases in computing power, access to large data sets, and advancements in algorithmic techniques. However, complex issues related to safety, ethics, and sustainability also arise and must be addressed to ensure the responsible and efficient use of these AI-controlled and optimized military technologies.

The evolution of military robotic systems [1-7,10-15] is closely linked to the rapid advancement of technologies and AI [13,14,18]. The introduction of new innovations and AI offers the promise of significant progress in understanding the phenomena associated with science.

2. Main components of devices, mechanisms and sensors in terrestrial robotic systems used in modern military technology

Throughout history, nations have sought to employ various devices and systems to reduce the risk of damage and gain a tactical advantage over their adversaries. As technology advanced, countries began to rely on sophisticated robotic systems, both for military and civilian purposes.

Today, military robotic systems [1-7,10-15,17,21,22,24] are used for various applications, ranging from neutralizing/destroying explosive devices, surveillance, and logistics, to rescue operations. Over time, these systems will be increasingly deployed for reconnaissance, surveillance, and other specialized applications.

Initially, robotic systems were designed to perform repetitive, difficult, or dangerous operations across several industries. In military operations, robotic systems are used for the following purposes:

- To reduce personnel exposure to various dangers (rescue, decontamination, evacuation, biological attacks, intelligence gathering, etc.);
- To enhance decision-making under stressful conditions by integrating artificial intelligence assistance, enabling data collection, analysis, fusion, and providing suggestions for decision-making and execution;
- To reduce labor and operational costs associated with personnel in various missions.

In addition to these roles, robotic systems demonstrate specific capabilities, including:

- Robotic systems can perform tasks consistently due to their immunity to fatigue;
- Robots are immune to stress or emotions, enabling them to operate under extreme conditions without prior training;
- Robotic systems allow personnel to focus on other tasks;
- These systems are durable, capable of operating in extreme environments;
- Robotic systems are significantly faster than humans in terms of mobility, data analysis, and decision-making suggestion development.

The main disadvantage in developing these sophisticated systems lies in the complexity of the mechanical and electronic components required to create highly efficient and intelligent robots, capable of executing both simple and complex tasks.

The primary components that form the foundation of designing and developing a complex military robotic system include sensors, mobility mechanisms, power sources, electronic components, body elements, utility systems, attack and/or reconnaissance devices, and localization mechanisms.

2.1. Sensors used in robotic systems for military applications

Robotic systems can be equipped with a wide range of sensors [20,23], each serving specific functions that enhance surveillance, recognition, navigation, detection, and other operations. These sensors are generally used to enable the robot to analyze its surroundings, navigate, and execute both simple and complex missions. Below, we provide a detailed description of the main types of sensors used in military robotic systems:

a) Optical Sensors:

Optoelectronic devices record images of the surrounding environment. This category includes devices with visible spectrum vision and infrared (IR) vision for nighttime observation. IR devices use both image intensifier technology and thermal imaging. Optical sensors are typically employed for surveillance, reconnaissance, target identification, etc.

Image intensifier technology allows IR devices to detect radiation reflected by a body by amplifying the illumination level in the visualized field to a point where the object can be observed (see **Figure 1**).

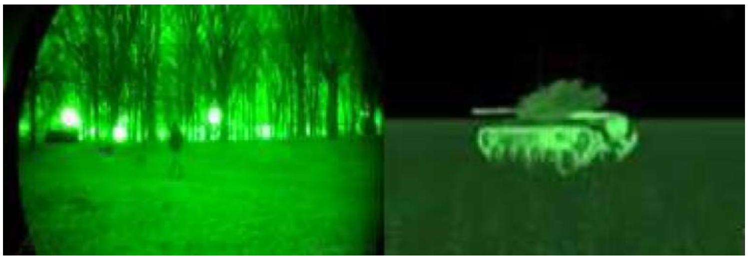

Fig. 1. Photos captured using IR cameras with image intensifiers

Thermal imaging technology enables IR devices to detect thermal energy emitted by objects within the field of view by creating an image based on the thermal contrast between the target and its background (see **Figure 2**).

Each of these two types of devices operates in distinct portions of the electromagnetic spectrum, specifically within different infrared domains, due to operational differences.

Fig. 2. Image obtained through thermal imaging

b) Proximity Sensors:
Proximity sensors are vital in the field of robotics, including military applications, as they detect the physical presence of nearby objects without making physical contact. These sensors are particularly useful in the development of autonomous navigation and obstacle avoidance systems.
• **Ultrasonic Sensors** [25]**:** These sensors operate on the principle of echolocation, similar to that used by bats. They emit sound waves at ultrasonic frequencies (typically between 25 kHz and 40 kHz, which are inaudible to humans) and measure the time it takes for the waves to return to the sensor after reflecting off an object.
• **LIDAR Sensors (Light Detection and Ranging)** (**Figure 3**) [27]**:** use laser light technology to measure various distances. These sensors scan the surrounding environment by emitting multiple light pulses and measuring the time it takes for each pulse to return to the sensor after reflecting off an object. Robotic systems commonly employ these sensors for precise 3D navigation and mapping.

Fig. 3. Example of a LIDAR sensor mounted on a terrestrial robotic system [28]

c) Acoustic Sensors:
Acoustic sensors, also known as microphones, are used in military robotic systems to detect and analyze sounds from the surrounding environment. These sensors are critical in reconnaissance, surveillance, rescue missions, and other operations, as they can capture sounds produced by vehicles, people, explosions, and other significant acoustic sources.
Functionality – Acoustic sensors convert sound waves from different environments into electrical signals. The physical properties of sound waves and their interaction with various materials determine how these sensors function. This process, known as acoustic transduction, involves several steps as outlined below:

1. **Sound Capture** – Sound waves are captured using a diaphragm, which is a thin membrane that vibrates in response to sound wave pressure. The diaphragm is the primary component of an acoustic sensor.

2. **Mechanical to Electrical Conversion** – The mechanical movement of the diaphragm is transformed into electrical signals through a transducer.
3. **Signal Processing** – The electrical signal generated by the microphone is typically weak and requires amplification and filtering. Additionally, acoustic analysis techniques, such as digital signal processing (DSP), are used to analyze the sound's characteristics, including the direction, type of sound (voice, vehicle, etc.), and the distance to the sound source.

d) RADAR Sensors (Radio Detection And Ranging):

In military operations, RADAR sensors are critical devices for navigation, detection, and tracking of distant objects, regardless of weather or lighting conditions. They work by emitting high-frequency radio waves and detecting their reflection from various encountered objects.

The essential components of a RADAR sensor include:

- **Transmitter:** Generates the high-frequency radio waves needed for target detection.
- **Receiver:** Captures the reflected waves and converts them into electrical signals. The sensitivity of the receiver is crucial for detecting distant targets.
- **Processing Unit and Display System:** This unit analyzes the signals from the receiver to extract data about targets, such as distance, angle, altitude, and speed. Advanced mathematical calculations, including Fourier transforms, are employed to interpret the frequency of signals, helping to determine whether a target is approaching or moving away from the radar.

e) Navigation Sensors:

Navigation sensors are vital components that enable military robotic systems to navigate through various environments while accurately determining their position and orientation. These sensors combine different technologies to ensure precise data collection needed for location determination.

- **GPS (Global Positioning System) Sensor** – This sensor uses a network of satellites that emit radio signals. A GPS receiver, such as the one installed on a military robot, captures these signals to pinpoint its exact position on Earth. By calculating the time difference between when the signals are transmitted by the satellites and when they are received by the robot's system, the GPS sensor can determine longitude, latitude, and altitude.
- **INS (Inertial Navigation System) Sensor** – Robotic systems that operate across three axes, such as aerial and underwater robots, need to be aware of their position, altitude, and speed. Inertial sensors, which include accelerometers and gyroscopes, are used to collect data around the X, Y, and Z axes of the robot. These sensors form an **Inertial Measurement Unit (IMU)** that provides crucial information for navigation and positioning.

Both **INS** and **GPS** sensors are essential for navigation and localization, each offering unique advantages and disadvantages. INS can outperform GPS in certain military applications, particularly in the following areas:

- **GPS Dependence –** While GPS is widely used for location determination, it relies on satellite signals, which may be blocked or jammed in hostile environments, such as urban warfare or under heavy foliage.
- **Autonomous Operation –** INS is independent of external signals, allowing it to continue providing location data even when GPS signals are unavailable, making it especially useful in GPS-denied environments.
- **Precision Over Time –** Although INS accuracy degrades over time due to drift (a gradual loss of precision), it can be highly effective for short-term precision in high-speed operations, where quick data feedback is necessary for stability and control.
- **Complementary Use –** In many military applications, both systems are used together, with GPS providing absolute position data and INS offering relative movement data to fill in the gaps during GPS signal outages.

By using a combination of GPS and INS, military robotic systems achieve enhanced reliability and accuracy in navigation, even in challenging and dynamic environments.

2.2. Mobility and propulsion platform of terrestrial robotic systems for military applications

Mobility and propulsion are key factors for achieving efficient movement and adapting robotic systems to the different environments in which they operate. The mobility platform varies from one robot to another, depending on mission requirements and terrain difficulty. Below, we will review the main types of mobility and propulsion platforms used in military robotic systems:

a) Wheel-Based Mobility:

Due to their efficiency, simplicity, and reliability, wheel-based propulsion is a preferred choice for many military robotic systems. These systems [11] are designed to offer mobility over various types of terrain but perform best on relatively smooth surfaces, making them ideal for logistics missions.

The most common types of wheels used in robotic systems are:

- **Standard Wheels** – These are used primarily on stable terrain and are the most common and easiest to manufacture.
- **Wheels with Independent Suspension** – These wheels enhance the stability and traction of the robotic system by absorbing shocks from uneven surfaces. Each wheel has its own suspension system, allowing for additional terrain adaptability.
- **Mecanum Wheels** – These wheels can rotate like ordinary (standard) wheels, moving simultaneously, but they can also rotate independently. This feature allows robots to move in any direction without turning their entire body. Thanks to the arrangement of rollers along the circumference of the wheels, they provide increased maneuverability in confined spaces.

Certain materials allow wheels to operate successfully on a variety of surfaces.

Rubber is one of the most commonly used and manufactured materials because it provides grip, reliability, and excellent shock absorption. In addition to rubber, **polymers** and **composites** are also used in special applications, offering enhanced properties such as abrasion resistance, chemical resistance, or reduced weight.

The selection of wheels depends on the intended use of the robotic system. Furthermore, the type of wheel chosen is determined by the steering mechanism available on the robot.

The steering mechanism can take several forms, including:

- **Fixed Steering** – In this configuration, the wheels do not turn laterally to change direction, and directional changes are achieved solely by varying the wheel speeds.
- **Articulated Steering –** The robot's direction can be changed by articulating or bending its body, which offers improved maneuverability over rough terrain.
- **Common (Standard) Steering –** This is the type of steering found in most vehicles, where only the front wheels steer.
- **Omnidirectional Steering –** This setup uses specialized wheels, such as the Mecanum wheels mentioned earlier or Omni wheels, which allow the robot to move in any direction by independently controlling the movement of each wheel.

Each steering mechanism is chosen based on the specific requirements of the mission and the environment in which the robotic system will operate, ensuring the optimal balance between mobility and control.

Each of the directional assemblies or wheels selected has advantages and disadvantages depending on the specific application, and choosing the right construction variant depends on the operational needs of the military robot, the terrain it must operate on, and other tactical mission requirements.

For the movement of robotic systems on the ground to be as efficient and smooth as possible, the type of suspension used must also be considered. Suspensions are essential components in the construction of military robots that use wheels for movement, as they absorb shocks from different types of terrain and improve traction during movement.

Suspensions are the elements that ensure the wheels remain in contact with the ground, even on rough terrain. These can be of several types, including:

- **Spring and shock suspension**, the most common type of suspension.
- **Independent suspension**, which allows control of each wheel independently from the others.

b) Mobility using tracks:

Ground robotic systems designed to perform missions over rough terrain must be equipped with appropriate mobility elements, such as **tracks**, as stability and traction are crucial for strict movement requirements. Tracks are used instead of wheels or other mobility elements because they provide better weight distribution and superior traction on challenging surfaces such as sand, mud, or rocky terrain.

The essential components of the crawler propulsion system include:

- **Tracks –** usually made from articulated steel plates, rubber reinforced with steel cables, or hard rubber. The material can be chosen depending on specific needs, such as durability, flexibility, or grip.
- **Drive wheels and tensioner wheels –** The drive wheels are usually located at the rear of the chassis and provide the power needed to move the tracks. These wheels engage with their own teeth in the gaps of the track to move the robotic system. The tensioner wheels are placed at the ends and help maintain tension on the track while also guiding it.
- **Support wheels** – These wheels help distribute the weight of the robotic system over a larger area and absorb shocks from rough terrain. They are placed along the chassis between the drive wheels and the tensioner wheels.

• **Suspension** – Ground robotic systems that use tracks as mobility means can be configured with multiple types of suspensions. Suspensions can range from simple systems using springs to hydraulic or pneumatic suspensions. They serve the same purpose as the suspensions used in wheels, helping to maintain stability and contact between the tracks and the surface.

The maneuverability of ground robotic systems using tracks is achieved through differential speed control between the two tracks. By reducing the speed of one track and accelerating the other, the robot can turn in the desired direction.

Ground robotic systems equipped with tracks as mobility elements have several advantages, including: uniform weight distribution due to the large contact surface area of the tracks, the ability to traverse obstacles such as bumps and craters, and overall stability.

The only "major" disadvantage is the need for regular maintenance of these track-type mobility elements; however, due to their benefits regarding flexibility across various terrains in military applications, they are unmatched.

c) Mobility using biomechanical elements:

Robotic systems with biomechanical mechanisms, meaning legs—either bipedal (two legs) or quadrupedal (four legs)—as mobility elements, represent proof of the continuous technological advancement in the field of robotics. These mechanisms are designed to mimic the biomechanics and dynamics of movement in animals or humans, providing the capability to navigate challenging environments where robotic systems with wheels or tracks are not as effective.

The primary characteristics of robotic systems that utilize biomechanical elements for movement on the ground include:

- **Imitation of natural movement** – Robotic systems [12] with biomechanical elements use joints or segments similar to bones and muscles to replicate the function of human or animal legs (see **Figure 4**).
- **The main components of these subassemblies** are actuators, which are responsible for generating the force necessary for movement. Actuators convert input signals into mechanical energy, which is developed by the joints, similar to how the muscles of humans or animals receive signals from the brain, thus enabling the required movement for the robots to traverse various surfaces.

Fig. 4. Atlas and Spot robots belonging to Boston Dynamics

The control of movement using legs is a complex phenomenon that requires extensive algorithms to coordinate their movements. The dynamics of walking, including adaptation to terrain changes or encountered obstacles, must be managed by well-optimized control systems.

Several advantages regarding mobility using biomechanical elements are presented below:

- **Traversal of rough terrain** – This refers to the capability of overcoming large obstacles, such as rocks, tree trunks, or stairs, which may be inaccessible to robotic systems utilizing wheels or tracks for movement.
- **Adaptability and flexibility** – This characteristic represents the ability to modify the direction of movement and adjust the steps of robotic systems based on the immediately encountered environmental conditions.
- **Silent movement** – In this case, we will discuss only the systems that utilize electric power sources for operation and thus can move relatively quietly on legs.

The disadvantages and challenges of these robotic systems with legs can be highlighted by the following aspects:

- **Control complexity** – Maintaining balance and coordinating movements present plausible technical challenges, requiring rapid processing of input data and the use of well-adapted algorithms.
- **Energy consumption** – Repetitive movements and maintaining balance can consume a lot of energy, potentially reducing the operational autonomy of robots when using electric power sources. Therefore, combustion engines can be used for long-duration applications where autonomy can be a strong point.
- **Durability and maintenance** – Due to performing missions on harsh/unfriendly terrains and mechanical complexity, the lifespan of the robotic system components may be shortened, leading to increased repair times and costs resulting from more frequent replacements of defective elements.

Propulsion of ground robotic systems that utilize wheels, tracks, or biomechanical elements (legs) for mobility can generally be powered by the following energy sources:

- **Rechargeable batteries based on electrical energy** – These are the most commonly used due to their ease of recharging.
- **Fuel-based energy sources** – These are typically used for long-duration operations in extreme environments or in larger robots.

The aspects mentioned above, encompassing the mobility and propulsion of robotic systems, pertain only to ground robotic systems. The chapter will continue with a discussion on aerial and maritime mobility and propulsion platforms.

2.3. Structure and classification of ground military robotic systems:

The **main components of ground military robotic systems are:**

- **Sensors:** These are used for navigation, surveillance, reconnaissance, and environmental detection. Examples include optical sensors, proximity sensors, acoustic sensors, RADAR, and GPS. Sensors are critical to ensure the efficiency of operations without human crews.
- **Mobility and Propulsion Platforms:** The variety of platforms includes systems with wheels, tracks, and biomechanical elements (legs), adapted for different terrains and missions. For example, tracks are used for rough terrain, while biomechanical legs are used for navigating complex environments.
- **Electronic Components and Control Programs:** This includes processing units (microprocessors, microcontrollers), memory, and other elements that enable control of robotic systems. They must be robust and able to withstand extreme conditions.

Classification of Robotic Systems:

- **Ground Systems (UGVs):** Ground robots are used in logistics missions, reconnaissance, and explosive ordnance disposal. Examples include robots with wheels, tracks, and biomechanical legs.
- **Maritime Systems (UMSs):** These are used for underwater operations and maritime surveillance. Propulsion with propellers and navigation systems are key elements in their operation.
- **Aerial Systems (UAVs):** These include drones used for reconnaissance and surveillance, as well as for attacks. Modern UAVs are equipped with advanced sensors and efficient propulsion systems.

Military Applications:
Military robotic systems are used for a wide range of applications, including explosive device neutralization, hostile territory surveillance, rescue and evacuation operations, and logistics. Technological advancements have enabled the creation of faster, more precise, and more efficient systems, reducing risks for human personnel.

3. Challenges and new approaches in ground robotic military technology

- **Control and Automation Technology:** The integration of artificial intelligence (AI) into robotic systems is a crucial step, facilitating autonomous and semi-autonomous capabilities.
- **Resilience and Durability:** The development of materials and mechanisms capable of withstanding extreme conditions is a constant challenge.
- **Security and Protection:** In addition to reliability and efficiency, cybersecurity becomes a critical aspect to protect robotic systems from attacks.

Global and regional insights from leaders in robotic and AI technologies for military applications:

- **North America (USA and Canada):** The United States has been a leader in developing military drones (UAS - Unmanned Aerial Systems) used for surveillance and targeted strikes. Canada focuses on AI technologies for logistics purposes and humanitarian missions.
- **Asia (Japan and South Korea):** Japan emphasizes the use of robotics for defense and dual applications, while South Korea has developed autonomous guard robots in the demilitarized zone with advanced detection and rapid response technologies.
- **Europe (Germany and France):** Germany focuses on international collaboration for developing interoperable technologies, emphasizing cybersecurity and ethics. France explores advanced technologies in autonomous ground and aerial vehicles, aiming to enhance logistics and reduce risk for human personnel.
- **Singapore** has made significant investments in military robotics and autonomous systems, focusing on urban warfare and defense against asymmetric threats. The country emphasizes the development of advanced drones and robotic platforms that enhance situational awareness and operational effectiveness in densely populated environments.
- **India** is rapidly advancing its capabilities in military robotics, with a particular focus on indigenous development. The Indian Armed Forces are exploring various unmanned systems, including drones and ground robots, for surveillance, reconnaissance, and logistics. India also aims to integrate AI into these systems to improve decision-making processes and operational efficiency.
- **The UAE (United Arab Emirates)** has emerged as a regional leader in military robotics, investing heavily in unmanned aerial vehicles (UAVs) and autonomous ground systems. The country has developed advanced platforms for surveillance, reconnaissance, and combat roles. Additionally, the UAE is exploring partnerships with leading defense firms to enhance its capabilities in robotic and AI technologies.
- **Italy** is actively developing military robotic systems, with a strong emphasis on collaborative efforts between industry and academia. The Italian Armed Forces are incorporating robotic solutions for logistics, reconnaissance, and explosive ordnance disposal. Italy also focuses on enhancing interoperability with NATO allies in the development of autonomous systems.
- **Spain** is investing in robotic technologies for military applications, particularly in the areas of maritime security and land operations. The Spanish military is exploring the use of drones and ground robots to enhance surveillance capabilities and improve operational responses in diverse environments. Spain is also engaged in international collaborations to further advance its military robotics initiatives.

Ethical Considerations: Although AI brings many benefits to the military field, such as surveillance, information gathering, detection, and developing suggestions in critical situations, it is important to consider the ethical implications of this type of technology before its use to mitigate potential problems that may arise during military operations. The prospect of fully autonomous weapons systems raises ethical concerns about accountability and decision-making.

Cost and Sustainability Challenges: Challenges regarding costs are determined by the design, development, production, and successful integration of military robotic systems into military operations. Sustaining these systems requires solutions for easy updates as technologies evolve and ecological considerations in their development process.

4. Conclusion

Advances in the field of military robotic systems are highlighted by the various technological initiatives of high-tech nations such as the United States, Japan, South Korea, Canada, Germany, and France. All these countries, together with EU members that have joined NATO, contribute significantly to the development of innovative solutions that promise to redefine the way military conflicts are managed.

However, as these technologies advance, it becomes essential to also address ethical and security issues by creating an international regulatory framework to ensure their responsible and effective use. The ethical implications [8,9,14,16,19], particularly regarding fully autonomous weapon systems, must be carefully considered to prevent potential misuse and to maintain accountability in decision-making processes.

Countries like the United States, Japan, South Korea, Canada, Germany, and France invest heavily in these advancements, highlighting the critical strategic importance of military robotics. These systems are not new, but progress in artificial intelligence (AI), autonomy, and cyber integration has brought them to the forefront of technological innovation.

Emerging players such as Singapore, India, and the UAE are rapidly catching up, introducing new dynamics in the global competition for military robotic supremacy. This reflects the growing democratization of advanced military technologies, which are no longer the exclusive domain of global superpowers.

As we look to the future, fully autonomous military robotic systems [4,13,17] are the next frontier, with challenges not only in technology development but also in ensuring that these systems are sustainable, cost-efficient, and resilient in diverse operational environments. The intersection of robotics, AI, and cybersecurity presents unprecedented opportunities, but it also demands careful oversight and strategic foresight.

Ultimately, the global military landscape will continue to evolve, shaped by these advancements. Ensuring that military robotic systems are developed, deployed, and regulated in a responsible manner will be critical to balancing the benefits of these technologies with the challenges they present. The continued pursuit of international cooperation and innovation will be essential in navigating the complex future of military robotics.

References

[1] Babu, M.C., Ch. Prathibha, P. Vennella, G. Sujitha Rani, and G. Sanjana. “Multifunctional Robot for Military Applications.” *International Journal for Research in Applied Science & Engineering Technology IJRASET* 12, no. 4 (April 2024): 5260-5264.

[2] Adams, J.A., J. Scholtz, and A. Sciarretta. “Human-Robot Teaming Challenges for the Military and First Response.” *Annual Review of Control, Robotics, and Autonomous Systems* 7 (July 2024): 149-173.

[3] Liu, J., S. Chen, F. Gao, Y. Long, Z. Wang, and B. Xi. “Development and Application of Robotics Technologies in Future Intelligent Soldier Squad.” Paper presented at the 35th Chinese Control and Decision Conference (CCDC), Yichang, China, May 20-22, 2023.

[4] Black, M., L. Slapakova, P. Fusaro, and J. Black. “Supporting the Royal Australian Navy's Campaign Plan for Robotics and Autonomous Systems: Human-Machine Teaming and the Future Workforce.” Research Report. RAND Australia, 2022.

[5] Shetty, D.K., G. Prerepa, N. Naik, R. Bhat, J. Sharma, and P. Mehrotra. “Revolutionizing Aerospace and Defense: The Impact of AI and Robotics on Modern Warfare.” Paper presented at the 4th International Conference on Information Management & Machine Intelligence ICIMMI '22, Jaipur, India, December 23 - 24, 2022.

[6] Lembang, I.A.R., R.O. Bura, and R.D.A. Navalino. “Indonesia Military Research and Development in Dealing With The Sixth Generation Warfare: The Use of Artificial Intelligence in War Operations.” *East Asian Journal of Multidisciplinary Research EAJMR* 2, no. 2 (2023): 649-660.

[7] Su, J., X. Zhi, S. Lu, Q. Zhang, and J. Dong. “Design of a Lightweight Robotic Mule.” Paper presented at ASME 2021 International Mechanical Engineering Congress and Exposition, Online, Nov. 1–5, 2021.

[8] Belk, R.W. "Ethical issues in service robotics and artificial intelligence." *The Service Industries Journal* 41, no. 13-14 (2021): 860-876.
[9] Bartneck, C., C. Lütge, A.R. Wagner, and S. Welsh. "Military Uses of AI." Chapter in *An Introduction to Ethics in Robotics and AI*. Springer Briefs in Ethics. Cham, Springer Nature, 2021.
[10] Irvin, C., S. Leo, and J.H. Kim. "GunBot: Design Concept of a Semi-Autonomous UGV with Omni-directional Mobility and Auto-Target Tracking". Paper presented at the 2012 Florida Conference on Recent Advances in Robotics. Boca Raton, Florida, USA, May 10-11, 2012.
[11] Woo, C.K., H.D. Choi, M.S. Kim, S.H. Kim, and Y.K. Kwak. "Optimal Design of a New Wheeled Mobile Robot by Kinetic Analysis for the Stair-Climbing States." Chapter in Zhang, H. (ed.). *Climbing and Walking Robots: towards New Applications*. IntechOpen. I-Tech Education and Publishing, 2007.
[12] Liang, C., M. Ceccarelli, and G. Carbone. "Design and Simulation of Legged Walking Robots in MATLAB® Environment." Chapter in Perutka, K. (ed.). *MATLAB for Engineers - Applications in Control, Electrical Engineering, IT and Robotics*. IntechOpen. I-Tech Education and Publishing, 2011.
[13] Feickert, A., J.K. Elsea, L. Kapp, and L.A. Harris. "U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress." Technical Report. Congressional Research Service, CRS R45392, November 20, 2018.
[14] Surywanshi, R., and S. Parab. "Artificial Intelligence in Military Systems and their Influence on Sense of Security of Citizens." *International Journal of Advanced Research in Science, Communication and Technology IJARSCT* 2, no. 9 (June 2022): 547-550.
[15] Pysarenko, T.V., and T.K. Kvasha. "Global technological trends in the field of weapons and military equipment." Ministry of Education and Science of Ukraine, DNU "Ukrainian Institute of Scientific and Technical Expertise and Information", Kyiv, 2020.
[16] de Swarte, T., O. Boufous, and P. Escalle. "Artificial intelligence, ethics and human values: the cases of military drones and companion robots." *Artificial Life and Robotics* 24 (2019): 291-296.
[17] David, W., P. Pappalepore, A. Stefanova, and B.A. Sarbu. "AI-Powered Lethal Autonomous Weapon Systems in Defence Transformation. Impact and Challenges." Paper presented at the 6th International Conference on Modelling and Simulation for Autonomous Systems MESAS 2019, Palermo, Italy, October 29-31, 2019.
[18] Bansal, M., U.D. Kumar, R. Aggarwal, and V. Aggarwal. "On an attempt to explore challenges for Artificial Intelligence and Machine Learning in Indian Military and Defence Sector and Studying the Possible Inter-relationship amongst them using ISM Methodology." *International Journal of Computer Applications* 117, no. 28 (December 2019): 5-10.
[19] Wasilow, S.M., and J.B. Thorpe. "Artificial Intelligence, Robotics, Ethics, and the Military: A Canadian Perspective." *AI Magazine* 40, no. 1 (2019): 37-48.
[20] Kolev, G.Y., E.P. Solomevich, E. Rodionova, E.E. Kopets, and V.G. Rybin. "Sensor subsystem design for small unmanned surface vehicle." *IOP Conference Series: Materials Science and Engineering* 630 (2019): 012022. Paper presented at the 3rd International Conference on Information Processing and Control Engineering, Moscow, Russian Federation, August 4–7, 2019.
[21] Krishna, V., Y.B. Reddy, Y.A. Sai, and D. Devi. "Unmanned Armed Ground Vehicle. " *Semantic Scholar*, Corpus ID: 164261323, March 19, 2019. Accessed September 2, 2024. https://www.semanticscholar.org/paper/UNMANNED-ARMED-GROUND-VEHICLE-Krishna-Reddy/ad556f17bc16674e919b232e669292bbac2ae280.
[22] Young, S.H., and A.S. Kott. "A Survey of Research on Control of Teams of Small Robots in Military Operations." *ArXiv* abs/1606.01288 (June 2016).
[23] Teji, M.D., T. Zou, and D.S. Zeleke. "A Survey of Off-Road Mobile Robots: Slippage Estimation, Robot Control, and Sensing Technology." *Journal of Intelligent & Robotic Systems* 109 (2023): 38.
[24] Kim, Y.H., Y.H. Choi, and J.O. Kim. "How to Derive the Autonomous Driving Function Level of Unmanned Ground Vehicles - Focusing on Defense Robots -." *The Journal of Korean Institute of Communications and Information Sciences* 42, no. 1 (January 2017): 205-213.
[25] ***. "What is Ultrasonic Sensor: Working Principle & Applications." *Robocraze website*. Accessed September 2, 2024. https://robocraze.com/blogs/post/what-is-ultrasonic-sensor.
[26] ***. "Multi purpose robot for military application." *Electronics workshop*, August 24, 2020. Accessed September 2, 2024. https://electronicsworkshops.com/2020/08/24/multi-purpose-robot-for-military-application/.
[27] ***. "Introduction to Lidar." *MathWorks – Help Center*. Accessed September 2, 2024. https://www.mathworks.com/help/lidar/ug/lidar-processing-overview.html.
[28] Bogdon, C. "Clearpath Brings Velodyne Lidar Technology to Robotics Community as Value-Added Partner." *Clearpath Robotics. Blog, In the News*, *Press Release*, March 26, 2019. Accessed September 2, 2024. https://clearpathrobotics.com/blog/2019/03/clearpath-velodyne-announce-a-value-add-partnership/.