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WiFi - Controlled Surveillance Car With Web Interface And Robotic Arm Integration

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Abstract- The ESP32 camera module surveillance car is an advanced remote-controlled vehicle designed for diverse surveillance and monitoring applications. Utilizing the ESP32 microcontroller, it offers high-resolution video streaming, precise movement control, and an intuitive web-based user interface. The ESP32 handles video capture, transmission, and user commands, allowing seamless interaction through a web browser without additional software. Equipped with an L298N motor driver and four DC gear motors, the car navigates precisely in all directions, making it ideal for detailed inspections. Its power system, comprising six 3.7V lithium batteries and buck converters, ensures efficient and reliable performance for all components.

Keywords— CAM, IOT, WIFI

I. Introduction

A Wi-Fi controlled surveillance car with a web interface and robotic arm integration offers remote monitoring and control capabilities, allowing users to navigate the vehicle and manipulate a robotic arm via a web browser, enhancing surveillance and potentially hazardous task capabilities. The car's movement and the robotic arm's actions are controlled remotely via a web interface accessible through a standard web browser. The car is equipped with a camera potentially a ESP32-CAM module to provide real-time video feed to the user, enabling remote surveillance. A robotic arm allows the car to perform tasks beyond simple navigation, such as picking up objects, manipulating items, or accessing hazardous areas. A user-friendly web interface allows the operator to control the car's movement, view the camera feed, and manipulate the robotic arm. This system deals with the design of a Surveillance Robot Car which can be controlled from anywhere around the world by using the IoT Technology. Wi-Fi module is used to control the robot car from the ground station and also to transmit the live video surveillance to the android application. The integration of modern microcontroller technology, particularly the ESP32, has transformed remote monitoring. The ESP32 camera module surveillance car demonstrates this advancement by combining mobility, wireless communication, and live video streaming in a cost-effective package. Its powerful processing capabilities and energy efficiency enable robust performance across various applications, including motion detection and face recognition.

II. Literature Survey

In recent years, the development of WiFi-controlled surveillance robots has gained significant attention due to their immense potential in remote monitoring, military reconnaissance, and smart security applications. These robots integrate wireless communication technologies, real-time video streaming, and web-based control systems, making them increasingly usable and accessible for various surveillance tasks. This trend reflects a growing interest in enhancing the versatility and functionality of robotic platforms for both commercial and military purposes.

One such study by Gawai et al. (2024) proposed an IoT-based surveillance robot that utilizes both WiFi and Zigbee communication modules. This robot is designed for real-time environmental sensing and video monitoring, all controlled through a smartphone or web interface. The integration of multiprotocol communication—such as WiFi and Zigbee—demonstrates the flexibility of wireless systems in complex surveillance environments, allowing for seamless data transmission and control over wide areas.

Similarly, Singh and Nandgaonkar (2018) introduced a cost-effective mini-robot capable of live audio-video streaming via WiFi. This robot can be controlled through a web server, addressing the growing demand for easy-to-deploy, budget-friendly surveillance solutions. The ability to control and stream video remotely through WiFi further enhances the utility of such systems, enabling them to be used in situations where traditional surveillance methods may not be feasible.

Wang et al. (2017) took the concept of WiFi-controlled surveillance robots a step further by implementing a full web-based interface for unmanned mobile robot monitoring. This approach not only facilitated real-time control and streaming but also integrated historical data storage, enabling enhanced analytics for long-term surveillance. By leveraging web-based interfaces, these systems allow users to access live and recorded data remotely, offering more comprehensive insights into monitored areas and improving situational awareness.

The integration of robotic arms into surveillance systems has also been a key area of exploration. Akilan (2021) demonstrated the use of a remote-controlled robotic arm that could move using a ZigBee communication system and embedded web server. This allowed for precise interaction with the environment, such as picking up objects or manipulating items remotely. Similarly,

Patel and Sobh's RISCBOT project utilized an 802.11b-enabled surveillance robot, emphasizing autonomous navigation features and the importance of computer vision for target identification and recognition. Together, these studies highlight the growing trend of combining wireless control, web interfaces, and robotic manipulation to create versatile, remotely accessible surveillance systems.

III. System Hardware

A. ESP32 Camera module

The ESP32-CAM is a compact development board that integrates an ESP32-S microcontroller with a built-in OV2640 camera module, making it ideal for low-power IoT and computer vision applications. It features a dual-core 32-bit LX6 processor, 520KB SRAM, and supports up to 4GB microSD card storage for image and video capture. The module offers Wi-Fi and Bluetooth connectivity, allowing for wireless streaming and remote control. It has multiple GPIO pins for connecting external sensors and components, as well as support for UART, SPI, and I2C communication protocols. Despite its small size, the ESP32-CAM delivers impressive performance for projects like surveillance, facial recognition, and smart home automation.

Fig 1. ESP32 Camera Module

B. ESP32 38 Pin Development Board

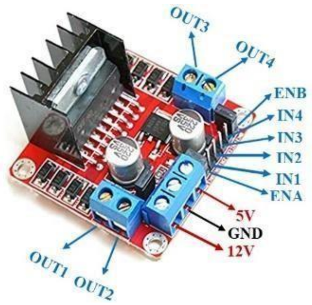
The ESP32 38-pin development board is a powerful microcontroller module based on the ESP32-WROOM-32 chip, featuring dual-core Tensilica LX6 processors running at up to 240 MHz. It comes with 520KB SRAM and 4MB flash memory, offering ample space for complex programs and data handling. The board includes built-in Wi-Fi and Bluetooth (v4.2 BR/EDR and BLE) for seamless wireless connectivity in IoT applications. With 38 pins, it provides access to a wide range of I/O options, including ADCs, DACs, UART, SPI, I2C, PWM, and touch sensors. It's compatible with the Arduino IDE and other development platforms, making it versatile for embedded systems, robotics, and smart home projects.

Fig 2. ESP32 38 Pin Development Borad

C. L298N Motor Driver

The L298N motor driver is a dual H-bridge module capable of controlling the speed and direction of two DC motors or a single stepper motor. It operates with a wide input voltage range of 5V to 35V and can deliver up to 2A of current per channel. The module features an onboard 5V regulator, which can power the logic circuitry if needed. It includes control pins for enabling each motor and setting their direction using standard logic signals, making it compatible with microcontrollers like Arduino and ESP32. With built-in heat sinks and protection diodes, the L298N is reliable for use in robotics, automation, and other motorcontrol applications.

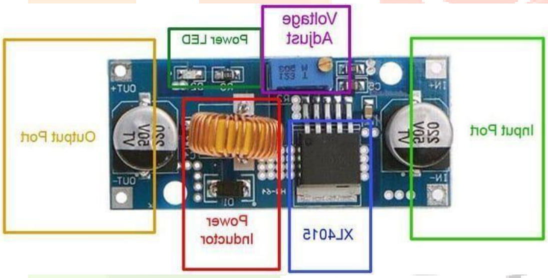
Fig 3. L298N Motor Drive Module



D. XL4015 Buck Converter

The XL4015 buck converter is a high-efficiency DC-DC step-down power module capable of converting an input voltage range of 5V to 36V down to an adjustable output between 1.25V and 32V. It can deliver up to 5A of output current, making it suitable for powering a wide range of electronic devices and projects. The module features high conversion efficiency, typically around 96%, and includes overheat and overcurrent protection for safe operation. It also comes with a built-in heatsink to improve thermal performance during high-load usage. The XL4015 is ideal for battery charging, LED drivers, and regulated power supply applications in DIY and industrial projects.

Fig 4. XL4015 Buck Converter



E. MG90 Micro Servo

The MG90 servo motor is a compact and high-performance micro servo, widely used in robotics and remote-controlled systems due to its small size and powerful torque. Internally, it features a coreless DC motor that drives a set of metal gears, which significantly enhances durability and reduces gear wear compared to plastic-geared counterparts. The coreless motor design eliminates the iron core in the rotor, resulting in reduced inertia, faster response, and smoother rotation. An internal control circuit receives Pulse Width Modulation (PWM) signals, which it interprets to determine the desired angle of rotation. This circuit continuously adjusts the motor's position using a feedback loop mechanism involving a potentiometer attached to the output shaft. The feedback from the potentiometer allows the control circuit to maintain precise angular positioning, typically within a 0 to 180-degree range. The use of metal gears ensures better torque delivery, rated at around 2.2 kg·cm at 4.8V and up to 2.5 kg·cm at 6V, making the MG90 suitable for applications requiring both speed and strength. Additionally, the internal components are housed in a lightweight yet robust casing, offering a balance between performance and durability.

Fig 5. MG90 Servo Motor

F. DC Gear Shift Motor

A DC gear shift motor is a type of electric motor integrated with a gearbox and used in automotive and industrial applications for precise control of rotational motion and torque, especially in gear shifting mechanisms. Internally, the motor operates on the principle of electromagnetic induction, where electric current flows through the armature winding inside a magnetic field generated by permanent magnets or field windings. This interaction produces torque, causing the rotor to turn. Attached to the rotor is a set of gears housed in a gearbox, which modifies the speed and torque output of the motor. The gearbox allows for increased torque at reduced speeds, which is essential for shifting gears under load. In gear shift applications, the motor's movement is typically controlled by an electronic control unit (ECU) that sends signals based on input from sensors monitoring speed, position, and driver commands. The motor may also include feedback mechanisms like encoders or potentiometers to ensure accurate positioning, allowing smooth and reliable gear changes.

Fig 6. DC Gear Shift Motor

G. 3.7v Lithium Battery

A 3.7V lithium battery is a rechargeable power source commonly used in portable electronics, drones, and IoT devices due to its lightweight and high-energy density. It typically provides a nominal voltage of 3.7V with a fully charged voltage around 4.2V and discharges to a cutoff voltage of approximately 3.0V. The battery's capacity can vary widely, ranging from 100mAh to several thousand mAh, depending on the application. With a relatively low self-discharge rate, these batteries offer long operational periods and can endure hundreds of charge-discharge cycles. They are also known for being compact and having a high power-to-weight ratio, making them ideal for mobile applications.

Fig 7. 3.7V Lithium Battery

H. Robotic Arm

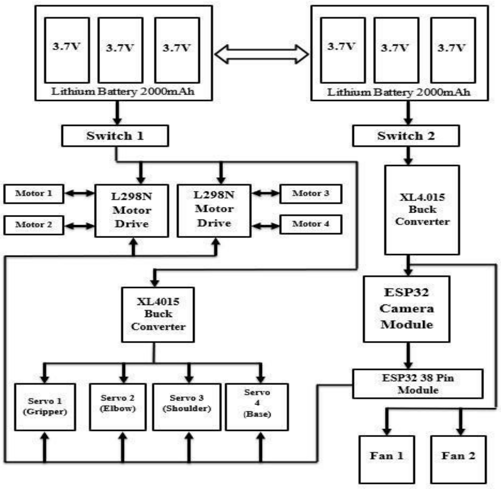
A robotic arm is a programmable mechanical device designed to perform tasks typically carried out by human hands, with a high degree of precision and flexibility. It consists of multiple joints (usually three to six) that allow for a wide range of movement, often powered by servo motors or stepper motors. These arms are controlled using microcontrollers or computer systems, with capabilitiessuch as pick-and-place, assembly, welding, or painting. Robotic arms come in various sizes and load capacities, ranging from small-scale hobbyist models handling lighter objects to industrial arms capable of lifting several kilograms. They are widely used in automation, manufacturing, and research applications due to their efficiency, accuracy, and ability to perform repetitive tasks.

Fig 8. Robotic Arm

IV. System Architecture

This robotic system is powered by 11.1V/2000mAh 18650 lithium battery packs arranged in a series-parallel configuration, divided into two main power sections controlled by separate switches. XL4015 buck converters are used to step down the voltage from 11.1V to 5V, supplying power to the ESP32 38-pin board, ESP32-CAM, servo motors, and cooling fans. Each power section drives an L298N motor driver, which controls two DC motors, enabling omnidirectional movement in eight directions. Motor speed is controlled using PWM signals, and the system is operated via a Wi-Fi-based web interface built with HTML and CSS. The system also features a four-servo articulated robotic arm, with each servo assigned to a specific function: Gripper, Elbow, Shoulder, and Base. The ESP32 serves as the central controller, managing both motor drivers and servo operations, while the ESP32-CAM module provides potential vision capabilities such as object detection. Two cooling fans powered by another buck converter maintain thermal stability, and a data transmission link ensures communication between modules, likely through wired connections. This versatile setup is suitable for advanced robotics applications like mobile robots, robotic arms, and intelligent surveillance systems.

Fig 9. Block Diagram



V. Result

The WiFi-controlled surveillance car successfully demonstrated remote navigation and real-time video streaming via a web interface.The ESP32-CAM provided stable 640x480 live video transmission over WiFi.The car moved smoothly in all directions using DC motors controlled by PWM signals.Robotic arm functions—including gripping, lifting, and rotating—were responsive and precise.The web interface allowed seamless control of both movement and arm articulation.WebSockets enabled real-time communication between the interface and hardware components.Overall, the system operated reliably, integrating vision, mobility, and manipulation effectively.

Fig 10. Picking an Object

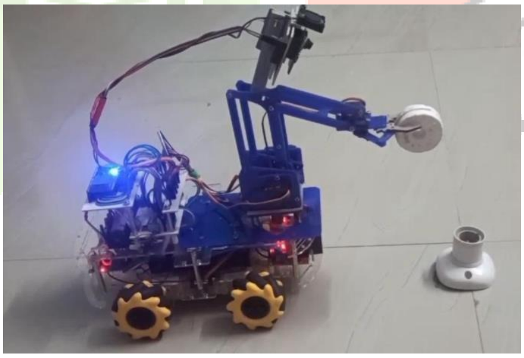


Fig 11. Night Vision Working

VI. Applications

- Home Security: Monitoring homes and properties for intruders, providing real-time video feeds to homeowners.
- Search and Rescue: Navigating disaster areas to locate trapped or injured individuals where human access is difficult or dangerous.
- Industrial Inspection: Inspecting machinery, pipelines, and other equipment in hazardous or hard-to-reach areas within industrial facilities.
- Agricultural Monitoring: Surveying large farmlands to monitor crop health, detect pests, or assess irrigation systems remotely.
- Research and Education: Serving as a practical tool for students and researchers to learn about robotics, IoT (Internet of Things), and real-time data acquisition.
- Area Monitoring: Remotely explores dangerous or confined spaces with real-time video feed to ensure human safety.
- Night and Low-Light Surveillance: Navigates dark environments with enhanced camera capabilities for rescue and research missions.

VII. Future Work

Future development of the WiFi-controlled surveillance car can focus on adding autonomous navigation through obstacle detection using ultrasonic or infrared sensors. Integrating AI-based object recognition with the ESP32-CAM would enhance surveillance and target identification capabilities. Incorporating a GPS module could enable real-time tracking and route mapping for outdoor applications. Battery monitoring systems with low-power alerts would ensure uninterrupted operation during extended missions. Enhancements to the web interface, such as live camera angle control and movement logs, could improve user interaction and functionality. Additionally, integrating voice or gesture control via a smartphone app would offer more intuitive control options. To extend usability in low-light environments, night vision functionality using IR LEDs can be introduced.

VIII. Conclusion

The development of the WiFi-controlled surveillance car with a web interface and robotic arm integration marks a significant advancement in modern surveillance systems. This project effectively combines wireless communication, real-time video streaming, robotic control, and web-based interfaces into a compact unit.

The ESP32-CAM module enabled live video transmission over the internet for remote monitoring with low latency, while the web interface simplified control without the need for specialized software. The robotic arm added versatility by allowing remote interaction with objects, transforming the system from a passive observer to an active participant in its environment. This integration demonstrates the potential of merging IoT, robotics, and web technologies for practical applications.

The project's flexibility makes it suitable for a variety of real-world scenarios such as bomb detection, hazardous material handling, and search-and-rescue missions. The modular design allows for future upgrades like AI-based object detection or integration with cloud-based systems. Serving as both an educational tool and a practical platform, this surveillance car highlights the intersection of automation, communication, and intelligent control systems. The success of this project not only provides valuable experience in system integration and embedded systems but also underscores the growing importance of interdisciplinary approaches to solving complex, real-world challenges.

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