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Design and Development of Industrial Surveillance Robot

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***Abstract*--** **The aim of the research is to build an effective Autonomous Industrial Surveillance Robot with an application for automatic security, monitoring and real-time emergency response in large- scale complex environments such an industries, warehouses, transportation hubs and university campuses. This robot is designed to respond directly to operational deficiencies, namely the inherent high levels of human error and fatigue due to traditional patrolling. And this robot is designed to reduce the risks of human safety and improve overall efficiency in patrolling. The robot is based on a skid steering mechanism and Autonomous Path following which offers reliable autonomous navigation in the dynamic industrial environment. With intelligence, utilization Edge Computing structure by using a powerful YOLO-based neural network for front-end AI detection of important threats like not wearing PPEs such as safety helmets, safety vests, along with fire detection in the surrounding. This robot also detects and gives a real time alert. The successful deployment of this robot will result in a highly efficient, self-patrolling surveillance capability that provides real-time alerts, dramatically enhancing overall site safety, minimizing human operational fatigue, and ensuring uninterrupted, high- precision security monitoring.**

***Keywords*--Autonomous robot, YOLO, personnel protection equipments, surveillance, safety, fatigue**

I. INTRODUCTION

An autonomous industrial robot is a sophisticated, self-governing machine designed to perform tasks and make decisions within a factory or industrial setting without continuous human intervention. These robots are equipped with sensors and possess the ability to adapt their actions to the dynamic environment in which they operate. They autonomously execute both physical and computational behaviors to fulfill their operational mission, often in environments where human control is impractical, cost-prohibitive, or unsafe. They are built with advanced software, striving for a high degree of self-control and a well-developed operation to safely and rationally complete complex tasks. The implementation of autonomous robotic systems is a significant global trend in industry and public infrastructure, driven by the need to optimize efficiency and operational continuity. This project introduces an Autonomous surveillance robot intended to perform security and safety management across expansive industrial, public, and educational facilities by mitigating human error and operational fatigue. The core methodology relies on sensors, employing a skid steering platform with automatic path patrolling over the pre given path along with a secondary manual control over the autonomous system, guaranteeing robust autonomous outdoor and indoor navigation. The Robot collects Data from various sensors to identify the risks that processes data from sensors, and a YOLO based vision system, enabling the immediate detection of critical hazards such as not wearing of Safety helmets, vests, and fire which can occur in an industrial environment. The successful deployment of this UGV will result in a highly efficient, self- patrolling surveillance capability also with a manual driving control for inspecting potential hazardous or no go zones for humans and provides real time alerts dramatically enhancing overall site safety, minimizing human operational fatigue, and ensuring uninterrupted, high- precision security monitoring.

II. MECHANICAL DESIGN AND FABRICATION

2.1. Computer Aided Design

The development of the Unmanned Ground Vehicle (UGV) commenced with a detailed 3D modeling phase to ensure structural integrity and optimal component placement prior to manufacturing. The chassis and outer body were designed using Autodesk Fusion360. Initially, multiple designs were modeled. The final CAD model established a compact, low-profile footprint suitable for navigating industrial environments, with an overall length of 450 mm, a breadth of 280 mm, and a structural height of 110 mm. This design is suitable for the prototype and can be modified for future scope.

2.2. Manufacturing and assembly

The physical fabrication of the robot was divided into sequential joining and assembly processes. The fabricated structure of the robot is shown in fig.1.

Fig.1.Fabricated structure of the robot

The primary mild-steel frame was constructed entirely using a metal welding process to permanently join the square tubes, ensuring the structural joints could withstand dynamic loads during operation.

Standard nut and screw assemblies were utilized to mount the electromechanical components, specifically securing the DC motors firmly to the EG steel base platform. And the top portion of the robot is screwed so that to easily open and close. The protective polycarbonate sheets were permanently affixed to the welded mild-steel frame using a riveting process, ensuring a secure, vibration-resistant enclosure for the control of electronics and sensor array.

Mild steel square pipes (utilizing 0.5-inch x 0.5-inchcross-sections with a 2 mm thickness) were chosen for the main skeletal frame to provide maximum rigidity. These pipes are ductile, allowing them to be easily cut, bent, or drilled without losing strength. They are highly weldable, making them ideal for rapid fabrication and prototyping.

Japan Electro galvanized (EG) steel sheets (Grade 21) were selected for the lower chassis platform. This material offers a robust, corrosion-resistant foundation capable of supporting the weight of the drive system and battery. Polycarbonate sheets, 5 mm thick, were selected for the external body. Polycarbonate provides high impact resistance and structural shielding for the internal components while keeping the overall weight of the upper body to a minimum as well as it offers a transparent appearance which also contributes to aesthetics.

2.3 Hardware integration and Automation

2.3.1 Drive system and Actuation

The mobility of the Unmanned Ground Vehicle (UGV) is achieved through a2-wheel differential drive configuration. The primary actuation is provided by 12V planetary gear DC motors, operating at a rated speed of 96 RPM, which offer the necessary torque for navigating industrial terrains. These motors are interfaced with a dedicated DC motor driver, which receives control signals to regulate speed and rotational direction for precise maneuvering.

To provide physical stability while maintaining rotational freedom, the front side of the chassis is equipped with two omni-directional castor wheels. The rear end is mounted with 100 mm diameter robot wheels directly coupled to the drive motors. This robust setup is specifically designed to ensure the robot can reliably navigate the rough concrete surfaces typical of most industrial floors.

2.3.2 Processing and control Architecture

A distributed, multi-tier computing architecture was implemented to optimize resource allocation and ensure real-time system performance.

For on board High-Level Processing, A Raspberry Pi 5(4GBRAM), equipped with an active cooler, serves as the primary central node on the UGV. Running on the Ubuntu 24 operating system, it utilizes the Robot Operating System (ROS 2 Jazzy) to manage the navigation stack, system states, and hardware communication. Crucially, to avoid computational bottlenecks, the Pi operates as a high-bandwidth video streaming node rather than an edge-AI processor, transmitting live camera feeds over a network bridge.

For off board Vision Processing (Ground Station), to circumvent the processing limitations of deploying complex AI models directly on to edge hardware, computer vision tasks are offloaded. A remote laptop functions as the ground control station, receiving the bridged video feed from the Raspberry Pi. This laptop executes the computationally intensive YOLO v8 model to rapidly detect industrial hazards and unsafe acts in real-time.

For low-Level Hardware Control, An ESP32 microcontroller acts as the real-time hardware interface layer. It is responsible for rapidly polling the sensor arrays (IR and ultrasonic) and executing the motor control logic, ensuring immediate physical responses without the overhead delays of a full operating system. The ultrasonic sensor will detect the nearby obstacle and the signal is sent back to avoid collision. The detection range can be changed according to the requirements.

2.4. System Architecture and operation flow

The system architecture and operational flow diagram of the robot is shown in Fig.2.

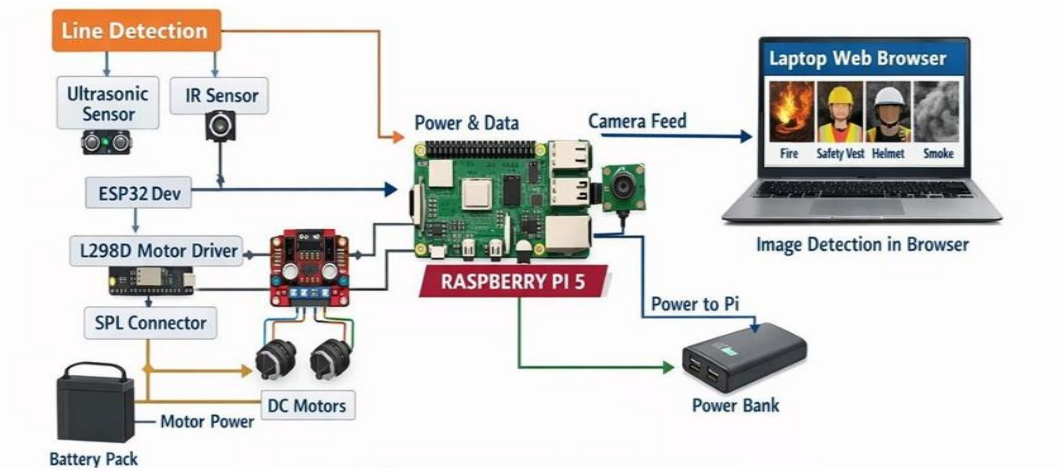


Fig.2.System architecture and operational flow

2.5. Line detection and Autonomous navigation

The autonomous navigation of the robot is governed by a reactive control loop managed by the ESP32 development board. To ensure zero-latency responses, the ESP32 continuously processes digital signals from downward-facing IR sensors to track a designated high-contrast line, while simultaneously polling forward-facing ultrasonic sensors to detect unexpected physical obstacles.

2.5.1 Robot following the path

Based on this sensory input, the microcontroller executes the navigation logic by outputting targeted Pulse Width Modulation (PWM) and directional signals to the L298D motor driver. This driver acts as a high- current switch, translating logic-level commands into the physical voltage required to actuate the wheel. The robot following the path is shown in Fig.3

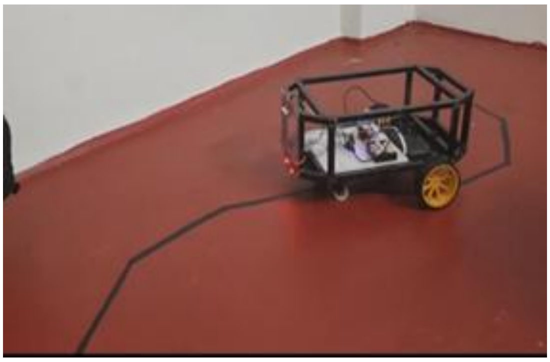
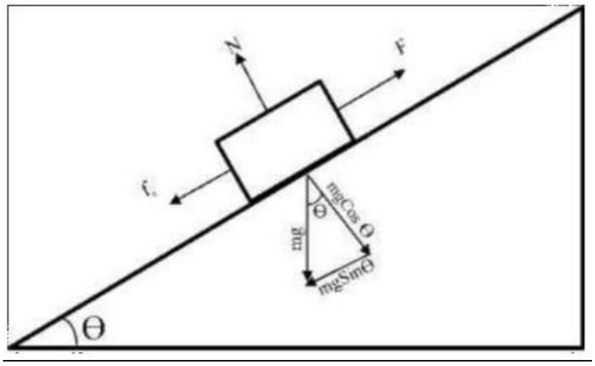


Fig.3 The robot following the stipulated path

2.6. Calculations

2.6.1. Robot Drive Train and Power System Design



Free body diagram

<u>*Design Parameters:*</u>

μ = 0.587 (Rubber + concrete)

<u>*Force Analysis and Total Power*</u>

Normal Force (N):

N= mg cos(30°)≈ 42.48N

Gravity Force along Slope (Fg_{slope}), Fg_{slope} = mgsin(30°) ≈ 24.525N

Rolling Resistance (F_{roll}): C_{rr}×N Cr = 0.01 to 0.04 Assumed as 0.02

F_{roll}=0.02×42.48=0.849N

Total Driving Force Required (F_{total}):

F_{total}=Fg_{slope}+F_{roll}=24.525N+0.849N=25.37N

Total Mechanical Power

Formula: $P_{total} = F_{total} \times V$
Result: 25.37N×0.5m/s= 12.68W

Power per Motor (2Motors): 6.34W

Torque and Wheel Speed

Wheel Parameters:

Wheel Radius (R): 5cm(0.05m)

Total Torque Required at Wheels(τ_{total}):

$\tau_{total} = F_{total} \times R = 25.37N \times 0.05m = 1.268Nm$

Torque per Wheel(τ_{wheel}):

$\tau_{wheel} = 1.268 \div 2 \approx 0.634Nm$

Wheel RPM

Target Linear Velocity (V) : 0.5m/s

$\omega = V/R = 0.5/0.05 = 10$ rad/s

$\omega = 2\pi N/60$

Required Wheel Speed(N_{wheel}): $10 \times 60/2\pi$

$= 95.5 \approx 96$ rpm

Motor and Gearbox Specifications

Gear Ratio and Motor Torque:

Assumed Motor Speed(N_{motor}): 1500to4000rpm

Gear Ratio (G):

$G = 3000 \div 96 \approx 31.25$

Gearbox Efficiency(η):0.9

Required Motor Torque(τ_{motor}):

$\tau_{motor} = 0.634/(31.25 \times 0.9) \approx 0.02254$ Nm

Motor Output Power

Motor Power $P_{motor} = \tau_{motor} \times \omega$

$= 2\pi N \tau_{motor}/60$

$= 2\pi \times 3000 \times 0.02254 /60 = 7.08$ W

$P_{imp} = 7.08/0.8 = 8.85$

System Power Estimate (with Margin)

Final Power Requirement:

Total Mechanical Power(P_{total}): $2 \times 8.85 = 17.7$W

Margin/Loss Added: 50%

Total Power with Margin(P_{margin}):

Battery Selection and Capacity

Energy Requirement:

Target Run Time (T):1hours

Energy Required (E):

Final Battery Selection

Selected Capacity:2.5Ah(2500mAh)

III. RESULTS

Navigation and Obstacle avoidance Testing:

To validate the autonomous capabilities of the UGV, a series of controlled tests were conducted to evaluate the response times and accuracy of the ESP32 sensor loop.

Line-Following Accuracy and Locomotion Dynamics:

The robot was placed on a designated high-contrast path. While straight-line tracking was highly stable, the UGV exhibited slightly jittery, oscillatory motion when navigating curved sections. This behavior was directly attributed to minor imperfections in the physical layout of the curve; the irregular edges caused the dual IR sensors to rapidly alternate states, prompting the ESP32 to issue high-frequency, aggressive PWM corrections to the motor driver. Despite this jitter, the robot successfully maintained the overall trajectory without losing the path.

Dynamic Obstacle Detection and System Limitations:

To evaluate the real-time reactivity of the forward-facing HC-SR04 ultrasonic sensors, a physical obstacle (a backpack) was suddenly introduced directly into the UGV's patrol path. The ESP32 instantaneously registered the proximity alert and successfully triggered a halt command to the L298D motor driver, successfully preventing a collision. Once the obstruction was manually removed, the sensor loop immediately cleared the halt state, and the UGV autonomously resumed its forward motion.

However, testing highlighted a limitation in the current autonomous logic. If an obstacle is static and does not move, the robot will remain halted indefinitely without issuing a remote alert to the operator or attempting to calculate an alternative path. Under the current system architecture, recovering from a permanent path blockage requires the operator to engage the Bluetooth manual override via the smart phone application to manually steer the UGV around the obstruction and realign it with the high- contrast tracking line.

System Integration and Tele operation Testing:

The final testing phase evaluated the communication bridge between the AI hazard detection, the physical alert systems, and the manual override controls.

Alert System Latency and Audio Looping:

When a hazard was positively identified, the system was programmed to issue an automated voice command alert. However, during field testing, this audio feedback experienced noticeable lag and continuous, overlapping repetition.

This software issue occurred because the script continuously triggered the audio playback function for every individual video frame where the hazard was detected, causing a backlog of audio threads. Implementing a time- delay "cool down" or a state-change flag in the Python script is recommended for future optimization to prevent this looping.

Manual Override Reliability:

Despite the audio alert latency, the manual tele operation mode performed successfully. By connecting a smart phone to the ESP32 via Bluetooth, the operator was able to seamlessly interrupt the autonomous line-following loop and manually navigate the robot using the custom Arduino IDE interface, proving the effectiveness of the fail-safe override system.

IV. CONCLUSION

The objective of this project was to design and fabricate a functional, low-cost Unmanned Ground Vehicle (UGV) prototype capable of performing autonomous industrial surveillance. By integrating a welded mechanical chassis with a distributed processing architecture, the project successfully demonstrated a working prototype. The ESP32 effectively managed real-time hardware actuation, including IR line- following and ultrasonic collision prevention, while the Raspberry Pi5 successfully bridged live environmental data to an off board station.

The implementation of the YOLOv8 machine learning model successfully proved the viability of using computer vision to detect safety compliance (vests and helmets) and imminent hazards (fire) in real-time, fulfilling the core surveillance mandate of the project.

REFERENCES

[1] Chitram, S., Kumar, S.,& Thenmalar, S.(2024). Enhancing fire and smoke detection using deep learning techniques. *Engineering Proceedings*, *62*(1), 7.

[2] Gupta, S., Ray, K., & Kaiser, S. (2025). Self-balancing mobile robot with Bluetooth control: Design, implementation, and performance analysis. *Automation*, *6*(3), 42.

[3] Horelican, T. (2022). Utilizability of Navigation2/ROS2 in highly automated and distributed multi-robotic systems for industrial facilities. *IFAC-Papers On Line*, *55*(4), 109–114.

[4] Jia, F., Afaq, M., Ripka, B., Huda, Q., & Ahmad, R. (2023). Vision- and lidar-based autonomous docking and recharging of a mobile robot for machine tending in autonomous manufacturing environments. *Applied Sciences*, *13*(19), 10675.

[5] Kundu, R., & Sanyal, A. (2025). Implementation and reliability study of a Bluetooth controlled autonomous car. *Metaversalize*, *2*(2), 69–78.

[6] Li, Y., An, J., He, N., Li, Y., Han, Z., Chen, Z., & Qu, Y. (2025). A review of simultaneous localization and mapping algorithms based on lidar. *World Electric Vehicle Journal*, *16*(2), 56.

[7] Samal, P., Lokhande, P., Vikram, C., Patil, N., & Shinde, M. A. (2023). Line follower robot. *International Journal of Scientific Development and Research*, *8*(2), 813–815.

[8] V lasceanu, A., Avram, M., Constantin, V., & Moraru, E. (2025). Research on indoor positioning systems and autonomous mechatronic systems for surveillance of intra building zones. *Applied Sciences*, *15*(2), 918.