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VigiTrak: Vision-Based Terrain-Adaptive Surveillance Robot with GPS Tracking

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Abstract

This paper presents the design and implementation of a compact terrain-adaptive surveillance robot integrating real-time imaging, wireless control, and geolocation capabilities. The system employs an Arduino-based embedded platform interfaced with an L293D motor driver, HC-05 Bluetooth module, GPS receiver, and Wi-Fi IP camera to enable synchronized mobility and continuous video transmission. A reinforced metal chassis with a belt-driven wheel mechanism ensures mechanical stability and effective navigation across diverse surfaces. The Android control interface provides directional commands, camera orientation control, and live visual feedback for remote situational awareness. Integrated software functionalities support object detection and GPS-based positional reporting, enhancing the system's applicability for security monitoring, hazardous-area inspection, and autonomous patrol operations. Overall, the proposed architecture demonstrates a low-cost yet robust framework suitable for scalable intelligent surveillance systems.

Keywords
Surveillance Robot, Wireless Control, Arduino, GPS Tracking, Wi-Fi Streaming, Terrain Navigation, Object Detection

1. Introduction
Robots can now move more quickly, accurately, and intelligently thanks to greatly enhanced robotic control systems brought about by advances in high-speed technology and processing power. (P. Atreya et al. 2023; H. He et al. 2024) Thanks to their sophisticated control algorithms and effective drivers, these systems are now extensively utilized in a variety of industries for automation, precise work, and operations in dangerous conditions. (Y. Xie et al. 2024; Z. Liu et al. 2022) ,

Robots are now indispensable in industries like manufacturing, space exploration, disaster relief, and surveillance because they can carry out repetitive, hazardous, or impossible-for-human tasks. (A. Dzedzickis et al. 2021; N. Fallahiarezoodar et al. 2024; G. Wilk-Jakubowski et al. 2024; H. Surmann et al. 2024) George C. Devol created Unimate, the first reprogrammable manipulator, in the 1950s, revolutionizing industrial automation and laying the groundwork for modern robotics. (S. Moosavi et al. 2024; R. R. Murphy et al. 2024).

An essential defense and security function, surveillance has historically relied on human monitoring, which is constrained by accessibility issues and safety hazards. This project suggests a smartphone-controlled mobile robot as a flexible and affordable way to overcome these constraints. To control robot movements like forward, reverse, left, and right, the system interfaces with an Android application and consists of an Arduino Uno, HC-05 Bluetooth module, and L293D motor driver. (M. A. Kamal et al. 2021; E. Hoq et al. 2019; E. Demir et al. 2021; Mahbub, F et al. 2024). Conventional robot control systems frequently depend on fixed programming and wired communication, which restricts their adaptability, mobility, and user-friendliness. Such systems are inefficient and time-consuming to reprogram for task modification. (Y. Zhang et al. 2025; M. F. R. Lee, 2022) Furthermore, there are operational difficulties and safety risks associated with human surveillance in dangerous or inaccessible locations. (H. Chitikena et al. 2023; C. Zhang, 2024).

The objective of this study is to develop a low-cost, smartphone-operated surveillance robot capable of real-time monitoring and remote navigation in diverse environments. The system integrates an Arduino-based control architecture with Bluetooth communication for responsive motion control, a Wi-Fi IP camera for continuous day-and-night video streaming, and onboard object detection to identify and classify targets during operation. Additionally, a GPS module is incorporated to provide accurate geolocation tracking and map-based positioning of the robot. The mechanical platform is designed with a belt-driven metal chassis to ensure stable terrain adaptability. Overall, the project aims to deliver an efficient, multifunctional mobile surveillance system that combines wireless control, live imaging, object recognition, and location tracking within a compact and affordable robotic platform.

2. Methodology
2.1 Block Diagram
The block diagram of the Android app-controlled surveillance robot system is displayed in Figure 1. This block diagram displays the block diagram of the Android app-controlled surveillance robot system. This block diagram shows the Arduino Uno controlling the Arduino-based surveillance robot. The servo motor, DC motor, Bluetooth module, and GPS module are all connected to the Arduino in this robot. A servo motor is connected to a mini-Wi-Fi IP camera, and our application retrieves and displays the live video. This film was produced with the aid of WiFi technology. Two servo motors for camera motions and two dc motors for robot movements are controlled by the Arduino Uno. The location is tracked by the GPS module. Two DC voltage sources make up the power unit: the motor driver uses 12 volts, and the Arduino Uno uses 5 volts. Multiple tasks can be controlled by Arduino Uno microcontrollers. Here, the Arduino Uno serves as the system's brain, processing user-sent commands over the

internet and controlling the motors in accordance with the code. The Arduino Uno is also coupled to the Bluetooth module HC-05 and the GPS module NEO-6M. They use motor drivers that run on a 12V DC power source.

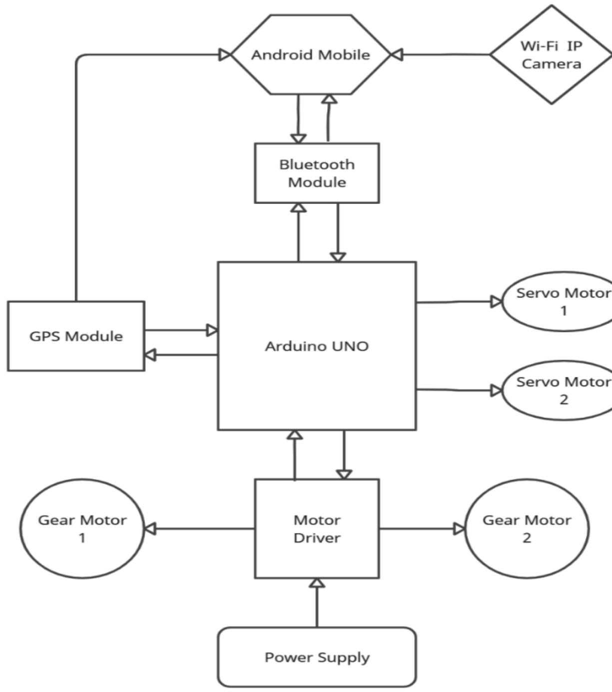
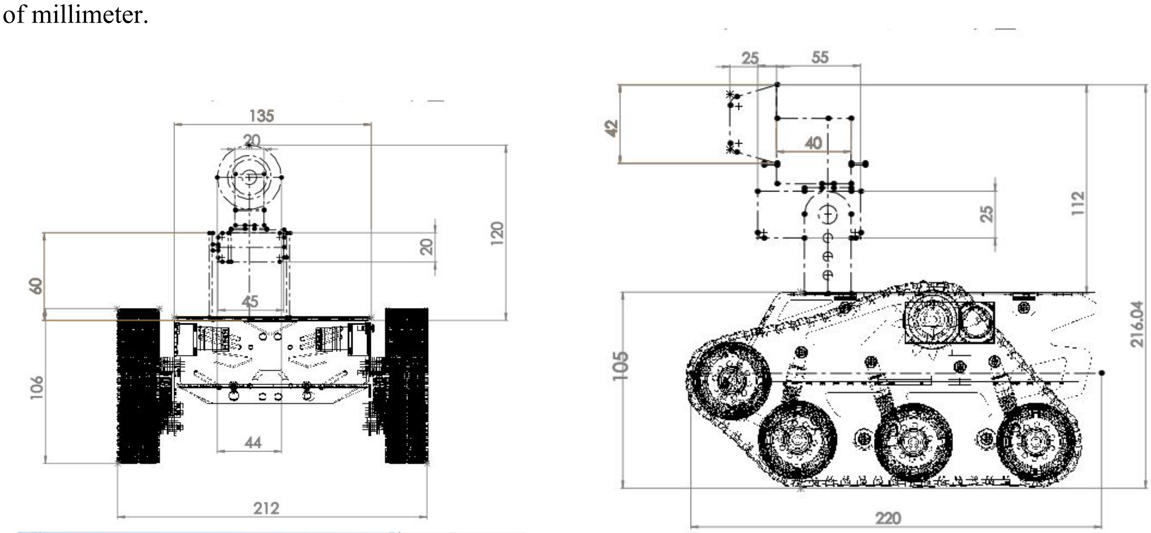


Figure 1. Block Diagram of a Surveillance Robot Controlling System using android app.

2.2 Mechanical Drawing

Figures 2,3,4,5,6 represents the 2D mechanical drawings of the Surveillance Robot with measurements. These drawings are about Front view, Side view and Top view of mechanical design and all the measurement is in the scale of millimeter.



(a) (b)

Figure 2. (a) Front view of mechanical drawing in millimeter scale (b) Side view of Mechanical Drawing in millimeter scale

2.3 Electrical Design

Figure 3. shows the circuit diagram of the Surveillance robot-controlled system using the android application.

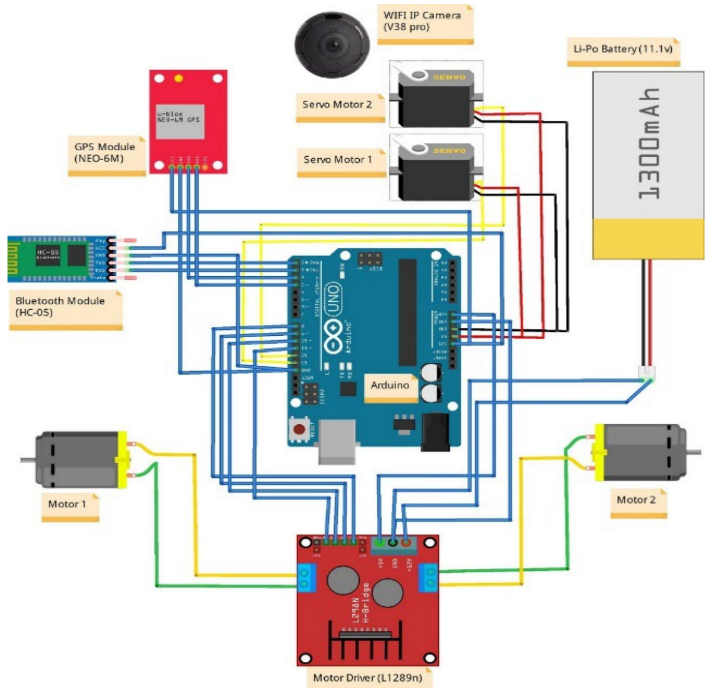


Figure 3. Circuit Diagram of a Surveillance Robot Controlling System

2.4 Flow Chart

Figure 4 represents the flow chart of the Surveillance robot controlled using the android app. The objective here is to design a real-time control surveillance robot and monitoring system, at the same time a wireless mini-IP camera transmitting real-time video with night vision. Here we are using a different microcontroller (Arduino uno) and motor driver (L293D) for controlling multiple tasks.

In this implementation model, we used Arduino uno with a Bluetooth module. This module is connected to an Arduino uno board for controlling surveillance robot, an Arduino motor shield driver which controls the robot through the geared dc motors. One of the advantages of this is that the operator can control the movement of the robot through the live video seen using the mobile robot control platform. The Arduino uno is powered by a 5v, 2400mAh battery, which sends a sizeable current to the dc motor for its movement and also powers the Wi-Fi module for visual transmission and recording of data which also sends current to the servo motors for tilting the robot camera module for optimum visual. The Arduino also powers the GPS module for tracking the location of the robot.

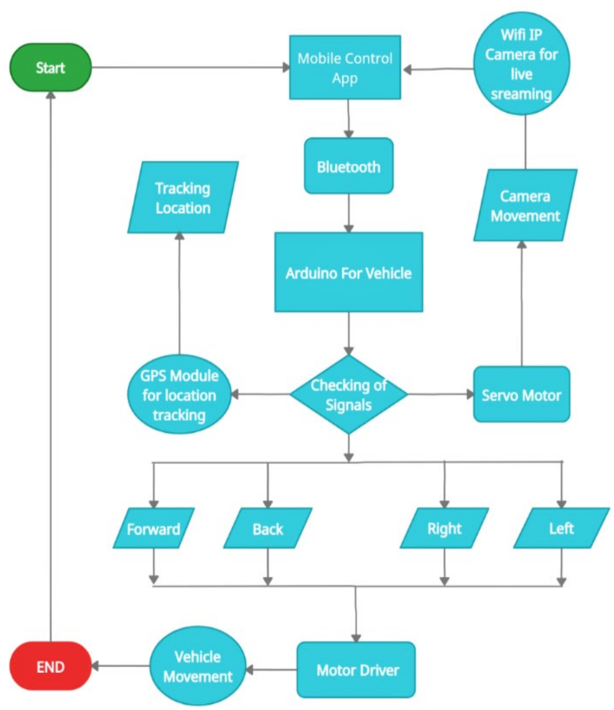


Figure 4 Flow Chart of the Surveillance Robot

The Android application transfers the input data signals to the Arduino uno via Bluetooth on the user's smartphone. Arduino uno recognizes all input signals coming from the connected device which are sent to the Arduino motor shield which sends signals that should be addressed to the drive motor. Thus, Tthe robot vehicle moves in certain directions to the corresponding input signals received. The user can command the movements of the robotic vehicle such as forward and backward movement and clockwise and anti-clockwise rotations, the robot from the user's Android smartphone.

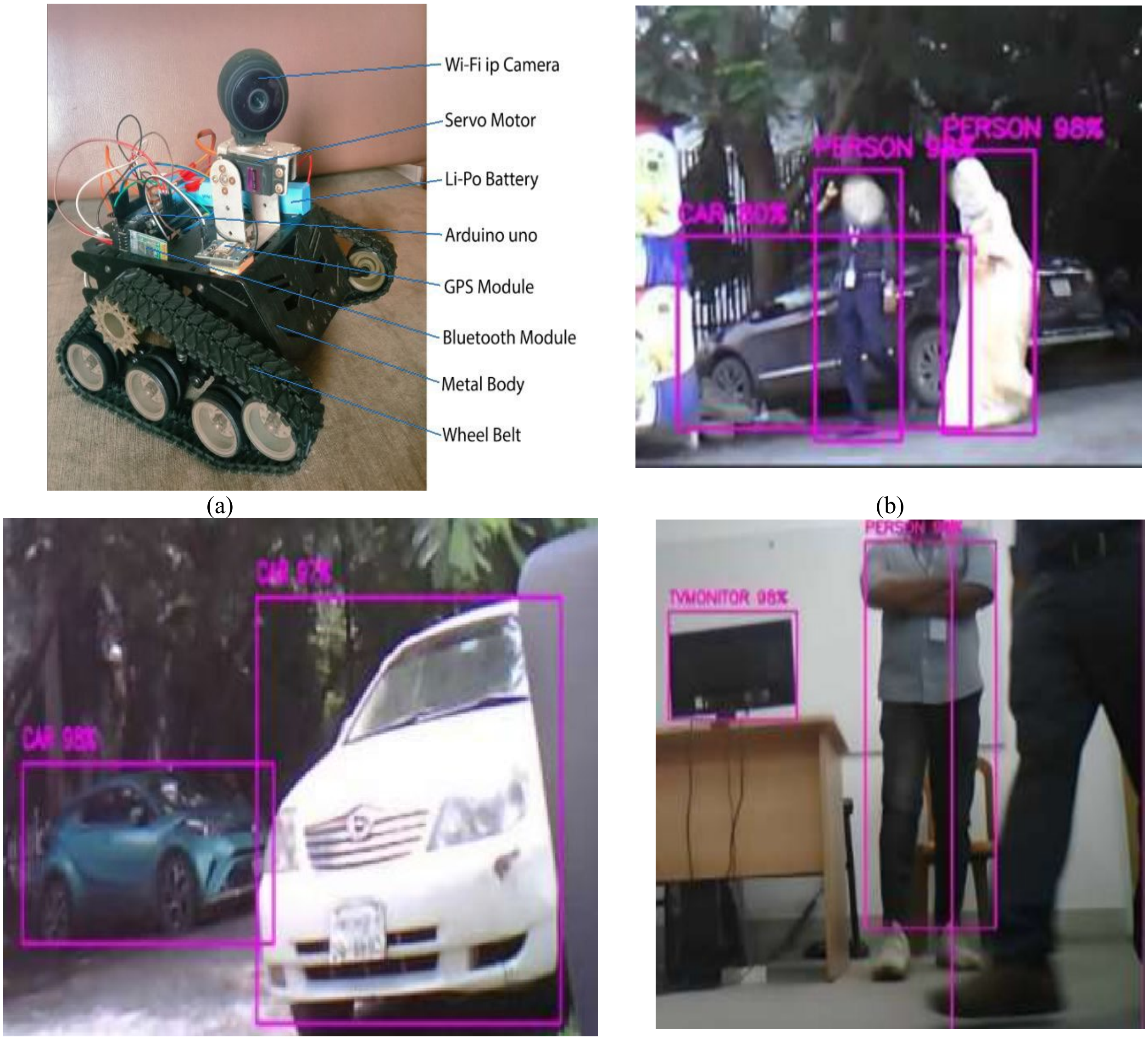
Since the Arduino uno cannot directly power a DC motor due to insufficient current, motor drivers, with their power supply are used. Each motor driver can control DC motors. Hence, a motor driver is used. In our implementation, the Arduino sends control signals to two L293D motor drivers, each powered by a 12-volt battery.

For real-time monitoring, the data received by Arduino uno from all of the modules (Bluetooth, GPS, Servo motor). When all the modules are satisfied with the program condition then Arduino uno converts the output signal and also transmits the signal to android apps. If any error happens again, it goes back to initializing stages.

3. Results and Discussion

This Figure 5 demonstrates the real-time video streaming and object detection performance of the VigiTrak surveillance robot. The IP camera integrated with robot streams live video to a web browser interface, where detection and classification objects are performed using embedded image processing algorithms. Detected objects are visually confirmed and enclosed within bounding boxes labeled with their respective confidence levels.

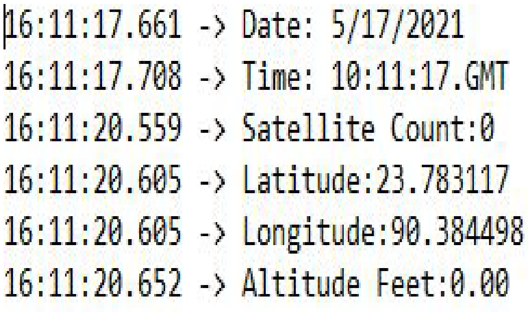
Tests 1–8 illustrate the robot's ability to accurately detect and classify various objects such as persons, cars, cell phones, laptops, backpacks, bottles, handbags, and monitors under different lighting and environmental conditions. The system achieves reliable detection during both indoor and outdoor operations, confirming its adaptability for real-world surveillance tasks. The visual output confirms VigiTrak's capability to provide continuous monitoring, real-time target recognition, and situational awareness through wireless video transmission.

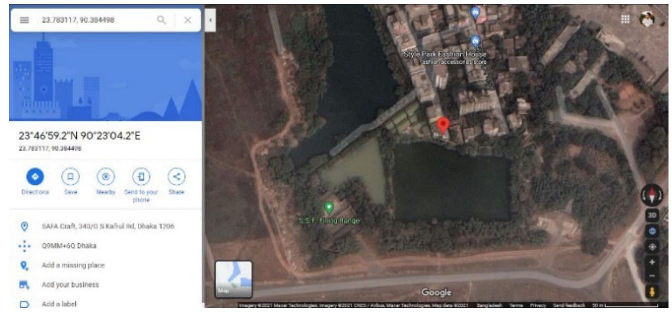


(c) (d)

Figure 5. *Real-time video streaming and object detection results of the VigiTrak robot, (a)* Project view of a Surveillance Robot (b) CAR 96%, HANDBACK 85%, PERSON 99%, PERSON 98%) (c) CAR 98%, CAR 97% (d) TV MONITOR 98%, PERSON 99%

We also use the GPS module attached to the Robot's body for receiving the latitude, longitude and location of the Robot monitoring from Google Maps





(a) (b)

Figure 6. (a) Latitude, Longitude from Arduino Serial Monitor Figure (b): Monitoring Location of the Surveillance Robot.

At Figure 6 showing screen shot of serial monitoring data of GPS module from Arduino software, which shows the Date, Time, Satellite count Latitude, Longitude, Altitude and Location serially.

At Figure 7 showing the position of Surveillance Robot by putting the Latitude of “23.783117 N” and Longitude of “90.3874498 E”. This is the Satellite footage of Google Map by connecting GPS module to Satellite. The GPS module takes some time to connect to the Satellite. For getting the location we put the GPS code to Arduino uno and connect the GPS module to the Arduino, then

Figure 7. Arrow keys interface of the Android App

we can see the Latitude and Longitude on the serial monitor of the Arduino software. We put the that latitude and longitude on Google map and get the actual location of the Robot.

Figure 8 shows the arrow keys interface of the android application. The Arrow button interface is for the controlled movement of the surveillance robotic. All buttons are provided like forward and backward arrow buttons, anticlockwise buttons, and clockwise arrow buttons. When a button is clicked on the Android smartphone the input is sent via Bluetooth to the robotic vehicle then the robot moves accordingly. The forward button and backward arrow buttons are for the robot movement towards forwarding and backward direction respectively whereas the anti-clockwise button, and clockwise arrow buttons are for robot anticlockwise and clockwise rotation by the user (Table 1).

Table 1. Number of Test Cases Passed/Failed

Date/ Time	Location	Test cases executed	Test cases passed	Test cases failed
13-06-2025	South Kafrul, Dhaka	10	7	2
14-06-2025	South Kafrul, Dhaka	15	13	1
15-07-2025	South Kafrul, Dhaka	20	20	Nil

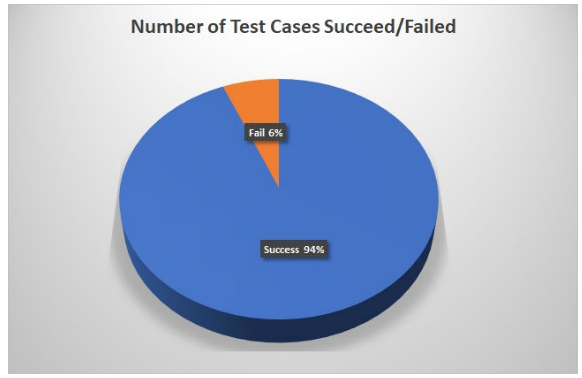


Figure 8. Pie Chart of Number of Test Cases Succeed/Failed

First observation launching the project and within 7-times success but 2 time failed. Because a DC motor was not rotating properly. For that the robot could not go through straight line. Second observation launching the project and within 13-times success but 1 time failed. Because the GPS module could not connect to the Satellite properly because of confined space. That's why we were not getting the signal. In third observation launching the project within 20 times success and no failed.

The Observation of Power Consumption (w) on Surveillance Robot is shown in Table 2

Table 2. Power Consumption (w) on the Surveillance Robot

SL. No	Name of Components	Power Consumption	Quantity	Total Power
1	Servo Motor	5.76 w	2	11.52 W
2	DC Motor	3.47 w	2	5.94 W
3	Motor Driver	.5 w	1	.5 W
4	Bluetooth Module	1 w	1	1 W
5	GPS Module	3 w	1	3 W
6	Wi-Fi IP Camera	5 w	1	5 W
7	Arduino UNO	0.29 w	1	0.29 W
				Total Power 27.25 W

Advantages

The proposed system exhibits several technical advantages that enhance its operational reliability and usability. Its interface design incorporates a low-complexity human–machine interaction layer, enabling efficient control with minimal user effort. The hardware architecture employs low-power components with extended operational lifetime, contributing to overall system sustainability. In addition, the processing workflow is optimized to maintain stable performance with minimal computational overhead, ensuring consistent functional efficiency. The mechanical design avoids wear-prone elements, significantly lowering maintenance requirements during long-term deployment. Furthermore, embedded autonomous control logic allows the system to function without continuous human supervision, increasing dependability in repetitive or remotely operated tasks.

Limitations

Despite its strengths, the system presents several technical limitations that may constrain its broader applicability. The Bluetooth-based communication module restricts the effective transmission range to approximately 10 meters, limiting suitability for large-area or distributed deployments. The enclosure lacks formal ingress protection, making the system vulnerable to moisture, dust, and outdoor environmental exposure. Additionally, the system relies on a continuous external power supply due to the absence of integrated energy-storage or adaptive power-management mechanisms, reducing resilience in environments with unstable or intermittent power availability.

3. Conclusion and Recommendation

It has been successfully implemented the working of the wireless video surveillance robot controlled using an android mobile device. The robot is effectively controlled by using the android application through wireless Bluetooth technology. Even the real-time video feel is successfully achieved using Wi-Fi technology on our designed android application. Overall, the objectives of this thesis have been achieved which are developing the hardware and software for Arduino uno base Surveillance Robot, moves so smoothly, monitoring any objects by moving camera and tracking the location from GPS of the robot that meets the standards of purpose thesis. From the analysis that has been made, it is clearly shows that vehicles move to any direction, getting the live video footage and tracking the Google map position.

Recommendations

In the future, the proposed project will be developed and implemented through the integration of three core components to enhance system performance and operational efficiency. These components include:

1. **Headset with Full HD Display:** The headset will provide users with a high-resolution, immersive visual experience. It will facilitate real-time data visualization and situational awareness, enabling efficient monitoring and decision-making during operations.
2. **High-Megapixel Monitoring Camera:** A high-resolution monitoring camera will be incorporated to ensure accurate image capture and detailed environmental observation. This component will enhance detection capabilities and improve the reliability of data acquisition for analysis and evaluation.
3. **Mission Control Center:** The mission control center will serve as the central hub for data processing, coordination, and system management. It will enable remote monitoring, data integration, and operational control, ensuring effective communication between all components of the system.

This integrated design aims to create a robust, real-time monitoring and control framework suitable for future expansion and advanced applications.

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Biographies

Enamul Hoq is an Assistant Professor and Course Coordinator in the Department of Mechatronics Engineering at the World University of Bangladesh (WUB). He earned his B.Sc. in Mechatronics Engineering from WUB in 2013 and is currently pursuing an M.Sc. in Mechanical Engineering at the Military Institute of Science and Technology (MIST), Bangladesh. Since joining WUB in June 2013, he has been actively involved in both teaching and departmental coordination.Hoq has contributed to several book chapters published by Springer, covering topics such as sensors and actuators, control systems, and applications of mechatronics engineering. His research interests include robotics, automation, and renewable energy systems. Notably, he co-authored a study on the development of an automatic wind turbine system presented at the 2nd International Conference on Mechanical Engineering and Applied Sciences (ICMEAS) in 2022. Additionally, he was involved in designing and constructing an obstacle-avoiding, line-following luggage-carrying robot, showcased at the 5th International Conference on Industrial & Mechanical Engineering and Operations Management in Dhaka. He has also conducted a review on the effect of temperature and solar panel position on solar PV system performance.

Mohammad Quamruzzaman is a Professor and Head of the EEE Department at the World University of Bangladesh. He earned his BSc in EEE from John Moore University (UK) and completed his MSc and PhD from the University of Dhaka. He has over 29 years of professional experience at the Bangladesh Atomic Energy Commission, where he served as Chief Engineer, Director, Director General, and Member (Engineering). He also taught at IUT, Southeast University, and Daffodil International University. Quamruzzaman has implemented more than 10 major projects, holds 2 patents, installed Bangladesh’s first Nucleonic Control System, and established the first VLSI laboratory at BAEC. He has over 50 scientific publications, numerous reports and articles, and one book published by Bangla Academy. His current research focuses on the effects of electromagnetic radiation (EMR) on living systems, with multiple international publications in this field. He is a Fellow/Member of several professional organizations including IEB, BEIS, and IEE (UK).

Md. Mizanur Rahman is currently employed as a professor at the World University of Bangladesh. In addition, he has worked on the Renewable Energy Technology in Asia (RETs in Asia) project at KUET and AIT from January 1999 to December 2004 as a research assistant, research engineer, and consultant. Following that, he went to work for an NGO called BRAC Bangladesh as a program support professional. He joined Rural Power Company Ltd. (RPCL) in February 2006 and remained there as assistant manager until July 2007. In July 2007, he began his doctoral studies at Universiti Malaysia Sabah in Natural Draft Chimney. Dr. Rahman began serving as a lecturer at the TAS Institute of Oil and Gas in July 2009 and continued to do so till August 2012. He then moved on to become a senior lecturer at Universiti Malaysia Sabah before enrolling in the World University of Bangladesh. In addition, he holds a life fellowship in the Institutes of Engineers Bangladesh and is a professional member of the IEOM**.**

Rezwan us Saleheen is currently serving as an Assistant professor in the Department of Mechatronics Engineering at the World University of Bangladesh. Mr. Saleheen pursued his Master of Science in Biomedical Physics and Technology from the University of Dhaka, Bangladesh followed by his graduation. He graduated in Electrical & Electronic Engineering (EEE) from AIUB. His research interests include Biomedical instrumentation, Electronics, Artificial Intelligence (AI), and Automation. He is one of the editors of the book 'Mechatronics: Fundamentals and Applications' which is published by Springer-Nature. He also has several journal and conference publications on his respective fields.

Md Shariful Islam is a lecturer in the mechatronics engineering department at the World University of Bangladesh. He received his B.Sc. in Mechanical Engineering from the Department of Mechanical Engineering at the Dhaka University of Engineering and Technology (DUET) in 2013 and his M.Sc. in Mechanical Engineering from the Khulna University of Engineering and Technology (KUET) in 2017. Currently, he is pursuing his PhD in Mechanical Engineering at Khulna University of Engineering and Technology (KUET). He began his career at the Khulna City Corporation (KCC) in 2014 as an assistant engineer under the project “Solid waste management and asphalt plant establishment project” in Khulna, Bangladesh. Later, Md. Shariful Islam moved to Zaozhuang University in China as an assistant professor in 2019. He is an active Member of the Institution of Engineers Bangladesh (IEB).