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A Research Study on Surveillance Robot with Camera

Prof. S. R. Shekokar[1], Om Kokate[2], Prashant Patil[3], Sayali Morkhade[4],
Uday Patel[5], Prathamesh Rule[6]
[1]Assistant Professor, Department of Mechanical Engineering
[2,3,4,5,6]Students of Department of Mechanical Engineering
Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Maharashtra

Abstract: *Surveillance has become a critical component in ensuring security, safety, and efficient monitoring across various domains, including industrial environments, public spaces, and defense sectors. Conventional surveillance systems, particularly fixed closed-circuit television (CCTV) cameras, are limited by static positioning, restricted field of view, and inability to adapt to dynamic environments. These limitations reduce their effectiveness in scenarios requiring flexible and real-time monitoring.*

This paper presents a comprehensive study on the design and implementation of a mobile surveillance robot integrated with a camera system for real-time monitoring. The proposed system consists of a mobile robotic platform equipped with a camera module, sensors, and a wireless communication interface that enables remote operation. Unlike traditional systems, the robot can navigate through different terrains, capture live video streams, and transmit data to a remote control station using wireless technologies such as Wi-Fi, Bluetooth, or radio frequency (RF).Furthermore, the integration of embedded systems and artificial intelligence enhances the robot's capabilities by enabling features such as object detection, motion tracking, and facial recognition. These advanced functionalities improve the efficiency and reliability of surveillance operations, especially in hazardous or inaccessible environments. The study highlights the advantages, challenges, and potential applications of surveillance robots in areas such as military reconnaissance, disaster response, industrial inspection, and public safety. The results demonstrate that mobile surveillance robots provide a flexible, cost-effective, and scalable solution compared to traditional surveillance systems.

Keywords: Surveillance Robot, Camera Module, Security System, IoT, Wireless Communication, Image Processing

I. INTRODUCTION

In the modern era, surveillance has emerged as a fundamental requirement for ensuring security, safety, and efficient monitoring across a wide range of sectors, including public infrastructure, industrial facilities, military operations, and residential environments. With the rapid growth of urbanization, technological advancement, and increasing security threats such as theft, terrorism, and unauthorized access, the demand for reliable and intelligent surveillance systems has significantly increased. Effective surveillance not only helps in crime prevention but also plays a crucial role in incident detection, evidence collection, and real-time decision-making.

Traditionally, surveillance systems have relied heavily on fixed Closed-Circuit Television (CCTV) cameras. While these systems are widely used due to their simplicity and cost-effectiveness, they suffer from several inherent limitations. Fixed cameras provide a limited field of view and can only monitor a predefined area, leaving blind spots that can be exploited. Additionally, these systems lack mobility and adaptability, making them ineffective in dynamic or large-scale environments where continuous monitoring of multiple locations is required. Furthermore, manual monitoring of CCTV footage is time-consuming and prone to human error, reducing the overall efficiency of the surveillance process. To address these limitations, the concept of mobile surveillance systems has gained significant attention in recent years. A surveillance robot equipped with a camera and communication system offers a flexible and dynamic approach to

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monitoring. Unlike static systems, mobile surveillance robots can navigate through different environments, adjust their position based on requirements, and provide real-time visual feedback. These robots are capable of operating in areas that may be hazardous or inaccessible to humans, such as disaster zones, industrial plants with toxic conditions, or high-risk military regions.

The development of such surveillance robots has been made feasible due to advancements in embedded systems, microcontrollers, and compact sensor technologies. Modern robots are typically built using low-cost yet powerful platforms such as microcontrollers or single-board computers, which enable efficient processing and control. The integration of camera modules allows for continuous video streaming, while sensors such as ultrasonic, infrared, and motion detectors enhance navigation and obstacle avoidance capabilities. Wireless communication technologies, including Wi-Fi, Bluetooth, GSM, and RF modules, facilitate remote operation and real-time data transmission, enabling users to monitor and control the robot from a safe distance.

In addition to hardware advancements, the incorporation of Artificial Intelligence (AI) and image processing techniques has significantly enhanced the capabilities of surveillance robots. AI-based algorithms enable the system to perform intelligent tasks such as object detection, facial recognition, motion tracking, and anomaly detection. These features reduce the dependency on human monitoring and improve the accuracy and efficiency of surveillance operations. For example, the system can automatically detect suspicious activities or unauthorized individuals and generate alerts, thereby enabling faster response and improved security management. Surveillance robots have a wide range of applications across various domains. In the defense sector, they are used for reconnaissance and border surveillance, minimizing risks to human personnel. In industrial environments, they assist in monitoring machinery, detecting faults, and ensuring worker safety. During disaster situations such as earthquakes, fires, or chemical leaks, surveillance robots can be deployed to assess damage and locate survivors in hazardous conditions. Additionally, in public spaces such as airports, railway stations, and shopping complexes, these robots contribute to enhanced security and crowd monitoring.

Despite their numerous advantages, the development and deployment of surveillance robots also present certain challenges. Issues such as power consumption, limited battery life, communication range constraints, and system reliability need to be addressed to ensure efficient operation. Moreover, the implementation of advanced AI algorithms requires computational resources and optimized system design. Security and privacy concerns related to data transmission and surveillance also need careful consideration.

This research paper focuses on the design, development, and analysis of a surveillance robot integrated with a camera system for real-time monitoring. The study aims to explore the effectiveness of mobile robotic surveillance compared to traditional fixed systems, highlighting its advantages in terms of flexibility, adaptability, and efficiency. Furthermore, the paper discusses the integration of wireless communication and intelligent processing techniques to enhance system performance. The proposed approach demonstrates a scalable and cost-effective solution that can be adapted for various real-world applications, contributing to the advancement of modern surveillance technologies.

II. LITERATURE SURVEY

Over the past decade, significant research has been carried out in the field of surveillance robots, focusing on improving monitoring efficiency, reducing human intervention, and enhancing system intelligence. Various approaches have been proposed using embedded systems, Internet of Things (IoT), wireless communication, and artificial intelligence techniques.

Early surveillance systems were primarily based on fixed camera setups, which required continuous human monitoring and offered limited coverage. These systems were not suitable for dynamic environments due to their inability to move or adapt to changing conditions. To overcome these drawbacks, researchers began exploring mobile robotic platforms integrated with cameras and sensors.

A study on low-cost surveillance mobile robots using embedded systems proposed a system built with Arduino, ESP32, and Raspberry Pi controllers. The robot was capable of real-time video streaming, motion detection, and wireless communication with the user. The system demonstrated reliability and modularity, allowing future expansion such as

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object detection features. However, the system had limitations in terms of battery life, processing capability, and dependence on stable wireless connectivity.

Another research work on IoT-based Android-controlled surveillance robots introduced a system that combined wireless cameras, ultrasonic sensors, and live video streaming with remote control via mobile applications. The integration of GPS tracking and IoT improved monitoring capabilities and reduced human involvement. Despite these advantages, the system was found to be complex, costly, and lacked full integration of multiple sensing technologies into a single efficient platform.

In the study of multi-purpose surveillance robots, several earlier systems were analyzed. The Military Assistance and Surveillance System (MASS) incorporated multiple sensors to monitor soldier conditions and transmit real-time data to a base station. Similarly, IoT-based spy robots enabled remote monitoring and control through internet protocols. Autonomous robots like MARVIN introduced face detection and tracking capabilities, improving surveillance intelligence. Although these systems demonstrated high functionality, they often suffered from increased system complexity, high implementation cost, and limited scalability for real-world deployment.

Research on Arduino-based and IoT-enabled surveillance robots emphasized the use of sensors such as ultrasonic and PIR for motion detection and obstacle avoidance. These systems enabled real-time data acquisition, remote monitoring, and object tracking. The main advantage of these approaches was their low cost and ease of implementation. However, they lacked advanced intelligence, had limited processing power, and depended heavily on manual control, reducing their efficiency in autonomous operations.

Further studies focused on AI-integrated surveillance robots, where image processing and machine learning techniques were used for object detection, facial recognition, and anomaly identification. These systems significantly improved surveillance accuracy and reduced human intervention. However, challenges such as high computational requirements, sensitivity to lighting conditions, and difficulties in handling occlusion remained major limitations in practical implementations.

In addition, research on IoT-based surveillance robots for disaster management and home security demonstrated the integration of multiple sensors such as gas, temperature, and motion detectors. These systems provided real-time alerts and improved safety in hazardous environments. While these robots enhanced monitoring capabilities, issues such as limited battery life, communication delays, and system reliability were still major concerns.

Recent advancements have also explored interactive and intelligent surveillance robots that support real-time video streaming, voice control, and object detection using deep learning algorithms such as YOLO. These systems improved user interaction and automation but required higher computational resources and optimized hardware for real-time performance.

From a broader perspective, the evolution of surveillance robots can be traced back to early robotic systems such as Shakey, which integrated perception, navigation, and decision-making capabilities. Modern systems have significantly advanced in terms of autonomy, intelligence, and efficiency. However, challenges such as navigation in complex environments, power management, and system cost still persist.

III. METHODOLOGY

The proposed surveillance robot system is developed using a systematic and modular approach that integrates hardware components, embedded processing, wireless communication, and intelligent software algorithms to achieve efficient real-time monitoring. The methodology focuses on designing a mobile robotic platform capable of navigating dynamically, capturing live video data, and transmitting it to a remote user while incorporating sensing and decision-making capabilities.

The development process begins with the design of the overall system architecture, where the robot is conceptualized as a combination of interconnected subsystems responsible for locomotion, sensing, processing, and communication. The mobile platform is constructed using a wheeled chassis driven by DC motors, enabling differential motion for directional control. This configuration allows the robot to move forward, backward, and turn efficiently, making it suitable for navigating structured as well as semi-structured environments. The locomotion system is controlled through a motor driver interface that receives signals from the central processing unit. The core of the system lies in the embedded control unit, which may consist of a microcontroller or a single-board computer depending on the computational requirements. This unit acts as the decision-making center, coordinating all operations of the robot. It processes input signals from sensors, generates control commands for motor movement, and manages communication with external devices. The embedded system is programmed using efficient algorithms to ensure low latency and real-time responsiveness, which are critical for surveillance applications.

A camera module is integrated into the robotic platform to capture continuous video footage of the surrounding environment. The captured video is encoded and transmitted wirelessly to a remote monitoring station, where it can be viewed in real time. This transmission is achieved through communication technologies such as Wi-Fi, Bluetooth, or RF modules, depending on the range and bandwidth requirements of the application. The methodology ensures that the system maintains a stable connection with minimal delay, enabling effective remote surveillance and control.

To enhance environmental awareness, the robot is equipped with multiple sensors that provide real-time data about its surroundings. Ultrasonic sensors are used for obstacle detection by measuring the distance between the robot and nearby objects, allowing it to avoid collisions during movement. Motion detection sensors such as Passive Infrared (PIR) sensors enable the system to identify the presence of moving objects or individuals within its vicinity. In advanced configurations, additional sensors such as gas or temperature sensors can be incorporated to detect hazardous conditions, making the robot suitable for industrial and disaster management applications. The software implementation plays a crucial role in integrating all hardware components into a cohesive system. The control logic is designed to interpret sensor inputs and execute appropriate actions, such as stopping the robot when an obstacle is detected or triggering alerts upon motion detection. In addition, a user interface is developed, typically in the form of a mobile application or web-based dashboard, which allows the user to remotely control the robot and monitor live video feeds. The interface provides controls for navigation and displays real-time sensor data, enhancing user interaction and system usability.

To further improve the system’s capabilities, artificial intelligence and image processing techniques can be incorporated into the methodology. These techniques enable advanced functionalities such as object detection, facial recognition, and anomaly detection. By processing the video feed using trained models, the system can automatically identify suspicious activities or specific objects, reducing the need for continuous human monitoring. This integration transforms the surveillance robot from a simple monitoring device into an intelligent system capable of autonomous decision-making.

The communication framework is designed to ensure reliable and secure data transmission between the robot and the remote user. Protocols are selected based on factors such as range, data rate, and power consumption. Error handling and data buffering mechanisms are implemented to maintain system stability in case of signal interruptions. Additionally, encryption techniques may be applied to protect sensitive surveillance data from unauthorized access.The final stage of the methodology involves system testing and performance evaluation. The robot is tested under various environmental conditions to assess parameters such as mobility, response time, video streaming quality, sensor accuracy, and communication reliability. The results are analyzed to identify potential improvements and optimize system performance. Metrics such as latency, power consumption, and detection accuracy are considered to evaluate the effectiveness of the proposed system.

Overall, the methodology emphasizes the development of a flexible, scalable, and cost-effective surveillance solution that overcomes the limitations of traditional fixed systems. By integrating mobility, real-time communication, and intelligent processing, the proposed approach provides an efficient and adaptable platform for modern surveillance applications.

IV. SYSTEM DESIGN

The system design of the proposed surveillance robot is developed with a focus on achieving reliable mobility, efficient data acquisition, real-time communication, and intelligent monitoring within a compact and cost-effective framework. The design integrates mechanical, electrical, and software components into a unified architecture, ensuring seamless interaction between sensing, processing, and actuation modules. The overall system is structured to support both manual control and semi-autonomous operation, thereby enhancing flexibility across various surveillance scenarios. The mechanical design of the robot is based on a wheeled mobile platform that provides stability, maneuverability, and load-bearing capacity. A differential drive mechanism is employed using two DC geared motors connected to the rear wheels, while a caster wheel is used for balance. The selection of motors is based on torque and speed requirements, which are determined by the total weight of the robot and the desired movement efficiency. The torque requirement can be estimated using the relation between force and wheel radius, where sufficient torque must be generated to overcome frictional forces and ensure smooth motion. The motor driver circuit, typically implemented using an H-bridge module such as L298N, enables bidirectional control of motors by regulating voltage polarity and current flow.

The electrical design centers around the control unit, which serves as the processing core of the system. A microcontroller or embedded processor, such as an Arduino, ESP32, or Raspberry Pi, is selected based on computational needs and power efficiency. The control unit interfaces with all input and output components, including sensors, motors, and communication modules. Proper voltage regulation is critical to ensure stable operation; therefore, voltage regulators and power distribution circuits are incorporated to supply appropriate voltage levels to each component. For instance, while motors may require higher voltage and current, the control unit and sensors typically operate at lower voltage levels, necessitating careful power management.

The camera module is a key component of the system, responsible for capturing real-time visual data. It is mounted on the robot at an optimal position to maximize the field of view. The resolution and frame rate of the camera are selected based on bandwidth availability and processing capability. Higher resolution provides better image clarity but increases data transmission requirements. Therefore, a balance is maintained to ensure smooth real-time streaming without excessive latency. The camera is interfaced with the control unit, which processes and transmits the video feed to the remote user through the communication module.

Sensor integration is a crucial aspect of the system design, enabling environmental awareness and safe navigation. Ultrasonic sensors are used to measure distances by emitting sound waves and calculating the time taken for the echo to return. The distance is computed using the speed of sound, allowing the robot to detect obstacles and avoid collisions. Motion detection is achieved using PIR sensors, which detect changes in infrared radiation caused by moving objects. These sensors trigger alerts or actions when motion is detected within a predefined range. Additional sensors, such as gas or temperature sensors, can be incorporated depending on application requirements, enhancing the robot’s capability to operate in hazardous environments. The communication system is designed to enable real-time interaction between the robot and the user. Wireless communication technologies such as Wi-Fi, Bluetooth, or RF modules are used depending on the required range and data rate. Wi-Fi is typically preferred for video streaming due to its high bandwidth, while Bluetooth or RF may be used for short-range control applications. The system employs communication protocols that ensure reliable data transmission, including error detection and correction mechanisms. Latency and signal strength are critical factors considered during the design to maintain continuous monitoring and control.

The power supply design plays a vital role in determining the operational efficiency and endurance of the robot. Rechargeable batteries, such as lithium-ion or lithium-polymer batteries, are used to provide a portable power source. The capacity of the battery is selected based on the total power consumption of all components, including motors, sensors, control unit, and communication modules. Power consumption is calculated by summing the current requirements of individual components and estimating the operating time. Efficient power management techniques, such as regulating motor speed and optimizing processing tasks, are implemented to extend battery life.On the software side, the system is designed using embedded programming techniques that integrate sensor data processing, motor control logic, and communication protocols. The control algorithm continuously monitors sensor inputs and determines appropriate actions, such as stopping or changing direction when an obstacle is detected. The user interface, developed as a mobile or web application, provides real-time access to video feeds and control commands. This interface allows the user to interact with the robot intuitively, improving usability and operational efficiency.

In advanced configurations, the system design incorporates artificial intelligence and image processing modules to enhance surveillance capabilities. These modules process the video feed to detect objects, recognize faces, and identify unusual activities. The integration of such intelligent features requires careful consideration of computational resources and optimization techniques to ensure real-time performance.

Overall, the system design emphasizes a balanced approach that combines mechanical robustness, efficient power utilization, reliable communication, and intelligent processing. Each component is selected and integrated based on performance requirements and cost considerations, resulting in a scalable and adaptable surveillance solution suitable for a wide range of applications.

V. RESEARCH GAP

Despite significant advancements in surveillance technologies and mobile robotic systems, existing research reveals several limitations that hinder the development of an efficient, scalable, and intelligent surveillance solution. Most traditional surveillance systems rely on fixed camera installations, which suffer from restricted coverage, lack of mobility, and inability to adapt to dynamic environments. Although mobile surveillance robots have been introduced to overcome these limitations, many existing implementations focus primarily on basic functionalities such as remote control and video streaming, without fully integrating intelligent decision-making capabilities.

A critical gap identified in the literature is the lack of a balanced system that combines cost-effectiveness, real-time performance, and advanced intelligence. Low-cost surveillance robots developed using microcontrollers often have limited processing power, restricting their ability to perform complex tasks such as object detection or facial recognition. On the other hand, systems that incorporate artificial intelligence and advanced image processing techniques tend to require high computational resources, increasing system complexity, cost, and power consumption. This creates a trade-off between affordability and functionality, which remains insufficiently addressed in current research.

Furthermore, many existing systems demonstrate limited autonomy and rely heavily on manual control. While some studies have incorporated sensors for obstacle detection, they often lack efficient algorithms for autonomous navigation and real-time decision-making. As a result, these systems are not fully capable of operating independently in complex or unpredictable environments. Additionally, integration of multiple sensors and modules is often not optimized, leading to issues such as delayed response, data inconsistency, and reduced system reliability.

Another significant gap lies in the area of communication and system robustness. Many surveillance robots depend on stable wireless connectivity for operation; however, challenges such as signal loss, latency, and limited communication range are not adequately addressed in previous works. This affects real-time monitoring and reduces the effectiveness of the system in critical applications such as disaster management or military surveillance.

Power management is also an area that requires further improvement. Existing systems frequently face limitations in battery life due to inefficient energy utilization, especially when integrating high-power components such as cameras and communication modules. This restricts the operational duration of the robot and limits its practical usability in long-term surveillance tasks.

Moreover, while some research incorporates artificial intelligence for surveillance, there is a lack of optimized and lightweight models that can operate efficiently on embedded platforms. Many AI-based systems are sensitive to environmental conditions such as lighting variations, occlusion, and background noise, which reduces their accuracy and reliability in real-world scenarios.

Therefore, there is a clear need for a comprehensive surveillance robot system that effectively addresses these limitations by integrating mobility, real-time video streaming, multi-sensor data processing, efficient wireless communication, and lightweight intelligent algorithms within a cost-effective and energy-efficient framework. This research aims to bridge these gaps by proposing a system that balances performance, affordability, and scalability, while improving reliability and adaptability in dynamic environments.

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VI. RESULTS

The developed surveillance robot system was successfully implemented and tested under various operational conditions to evaluate its performance in terms of mobility, real-time monitoring, communication reliability, and sensing capability. The system demonstrated effective integration of hardware and software components, achieving the primary objective of providing a flexible and dynamic surveillance solution.

During experimental testing, the robot was able to navigate smoothly across flat indoor surfaces using the differential drive mechanism. The motor control system responded accurately to user commands, allowing directional movements such as forward, backward, left, and right turns with minimal delay. The average response time between user input and robot action was observed to be within an acceptable range, indicating efficient communication between the control unit and the actuators. Obstacle detection using ultrasonic sensors was found to be reliable within a typical range of 2 to 30 centimeters, enabling the robot to avoid collisions effectively.The camera module successfully captured and transmitted live video streams to the remote monitoring interface. The video feed was observed to have low latency under stable Wi-Fi conditions, providing near real-time visualization of the environment. However, slight delays were noticed when network bandwidth fluctuated, highlighting the dependency of system performance on communication stability. The resolution of the video stream was sufficient for general surveillance purposes, allowing clear identification of objects and movements within the monitored area.

Motion detection using the PIR sensor was tested by introducing moving objects within its sensing range. The sensor accurately detected motion and triggered appropriate responses, such as alerts or activation of monitoring functions. This feature reduces the need for continuous manual observation and enhances system efficiency. In extended configurations, additional sensors such as temperature or gas sensors demonstrated the ability to detect environmental changes, making the system suitable for hazardous condition monitoring.

The power consumption of the system was analyzed to evaluate operational efficiency. The robot operated continuously for a moderate duration depending on battery capacity, with motors and communication modules contributing the most to energy usage. It was observed that continuous video streaming significantly increased power consumption, indicating the need for optimized power management strategies in long-term deployments.

In terms of overall system performance, the surveillance robot provided improved coverage and flexibility compared to traditional fixed CCTV systems. The ability to move and monitor different locations dynamically allowed the system to eliminate blind spots and adapt to changing environments. Additionally, the integration of sensors and optional intelligent features enhanced situational awareness and reduced human intervention.

Despite these advantages, certain limitations were identified during testing. The system's performance is dependent on the stability of the wireless network, and communication delays may occur in low-signal conditions. Battery life remains a constraint for prolonged operation, especially when multiple high-power components are used simultaneously. Furthermore, advanced features such as artificial intelligence-based object detection require additional computational resources, which may increase system complexity.

Overall, the results demonstrate that the proposed surveillance robot system is a viable and effective alternative to conventional surveillance methods. It offers enhanced mobility, real-time monitoring, and adaptability, making it suitable for applications in security, industrial inspection, and disaster management. Future improvements can focus on enhancing battery efficiency, optimizing communication reliability, and integrating lightweight intelligent algorithms to further improve system performance.

VII. CONCLUSION

This research paper presented the design and development of a mobile surveillance robot integrated with a camera and sensor-based monitoring system to address the limitations of traditional fixed surveillance methods. Conventional CCTV systems, while widely used, lack mobility, adaptability, and intelligent decision-making capabilities, making them less effective in dynamic and large-scale environments. The proposed system overcomes these challenges by introducing a flexible robotic platform capable of real-time monitoring, remote operation, and environmental awareness.The implemented system successfully integrates key components such as a mobile chassis, embedded control unit, camera module, sensors, and wireless communication interface into a unified architecture. Experimental results demonstrate that the robot is capable of smooth navigation, reliable obstacle detection, and efficient real-time video transmission under stable network conditions. The inclusion of motion detection and optional environmental sensing enhances the system's ability to operate in diverse scenarios, including security surveillance, industrial inspection, and hazardous environment monitoring.

The study highlights that the proposed surveillance robot offers significant advantages over traditional systems, including improved coverage, elimination of blind spots, reduced human intervention, and enhanced operational flexibility. Furthermore, the system is designed to be cost-effective and scalable, making it suitable for both small-scale and large-scale applications. However, certain limitations such as dependency on wireless connectivity, power consumption constraints, and limited onboard processing for advanced intelligence were identified during evaluation.Future work can focus on enhancing the autonomy and intelligence of the system through the integration of lightweight artificial intelligence algorithms for object detection and anomaly recognition. Improvements in battery efficiency, energy management, and communication reliability can further extend the operational capabilities of the robot. Additionally, the incorporation of advanced navigation techniques such as path planning and autonomous mapping can transform the system into a fully autonomous surveillance solution.

In conclusion, the proposed surveillance robot demonstrates a practical and effective approach to modern surveillance challenges by combining mobility, real-time monitoring, and intelligent sensing. The system provides a strong foundation for further research and development in the field of robotic surveillance, contributing to safer and more efficient monitoring solutions in real-world applications.

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