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Guardian Eye: Mobile Surveillance and Defense System for Military Safety

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Abstract: In high-risk military scenarios like terrorist attacks, ensuring the safety of troops and maintaining efficient operations is crucial. This project introduces "Guardian Eye"- a mobile surveillance and defense system controlled via a mobile application. It combines a standard-definition camera with a defensive mechanism for real-time monitoring and threat response. Using PIR sensors, the system enhances detection accuracy from bunkers. Ultrasonic sensors provide radar-like capabilities, allowing for precise distance measurement to nearby objects. With the Centroid-Tracker algorithm, the system accurately tracks intruders. The mobile app facilitates smooth control of the device across rugged terrains, delivering consistent surveillance and automated threat mitigation.

Key Terms: Internet of Things (IOT), Machine Learning (Centroid Tracker), Mobile App Interface, Embedded Systems

I. INTRODUCTION

Modern military operations demand advanced surveillance and defense systems to ensure personnel safety and effective threat detection in hostile environments. This paper presents Guardian Eye, a mobile-application-controlled payload system designed to enhance military surveillance through real-time video streaming, autonomous threat detection, and remote defense capabilities [1]. The system integrates multiple modules, including a camera-equipped surveillance unit, a remotely operable defense mechanism, and sensor-based intruder detection technologies.

The payload employs PIR and Ultrasonic sensors to detect motion and heat signatures from living entities, enhancing situational awareness in restricted zones. In addition to these, ultrasonic sensors are used to enable radar-like detection by measuring the distance to surrounding objects through sound wave reflections [6]. This allows for real-time obstacle identification and navigation support, which is crucial for ensuring safe operation in complex or cluttered environments. The Centroid Tracking Algorithm is a straightforward but reliable technique used to track objects in video footage. It works by finding the center point (or centroid) of detected objects and matching them across frames based on how close they are [10]. This allows the system to follow the same object consistently over time, even as it moves around the scene. The mobile application (MIT App Inventor) provides an intuitive interface for live monitoring, receiving instant alerts. By combining machine learning algorithm and sensor fusion, Guardian Eye offers a robust and intelligent solution for modern military surveillance and safety [1].

II. LITERATURE SURVEY

[1] Ghute, Minal S., Kanchan P. Kamble, and Mridul Korde. "Military Surveillance System Based on IoT." 2022.
The paper presents an innovative military surveillance system utilizing IoT technology, integrating an ESP8266 controller with various sensors to enhance battle- field surveillance. It employs an ESP32 camera for live streaming and face recognition, crucial for identifying intruders. Additionally, the system monitors environ- mental conditions, such as temperature and gas levels, ensuring soldier safety in hostile environments.

[3] Kannan, B. Maruthu, et al. "Secure Communication in IoT-enabled Embedded Systems for Military Applications using Encryption." 2023 2nd International Conference on Edge Computing and Applications (ICECAA). IEEE, 2023.
This study explores the critical need for secure communication in IoT-enabled embedded systems within military applications. It highlights how real-time monitoring enhances situational awareness but underscores the vulnerabilities these systems face from cyberattacks. The research reviews various encryption protocols and their effectiveness in protecting communication integrity, along with case studies that illustrate successful implementations in military settings.

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[4] Pandey, Arvind Kumar, and Warish Patel. "A Smart Vehicle Control Remotely using Wifi." 2022 11th International Conference on System Modeling Advancement in Research Trends (SMART). IEEE, 2022.
This paper discusses the development of a remote-controlled vehicle using Wi- Fi technology, emphasizing the significance of autonomous vehicle control in military and rescue operations. The authors explore the integration of a Raspberry Pi for processing and communication, enabling real-time video transmission and object recognition. The study highlights the potential for enhancing remote monitoring capabilities, particularly in hazardous environments where human presence is risky.

[6] Hemalatha, R., et al. "Sentinel Rover: Cutting-Edge Wireless Mine Detection and Alert System for High-Risk Terrains." 2023 International Conference on Self Sustainable Artificial Intelligence Systems (ICSSAS). IEEE, 2023.
The Sentinel Rover (SR) is a wireless-operated land rover designed to enhance mine clearance operations in dangerous terrains. It integrates advanced sensors, including metal detectors, ground-penetrating radar, thermal imaging, and acoustic sensors, to detect landmines effectively. The rover's robust design allows it to navigate challenging environments while minimizing risks to human personnel. Its alert system ensures timely communication of detected threats to remote operators, emphasizing the importance of human oversight in mission planning.

[7] Mallikarjun, B. C., et al. "Intruder detection system-a LoRa based approach." 2020 5th International Conference on Communication and Electronics Systems (ICCES). IEEE, 2020.
The proposed Intruder Detection System utilizes Passive Infrared Sensors (PIR) to detect unauthorized entry into restricted areas. It processes the sensor data using Long Range (LoRa) technology, allowing for effective communication over long distances. The system is designed to enhance internal security by locating intruders in sensitive regions, demonstrating the importance of data processing and analysis in military applications. Implementation results validate the system's effectiveness and underscore the crucial role of sensor networks in maintaining security.

[10] Rakshitha M, Spandana L L, Vandana K B, Mohan Kumar M, "A Review on Intruder Alarm System," DOI: 10.22214/ijraset.2023.51053, 2023.
The paper reviews various security technologies from a security and accessibility perspective, emphasizing the critical need for effective home security solutions. It identifies the drawbacks of existing systems, including high costs and vulnerabilities. The authors discuss advancements in security automation technologies such as fiber sensors, accelerometers, and IoT-based systems, highlighting the de- creasing costs of sensors, which make vibration signature identification a viable alternative to traditional systems.

BLOCK DIAGRAM

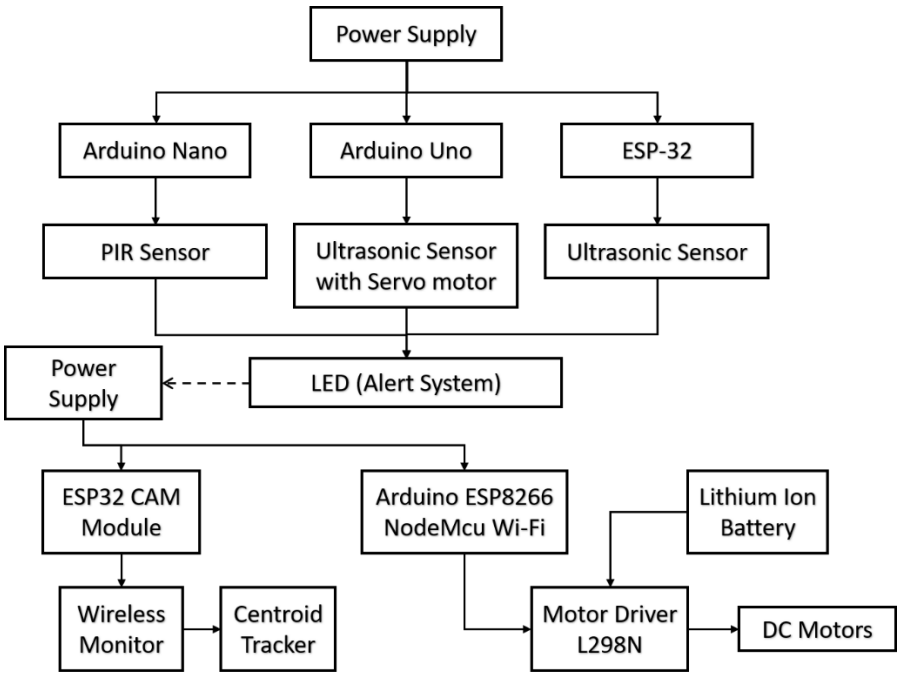

Fig. 1 Sensors Integration and Payload Unit

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The above Fig. 1 block diagram titled "Sensors Integration and Payload Unit" illustrates a modular surveillance and defense system built around multiple microcontrollers. The system integrates Arduino Uno, Arduino Nano, ESP32, and NodeMCU (ESP8266) boards to distribute functionality across specialized modules.

An ultrasonic sensor with a servo motor, connected to the Arduino Uno, functions as a basic radar system by scanning the surroundings and detecting nearby objects using reflected sound waves. Another ultrasonic sensor, connected to the ESP32, provides static proximity detection to support obstacle awareness and short-range object tracking.

A PIR sensor, connected to the Arduino Nano, enables motion and heat source detection. Sensor outputs activate an LED-based alert system, providing real-time visual notifications. This local processing ensures immediate response and triggers further system actions when necessary.

For visual surveillance, the system employs an ESP32-CAM module, powered by a lithium-ion battery. It streams real-time video to a wireless monitor and interacts with a centroid tracker to support object tracking functionality.

Mobility is handled by an Arduino ESP8266 NodeMCU Wi-Fi module, which interfaces with an L298N motor driver to operate DC motors. This enables bidirectional movement control, facilitating mobile surveillance.

A centralized power supply, in combination with a lithium-ion battery, ensures stable and reliable energy distribution across all modules. The distributed and modular system architecture enhances both real-time responsiveness and operational reliability, making it ideal for deployment in high-risk military surveillance scenarios.

III. HARDWARE REQUIREMENTS

- ***Arduino Uno, Nano and ESP32***

Arduino Uno, Arduino Nano, and ESP32 are some of the most commonly used microcontroller boards in electronics and embedded system design [1][4]. The use of Arduino Uno and Nano boards for microcontroller-based control is shown in Fig. 2. The Arduino Uno, powered by the ATmega328P chip, is known for its simple layout and user-friendly interface, making it a great starting point for beginners. It offers a good mix of digital and analog input/output pins, perfect for basic projects and prototyping.

The Arduino Nano packs the same functionality into a much smaller form, designed to fit neatly onto a breadboard. It's ideal for compact or space-sensitive builds where size matters but performance can't be compromised.

The ESP32, developed by Espressif Systems, steps things up with more processing power, dual cores, and built-in Wi-Fi and Bluetooth capabilities. It's well-suited for advanced applications like smart devices and IoT systems that require wireless communication.

Despite their differences, all three boards are easy to program using the Arduino IDE, which makes them accessible to both beginners exploring the world of microcontrollers and professionals building sophisticated systems.

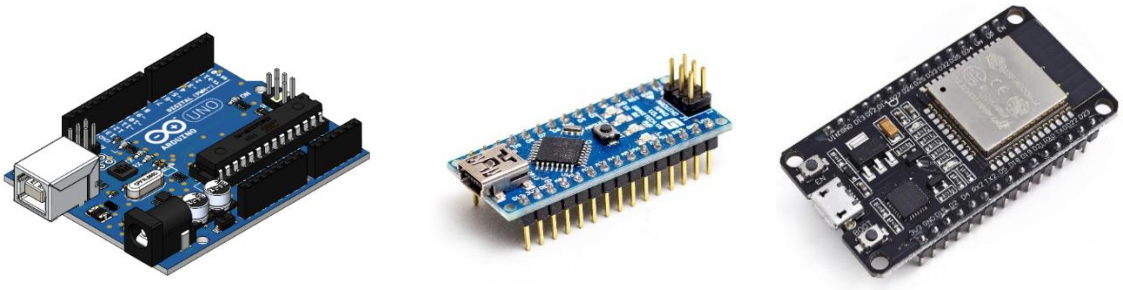

Fig. 2 Arduino Uno, Nano and Esp-32

- ***PIR and Ultrasonic Sensors***

PIR (Passive Infrared) Sensor: Detects motion by sensing heat emitted from people or animals. It's useful for spotting movement in restricted zones [11].

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Ultrasonic Sensor: Works by sending out high-frequency sound waves and measuring how long they take to bounce back. This allows it to calculate distances, making it an effective tool for obstacle detection and basic radar functionality [6].

Together, these sensors help identify intruders, measure surroundings, and support safe navigation as shown in Fig. 3.

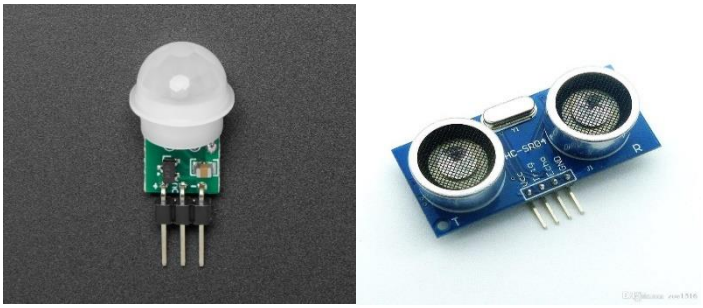

Fig. 3 PIR and Ultrasonic Sensors

- ***Motor driver(L298N)***

The L298N is a motor driver module capable of controlling the speed and direction of two DC motors or one stepper motor [4]. It works by receiving signals from the microcontroller (like an Arduino) and adjusting motor movement accordingly. Because it handles higher current and voltage, it's well-suited for robotics and automated vehicles.

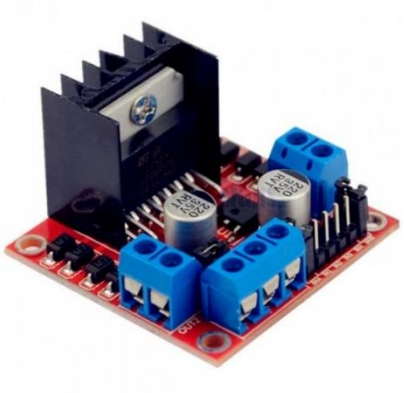

Fig. 4 L298N Motor Driver

- ***DC Motors and Servo Motors***

DC Motors: Used to drive wheels or create movement. These motors can rotate in both directions and support speed control, making them ideal for general mobility.

Servo Motors: Provide precise movement, typically rotating to specific angles. They're often used in robotic arms or systems that require accurate positioning.

Fig. 5 DC and Servo Motors

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- ***Chassis Kit***

The **chassis kit** serves as the physical base of the system. It usually includes a sturdy platform, wheels, motors, and mounting hardware. It holds all the electronics together and supports smooth movement, especially across uneven or rugged terrain.

Fig. 6 Chassis Kit

- ***Esp-32 Camera Module***

The **ESP32-CAM** is a small, affordable module that combines a camera with a Wi-Fi/Bluetooth-enabled microcontroller. It captures images and streams video over a network, making it perfect for surveillance tasks. Additionally, its GPIO pins allow for easy integration with other sensors and components, expanding its use in various smart electronics or IoT applications.

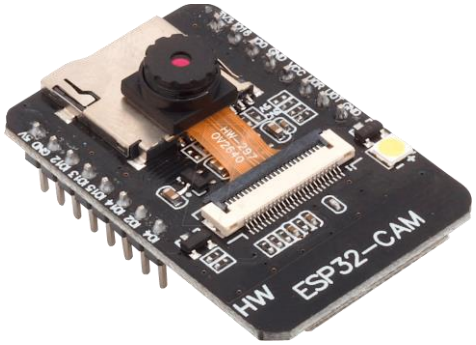

Fig. 7 Esp32-Camera Module

- ***Arduino ESP8266 NodeMCU Wi-Fi Development Board***

The NodeMCU (ESP8266) is a compact, low-cost microcontroller board with built-in Wi-Fi capability, making it ideal for wireless IoT and automation projects. It supports programming via the Arduino IDE and features multiple GPIO pins for connecting sensors, actuators, and motor drivers. With its reliable network connectivity and ease of integration, the ESP8266 NodeMCU is well-suited for applications such as remote monitoring, wireless control, and real-time data transmission.

Fig. 8 Arduino ESP8266 NodeMCU

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- ***Buzzer and Led***

The buzzer is used to give audible alerts or warnings based on specific conditions in the project. The LED acts as a visual indicator to show the status or activity of the system.
Together, they enhance user interaction by providing clear audio-visual feedback.

Fig. 9 Piezoelectric Buzzer and LED

SOFTWARE REQUIREMENTS

- ***Arduino IDE***

The **Arduino IDE (Integrated Development Environment)** is a free software used to write, edit, and upload code to Arduino boards and other compatible devices like the ESP32-CAM. The software environment used for programming the microcontrollers is shown in Fig. 9. It has a simple interface where you can type your code, check for errors, and send it to your device using a USB cable. The Arduino IDE supports many built-in examples and libraries, making it easy for beginners to learn programming and build electronic projects.

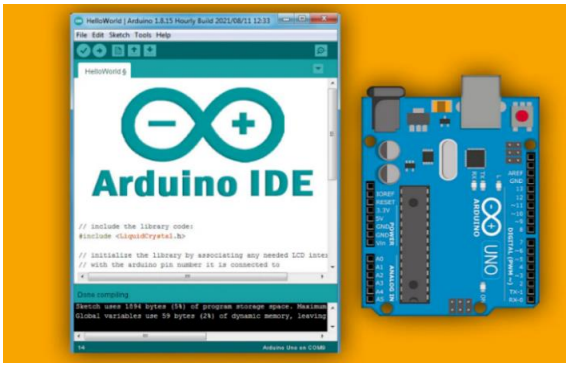

Fig. 10 Arduino IDE

- ***MIT App Inventor***

The platform used to create the Android application is shown in Fig. 11. MIT App Inventor is a web-based, open-source platform developed by MIT that enables users—especially beginners and students—to design and build Android applications using a simple, block-based programming language. It promotes creativity and problem-solving by allowing users to quickly prototype and deploy apps with access to phone sensors, media, databases, and more.

Fig. 11 MIT App Inventor

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- ***Python IDE***

A Python IDE (Integrated Development Environment) is a software tool that offers a comprehensive environment for writing, editing, running, and debugging Python code. It typically includes features like syntax highlighting, code suggestions, and debugging tools to streamline the development process. The development tool used for algorithm design is shown in Fig. 12.

Fig. 12 Python IDE

IV. METHODOLOGY

The Methodology can be basically divided into 3parts which is

1. Alert System

- The alert system is designed to quickly detect nearby movement or objects and notify users through visual signals. At its core, a PIR sensor is connected to an Arduino Nano [1][6]. When it detects motion or the presence of a heat source, such as a person or animal, an LED lights up to provide a clear visual cue is shown in Fig. 13.
- An ultrasonic sensor, connected to the ESP32 module, measures the proximity of nearby objects by emitting sound waves and analyzing their echoes [6]. If an object comes too close, a separate LED is activated as a warning. This radar-like functionality is illustrated in Fig. 14, which demonstrates how ultrasonic sensors measure distance using sound waves.
- To ensure the alert system is responsive, LED indicators are used with both the Nano and ESP32. Whenever any sensor is triggered, an appropriate LED turns on immediately, providing a distinct and noticeable visual alert.

Additionally, a servo motor is connected to an Arduino Uno, working in sync with the ultrasonic sensor to scan the surroundings similar to how radar operates. This rotating motion helps the system not only detect objects but also estimate the direction and position of the detected object, giving a clearer understanding of the environment.

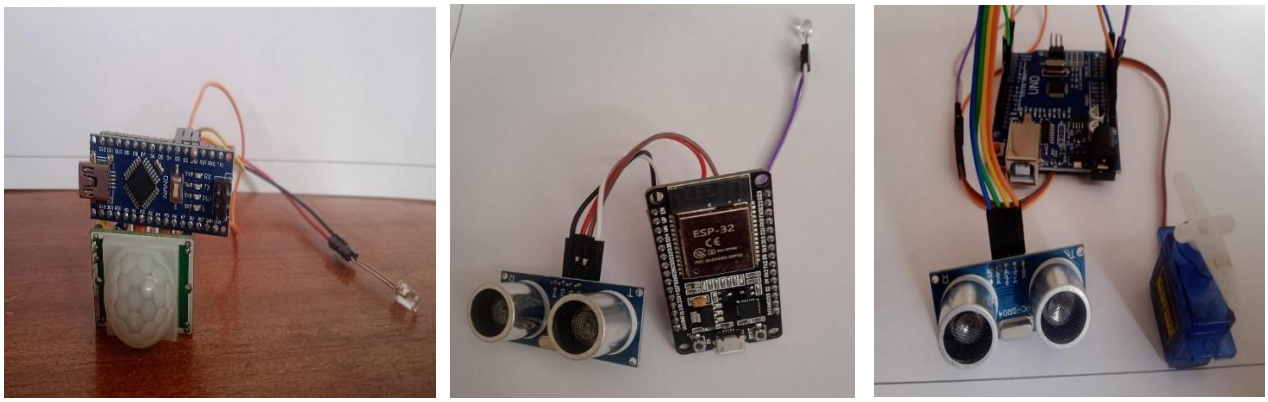

Fig. 13 Alert System

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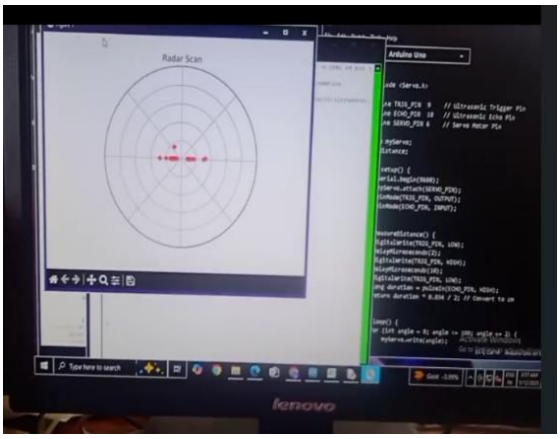

Fig.14 Radar Detection

2. Payload Unit

- Once the sensors detect a possible threat or object, the system activates a mobile payload unit to investigate and respond. This unit is built on a motorized chassis driven by DC motors, with movement precisely controlled by an L298N motor driver, which is operated by the NodeMCU (ESP8266) [4] is shown in Fig. 15. The motorized chassis and its support structure are shown in Fig. 6. The unit is capable of smooth, multi-directional movement, allowing effective navigation across varied terrain.
- Mounted on the chassis is an ESP32-CAM module, which streams live video of the surrounding area. The ESP32-CAM, depicted in Fig. 7, is powered directly by a Lithium-Ion battery for stable operation. For control, a custom-built mobile application, developed using MIT App Inventor, connects wirelessly to the NodeMCU over Wi-Fi. Through this app, the user can control the unit's movement in real time while simultaneously viewing the live video feed from the ESP32-CAM. The mobile app interface is shown in Fig. 16.
- The camera's footage is streamed directly to a display monitor, giving the operator clear visibility of the environment. This greatly aids in decision-making, particularly in high-risk or inaccessible areas. Altogether, this integrated setup merges intelligent hardware with responsive software to deliver a dynamic remote surveillance system that effectively reacts to real-time sensor inputs.

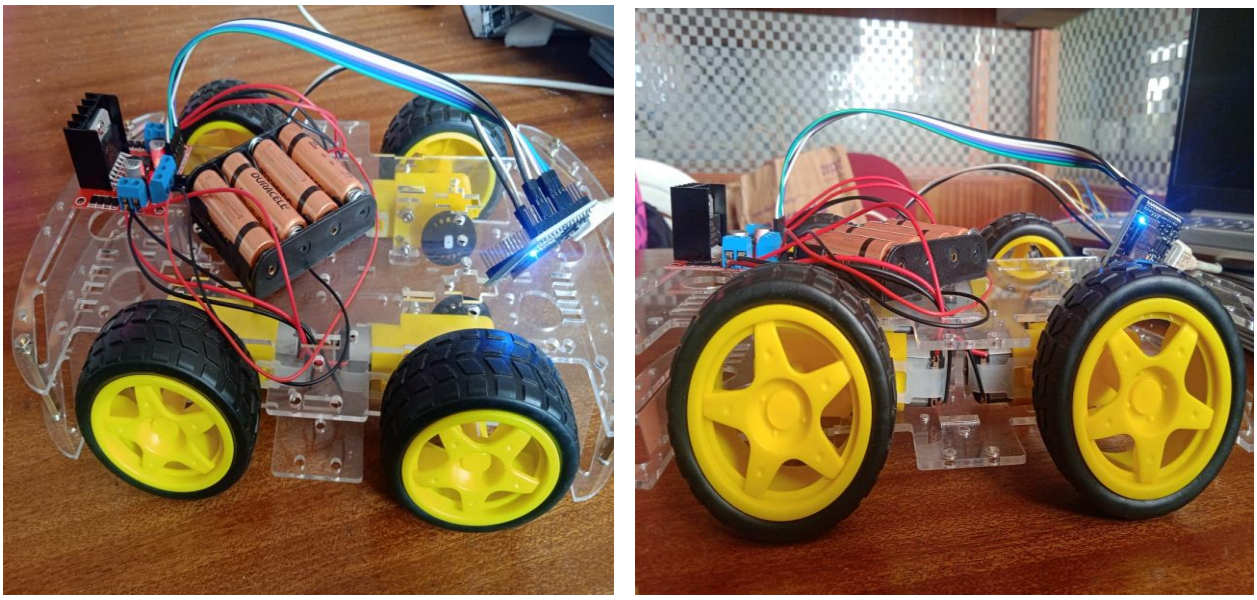

Fig. 15 Payload Unit

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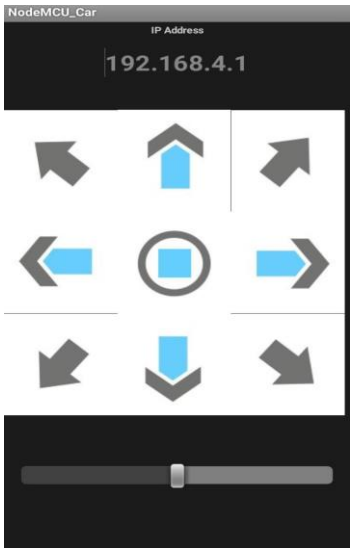

Fig. 16 Mobile Application Interface

3. Centroid tracker algorithm

- The Centroid Tracker algorithm helps keep track of people by finding the center point of their faces in video frames. The face tracking capability using the Centroid Tracker is illustrated in Fig. 17.
- It uses a Haar Cascade classifier, which is trained to recognize human faces quickly and accurately. Once a face is spotted, the system marks its center and follows it as the person moves. By matching these center points from one frame to the next, it gives each person a unique ID. This makes it easy to track exactly where someone is going over time.
- It's a smart, real-time way to monitor intruders and ensure better security.

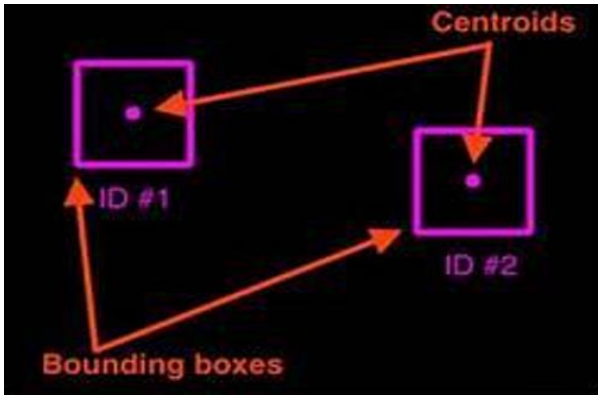

Fig. 17 Centroid Tracking

V. RESULT AND DISCUSSION

The sensor-integrated surveillance solution demonstrated reliable performance in detecting motion, heat, and obstacles using a combination of PIR and ultrasonic sensors [1][6]. LED indicators were promptly triggered upon detection, providing immediate visual alerts to potential threats. The ESP32-CAM, powered directly by a Lithium-Ion battery, consistently delivered real-time video streaming while mounted on a mobile chassis, enabling clear and continuous monitoring during movement [3][4]. The integration of the Centroid-Tracker algorithm further enhanced intruder tracking accuracy under various test conditions [10].

A custom mobile application, developed using MIT App Inventor, offered smooth and responsive control, enabling users to navigate the system in real time with minimal latency [9]. The NodeMCU (ESP8266), responsible for motor control through the L298N driver, ensured reliable mobility across different terrains. The system also exhibited low power consumption, allowing for prolonged deployment in field conditions without compromising functionality.

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These outcomes underscore the Guardian Eye system's effectiveness in real-time surveillance and rapid response scenarios. The fully integrated model, combining multiple microcontrollers, sensors, wireless streaming, and smart tracking, is shown in Fig. 18.

The Guardian Eye project successfully merged PIR and ultrasonic sensors, the ESP32-CAM, and a Centroid-Tracker algorithm to deliver a comprehensive surveillance solution. With real-time alerts via LEDs, stable video transmission, and wireless mobile control, the system demonstrated robust performance, efficient energy use, and adaptability for use in dynamic and high-risk environments.

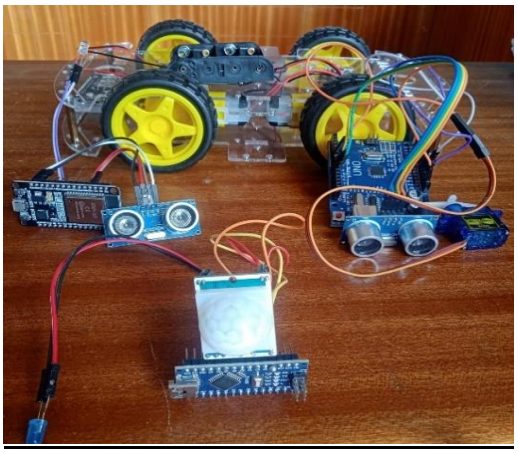

Fig. 18 Final Model

VI. CONCLUSION AND FUTURE ENHANCEMENTS

The Guardian Eye system delivers reliable real-time surveillance using sensor-based alerts, live video streaming, and mobile app control. It ensures quick detection and response to threats, making it ideal for military and bunker security applications.

Future enhancements can me made include adding a firing mechanism for active defense, GPS for location tracking, and AI models for smarter intruder classification and Face detection advancing the system toward full field deployment readiness [8][10]. These upgrades will enhance autonomous decision-making and expand the system's operational range. With improved intelligence and mobility, the Guardian Eye aims to offer a fully integrated and responsive security solution for high-risk zones.

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