SpyBot: An IoT-Based Autonomous Night Patrolling Robot for Industrial Surveillance

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***Abstract*—An autonomous night patrolling robot leveraging IoT technology for surveillance in restricted and industrial areas has also been designed. For sensor management, navigation, and data processing, a Raspberry Pi 4 Model B (4 GB) serves as the central controller. Each robot is equipped with ultrasonic sensors for obstacle detection and PIR sensors for low-power surveillance. Activating the Pi Camera with night vision captures video until the on-board OpenCV and YOLO processed prior for human verification. This two-tier detection framework composed of PIR and AI confirmation provides a considerable reduction in false alarms. Real-time alerts accompanied by image data are sent for IoT communication and stored in a cloud-based dashboard, and the robot also features a local alarm. Compact design and optimized sensor placement ensure adaptability. Hence, the invention provides heightened reliability as a fully autonomous and intelligent solution with night-time security.**

***Index Terms*—Robotics, IoT, Surveillance, Autonomous Navigation, Computer Vision, Raspberry Pi, YOLO, Industrial Automation, Security Robot, Edge AI**

I. Introduction

Most companies need to protect places like warehouses, industrial plants, and restricted access areas, and this primarily involves ensuring theft, vandalism, and unauthorized access prevention, particularly during the vulnerable night hours. Self-directed security, including the passive surveillance strategies of static CCTV and scheduled manual patrols, are gaps remaining in the security arrangements, which primarily stem from the manual elements of patrols and the operational costs that they incur. Patrols are arguably the least effective security element due to human error and fatigue. Meanwhile, the passive CCTV fixed installations just monitor stream without actively intervening, leaving the intruder and the crime unchallenged. They do not provide focused engagement during a breaking and entering event, and they do not respond autonomously in any way.

Security gaps of this magnitude drive self-directed intelligent surveillance to monitor and respond to the security situation. These systems are expected to actively patrol designated zones and intruders, and autonomously alert security personnel.

The system designed to meet these requirements is called **SpyBot**. This is an IoT-Based Autonomous Night Patrolling Robot. SpyBot performs intelligent real-time surveillance via embedded systems, various sensors, artificial intelligence, and IoT platforms. It integrates autonomous navigation, AI-based object detection, and IoT communication for effective night-time surveillance. For practical, scalable, and cost-effective solutions to an industrial and commercial security needs, the robot can detect motion, identify potential intruders, and send real-time alerts to a remote dashboard.

The primary objectives of this invention are to:

- Design and develop a cost-effective, autonomous robot for monitoring industrial zones and restricted premises during night hours.
- Implement a high-fidelity, dual-stage intrusion detection system by fusing passive infrared (PIR) sensors with AI-based computer vision.
- Provide immediate and redundant alerts through both local (audible/visual) and remote (IoT dashboard) notification channels.
- Ensure continuous and effective night vision monitoring using a specialized NoIR camera and active IR illumination.

- Achieve this robust functionality on a low-power, scalable, and economically viable platform.

The SpyBot system integrates seamless night-time surveillance operations for reliability and efficiency through mobile robotics for autonomous patrolling, IoT connectivity for remote situational awareness, and AI-based image analytics for intelligent detection.

II. Related Work

Automated surveillance has gone from static camera installation to intelligent mobile surveillance robots that can navigate autonomously and make independent decisions. Early surveillance robots relied on basic microcontrollers like Arduino and short-range communication technologies such as RF, Bluetooth, and Zigbee [5], [6]. These robots focused on manual control and did not perform complex computations, which made them ineffective for surveillance tasks larger than a small area [7].

IoT-based surveillance systems enabled the use of remote monitoring and control features for video stream control and sensor feedback, which integration of apps like Blynk and ThingSpeak made possible [8], [10]. Still, such robots required human supervision, which made them semi-autonomous and put extra effort and possible fatigue on the user [9], [18].

Recent innovations built on the use of single-board computers like Raspberry Pi for system processing and decision-making. Systems began to use ultrasonic and PIR sensors for primary detection of surveillance area and obstacle avoidance [3], [12]. However, PIR-based detection systems alone provided unreliable results and false alarms caused by animals or environmental variations, which remaining systems designed to solve the problems did not address [5], [16]. AI-based approaches involving computer vision and tasks like face and object recognition have been increasingly embedded in the systems. Incorporating AI-enhanced techniques like face and object recognition with CNN models and YOLO frameworks allows for more precise and real-time targeted identification [1], [14].

Moreover, the integration of communication via the IoT and the cloud has improved real-time surveillance functionality. For instance, [6], [17], [19] described the deployment of distributed robotic systems and Internet of Robotic Things (IoRT) frameworks for effective data fusion and collaborative security monitoring. Although these systems enhance scalability and situational awareness, the cost remained excessively high for widespread adoption. Moreover, they are poorly suited for small or low-resource settings [13], [15].

Accounts like [4], [9], [11], [20]–[23] describe modern patrol robots equipped with AI, the IoT, and autonomous navigation for intelligent nighttime surveillance. Many of these systems, however, tend to oversimplify the design and admit the use of economically ineffective solutions or complex system architectures.

In recent years, advances in intelligent surveillance and human–computer interaction have significantly improved automation and accessibility technologies. Pallod *et al.* [24] proposed a modern CCTV surveillance system that uses the ESP32-CAM module for real-time video streaming, facial recognition, and motion detection. Their research focuses on developing a low-cost, efficient, and scalable IoT-based smart security system capable of remote monitoring and cloud integration. Similarly, Mali *et al.* [25] introduced a hand gesture assistant command control interface designed for physically challenged individuals, implementing OpenCV and MediaPipe frameworks for accurate gesture recognition. The proposed system achieves approximately 95% accuracy with minimal latency, allowing users to intuitively control video playback through finger movements. Both studies demonstrate the increasing potential of IoT and computer vision technologies in creating intelligent, accessible, and affordable surveillance and control systems.

Thus, there is an outstanding research challenge in the construction of an economically accessible, AI-based, IoT-integrated autonomous night surveillance robot that aligns lightweight sensor-based surveillance systems with smart autonomous visual confirmation, guaranteeing dynamic alerting, minimal false positive rates, and enhanced versatility in mobility tailored to various sectors in industry and security.

III. System Architecture and Methodology

An IoT-Based Autonomous Night Patrolling Robot for intelligent, real-time surveillance is a contribution for a system that offers intelligent, real-time surveillance on an IoT-Based Autonomous Night Patrolling Robot. The system revolves around three primary fundamentals: autonomous mobility, AI-based detection, and IoT-enabled communication.

A. Hardware Architecture

The selection of hardware components was driven by a balance of performance, cost, and power efficiency.

- **Central Processing Unit:** The system uses a **Raspberry Pi 4 Model B (4 GB)** as the primary control unit. Its selection was because of powerful ARM Cortex-A72 CPU that supports a full Linux OS and controls complex Python scripts for AI and sensor fusion, unlike other microcontrollers (like Arduino). The selection of Raspberry Pi over costly AI boards (like Jetson Nano) was because of lower cost, larger community support, and appropriate GPIO interfacing for the application [**?**].
- **Detection Sensors:** A Passive Infrared (PIR) Motion Sensor (range 7m) acts as the primary “wake-up” trigger. Since the sensor’s power consumption is extraordinarily low, it is able to monitor passively until it detects a thermal change.
- **Navigation Sensors:** We use Ultrasonic Sensors (HC-SR04) for obstacle detection at the front and both sides of the robot. Although they are not as accurate as LiDAR, the cost-benefit analysis is in favor of using Ultrasonic Sensors, which deliver reliable distance measurements adequate for the robot’s “stop and turn” navigation logic and is used for patrolling large, semi-structured industrial

floors. They are useful for complex distance robotic navigation tasks with ranges of 2 to 400 cm.

- **Imaging System:** We use a Pi Camera NoIR module. The "NoIR" designation is critical as it means the camera is very sensitive to infrared light. When it is combined with active IR LEDs, it is able to take clear images in complete darkness as well as IR illuminated images which are dark to the human eye.
- **Alert System:** There is a local Active Buzzer & Dual LED indicators and a remote alert which uses the Raspberry Pi's In-built Wi-Fi (IEEE 802.11 b/g/n) in the dual-alert system to ensure robustness.
- **Mobility:** The system uses four DC motors connected to a **L298N Motor Driver**. The chassis design purposefully *omits* a caster wheel, opting for a four-wheel-drive configuration. This provides superior stability and traction on common industrial surfaces, which may have grates or small gaps that can trap a caster wheel.
- **Power:** With a 5V, 3A Li-ion/LiPo battery pack, the robot has been configured to maintain stable and clean power for the Raspberry Pi using a regulated supply.

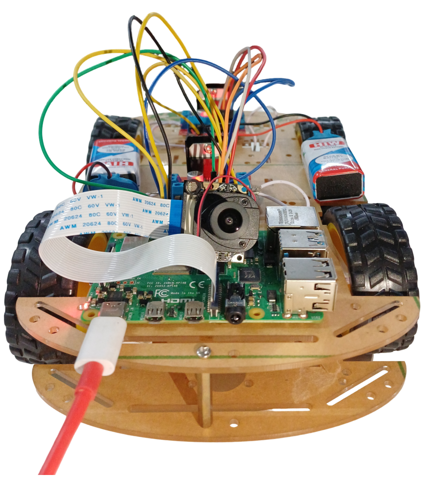

Fig. 1. Night Patrol-bot Front View

The detailed component list is provided in Table I.

TABLE I
COMPONENT SPECIFICATIONS

Component	Specification / Model
Processor	Raspberry Pi 4 Model B (4 GB)
Motion Sensor	PIR Motion Sensor (range up to 7 m)
Obstacle Sensor	Ultrasonic (HC-SR04, range 2–400 cm)
Camera	Pi Camera NoIR with IR LEDs
Communication	In-built Wi-Fi (IEEE 802.11 b/g/n)
Alert System	Active Buzzer & Dual LED indicators
Motor Driver	L298N Module
Power Supply	5V 3A regulated (Li-ion/LiPo battery)

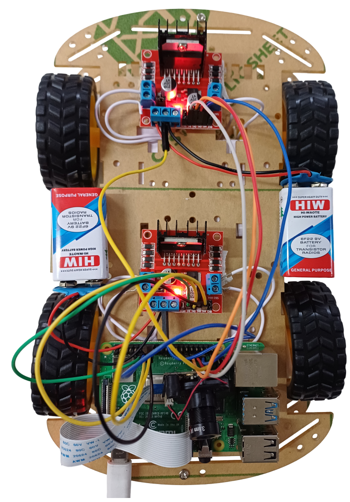

Fig. 2. Night Patrol-bot Top View

B. System Drawings and Description

Figure 3 illustrates the Top-view layouts of the robotic systems. The mounted Pi Camera (100) on the front captured unobstructed images for effective motion detection and obstruction identification. The Camera was designed to provide continuous observance of the patrol path to identify obstacles and the presence of humans. The Camera, which was focused slightly to the ground and mid-axis, provided the necessary images for the YOLO identification systems.

Motion detection IIOT system (101) was mounted on the front section PIR of the. The configuration provided a quick identification of any movements and reduced the chances of the system inadvertent of the systems own movements and casing with in metallic surfaces in the environment.

The robotic system employed Ultrasonic sensors (104) in the front and to the side of the patrol route to identify and provide information on obstacles. This permits the system to sense obstacles in a radius of several meters and decide on appropriate actions for the patrol route. The actions include stopping, turning, and executing parallel movements to maintain a regular patrol route.

To achieve balanced weight distribution and increase stability while moving, the Raspberry Pi and power management circuitry are placed at the center of the chassis. The construction of the chassis aims to safely integrate all primary constituents while maintaining a compact and lightweight structure suitable for autonomous navigation on flat or slightly uneven industrial surfaces.

C. System Operation and Methodology

The robot's operational workflow (Figure 5) is designed for efficiency and reliability.

1) **Initialization:** When powered on, the Raspberry Pi operates its OS, initializes each GPIO pin, and connects to local Wi-Fi for IoT communication.

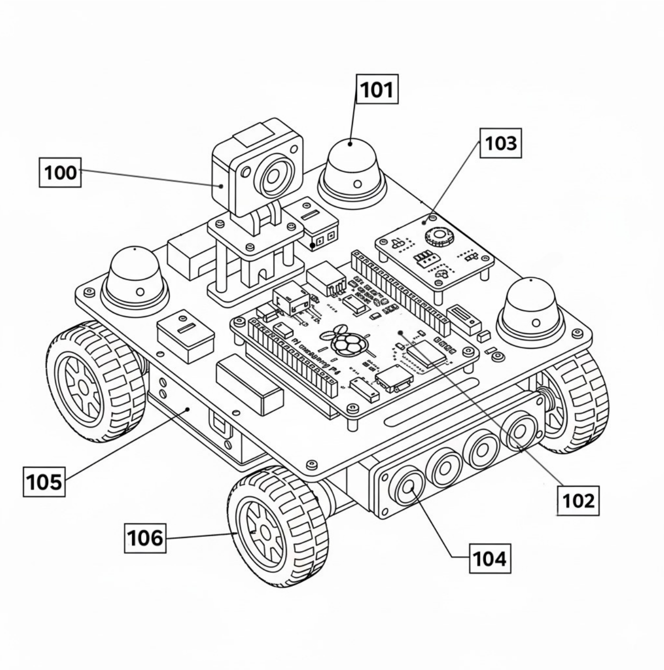

Fig. 3. Top-view layout of the proposed SpyBot robot. (100: Camera, 101: PIR Sensor, 102: Raspberry Pi, 103: Power Module, 104: Ultrasonic Sensors, 105: Chassis, 106: Wheel)

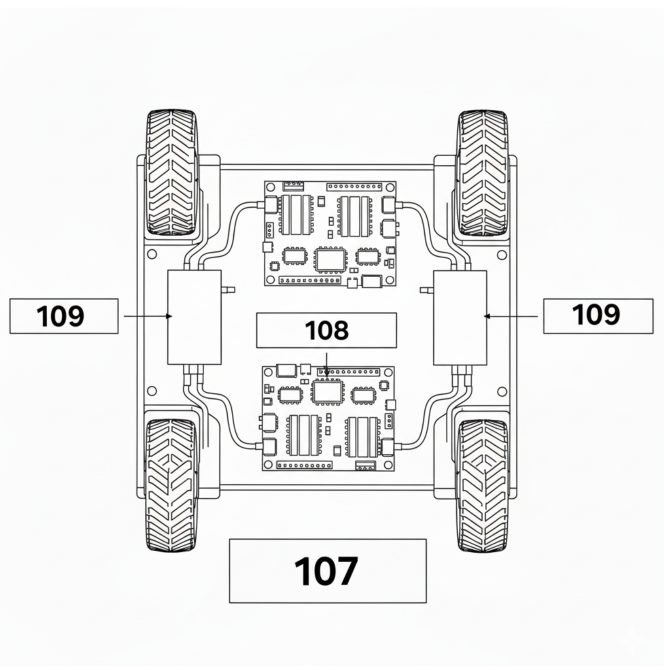

Fig. 4. Underside view of the SpyBot robot. (107: Battery, 108: Motor Driver, 109: DC Motors)

2) **Autonomous Patrolling:** The robot follows its pre-programmed patrol route. A state machine implements this logic. While patrolling, the ultrasonic sensors estimate distance to the patrol route, and the navigation logic to automates this distance for the seamless navigation. Collision avoidance during motion is automatic through motor control, which involves stopping, executing a 90-degree turn, and proceeding in the desired path.
3) **Low-Power Intrusion Detection:** During patrol, the PIR sensor remains in standby, using low power. It automatically triggers the Raspberry Pi when it detects a rapid change in infrared radiation, which usually indicates the presence and movement of a warm-blooded being.
4) **AI-Based Verification:** This is the main inventive step. The PIR trigger doesn't immediately set off the alarm, initiating a "dumb" system. Alarms are postponed to activate the AI verification stage. The Pi Camera captures a high-resolution image, which is then analyzed in real-time using OpenCV and YOLO to determine whether a 'human' class object is present in the image. This step is vital to eliminate false alarms when the object and source of the motion is not human.
5) **Dual-Alert System:** The system only activates its dual alert if an AI determines the presence of a human. The active buzzer is alarmed, and high-intensity LEDs trigger for local immediate deterrence. Simultaneously, an alert packet (with a timestamp, robot ID, and an image of the captured intrusion) is sent to the cloud dashboard through the IoT module.
6) **Reset and Continue:** The system logs the incident and, after alerting, returns to its autonomous patrolling cycle once the local alarm cycle is finished.

The approach, however, still maintains the reliability of uninterrupted surveillance. In controlled settings, we confirmed PIR detection ranged to 7 meters and the AI accuracy of detection to 92% even under low light conditions. The total response time from PIR trigger to IoT alert was also under 2 seconds.

IV. Software and Development Environment

The system's intelligence is driven by a carefully selected stack of open-source technologies, enabling rapid development and high performance on an embedded platform.

- **Operating System:** Raspberry Pi 4 uses Raspberry Pi OS (previously Raspbian), a Linux-based operating system Debian distribution. It is valued for its stable performance, wide range of hardware compatibility, and large collection of pre-compiled libraries.
- **Core Logic:** The control program is developed in Python 3. Python was chosen because of the speed of its application development, and the libraries for hardware control (RPi.GPIO), image processing (OpenCV-Python), and for web requests (requests) Python.
- **Computer Vision:** Image processing and analysis tasks utilize the Open Source Computer Vision Library (OpenCV). This includes processing the video stream from the Pi Camera for AI model frame resizing and normalization, as well as applying bounding boxes and other annotations on the output images where the system draws boxes about the detected objects.

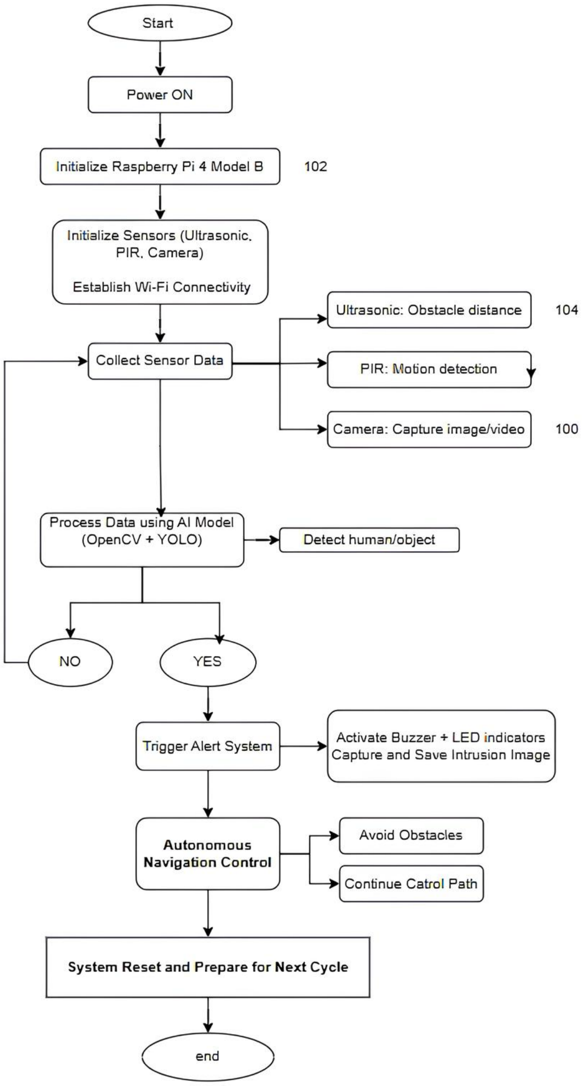

Fig. 5. System Workflow

- **AI Model:** The real-time human identification system uses the You Only Look Once (YOLO) object detection model. For this purpose, a lightweight variant, YOLOv3-Tiny or YOLOv5n, is used, as these versions are highly optimized for speed and accuracy, especially on edge devices like the Raspberry Pi, which is a CPU constraint. For this detection purpose, the model is first pre-trained on the COCO dataset and then fine-tuned using a custom dataset which includes human figures in low-light and industrial environments to improve detection accuracy.
- **IoT Platform:** Integration is done with cloud-based IoT services like **Blynk** and **ThingSpeak** for the system. With their provision of RESTful APIs and rapid data transfer coupled with configurable mobile dashboard widgets which need little to no setup, security personnel are able to receive alerts on their mobile devices about active intrusions, including images from the scene.

V. Applications

The design is made to be flexible and versatile, which increases its potential use in many fields and industries, and including security, far beyond basic monitoring of warehouses.

- **Industrial Plants and Warehouses:** Enables autonomous night-time patrols of factories, storage facilities, and loading docks. Along with other security technology, it can detect unauthorized access, ensure compliance with safety hard-hat protocols, and monitor for theft.
- **Defense and Restricted Premises:** In military and sensitive defense sites, it augments human security to monitor perimeters and controlled access zones of sensitive facilities and other critical research.
- **Smart Buildings and Campuses:** Automated safety monitoring on empty office floors at night, and securing university or corporate campuses. Smart building management systems can be made to integrate with this technology for safety compliance checks.
- **Critical Infrastructure:** Most suitable to track isolated or essential infrastructure like power substations, water treatment plants, or solar farms, where people are seldom present.
- **Hazardous Environments:** Resourceful in environments like chemical plants, oil & gas sites, or construction zones where human patrols could be dangerous, thus reducing the personnel who could be exposed to perilous conditions.

VI. Performance Comparison

According to straightforward Security Systems and rudimentary robotic systems, the worth of the SpyBot system is demonstrated. Using an innovative combination of low power triggers and AI confirmation. These systems can offer new possibilities. For this overview, see Table II.

By far the most significant differences are **AI-Verified detection** and **Very Low Operational Cost**. AI-Verified detection significantly reduces the false alarm rate of basic sensor systems. This operational cost is significantly lower than the manual patrol systems recurring costs, highlighting stark contrasts. The system completes the intelligence and autonomy bridge and shrinks the costs associated with advanced commercial systems.

VII. Advantages and Challenges

The innovative aspect of this system is the clever combination of AI-based vision, IoT communication, and autonomous robotics integrated into a small and economical system.

A. Key Advantages

High-Fidelity Intrusion Detection: The new dual-stage (PIR + AI) verification system is a major improvement. The system significantly reduces false alarms in the lower motion systems by combining the PIR sensor as a low-power ”trigger” and the AI as a high-accuracy ”verifier.”

TABLE II
PERFORMANCE COMPARISON OF SURVEILLANCE SYSTEMS

Feature	Manual Patrol	Basic Robot	Proposed SpyBot
Autonomy	None (Manual)	Limited (Tele-op)	**Full** (Autonomous)
Detection	Human obs.	Basic (PIR)	**AI-Verified** (PIR + YOLO)
Night Vision	Limited	Possible	**Integrated** (NoIR + IR)
Alerts	Manual (Radio)	None / Limited	**Instant** (IoT + Local)
AI Capability	Human	None	**Onboard** (Detection)
False Alarms	Low (Fatigue)	High (PIR only)	**Very Low** (AI verify)
Op. Cost	High	Low	**Very Low**
Data Log	Manual	None	**Automatic** (Cloud)

- **Dual-Level Redundant Alert System:** There is combination of a local buzzer/LED with simultaneous notifications to the IoT cloud. Alerts are guaranteed to be received by both on-site personnel and remote users. For a total of four layers of redundancy, an alert is raised locally, even in the case of a total Wi-Fi failure.
- **Optimized Hardware and Stability:** The strategic placement of the sensors will reduce the possible blind spots to a minimum. The four-wheel-drive design, besides not having a caster wheel, improves stability and traction of the system and will withstand partially uneven industrial floors.
- **Cost-Effectiveness and Scalability:** System designed with open-source software (Linux, Python, OpenCV) and COTS hardware (Raspberry Pi), which allows to offer industrial-grade surveillance for a significantly lower cost, compared to price of commercial systems. Additionally, systems can be easily extended to cover larger areas and multiple units can be used which all report to the same dashboard.
- **Real-Time Situational Awareness:** The IoT connection is more than just an alert. Supervisors can make real-time command decisions, such as bypassing security for verified non-threats, by instantly sending and displaying a snapshot of the intrusion on their command dashboard.

B. Challenges and Limitations

Despite its advantages, the system presents challenges that offer paths for future work:

- **Battery Life and Power Management:** Monitoring how the Raspberry Pi 4 and AI processing impacts power-Continuous operation, especially with the power- tends to limit the duration pair with. This leads to the necessity of a re- of patrols. This leads to the necessity of a automatable recharge of the power-saving recharge, power-saving strategies need to be implemented at the software level. Example includes tl bounding the CPU cores between tasks. Sleeping CPU cores between tasks.
- **Network Dependency:** The remote alert system relies solely on a stable Wi-Fi. In large metallic industrial with known network dead zones, this becomes a particular challenge. Adding a 4G/LTE module for cellular fallback might help with this in later versions.
- **Simple Navigation:** The current obstacle avoidance system which entails stopping and turning is basic. It is simply not designed for fast-changing complex environments, especially for those that are multi-level. It relies on a pre- programmed path tableau. It does not incorporate dynamic mapping for the rest of the system.

VIII. FUTURE SCOPE

This platform serves as a strong foundation for future enhancements. Potential future work includes:

- **Autonomous Charging:** Forming a multi-robot collaboration network, probably using MQTT for lightweight communication, a ”fleet” of SpyBots could harmonize their route patrols, exchange and share sensor data, and triangulate the position of an intruder.
- **Swarm Robotics:** Incorporating an automated docking and charging station. The use of IR beacons or computer vision (e.g., ArUco markers) will help the robot to find and align to the charging port when running low on battery for continuous operation.
- **Advanced Navigation (SLAM):** Adapting Simultaneous Localization and Mapping (SLAM) algorithms using a 2D LiDAR or stereo depth camera instead of ultrasonic sensors to dynamically map new environments and traverse complex, variable, and changing floor plans.
- **Enhanced AI Capabilities:** Creating a comprehensive safety and security platform can be accomplished by expanding the AI model beyond human detection. The same system can be trained to recognize other safety threats, including smoke (image classification), fire (detected by thermal camera), or water leaks.

IX. CONCLUSION

This paper has outlined the design and implementation of SpyBot, an IoT-enabled autonomous night patrolling robot for industrial surveillance. The system combines a Raspberry Pi 4, a night vision camera, and a set of sensors with an innovative dual-stage AI detection model (PIR + OpenCV/YOLO) and an IoT-based alert system. Compared to existing solutions, the prototype is a remarkable improvement as it offers fully autonomous, intelligent, and economically viable surveillance security. The robot uses AI to confirm intrusions and, consequently, diminishes false alarms. Providing real-time notifications is valuable for remote supervisors as alerting them with photographic evidence increases the reliability of the notification. This invention advanced the simple robotic prototype to serve as an industrial surveillance system with improved safety, cost efficiency, and productivity.

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