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Unmanned Ground Vehcile For Defence Applications

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ABSTRACT

The advancement of autonomous systems has significantly enhanced modern defence technology, enabling safer and more efficient military operations. This project focuses on the design and implementation of an Unmanned Ground Vehicle (UGV) that can operate autonomously in defence and surveillance environments. The proposed system utilizes a Raspberry Pi 3 Model B+ as the central processing unit, integrating ultrasonic sensors, motor drivers, and a Pi camera to achieve real-time environmental monitoring and obstacle detection. Through the implementation of computer vision and image processing techniques using OpenCV, the UGV is capable of identifying paths, avoiding obstacles, and navigating autonomously in dynamic environments. The system also allows for live video streaming, making it suitable for border surveillance, reconnaissance missions, and hazardous area monitoring where human access is limited or risky. Furthermore, the proposed UGV architecture emphasizes modularity and ease of expansion, allowing additional sensors such as GPS, infrared, gas sensors, or weapon detection modules to be integrated in future enhancements. This work lays a strong foundation for further research into advanced artificial intelligence algorithms, swarm robotics, and secure communication systems, contributing toward the development of next-generation autonomous ground systems for defence and security applications.

KEYWORDS: Artificial Intelligence, Arduino Microcontroller, Raspberry Pi, GSM, Suspension System

1. INTRODUCTION

An **Unmanned Ground Vehicle (UGV)** is a land-based robotic system that operates without a human onboard, either through remote control or autonomous navigation. UGVs are designed to perform tasks in environments that are dangerous, difficult, or inefficient for humans, such as military reconnaissance, bomb disposal, disaster response, and industrial inspection. Equipped with sensors, cameras, GPS, and artificial intelligence, UGVs can navigate terrain, detect obstacles, collect data, and execute missions with high precision and safety. As automation and AI technologies advance, UGVs are becoming increasingly reliable and widely used across defines, agriculture, mining, healthcare, and smart logistics sectors. UGVs play a vital role in modern applications such as military surveillance, explosive ordnance disposal, border security, disaster management, search and rescue operations, and industrial automation. In civilian domains, they are increasingly used in agriculture for precision farming, in mining for inspection and material handling, and in smart cities for monitoring and logistics. By reducing human risk, increasing operational efficiency, and enabling continuous operation, UGVs represent a key advancement in robotics and autonomous systems technology. UGVs can operate in structured and unstructured environments, including rough terrain, urban areas, and hazardous zones where human presence is risky or impossible. These vehicles use a combination of sensors, control systems, communication technologies, and artificial intelligence to perceive their surroundings and perform assigned tasks.

2.LITERATURE SURVEY

Liu et al. - Provide a broad survey of vehicle detection technologies for UGVs, classifying the sensors used (camera, LiDAR, radar, ultrasonic), comparing their advantages and disadvantages, and reviewing simulation platforms and datasets. The paper emphasises that environmental perception is foundational to UGV operation, and that sensor selection involves trade-offs in range, resolution, illumination robustness, and computational load. From this work, one takeaway is that multi-modal sensing (e.g. fusion of LiDAR + radar + visual) often yields better reliability under adverse condition (night, weather, cluttered background), which is directly relevant for defence-oriented UGVs.

Beycimen, Ignatyev & Zolotas - A Comprehensive Survey of Unmanned Ground Vehicle Terrain Traversability for Unstructured Environments and Sensor Technology Insights. They categorize traversability methods into appearance-based, geometry-based, and mixed- models. They also review cost-based traversability metrics, machine-learning / deep-learning / reinforcement learning approaches for traversability estimation, and sens or configurations suitable for unstructured / off-road environments.
One key insight from this survey is that mixed methods combining exteroceptive sensors (camera / LiDAR) with proprioceptive feedback (wheel slip, IMU data) lead to more reliable traversability estimates under variable terrain. Another interesting recent work is by Wang et al. (2024) in MDPI Machines, which surveys path planning in unstructured environments. That article frames path planning as hierarchical vs end-to-end approaches, emphasizes terrain cost estimation (safety cost, energy cost, comfort cost), and highlights vehicle–terrain interaction constraints (e.g. slope, roughness) as central to planner design.

Carvalho et al. - traversability analysis in forest / natural terrain environments, focusing on irregular terrain, occlusions, and dynamic obstacles such as vegetation. Although not explicitly defence-only, its methods are applicable to UGVs deployed in natural or semi-natural terrain (e.g. border areas, remote perimeters). The study points to emerging techniques such as feature-learning for mechanical effort estimation, and underscores open challenges such as negative-obstacle detection (ditches, holes), and on-line adaptation to changing terrain properties.

Zhang et al. - The development of **vision-based autonomous systems** for Unmanned Ground Vehicles (UGVs) using artificial intelligence techniques. Their research employed **deep learning models**, particularly convolutional neural networks, to process visual data obtained from onboard cameras for obstacle detection and terrain classification. By relying on vision sensors, their approach reduced dependency on costly hardware such as LiDAR while maintaining reliable navigation performance. Zhang et al. also integrated visual perception with autonomous path planning and motion control, enabling UGVs to operate effectively in unstructured and dynamic environments.

3. EXISTING SYSTEM

In recent years, several unmanned ground vehicles (UGVs) have been developed and deployed in both defence and industrial sectors. Existing UGV systems are primarily designed for surveillance, reconnaissance, explosive ordnance disposal (EOD), logistics, and remote inspection in dangerous or inaccessible environments. These systems combine mechanical robustness with embedded electronics, sensor suites, and wireless communication for remote control or limited autonomy. These systems integrate mechanical robustness with embedded electronics, advanced sensor suites, and wireless communication technologies to enable either remote teleoperation or limited autonomous functionality. Depending on mission requirements, UGVs may operate using line-of-sight radio control, long-range RF communication, or network-based control systems. Most current UGV platforms emphasize reliability, rugged terrain mobility, and mission-specific payloads rather than low cost or scalability. They often incorporate cameras, thermal imaging sensors, LiDAR, robotic manipulators, and navigation modules to perform complex tasks under hostile conditions. However, many of these systems rely heavily on human operators for navigation and decision-making, limiting their autonomy and increasing operational workload.

4. PROPOSED SYSTEM

The proposed Unmanned Ground Vehicle (UGV) for Defence Applications is designed to overcome the limitations of existing UGV platforms by integrating autonomous navigation, intelligent area monitoring, and real-time data transmission using modern embedded systems and open-source robotics software. Unlike conventional teleoperated systems that require continuous human control, the proposed system emphasizes onboard intelligence to enhance operational efficiency and reduce operator workload in hostile or inaccessible environments. The system is developed as a low-cost, reliable, and semi-autonomous robotic platform capable of performing surveillance, reconnaissance, and area patrolling tasks in defence and security operations with minimal human intervention. A Raspberry Pi–based processing unit serves as the core controller, enabling the integration of multiple sensors, motor control modules, and a vision system. This architecture allows the UGV to process sensor data locally, make navigation decisions in real time, and respond effectively to dynamic environmental conditions. Overall, the proposed system demonstrates a practical and cost-effective approach to developing intelligent autonomous ground vehicles for defence applications. By combining embedded system design, real-time image processing, and wireless communication, the UGV provides a flexible platform for research and deployment in next-generation defence and security operations.

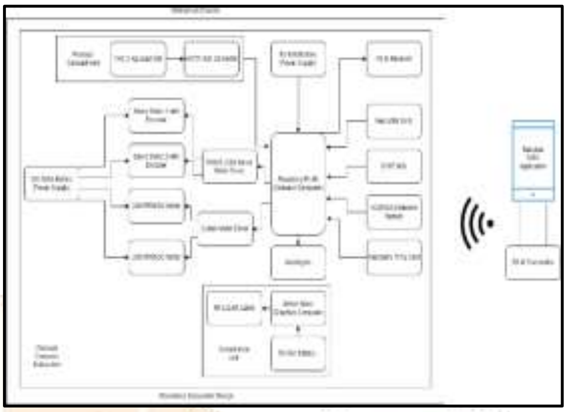
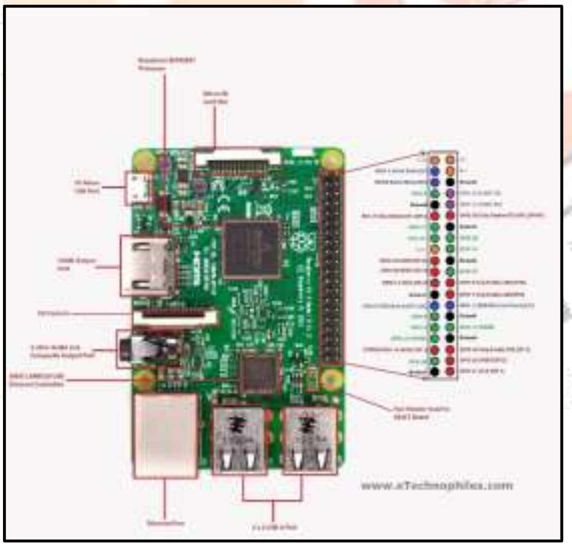


Fig 1 : Block Diagram

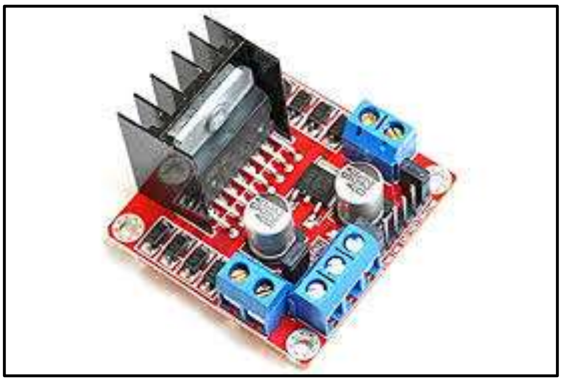
5.HARDWARE DESCRIPTION

5.1 RASPBERRY PI 3 MODEL B+ :



The Raspberry Pi 3 Model B+ is a compact and powerful single-board computer developed by the Raspberry Pi Foundation. It serves as a cost-effective and energy-efficient platform for embedded systems, robotics, and IoT applications. In this project, the Raspberry Pi 3 Model B+ acts as the central processing and control unit of the Unmanned Ground Vehicle (UGV), responsible for sensor integration, image processing, decision-making, and communication with the operator.

5.2 MOTOR DRIVER MODULE (L298N OR L293D):



The Motor Driver Module is used to control the speed and direction of DC motors in a UGV and acts as an interface between the **Raspberry Pi** and the motors. Since the Raspberry Pi cannot supply sufficient current to drive motors directly, the motor driver handles power control. The L293D is suitable for low-power motors, while the L298N supports higher current motors, enabling forward, reverse, and speed control using GPIO signals. These modules are widely used in UGVs due to their reliability, and ease of integration with controllers like Arduino.

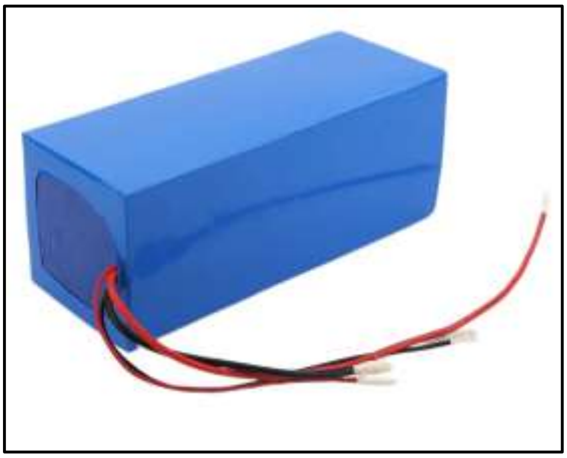
5.3 DC GEARED MOTORS:

DC geared motors are commonly used in UGVs to provide high torque at low speeds, which is essential for smooth and controlled movement. The gearbox attached to the DC motor reduces speed while increasing torque, making it suitable for carrying loads and navigating uneven terrain. These motors are easy to control using motor driver modules and offer reliable performance for ground vehicle applications. They also ensure precise speed control and stable motion when driven using PWM signals from the controller.

5.4 CAMERA MODULE (RASPBERRY PI CAMERA OR USB WEBCAM):

The Camera Module (Raspberry Pi Camera or USB Webcam) is a key sensing component in a UGV, used for real-time visual monitoring and perception. It enables the UGV to capture images and live video for applications such as remote surveillance, obstacle detection, and navigation. When connected to a **Raspberry Pi**, the camera supports image processing and computer vision tasks using software libraries like OpenCV. This visual data helps the UGV understand its surroundings, make autonomous decisions, and allows operators to monitor the vehicle remotely in real time.

5.5 POWER SUPPLY / BATTERY UNIT:



The Power Supply / Battery Unit supplies electrical energy to all components of the UGV, including the Raspberry Pi, motor drivers, sensors, and motors. Lithium-ion batteries are preferred for lightweight and portable UGVs due to their high energy density, fast charging, and longer lifespan. On the other hand, 12V lead-acid batteries are more suitable for heavy-duty UGVs as they can deliver high current and are mechanically robust. The choice of battery depends on power requirements, operating duration, and vehicle load to ensure stable and efficient system performance.

5.6 CHASSIS FRAME:

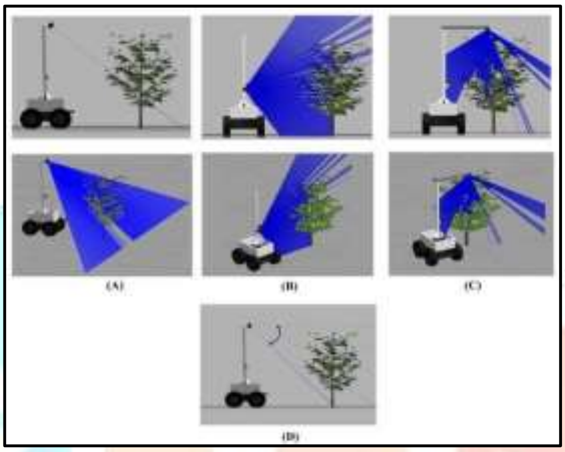
The Chassis Frame forms the structural backbone of the UGV and supports all major components such as motors, battery, motor drivers, Raspberry Pi, and sensors. It is designed to provide strength, stability, and proper weight distribution while allowing the vehicle to move smoothly over different terrains. Chassis frames are commonly made from materials like aluminium, steel, or high-strength plastic to balance durability and weight. A well-designed chassis improves traction, protects internal components from damage, and enhances the overall reliability and performance of the UGV.

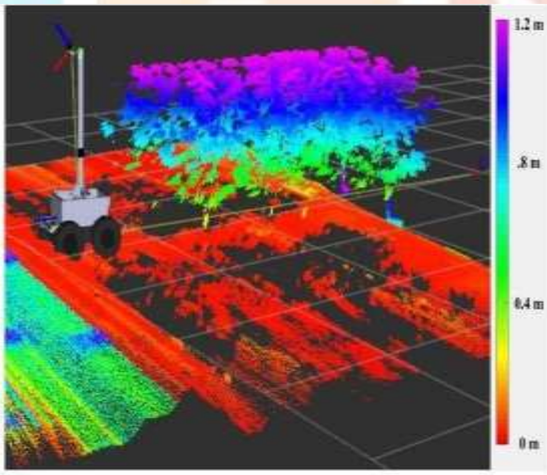
5.7 WI-FI / RF COMMUNICATION MODULE

The Wi-Fi / RF Communication Module enables wireless communication between the UGV and the control station or operator. It allows real-time transmission of control commands, sensor data, and live video from the UGV to a remote device. Wi-Fi modules are commonly used with Raspberry Pi for high-speed data transfer and internet-based control, while RF modules provide reliable long-range communication with low power consumption. This communication system is essential for remote monitoring, control, and autonomous operation of the UGV.

6. RESULT

The developed Unmanned Ground Vehicle (UGV) for defence applications was successfully designed, assembled, and tested under controlled conditions. The vehicle demonstrated reliable remote operation using wireless communication, allowing safe navigation without direct human presence in hazardous areas. The UGV was able to move forward, backward, and turn smoothly, showing good stability on uneven surfaces. The onboard camera provided real-time video feedback, enabling effective surveillance and situational awareness. Obstacle detection sensors accurately identified nearby objects and helped prevent collisions, improving operational safety. The system responded promptly to control commands with minimal delay, indicating efficient communication performance. Power consumption remained within acceptable limits, allowing continuous operation for the expected duration. Overall, the results confirm that the UGV can effectively support defence operations such as reconnaissance, border patrol, and monitoring of high-risk zones, reducing risks to human soldiers and enhancing mission safety and efficiency.





7.CONCLUSION

The development of the Unmanned Ground Vehicle (UGV) for Defence Applications successfully demonstrates the effective integration of embedded systems, image processing, and autonomous navigation techniques to address the growing demand for intelligent robotic solutions in modern military and surveillance operations. By employing the Raspberry Pi 3 Model B+ as the central processing unit, along with ultrasonic sensors, motor drivers, and a Pi camera, the system is capable of performing real-time environmental monitoring, obstacle detection, and autonomous movement with reliable performance.

Overall, this project highlights the potential of Raspberry Pi–based UGVs as a practical solution for defence automation and smart surveillance. With further enhancements such as GPS-based navigation, thermal imaging, artificial intelligence–based object recognition, and secure long-range communication, the proposed system can be extended into a fully autonomous and robust defence-grade robotic platform capable of operating effectively in complex real-world scenarios.

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