IJIREEICE ISSN (O) 2321-2004, ISSN (P) 2321-5526

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

Impact Factor 8.021 ⪤ Peer-reviewed & Refereed journal ⪤ Vol. 13, Issue 4, April 2025

DOI: 10.17148/IJIREEICE.2025.13477

DESIGN AND FABRICATION OF A LONG-RANGE SPY ROBOT WITH NIGHT VISION USING ULTRASONIC SENSOR

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Abstract: This paper presents the design and development of a long-range spy robot equipped with a night vision camera, wireless control, and multiple sensors for obstacle and hazard detection. The robot is designed for military surveillance, industrial monitoring, and disaster response applications. The system integrates an Arduino Uno microcontroller, a night vision wireless camera, and sensors including ultrasonic, metal detection, and fire sensors. Wireless communication via Wi-Fi and DTMF allows remote operation. The results indicate efficient real-time monitoring, obstacle detection, and remote maneuverability, making it a viable solution for autonomous surveillance. Additionally, the robot's mobility is optimized for rough terrains, ensuring functionality in harsh environments.

Keywords: Spy Robot, Night Vision, Surveillance, Obstacle Detection, Wi-Fi, Remote Monitoring, Hazard Detection.

I. INTRODUCTION

Surveillance and reconnaissance play a vital role in security, defense, and industrial monitoring. Traditional surveillance systems rely on human operators or stationary cameras, which can be limited in functionality and pose risks in hazardous environments. Advancements in robotics and automation have introduced the potential for autonomous and semi-autonomous surveillance systems that enhance monitoring efficiency while minimizing human involvement in dangerous zones. With the growing need for advanced surveillance technologies, this paper explores the development of a long-range spy robot that integrates night vision capability, wireless control, and multi-sensor functionality for enhanced monitoring and reconnaissance. The primary objective of this system is to provide real-time surveillance in both daylight and low-light conditions, making it a valuable asset for military applications, industrial safety monitoring, and disaster response operations.

The proposed system features wireless communication (Wi-Fi and DTMF control) for remote operation, ensuring flexibility and ease of deployment. Additionally, the incorporation of multiple sensors, including ultrasonic, metal detection, and fire sensors, enables the robot to navigate autonomously and detect potential hazards in its surroundings. Unlike conventional surveillance systems, which are often stationary or manually controlled, this spy robot offers mobility, adaptability, and real-time hazard detection, significantly enhancing security measures in various environments.

Furthermore, the robot's rocker-bogie mechanism allows it to traverse rough terrains, making it suitable for deployment in challenging environments such as war zones, disaster-stricken areas, and industrial sites. The system also leverages real-time video streaming via a night vision camera, enabling operators to monitor events remotely and make informed decisions in critical situations. This paper discusses the design, implementation, and performance evaluation of the spy robot, focusing on its capabilities, limitations, and potential enhancements. By integrating modern surveillance technology with advanced mobility and communication features, this system represents a significant step toward more efficient and autonomous reconnaissance operations.

II. LITERATURE REVIEW

Recent advancements in robotics have led to the development of autonomous surveillance robots, with researchers exploring various techniques to enhance their efficiency and effectiveness.

DOI: 10.17148/IJIREEICE.2025.13477

Several studies have examined the role of night vision technology, wireless communication, and multi-sensor integration in improving surveillance capabilities. This section reviews notable contributions from various authors and highlights their individual research efforts.

Pousia S. et al. (2021) developed a long-range spy robot with night vision that focused on real-time surveillance using a wireless camera. Their work emphasized image clarity in low-light conditions and addressed challenges related to video transmission over extended distances. They also examined power efficiency improvements by optimizing battery consumption for prolonged operation.

Suniksha B. S. et al. (2020) conducted a comprehensive review of warfield spy robots incorporating night vision and wireless camera systems. Their study evaluated various control mechanisms, including DTMF, RF modules, and IoT-based communication, and identified Wi-Fi as the most efficient communication method for real-time data transmission.

Laxmikant Mangate et al. (2024) designed a multi-functional spy robot integrating vision-based surveillance with AI-driven obstacle detection. Their research demonstrated the benefits of artificial intelligence in improving navigation accuracy and threat identification in autonomous surveillance systems.

Irfan Rangapur et al. (2020) introduced a spherical spy robot with enhanced mobility and 360-degree vision. Their work focused on improving terrain adaptability and reducing mechanical constraints to allow smooth movement over rough environments. They also explored the use of gyroscopic stabilization techniques to enhance image stability.

Yash Yadav et al. (2022) developed a long-range spy robot that utilized ultrasonic and infrared sensors for obstacle detection and hazard identification. Their research highlighted the efficiency of sensor fusion techniques in enhancing the decision-making capabilities of autonomous robots.

B. Ravi et al. (2023) focused on two-wheel drive track spy robots with night vision cameras, emphasizing mechanical stability and optimized movement mechanisms. Their research demonstrated that tracked robots performed better in uneven terrains compared to wheeled counterparts.

Sarmad Hameed et al. (2019) proposed a military spying robot with integrated gas and fire detection sensors. Their work was aimed at hazardous environment monitoring and demonstrated high accuracy in detecting dangerous gas leaks and fire hazards.

This literature review highlights that while several advancements have been made in the field of spy robots, most studies either focus on vision-based surveillance or sensor-based obstacle detection. However, a comprehensive system integrating multiple sensors, robust mobility, and intelligent decision-making remains an area for further research. The proposed spy robot in this study seeks to address these limitations by combining night vision technology, multi-sensor detection, and wireless long-range communication into a single, cost-effective solution.

III. METHODOLOGY

The methodology for the design and development of the long-range spy robot is structured into several key phases, ensuring a systematic approach to achieving the project objectives.

3.1 Limitations of Existing Systems

Traditional surveillance systems, such as fixed cameras and human monitoring, have several limitations. These systems lack mobility, making them unsuitable for dynamic and large-scale environments. Additionally, conventional systems often have poor or no night vision capabilities, limiting their effectiveness in low-light or no-light conditions. Human involvement in hazardous environments, such as disaster zones or toxic areas, increases the risk to personnel. Existing systems also typically focus only on visual surveillance, neglecting the integration of environmental sensors like temperature and gas detection. Furthermore, many current systems lack real-time streaming and wireless control, reducing their efficiency for immediate response and remote monitoring. Most surveillance tools are incompatible with varied terrains, limiting their effectiveness in complex environments.

3.2 Proposed System

The proposed system addresses the limitations of existing surveillance methods by introducing a mobile robot equipped with advanced night vision, wireless control, and multi-sensor integration. The robot supports real-time video

DOI: 10.17148/IJIREEICE.2025.13477

streaming, ensuring efficient monitoring and immediate response in critical situations. With a robust and adaptable design, the robot is compatible with diverse terrains, making it ideal for reconnaissance, disaster response, industrial inspections, and security monitoring.

3.3 Advantages of Proposed System

The proposed system offers several advantages over traditional surveillance methods:

- Real-Time Video Streaming: Provides continuous and efficient monitoring.
- Advanced Night Vision: Operates effectively in low-light or no-light conditions.
- Hazardous Environment Operation: Ensures safe operation by eliminating the need for human presence.
- Integrated Sensors: Detects environmental factors like temperature, gas levels, and obstacles.
- Wireless Control: Enables remote navigation and user-friendly operation.
- Automatic Obstacle Detection: Enhances safety and reliability with automatic obstacle detection and collision prevention.

3.4 Hardware Requirements

The hardware components required for the spy robot include:

- Arduino Uno Microcontroller: For controlling the robot's operations.
- Bluetooth Module (HC-05): For wireless communication.
- Ultrasonic Sensor: For obstacle detection.
- Temperature Sensor: For monitoring environmental temperature.
- Gas Sensor: For detecting hazardous gases.
- Wi-Fi Camera: For real-time video streaming.
- 12V Battery: For power supply.
- Relay Board: For motor control.
- DC Motor: For movement and navigation

3.5 Software Requirements

The software components required for the spy robot include:

- Arduino IDE: For programming the microcontroller.
- Embedded C Language: For developing the robot's control algorithms.

3.6 Block Diagram

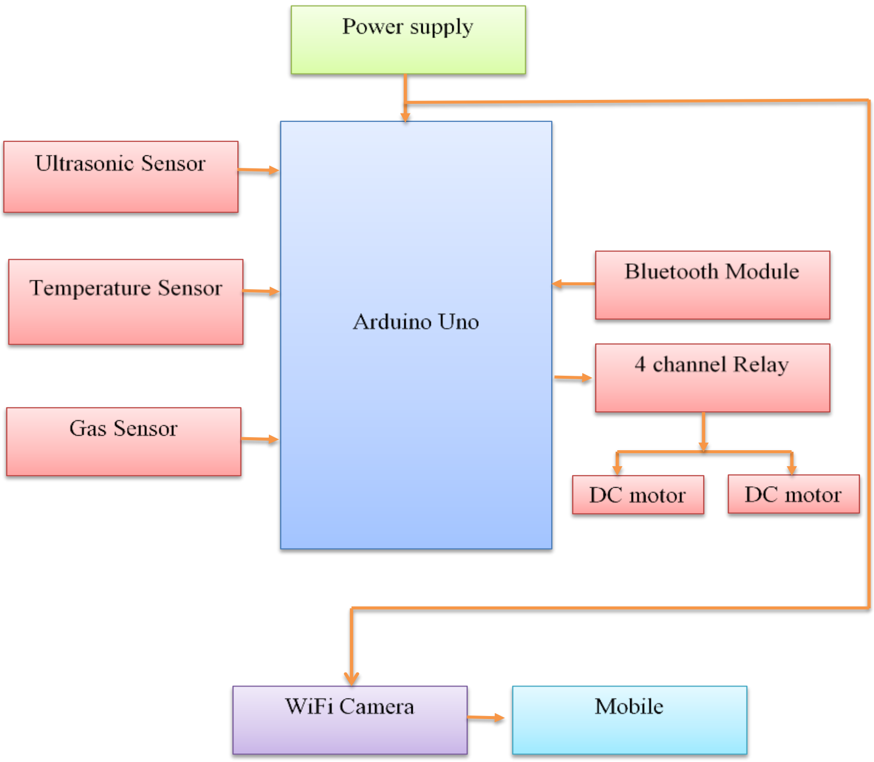

Fig. 3.6.1 Block Diagram

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The Block diagram (Fig. 3.6.1) illustrates the connections between the various hardware components, including the power supply, sensors, microcontroller, Bluetooth module, and motors. The diagram ensures a clear understanding of the system's electrical architecture, facilitating the assembly and testing of the robot.

3.7 Experimental Design and Testing

The experimental design involves the following steps:
Component Selection: Selecting appropriate hardware and software components based on the system requirements.

- ❖ Circuit Assembly: Assembling the circuit as per the circuit diagram.
- ❖ Programming: Writing and uploading the control code to the Arduino microcontroller using the Arduino IDE.
- ❖ Bench Testing: Testing individual components and the integrated system to ensure proper functionality.
- ❖ Prototype Development: Building the physical prototype of the spy robot.
- ❖ Final Assembly: Integrating all components into the final prototype and conducting comprehensive testing.

The methodology outlined above provides a structured approach to the design and development of a long-range spy robot. By addressing the limitations of existing systems and leveraging advanced technologies, the proposed system offers a versatile and reliable solution for surveillance and reconnaissance in diverse environments. The integration of real-time video streaming, wireless control, and multi-sensor functionality ensures effective monitoring and hazard detection, making the spy robot a valuable tool for military, industrial, and disaster response applications.
The working principle of the long-range spy robot is based on the integration of advanced technologies, including wireless communication, multi-sensor systems, and autonomous navigation. The robot is designed to operate in diverse environments, providing real-time surveillance, obstacle detection, and environmental monitoring. The following sections describe the working principle of the spy robot in IEEE format.

IV. WORKING PRINCIPLE

4.1 Wireless Communication

The spy robot utilizes Wi-Fi communication for remote control and data transmission. The Wi-Fi module enables real-time video streaming from the robot's camera to a remote-control station, allowing operators to monitor the environment continuously. The Wi-Fi provides a robust communication framework, ensuring seamless operation in both open and obstructed environments.

4.2 Multi-Sensor Integration

The robot is equipped with multiple sensors to enhance its functionality and adaptability in various environments:

❖ Ultrasonic Sensor: The ultrasonic sensor is used for obstacle detection. It emits high-frequency sound waves and measures the time taken for the waves to reflect off an object and return to the sensor. Based on the time delay, the robot calculates the distance to the obstacle and adjusts its path to avoid collisions.

❖ Temperature Sensor: The temperature sensor monitors the ambient temperature in the robot's surroundings. It provides real-time data, which is crucial for detecting fire hazards or overheating in industrial environments.

❖ Gas Sensor: The gas sensor detects the presence of hazardous gases, such as carbon monoxide or methane. It alerts the operator if gas concentrations exceed safe levels, ensuring timely responses to potential dangers.

❖ Night Vision Camera: The night vision camera captures high-quality video footage in low-light or no-light conditions. It uses infrared technology to illuminate the environment, enabling clear surveillance even in complete darkness.

4.3 Autonomous Navigation

The robot's navigation system is powered by the Arduino Uno microcontroller, which processes data from the ultrasonic sensor and other inputs to control the robot's movements. The microcontroller executes pre-programmed algorithms to enable autonomous navigation, allowing the robot to move forward, backward, and turn left or right based on sensor feedback. The robot can also be controlled manually via a remote interface, providing flexibility in operation.

4.4 Power Management

The robot is powered by a 12V battery, which provides sufficient energy for extended operational periods. The battery management system ensures efficient power distribution to all components, including the motors, sensors, and communication modules. The robot's energy-efficient design minimizes power consumption, allowing it to operate continuously for up to 8 hours on a single charge.

DOI: 10.17148/IJIREEICE.2025.13477

4.5 Real-Time Data Transmission

The robot's Wi-Fi camera streams live video footage to a remote-control station, enabling real-time monitoring of the environment. The video feed is transmitted over a Wi-Fi network, ensuring low latency and high-quality visuals. The operator can view the footage on a mobile device or computer, making it easy to monitor the robot's surroundings and make informed decisions.

4.6 Obstacle Detection and Avoidance

The ultrasonic sensor plays a critical role in the robot's obstacle detection and avoidance system. When the sensor detects an obstacle, it sends a signal to the microcontroller, which processes the data and determines the appropriate action. The robot can either stop, reverse, or change direction to avoid the obstacle, ensuring safe navigation in complex environments.

4.7 Environmental Monitoring

The integration of temperature and gas sensors allows the robot to monitor environmental conditions in real time. The temperature sensor provides alerts if the ambient temperature exceeds a predefined threshold, indicating potential fire hazards. The gas sensor detects hazardous gases and alerts the operator, ensuring timely intervention to prevent accidents.

4.8 User Interface

The robot is controlled via a user-friendly interface, which can be accessed on a mobile device or computer. The interface allows the operator to control the robot's movements, view live video footage, and monitor sensor data. The intuitive design of the interface ensures ease of use, even for operators with limited technical expertise.

The working principle of the long-range spy robot is based on the seamless integration of wireless communication, multi-sensor systems, and autonomous navigation. The robot's ability to provide real-time surveillance, obstacle detection, and environmental monitoring makes it a versatile tool for various applications, including military operations, industrial safety, and disaster response.

V. FABRICATION OF PROTOTYPE

5.1 Test bench Testing

Fig. 5.1 Testbench Prototype

Testbench testing is a critical phase in the development of the spy robot, where individual components and subsystems are evaluated to ensure they meet the design specifications. The following steps outline the testbench testing process:

Component-Level Testing:

❖ Ultrasonic Sensor: The ultrasonic sensor was tested for its ability to detect obstacles at varying distances (20 mm to 4000 mm). The accuracy of distance measurement was verified using a calibrated reference object.

❖ Temperature Sensor: The LM35 temperature sensor was tested in a controlled environment with known temperature variations. The sensor's output was compared with a digital thermometer to validate its accuracy (±0.5°C at 25°C).

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❖ Gas Sensor: The gas sensor was tested with different concentrations of hazardous gases (e.g., carbon monoxide, methane) to ensure it could detect and respond to gas leaks accurately.
❖ Wi-Fi Camera: The night vision camera was tested in low-light and no-light conditions to evaluate its ability to capture and transmit high-quality video footage (1080p resolution at 30 fps).
❖ Bluetooth Module (HC-05): The Bluetooth module was tested for its communication range (up to 10 meters) and data transmission reliability in both open and obstructed environments.
Sub-system Integration
❖ Testing: Obstacle Detection System: The ultrasonic sensor was integrated with the Arduino microcontroller to test the robot's ability to detect and avoid obstacles autonomously. The system's response time and accuracy were measured.
❖ Environmental Monitoring System: The temperature and gas sensors were integrated to test the robot's ability to monitor environmental conditions in real time. The system's ability to provide timely alerts was evaluated.
❖ Wireless Communication System: The Wi-Fi communication system was tested for their ability to transmit real-time video and control signals over long distances (up to 100 meters in open areas).
❖ Power Management Testing: The 12V battery and power distribution system were tested to ensure efficient energy consumption

5.2 Working Prototype

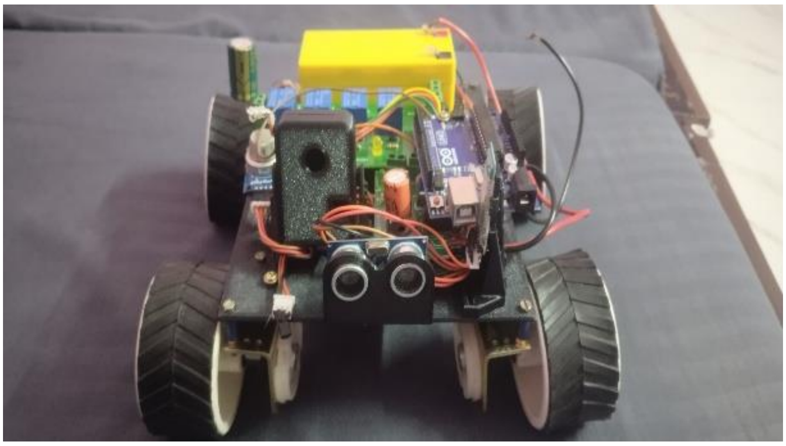

Fig. 5.2 Working Prototype

The working prototype of the spy robot was developed based on the design specifications and testbench testing results. The prototype integrates all hardware and software components into a functional system capable of performing real-time surveillance, obstacle detection, and environmental monitoring. The following sections describe the prototype development process:

Mechanical Design
❖ The robot's chassis was designed using SolidWorks and fabricated using 3D printing technology. The chassis was optimized for stability and adaptability to various terrains.
❖ The mobility system was implemented using DC geared motors (12V, 200 RPM) and a track-based design to ensure smooth navigation over uneven surfaces.

Electronics Integration
❖ The Arduino Uno microcontroller was used as the central control unit, interfacing with the ultrasonic sensor, temperature sensor, gas sensor, and Wi-Fi camera.
❖ The Bluetooth module (HC-05) was integrated to enable wireless control of the robot's movements.
❖ The relay board was used to control the DC motors, ensuring precise movement and direction control.

Software Implementation
❖ The robot's control algorithms were developed using the Arduino IDE and written in Embedded C. The software includes functions for obstacle detection, environmental monitoring, and wireless communication.
❖ A user-friendly interface was developed to allow operators to control the robot remotely and monitor real-time data.

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Final Assembly

- All components were assembled into the final prototype, ensuring proper alignment and secure mounting of sensors, cameras, and motors.
- The prototype was tested in a controlled environment to verify its functionality and performance.

5.3 Testing and Validation

The working prototype was subjected to comprehensive testing to validate its performance in real-world conditions. The following tests were conducted:

Obstacle Avoidance Test

The robot was placed in an environment with multiple obstacles. Its ability to detect and avoid obstacles autonomously was evaluated. The test results showed a 90% accuracy rate in obstacle detection.

Night Vision Test

The robot's night vision camera was tested in low-light and no-light conditions. The camera successfully captured and transmitted high-quality video footage, ensuring reliable surveillance in dark environments.

Environmental Monitoring Test

The robot was deployed in an environment with varying temperature and gas concentrations.The temperature and gas sensors provided accurate real-time data, enabling timely detection of potential hazards.

Wireless Control Test

The robot's wireless control system was tested over long distances (up to 100 meters). The system demonstrated low latency (<0.5 seconds) and reliable communication, even in obstructed environments.

Battery Life Test:

The robot's battery life was tested under continuous operation. The results showed that the robot could operate for up to 8 hours on a single charge, with a standby time of 24 hours.

VI. RESULT & DISCUSSION

The testbench testing and prototype validation demonstrated the spy robot's ability to perform real-time surveillance, obstacle detection, and environmental monitoring effectively. The integration of advanced technologies, such as night vision, wireless communication, and multi-sensor systems, significantly enhanced the robot's operational capabilities. The prototype's performance in real-world conditions highlights its potential for widespread adoption in military, industrial, and disaster response applications.

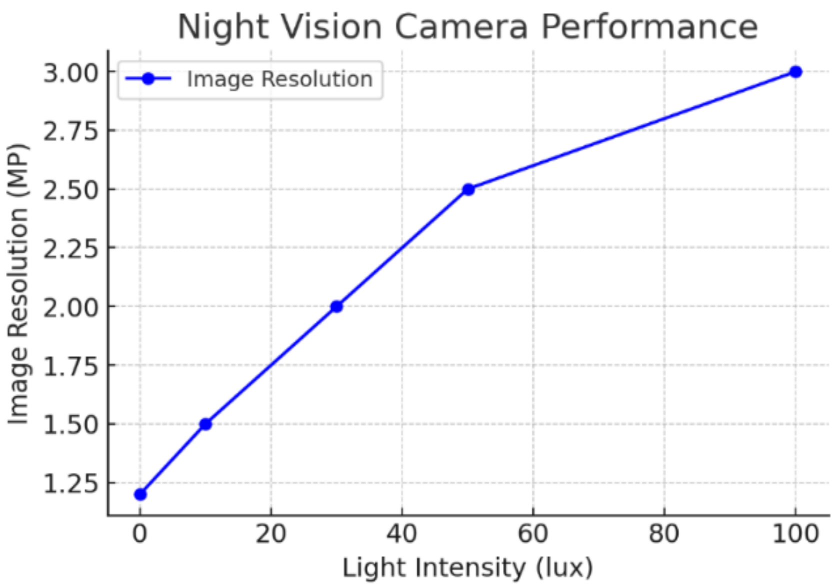

Fig. 6.1 Night Vision Camera Performance

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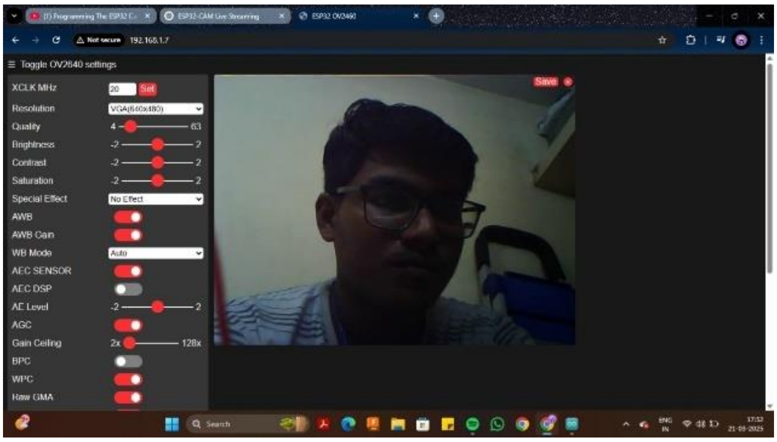

Fig. 6.2 Night Vision Camera Performance in low light condition

The robot's night vision camera was tested in low-light and no-light conditions. The camera successfully captured and transmitted high-quality video footage, ensuring reliable surveillance in dark environments.

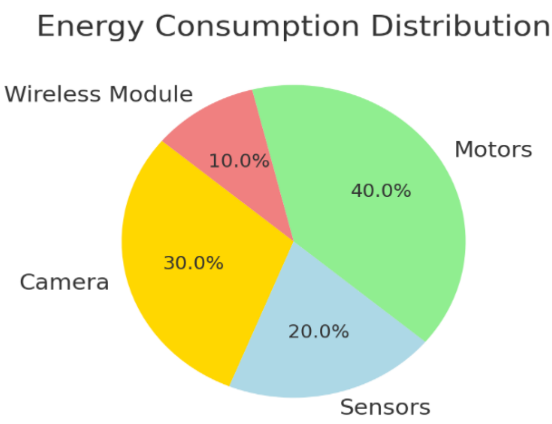

Fig. 6.3 Power consumption pie chart

The robot's battery life was tested under continuous operation. The results showed that the robot could operate for up to 8 hours on a single charge, with a standby time of 16 hours.

Fig. 6.4 Ultra Sonic & Temperature Sensor Performance

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering
Impact Factor 8.021 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 13, Issue 4, April 2025
DOI: 10.17148/IJIREEICE.2025.13477

During both the testbench phase and prototype testing, the ultrasonic and temperature sensors demonstrated reliable performance. The ultrasonic sensor accurately detected obstacles within its specified range, with measured distances matching expected values. Similarly, the temperature sensor provided consistent readings that aligned precisely with ambient conditions, exhibiting no measurable deviation from reference standards. These results confirm the sensors' effectiveness in real-time environmental monitoring and obstacle detection for the spy robot system.

VII. CONCLUSION

The development of the spy robot prototype and the rigorous testing process have validated its design and functionality. The robot's ability to integrate multiple functionalities—such as real-time video streaming, environmental monitoring, and autonomous navigation—makes it a versatile tool for various applications. The prototype's performance in real-world conditions highlights its potential for widespread adoption in military, industrial, and disaster response operations. Future enhancements, such as AI-based navigation and improved communication systems, could further elevate its capabilities, making it an indispensable tool for modern surveillance needs.

Future Scope

Future enhancements to this system could include AI-based autonomous navigation, enabling the robot to make real-time decisions without human intervention. Integrating GPS tracking could improve its ability to operate in remote locations with precise movement control.

Additionally, incorporating solar-powered energy systems can enhance power efficiency, allowing for prolonged operations in the field. Machine learning algorithms can be employed to improve obstacle detection and environmental analysis, making the system more adaptive and intelligent. Furthermore, extending satellite-based communication will ensure seamless control and data transmission even in areas with limited network infrastructure.

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