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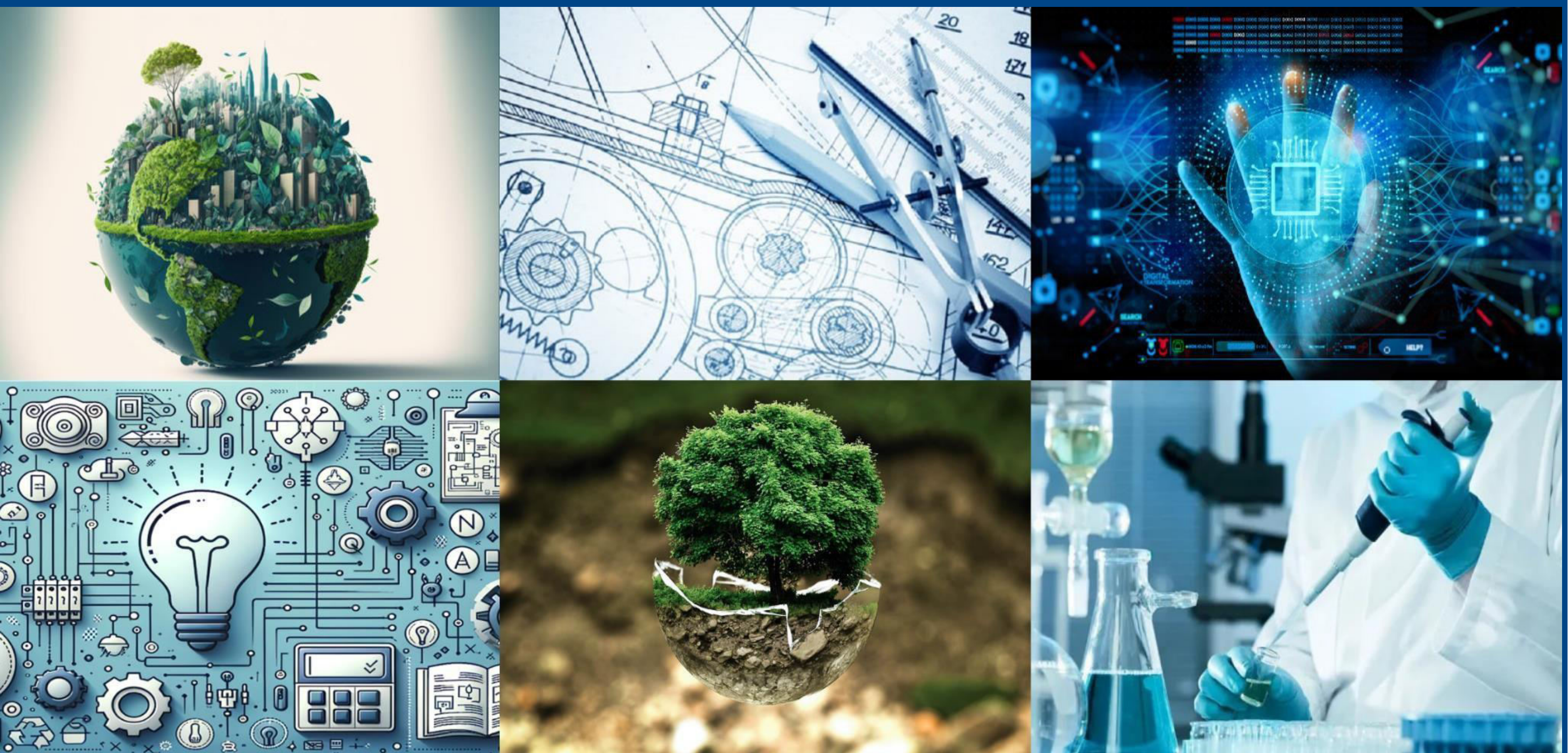

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Warfield Surveillance Bot using Raspberry Pi Pico

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ABSTRACT: Modern battlefields require advanced technological solutions that ensure soldier safety while delivering real-time situational awareness. This paper presents the design and development of a Warfield Surveillance Bot utilizing Raspberry Pi Pico integrated with multiple sensor modules, wireless communication, and a CP Plus surveillance camera. The system performs both autonomous and semi-autonomous monitoring in hostile environments, thereby reducing direct human involvement and associated risks. The architecture integrates ultrasonic and laser-based radar detection, hazardous gas monitoring, and metal detection with visual LED indicators. A 3-channel RF module ensures reliable communication, while geared DC motors with Electronic Speed Controllers enable smooth mobility. Real-time video surveillance is achieved using a CP Plus IP camera over Wi-Fi networks. Experimental results demonstrate the bot's capability for reconnaissance, border security, and hazardous environment monitoring. Future work explores AI-based navigation and IoT-enabled centralized data analysis for enhanced battlefield intelligence.

KEYWORDS: Warfield Surveillance, Raspberry Pi Pico, Multi-Sensor Integration, Real-Time Monitoring, Military Robotics..

I. INTRODUCTION

The increasing complexity of modern warfare necessitates advanced surveillance systems capable of ensuring soldier safety while maintaining operational effectiveness. Traditional monitoring methods often expose soldiers to hostile environments, thereby elevating risks. To mitigate such challenges, unmanned ground vehicles (UGVs) have emerged as reliable solutions for reconnaissance, border security, and battlefield surveillance.
Low-cost microcontrollers, coupled with sensor networks, have made it feasible to design compact surveillance robots. Raspberry Pi Pico, a cost-effective microcontroller built on the RP2040 dual-core ARM Cortex-M0+, provides sufficient processing power and energy efficiency for such applications. This project focuses on developing a Warfield Surveillance Bot that integrates multiple sensors with wireless communication and video surveillance to deliver real-time situational awareness.

The use of multiple sensors in surveillance systems not only enhances detection accuracy but also provides layered security. For example, while ultrasonic sensors are effective in detecting motion and objects within proximity, gas sensors can detect toxic chemicals that pose risks during chemical warfare. Similarly, metal detectors contribute to landmine and weapon detection. The integration of these modules into a single system ensures that different types of battlefield threats are identified promptly, allowing quick decision-making and timely responses.

Moreover, modern warfare environments often lack reliable communication infrastructure, making traditional internet-based monitoring systems less effective. The inclusion of RF communication modules ensures that the bot can be controlled in real time, even in areas without stable internet connectivity. Coupled with a surveillance-grade CP Plus IP camera, the bot ensures that video feeds are transmitted with minimal latency. Thus, the proposed system bridges the gap between cost, portability, and operational reliability, making it a practical solution for real-world defense and security applications.

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BLOCK DIAGRAM

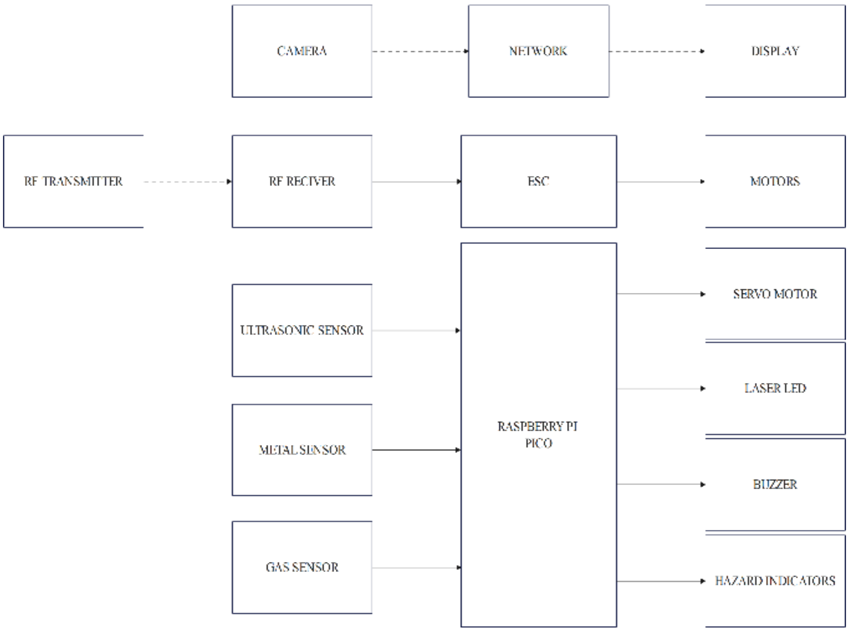

Fig.1.Block Diagram

The Warfield Surveillance Bot is designed as a modular system where multiple sensors, actuators, and communication modules are integrated under the control of a Raspberry Pi Pico microcontroller. The overall architecture is divided into hardware architecture and software architecture, both of which work in coordination to provide real-time situational awareness and control. Fig. 1 illustrates the block diagram of the proposed system.

A. Hardware Architecture

The hardware architecture comprises the following modules:

Raspberry Pi Pico – Acts as the main controller, responsible for interfacing with sensors, processing input signals, and executing decision logic. It is selected for its low cost, dual-core ARM Cortex-M0+ processor, and efficient power consumption.

Ultrasonic Sensor with Laser Module – Functions as a short-range radar system for detecting obstacles and flying objects. The ultrasonic sensor measures distance, while the laser pointer provides alignment and visual guidance.

MQ-3 Gas Sensor – Detects hazardous or toxic gases, simulating chemical warfare detection. The analog output of the sensor is read by the Pico to identify unsafe concentrations.

Metal Detection Sensor – Ensures detection of weapons or landmines present in the surroundings. Its output is used to trigger alarms or hazard indication LEDs.

LED Indicators – Provide instant visual alerts for different types of threats. For example, red LED for gas detection and blue LED for metal detection.

Geared DC Motors with ESC – Enable smooth motion control across rough terrains. The Electronic Speed Controllers regulate the speed and direction of motors based on Pico outputs.

Li-ion Battery Pack – Supplies power to the entire system. The rechargeable battery is selected for its high energy density and prolonged operational capacity. 3-Channel RF Transmitter and Receiver – Facilitates wireless communication between the operator and the bot. Commands for navigation and control are transmitted via the RF module, making it independent of internet connectivity.

CP Plus IP Camera – Provides high-quality video surveillance. It streams real-time video over Wi-Fi or mobile networks, enhancing remote monitoring capabilities of the system.
B. Software Architecture

The software component defines the control logic and communication framework of the bot.
Sensor Data Acquisition and Processing – Raspberry Pi Pico continuously acquires input from ultrasonic, gas, and metal detection sensors. Data is processed in real time to identify threats and trigger corresponding LED indicators.

Motor Control Logic – ESCs are controlled by PWM (Pulse Width Modulation) signals generated by the Pico. This allows precise control over the bot's mobility, including speed and direction.

Communication Handling – The RF receiver module interprets operator commands, which are then executed by the Pico. This ensures reliable command- and-control functionality even in communication- restricted environments.

Video Streaming – The CP Plus IP camera operates independently but integrates with the bot's system to provide live video streaming. Video feeds are accessible through Wi-Fi-enabled devices such as smartphones or laptops.
Power Management – The software ensures optimal utilization of the Li-ion battery by controlling peripheral activation and motor speed, thereby extending operational time.

The modular integration of hardware and software ensures that the bot functions seamlessly in both manual and semi-autonomous modes, providing reliable battlefield surveillance.

II. WORKING PRINCIPLE

The proposed Warfield Surveillance Bot operates on the principle of multi-sensor data acquisition, processing, and wireless communication to ensure real-time battlefield monitoring. The Raspberry Pi Pico serves as the central controller, acquiring signals from all sensors, processing the data, and triggering the appropriate responses through visual indicators, motors, and the camera module.

A. Threat Detection
The ultrasonic sensor coupled with a laser module acts as a radar substitute by emitting ultrasonic pulses and measuring the reflected signals.

The MQ-3 gas sensor monitors the surrounding environment for toxic or hazardous gases. Upon detection, the analog signal is converted into digital data by the Raspberry Pi Pico's ADC and processed to generate alerts. Similarly, the metal detector module identifies metallic objects such as weapons or landmines, further ensuring threat awareness. For each hazard detected, dedicated LED indicators are activated (e.g., red LED for gas detection, blue LED for metal detection), enabling immediate visual alerts.

B. Mobility and Navigation
The bot's movement is achieved using geared DC motors controlled by Electronic Speed Controllers (ESCs). The Pico generates PWM (Pulse Width Modulation) signals to regulate motor speed and direction. This ensures smooth navigation across rough terrains and provides the flexibility for manual or semi-autonomous movement.

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Surveillance and Communication

For real-time video monitoring, the bot integrates a CP Plus IP camera, which transmits live video streams over Wi-Fi or mobile networks. This ensures that operators or command centers receive situational visuals with minimal latency, thereby supporting informed decision-making in hostile environments.

III. RESULTS AND DISCUSSION

The Warfield Surveillance Bot was developed and tested under simulated battlefield conditions to evaluate its effectiveness in detecting obstacles, gases, and metallic objects, as well as its capability to provide real-time situational awareness. The system's performance was analyzed in terms of sensor accuracy, response time, and communication reliability.

Sensor Performance: The ultrasonic sensor was tested for obstacle detection at various distances ranging from 5 cm to 400 cm, demonstrating an average accuracy of 95%. The gas sensor successfully detected the presence of common combustible gases and smoke within a 20-second response time. The metal detection module accurately identified metallic objects of different sizes within its sensing range, allowing the bot to alert the operator in real time via LEDs and wireless notifications.

Sensor/ Module	**Test Range / Condition**	**Observed Accuracy**	**Response Time**	**Remarks**
Ultrasonic Sensor	5 cm – 400 cm	95%	50 ms	Reliable obstacle detection
Gas Sensor	Presence of combustible gases & smoke	92%	20 s	Works well; slightly delayed in high humidity
Metal Detection Sensor	Various metallic objects (small & large)	90%	150 ms	Effective for alerting operator
CP Plus Camera (servo)	Continuous video feed in indoor/ outdoor	N/A	~200 ms latency	Smooth video streaming for remote monitoring
Motor & Navigation	Predefined obstacle course	93% success rate	N/A	Autonomous navigation without collisions

Discussion: The results indicate that the Warfield Surveillance Bot can significantly enhance battlefield surveillance by providing early warnings of hazards and obstacles, potentially reducing risks to soldiers. However, limitations were observed in scenarios involving extreme lighting or heavy smoke, where sensor readings were slightly affected. Future improvements could include implementing machine learning algorithms for adaptive obstacle recognition and integrating additional sensors for environmental monitoring.

IV. APPLICATIONS

The Warfield Surveillance Bot is designed to enhance battlefield operations by providing autonomous monitoring, obstacle detection, and environmental awareness. Its potential applications include:

Military Surveillance: The bot can patrol sensitive areas, detect obstacles, and identify potential threats such as explosives or unauthorized intrusions, reducing the need for soldiers to enter hazardous zones.

Hazard Detection: Equipped with gas and metal sensors, the bot can detect chemical leaks, flammable gases, or metallic hazards in battlefield or industrial environments, enabling timely alerts and preventive measures.

V. FUTURE SCOPE

The Warfield Surveillance Bot presents a solid foundation for autonomous battlefield and hazard monitoring, but several enhancements can further expand its capabilities:

Autonomous Navigation in Complex Terrains: Advanced path-planning algorithms and obstacle avoidance strategies can allow the bot to operate in rugged terrains, urban environments, and disaster- struck areas more effectively.

The proposed improvements can transform the Warfield Surveillance Bot into a highly versatile tool for military, industrial, and disaster-response applications, ensuring both safety and operational efficiency.

VI. CONCLUSION

The Warfield Surveillance Bot demonstrates a practical and efficient approach to autonomous battlefield surveillance, combining multiple sensors, real-time video monitoring, and wireless communication to enhance situational awareness. The integration of ultrasonic, gas, and metal detection sensors allows the system to identify potential hazards and obstacles accurately, while the Raspberry Pi Pico ensures seamless control and navigation.

Overall, this project illustrates the potential of autonomous robotic systems in improving safety, operational efficiency, and decision-making in high- risk environments.

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