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ESP32 CAM-based Surveillance Car with Tilt, Pan, and Zoom Capabilities: A Review

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Abstract

This project focuses on developing a mobile surveillance robot using a Wi-Fi-enabled module controlled via a smartphone, designed for discreet observation and remote monitoring. The spy robot system includes essential hardware such as a camera, motor drivers, batteries, and wheels for movement. The main component is the AI Thinker ESP32-CAM module, featuring an ESP32-S processor and OV2640 camera, capable of capturing and streaming video at 640x480 resolution. The camera offers good performance in varying light conditions, ensuring clear real-time video transmission via the HTTP protocol. The robot's movement is powered by two DC motors, controlled through the L293D motor driver, allowing a speed of 10 cm/s with smooth directional control. Commands for navigation and operation are sent from the user's smartphone, while the video stream is transmitted over Wi-Fi, supporting a range of up to 50 meters. This enables the user to manage the robot's movement and video output remotely with ease. The system's flexibility, ease of deployment, and cost-effectiveness make it highly adaptable for various real-time monitoring applications, offering a reliable solution for surveillance tasks in both indoor and outdoor environments.

Keywords: ESP32-S processor, surveillance robot, Wi-Fi module, OV2640 camera, HTTP communication protocol, remote monitoring

INTRODUCTION

The landscape of security and surveillance is undergoing a drastic change, with advanced surveillance robots powered by state-of-the-art technology. A great answer to that is the platform powered by ESP32-CAM, a highly versatile tool for surveillance over a distance. A built-in high-resolution camera was used based on the ESP32 microcontroller. Compact, all power is available at its tiny heart, and it integrates live video capturing or streaming over wireless communication; thus, this is ideal for modern surveillance applications. The use of ESP32-CAM is a novel approach compared to existing alternatives, as it integrates tilt-pan-zoom functionalities, offering enhanced control over camera angles and more efficient real-time monitoring. The ability to control a robot remotely through Wi-Fi, combined with its flexibility, makes it a cost-effective solution for applications ranging from home security to industrial monitoring.

The ESP32-CAM-based surveillance robot enhances situational awareness and provides a reliable means of protecting people and property while transmitting live video feeds in real time. The versatility of this system enables it to navigate various environments, respond to commands from remote users, and provide intelligent surveillance capabilities. The core of this robot is the ESP32-CAM module, which enables wireless control through Wi-Fi and Bluetooth. The mobility of the robot is powered by motors attached to either wheels or tracks depending on the operational

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environment. The chassis serves as a platform for mounting all components, including the motor driver, sensors (such as ultrasonic and infrared sensors), and power sources, typically batteries or rechargeable LiPo cells.

By integrating tilt-pan-zoom functionalities, the ESP32-CAM surveillance robot can adjust the camera perspectives for enhanced coverage and real-time adaptability. This feature, coupled with the compact design and wireless connectivity of the robot, offers a practical and flexible solution for efficient surveillance across a range of environments. The combination of AI-based image recognition and remote control ensures real-time monitoring and responsiveness, setting it apart from traditional surveillance systems and making it highly effective for both indoor and outdoor security operations.

METHODOLOGY

The most fundamental requirement of any robot is a chassis that allows the mounting of the control electronics and actuators. In our design, the main objective was to enable the device to move based on button commands. Therefore, we developed a simple robot that moves forward, backward, left, and right when commanded by pressing a button.

Components Used

1. ESP32-CAM
2. Future technology devices international (FTDI) programmer
3. DC motors (2)
4. Motor driver (L293D)
5. Battery

As ESP32-CAM requires a USB harbor, a time delay and integration (TDI) board is fundamental for code uploading. The voltage common collector (Vcc) and ground (GND) pins of the ESP32 are connected to the corresponding pins on the TDI board, with the TX and RX linked in a similar manner, as shown in Figure 1.

The two DC motors on the bot are interfaced with the ESP32 through the L293D module so that the module's pins are connected to ESP32's IO4, IO2, IO14, and IO15 pins. The ESP32-CAM module of the surveillance bot has an ESP32-S processor, an OV2640 camera, and a slot for storing the captured images in a microSD card. Video streaming from the OV2640 camera is possible through the available HTTP communication protocol with the help of a web server.

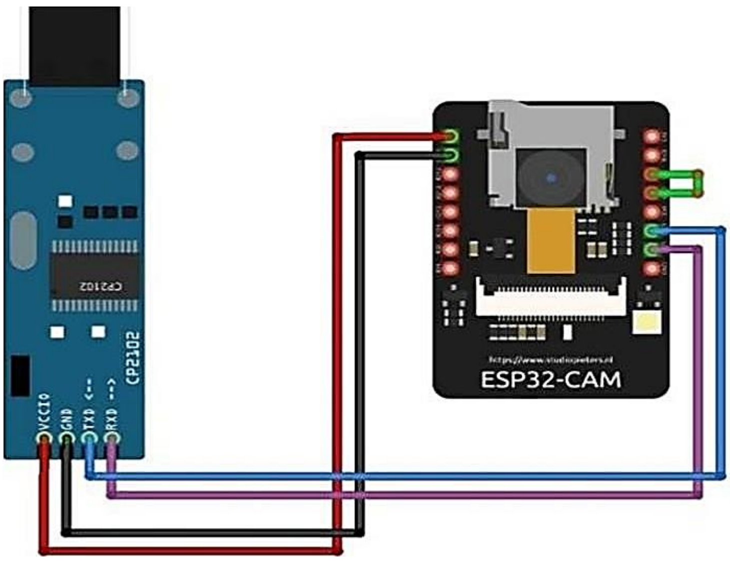

Figure 1. ESP32-CAM.

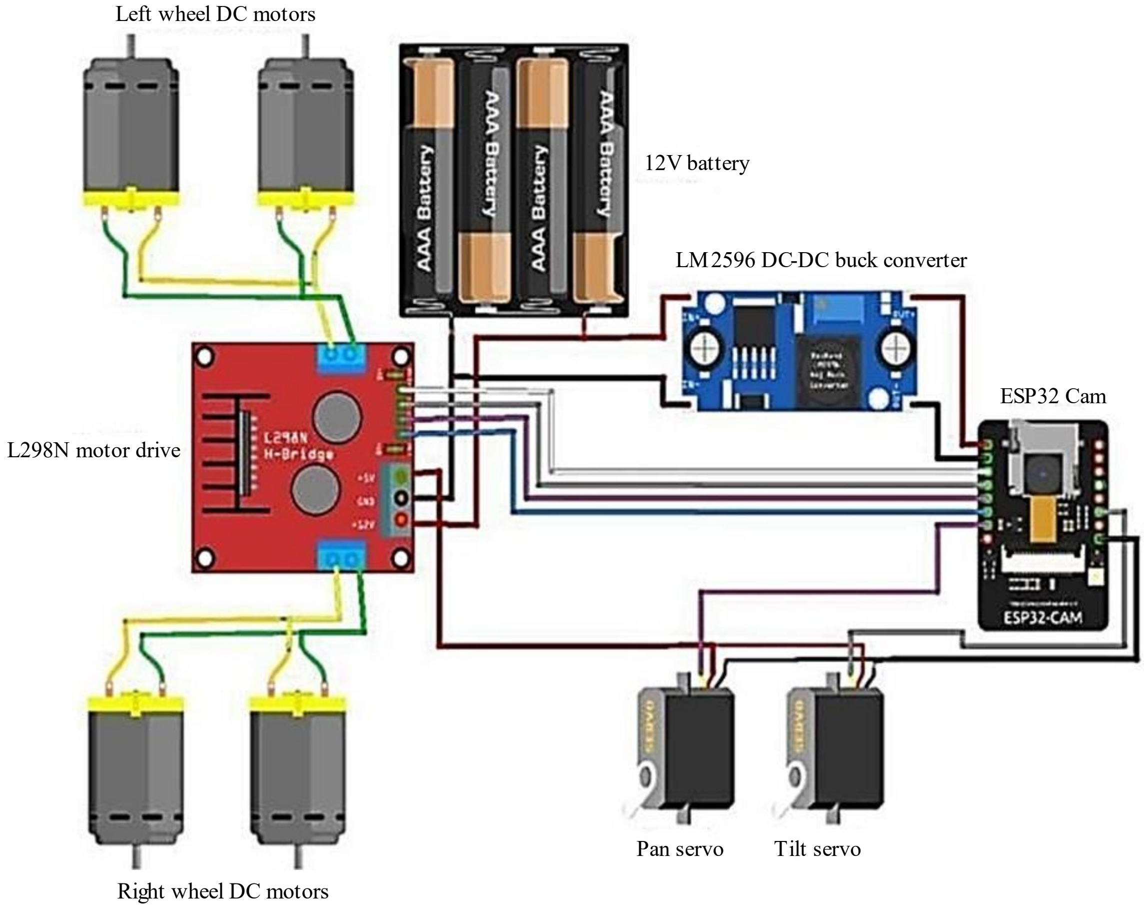

Figure 2. Surveillance remote-controlled robot.

Upload the code and then disconnect the GND from GPIO 0. The baud rate to 115200, open the serial monitor was opened, and the reset button of ESP32-CAM was clicked to print out its IP address. Disconnecting the TDI programmer turns it on after attaching it to the pan/tilt platform. Finally, an on-board reset button was used. To stream live videos to the Android app, we first access our router settings and enable port forwarding. Here, we allow the port range 80-81 and choose the ESP32-CAM device or its IP address depending on the specific router setup. The camera will start transmitting the video that live captures, as shown in Figure 2.

The L293D motor driver was selected for its capability to handle the current demands of the motors and its H-bridge configuration, allowing precise control over the motor speed and direction. Motors powered by a 7.4V LiPo battery were chosen for their ability to deliver consistent torque and movement, making the robot adaptable to various terrains.

For calibration, the brightness, contrast, and resolution settings of the camera were adjusted through a web interface to ensure optimal performance under different lighting conditions. This step is crucial to guarantee clear and consistent video quality, especially in low-light environments. The motor driver was calibrated by adjusting the Pulse Width Modulation (PWM) signals to achieve smooth and precise movements. This involved fine-tuning the control inputs to ensure that the robot responded accurately to the directional commands without jitter or lag.

Expected Outcomes

Although surveillance robots typically provide live video feeds, they cannot actively engage or provide detailed analysis. However, their utility in hazardous environments such as mining accidents or urban disasters is invaluable for remote assessment and damage evaluation. These robots help identify safe entry points and evacuation routes and reduce risks to human responders. In conflict zones, the danger of personnel being captured is eliminated. Mobile surveillance systems are also ideal for temporary monitoring in remote areas, such as agricultural fields or pastures, where stationary CCTV systems are impractical because of power or infrastructure limitations. These robots offer flexible and cost-effective alternatives to traditional surveillance, particularly in areas with limited accessibility.

Application with Scope

In today's technological landscape, robots have become crucial and are emerging as key components of the future. Icing virtual safety has become a necessity in any situation involving technology.

Patrolling

Consistently watching the boulevards guarantees open security and instantly caution specialists when vital. The probability of obtaining wrong or one-sided data was surprisingly high. Proficiently recognizing, gathering, and quickly transferring data to specialists in case it compares to an individual's criminal history in a criminal database. If a criminal is a side-stepping capture, the robot can transmit a message.

Military Applications

There are specific places where there could be areas for intelligence gathering and surveillance. To this extent, cars are considered to be a highly suitable solution for these areas. It can be fitted with up-to-date upgrades, offer real-time data, and assist with operations that the military is required to undertake.

Traffic Monitoring Applications

The bot can also monitor traffic regulations by checking whether subjects have helmets and seatbelts during events such as the COVID-19 pandemic, during which it can also monitor the wearing of masks and compliance with social distancing.

Environmental Issues

The bot can be applied in compliance with environmental regulations, such as monitoring adherence to wearing helmets and seat belts. During a public health crisis, such as the COVID-19 pandemic, it can also be leveraged to observe whether people are observing mask-wearing and social distancing rules.

LITERATURE SURVEY

Later inquiries in the field of portable reconnaissance frameworks investigated different advances and strategies to upgrade checking capabilities in different situations. Various considerations have been centered on creating clever reconnaissance arrangements that coordinate low-cost equipment, advanced imaging methods, and real-time information processing.

1. Dubey et al. [1] investigated the advancement of an observation robot using an ESP32-CAM board. ESP32-CAM is a low-cost module with built-in Wi-Fi and a compact camera, making it a perfect choice for versatile observation gadgets. Combined with robot chassis, the framework empowers development and video recording in different situations. The web interface permits clients to stream live videos, capture screenshots, and remotely control the robot. Furthermore, it can identify movements using computer vision calculations, such as question following and location, and caution the client in real time.
2. In a separate research study, Selvam, Nikhil, Ranjitha Reddy, Mounika, Reddy Sekhar, and Reddy Siva Sai [2] examined intelligent visual surveillance systems. They highlighted the move from manual to computerized observation by utilizing cameras for security checks. Their proposed framework combines dynamic sensors and real-time observations to diminish human intercession and address the challenges found in conventional frameworks. This improvement increases productivity by permitting ceaseless observations with negligible manual oversight.

3. Dev Jyoti Ghosh, Shaarang Sahane, Shreyash Bhandari, Vedant Shirale, and Mudit Kapoor [3] examined the use of Raspberry Pi in surveillance applications. Its adaptability and capacity to stream videos make it appropriate for different jobs, domestic computerization, and security frameworks. The integration of an Secure Shell (SSH) network guarantees secure communication, which is critical for the framework.
4. Krishna Marapalli, Pooja Dundgekar, Ashutosh Bansode, Nilesh Rathod [4]—The central objective of the paper is to move forward the innovative ability of the equipped strengths through the advancement of wirelessly monitorable clever vehicles. The usefulness of GPS is demonstrated by the Neo6M module, which empowers location-based information transmission to the Thing Speak Cloud in real time. IoT applications regularly utilize this cloud stage, which makes it possible to store and analyze information from an assortment of sensors. The obstacle discovery and engine control functionalities are shown by considering an ultrasonic sensor and a DC engine controller, individually. These characteristics are fundamental for brilliant vehicles, especially for military use, where exploring an assortment of territories may be troublesome.
5. Abhijeet Dhule, Neha Sangle, Supriya Nagarkar, Asmita Namjoshi [5]—The nearness of a passive infrared (PIR) sensor demonstrates that the framework has movement discovery capabilities that are habitually utilized to distinguish the nearness of individuals or other living things. A component for controlled development or introduction is suggested by the Servo Engine, and remote communication capability empowering inaccessible control or information trade is demonstrated by the HC205 Bluetooth Module. This paper is alluded to as a shrewd robot, and the military is said to be one of its intended applications. The work of these robots is emphasized as a cutting-edge innovation that diminishes the dangers to human life and protects human assets.
6. Anandravisekar, Anto Clinton, Mukesh Raj, Naveen [6]—The primary objective of the recommended system is to create a reconnaissance robot that employs Web of Things (WOT) innovation to overcome the limitations of limited-range observations. This suggests that the robot may be able to send data, counting possible video nourishes, over the web to permit further control and observation. Settling this limited extent is a vital movement, especially in observation circumstances where momentary data are crucial. Robots utilizing the Web of Things innovation propose that it might be a portion of a larger organization and that inaccessible access to and examination of its information is conceivable. This seems to hinder the adequacy of the observation exercises and increase the natural flexibility of the system.
7. Senthamil Selvi, Faesa Fathima, Dhivya, and Mouriya [7] discussed that the Raspberry Pi 3 microcontroller is a powerful and adaptable platform capable of performing a diverse range of tasks, as indicated by its specifications, The nearness of a Wi-Fi switch proposes that remote communication is conceivable, permitting for information exchange or farther control. It is conceivable that infrared (IR) and nearness sensors are utilized to distinguish impediments and make it possible for the robot to effectively explore its environment. When a DC engine driver is utilized, engine control capabilities are suggested, which enable the robot to move accurately and respond to its environment. These components together point to the plausibility of an all-encompassing automated reconnaissance framework.

PROBLEM STATEMENT

Despite advancements in surveillance technology, existing systems using ESP32-CAM often lack sophisticated object detection capabilities. Most implementations focus on basic video streaming and motion detection without utilizing machine learning (ML) algorithms for more precise identification of objects within the camera's field of view [8]. This limitation hinders the potential of ESP32-based systems to enhance safety and security in various applications such as home monitoring, industrial surveillance, and disaster response.

PROPOSED SYSTEM

To address this gap, we propose a novel surveillance system that integrates ML algorithms for object detection with ESP32-CAM. This enhanced functionality can be crucial for safety applications such as detecting intruders, monitoring hazardous environments, and assessing emergencies.

APPLICATION AND USE CASES

The surveillance car system powered by ESP32-CAM opens up a world of possibilities across different fields, making monitoring and security more accessible and effective [9]:

1. *Security monitoring:* Surveillance cars enhance security in various environments. For example, it was tested in a large shopping mall, where it provided real-time video feeds to security teams, successfully identifying and responding to potential threats, such as unauthorized access to restricted areas. Power consumption was addressed by integrating solar panels and extending operational hours.
2. *Home surveillance:* Homeowners benefit from the surveillance car's ability to monitor vulnerable areas that fixed cameras might miss. In the test case, the car was deployed in a suburban home, where it monitored entryways, backyards, and driveways. The car successfully identified movements and provided live footage to the homeowner's smartphone. Additionally, weather-resistant materials have been used to ensure reliable operation under outdoor conditions, such as light rain and wind.
3. *Industrial inspection:* The surveillance car was tested in a manufacturing plant, navigating hard-to-reach areas to inspect machinery and equipment. This helped maintenance teams identify issues, such as overheating equipment, without putting workers in potentially hazardous situations. The expected outcome is reduced downtime and improved worker safety as potential issues are flagged before they become critical. Wi-Fi mesh networks were used to maintain a stable connection across large factory floors, while the car components were shielded from dust and moisture.
4. *Emergency response:* In a real-world test during a mock fire drill in an industrial park, the surveillance car provided critical real-time insights to first responders from a safe distance, helping them identify safe entry points and assess the situation before sending personnel. The expected outcome is enhanced decision-making during emergencies, which reduces the risk to human life. The car's robust design ensures that it can operate under challenging conditions, such as smoke and heat. Solar-powered batteries were used to ensure that the car could function continuously during prolonged emergencies.
5. *Agricultural monitoring:* The surveillance car was tested on a farm to monitor crop health and livestock movement. It identifies areas with water stress in crops and helps track the movement of animals across farms. By using solar-powered batteries, the car was able to operate over long distances without needing frequent recharging, and its durable design ensured that it could withstand the dusty and hot conditions typical of agricultural environments.

CHALLENGES AND LIMITATION

The development and implementation of a surveillance car system using ESP32-CAM face several challenges [10].

1. *Power consumption:* The power requirements of the system can be significant, especially during video streaming. This challenge can be mitigated by integrating solar panels to extend the battery life and exploring the use of larger, more efficient batteries that can support longer operational periods. During testing, various battery capacities were evaluated, and solar charging systems were implemented to demonstrate the increased operational time in sunny environments.
2. *Range limitations:* The reliance on Wi-Fi can restrict the operational range, making it difficult to maintain a stable connection in large or remote areas. To overcome this challenge, implementing signal boosters or deploying a mesh network can significantly enhance connectivity. In field tests, mesh networks were established to demonstrate improved coverage across expansive areas, ensuring that the surveillance car could operate effectively without losing connections.
3. *Network challenges:* Real-time video streaming is susceptible to network congestion and poor connectivity, leading to delays and interruptions. To improve the performance, adaptive streaming techniques can be employed, which adjust the video quality based on the available bandwidth. Additionally, providing fallback options, such as switching to lower-resolution streams during poor connectivity, can help maintain a continuous video feed. This approach was tested during the experiments, and it showed improved resilience to fluctuating network conditions.

4. *Environmental factors:* Adverse weather conditions can affect the performance of surveillance vehicles. To ensure that the system is suitable for outdoor use, it is crucial to make it weatherproof and robust. During the experiments, the surveillance car was tested under various environmental conditions including rain and high winds. Protective casings were implemented to shield electronics from moisture and dust, and the durability of the materials in withstanding harsh weather conditions was evaluated.
5. *Image processing limitations:* Real-time image processing for object detection can strain the ESP32-CAM resources, which leads to performance issues. To enhance performance, optimizing algorithms for efficiency is essential. Exploring edge computing solutions, where some processing is offloaded to more powerful external devices, can help alleviate the burden on ESP32-CAM. In trials, algorithmic enhancements demonstrated improved detection speeds and accuracy, demonstrating the potential for better performance in real-time applications.

CONCLUSION

The surveillance robot features a user-friendly web interface that delivers live camera feeds, media retrieval, and remote operation, enhancing the user experience under various real-world conditions. As an iterative project, it continually evolves through consistent testing and user feedback, thereby improving functionality and performance. Future research should focus on enhancing the AI of the system for object detection and integrating ML for predictive surveillance, allowing the robot to anticipate security threats. In addition, exploring the scalability of large-scale deployments through modular designs and cloud solutions will facilitate broader applications. By prioritizing ethical considerations and adhering to privacy regulations, the surveillance robot is positioned as a sophisticated security tool.

Future Scope

Future improvements could focus on integrating more advanced ML algorithms for object detection, optimizing power efficiency, and extending the operational range. Further enhancements in network connectivity and weatherproofing would make the system even more reliable and versatile in various environments. With continued innovation, the ESP32-CAM-based surveillance car can play a crucial role in modernizing surveillance systems for safer and smarter monitoring.

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