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Autonomous Line-Following Robot

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Abstract: *Autonomous monitoring systems are increasingly required in hazardous and restricted industrial environments where human presence may pose safety risks. This paper presents the design and implementation of an autonomous line-following robot capable of performing real-time industrial parameter monitoring and wireless data transmission. The robot navigates along a predefined path using infrared line tracking sensors controlled by an ATmega328P microcontroller. A differential drive mechanism powered by DC motors and an L298N motor driver enables accurate movement and positioning at designated monitoring stations. At each station, the robot collects electrical and environmental parameters including voltage, load current, and humidity using dedicated sensing modules such as the ACS712 current sensor, voltage sensor module, and DHT11 humidity sensor. The measured data is processed by the microcontroller, displayed locally on a 16×2 LCD, and transmitted remotely to a registered mobile number through a GSM communication module. Experimental evaluation of the prototype demonstrates reliable navigation, accurate sensor measurements, and successful wireless transmission of monitoring data. The proposed system provides a cost-effective and practical solution for automated inspection and real-time monitoring in industrial environments, significantly reducing the need for manual supervision in restricted or hazardous zones*

Keywords: Autonomous Robot, Line Following Robot, Industrial Monitoring, GSM Communication, Embedded Systems, ACS712 Current Sensor

I. INTRODUCTION

Industrial environments such as power plants, radiation zones, and high-voltage installations require continuous monitoring of electrical and environmental parameters to ensure safe and reliable operation. However, manual inspection in such hazardous areas exposes personnel to significant risks including electrical hazards, toxic exposure, and radiation effects. Therefore, automated monitoring systems using mobile robots have been widely explored to reduce human intervention and improve operational safety in restricted industrial environments [1].Autonomous robotic systems are capable of navigating through predefined paths and performing inspection tasks without direct human control. Among various navigation methods, line-following robots are widely adopted because of their simplicity, low cost, and reliability. These robots use infrared sensors to detect a track or line on the ground and follow it using a microcontroller-based control algorithm, enabling accurate and stable navigation in structured environments [2]. Such systems are commonly used in industrial automation, material transportation, and monitoring applications. Several researchers have enhanced line-following robots by integrating additional sensing and communication technologies to improve functionality and safety. For instance, robotic systems equipped with obstacle detection mechanisms allow autonomous navigation even in partially dynamic environments, ensuring reliable movement and collision avoidance during monitoring operations [3]. Similarly, surveillance robots designed for hazardous areas use sensor modules and wireless communication technologies to monitor environmental conditions and transmit data remotely for analysis and supervision [4].

In addition to navigation and surveillance, modern robotic monitoring systems incorporate control techniques and sensor-based data acquisition for improved performance. The implementation of advanced control strategies such as PID control has been reported to enhance the accuracy and stability of line-following robots during operation, particularly when navigating complex paths [5]. Integrating such control mechanisms with embedded systems allows robots to perform reliable monitoring and inspection tasks in industrial environments. Motivated by these developments, this paper proposes an autonomous line-following robot designed for industrial parameter monitoring and remote data acquisition. The robot follows a predefined path using infrared sensors and stops at designated monitoring points to measure parameters such as voltage, load current, and humidity. The sensed data is processed by a microcontroller and transmitted to a registered mobile number through a GSM communication module for real-time monitoring. This approach provides a cost-effective and reliable solution for automated inspection in hazardous or restricted industrial environments while minimizing the need for direct human involvement.

II. LITERATURE REVIEW

Autonomous mobile robots have been widely investigated for industrial monitoring and hazardous environment inspection. Robotic monitoring systems are capable of collecting environmental data and transmitting it to remote locations, thereby reducing the need for human intervention in dangerous areas. A hazard detection and response robot developed for real-time monitoring demonstrated that mobile robotic systems equipped with sensors and communication modules can effectively monitor environmental parameters in hazardous zones while ensuring operator safety [1]. Line-following robots have become one of the most common approaches for autonomous navigation in structured environments. These robots use infrared sensors to detect a predefined track and follow it using microcontroller-based control algorithms. Research on automated line-following robots integrated with IoT technologies shows that such systems can perform reliable navigation while simultaneously collecting and transmitting monitoring data to remote systems for supervision and analysis [2]. Several studies have also focused on improving the functionality of line-following robots by integrating obstacle detection mechanisms. A robotic system incorporating ultrasonic sensors for obstacle detection demonstrated improved navigation reliability by enabling the robot to detect and avoid obstacles while maintaining accurate path tracking. This approach enhances the safety and practicality of robotic monitoring systems operating in industrial environments [3].

In addition to navigation capabilities, robotic monitoring platforms have been enhanced with wireless communication technologies to enable real-time surveillance. Surveillance robots designed for hazardous environments integrate multiple sensors and wireless communication modules to monitor environmental conditions and transmit collected data remotely, enabling continuous supervision without exposing human operators to dangerous conditions [4]. Furthermore, control strategies have been investigated to improve the stability and accuracy of line-following robots. The implementation of PID-based control algorithms has been shown to significantly improve path tracking performance and reduce navigation errors, allowing robots to operate more reliably in industrial monitoring applications [5]. Based on the analysis of existing research, it is evident that integrating autonomous navigation, sensor-based monitoring, and wireless communication technologies can significantly enhance industrial inspection systems. However, many existing systems focus primarily on navigation or surveillance alone. Therefore, the proposed system aims to integrate line-following navigation with electrical parameter monitoring and GSM-based remote data transmission to provide a practical and low-cost solution for industrial monitoring applications.

III. SYSTEM ARCHITECTURE

The proposed system consists of an autonomous line-following robot designed to perform industrial parameter monitoring and wireless data transmission. The overall architecture integrates navigation sensors, environmental monitoring sensors, an embedded control unit, a motor driving mechanism, and a communication module. The system enables the robot to move along a predefined path, stop at designated monitoring points, acquire sensor data, and transmit the collected information to a remote user through GSM communication. The overall architecture of the proposed system is illustrated in **Fig. 1**. The central controller of the system is the **ATmega328P microcontroller**, which is responsible for coordinating navigation, sensor data acquisition, and communication operations. Infrared line-tracking sensors are used to detect the black line path on the floor and provide feedback signals to the microcontroller for path correction. Based on the sensor inputs, the controller generates control signals to the **L298N motor driver**

module, which drives the DC motors in a differential drive configuration to enable forward movement and directional control of the robot.

In addition to navigation, the robot is equipped with multiple sensing modules for monitoring industrial parameters. A **voltage sensor module** is used to measure the supply or load voltage at monitoring stations, while an **ACS712 current sensor** measures the electrical current flowing through the load. Environmental conditions are monitored using a **DHT11 sensor**, which provides humidity measurements. The sensor outputs are processed by the microcontroller to obtain accurate monitoring data. To provide local feedback, the measured parameters are displayed on a **16×2 LCD display** mounted on the robot. For remote monitoring, the processed data is transmitted using a **GSM communication module**, which sends the sensor readings to a registered mobile number in the form of text messages. This enables real-time monitoring of industrial parameters without requiring the presence of personnel in restricted areas.

The integration of autonomous navigation, sensor-based monitoring, and wireless communication allows the robot to perform automated inspection tasks in hazardous environments. By following a predefined track and collecting data at specific monitoring points, the system ensures reliable data acquisition while minimizing human exposure to dangerous conditions.

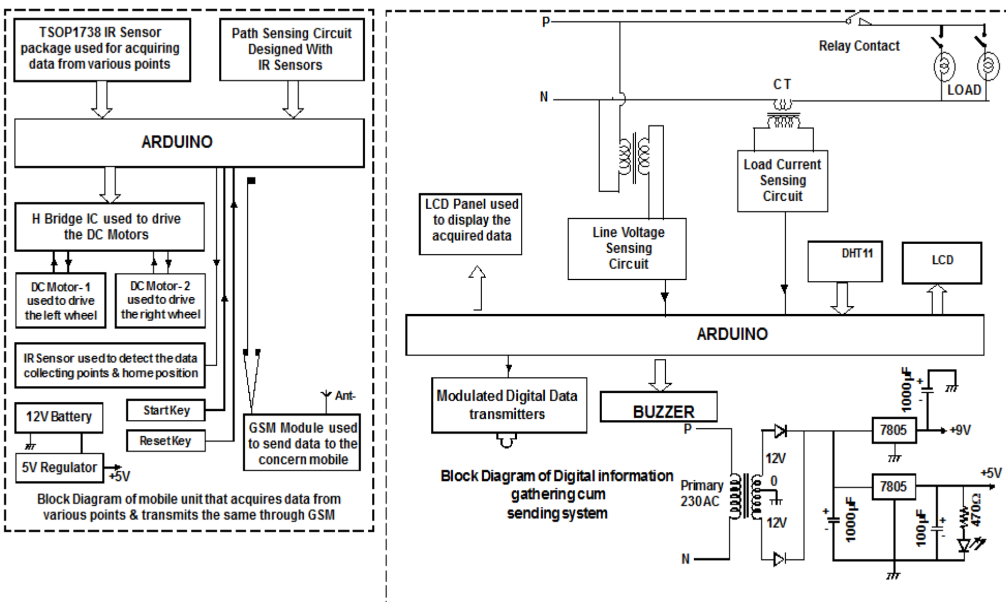

Fig.1. Block Diagram of Autonomous Line-Following Monitoring Robot

IV. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed autonomous monitoring robot consists of several electronic modules that work together to enable navigation, sensing, processing, and communication. The system is built around an embedded platform that integrates sensors, motor drivers, communication modules, and display interfaces to perform automated monitoring tasks. The **ATmega328P microcontroller** forms the core of the hardware system. It is responsible for reading sensor inputs, executing the navigation algorithm, processing monitoring data, and controlling communication between different modules. The microcontroller is programmed using the Arduino development environment, which simplifies hardware interfacing and control logic implementation. The robot uses **infrared line-tracking sensors** to detect and follow the predefined path. These sensors operate on the principle of infrared reflection, where the sensor distinguishes between the dark line and the lighter surface. The output signals from the sensors are continuously monitored by the microcontroller, which adjusts the motor speeds accordingly to maintain accurate path tracking.

The movement of the robot is achieved using **DC motors controlled by an L298N dual H-bridge motor driver module**. The motor driver receives control signals from the microcontroller and regulates the voltage supplied to the motors, allowing forward motion, turning, and stopping operations. A differential drive mechanism enables the robot to navigate smoothly along the path. For monitoring electrical parameters, an **ACS712 current sensor** is used to measure load current, while a **voltage sensor module** measures the voltage level of the monitored circuit. Environmental monitoring is achieved using the **DHT11 sensor,** which provides humidity data. The analog and digital outputs from these sensors are processed by the microcontroller to obtain meaningful parameter values. A **16×2 LCD display** is incorporated into the system to display sensor readings and system status locally. Additionally, a **GSM communication module** is integrated to transmit the collected data to a remote mobile device via SMS. This wireless communication capability allows real-time monitoring of industrial parameters from a safe distance.

The hardware components are mounted on a compact robotic platform powered by rechargeable batteries, making the system portable and suitable for operation in various industrial environments. The implemented hardware prototype demonstrates reliable integration of navigation, sensing, and communication functionalities required for autonomous industrial monitoring.

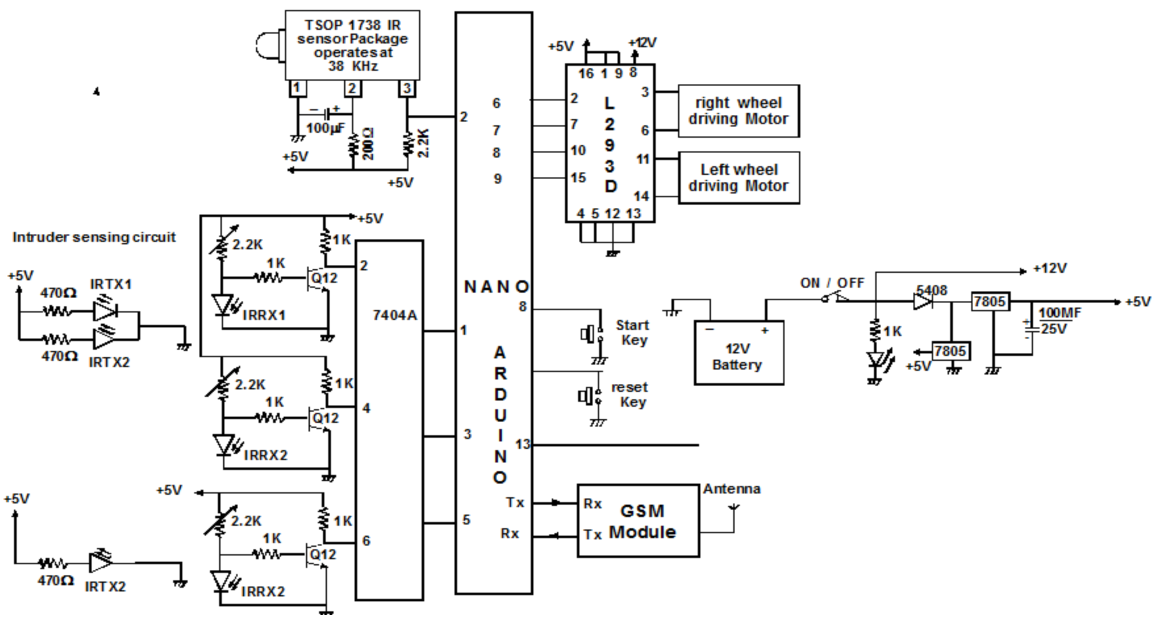

Fig. 2: Circuit Layout of Autonomous Monitoring Robot

V. PROPOSED SYSTEM

The proposed system is an autonomous line-following robot designed for industrial parameter monitoring and remote data transmission. The system is intended to operate in restricted or hazardous environments where direct human monitoring may not be safe or practical. The robot follows a predefined path using infrared line tracking sensors and stops automatically at designated monitoring points where electrical and environmental parameters are measured and transmitted to a remote user through GSM communication. The core of the system is the ATmega328P **microcontroller**, which controls navigation, sensor data acquisition, and wireless communication. The robot uses **infrared line sensors** to detect the path marked on the floor. These sensors continuously monitor the surface and provide digital signals to the microcontroller indicating the position of the line. Based on the sensor feedback, the microcontroller adjusts the motion of the robot by controlling the **L298N motor driver**, which drives two DC motors in a differential drive configuration. This allows the robot to move forward, turn left or right, and maintain accurate path tracking. When the robot reaches a designated monitoring station along the track, it stops automatically and activates the sensing modules to measure industrial parameters. A **voltage sensor module** is used to measure the voltage level of the monitored circuit, while an **ACS712 current sensor** measures the load current flowing through the system. Environmental conditions are monitored using a **DHT11 sensor**, which provides humidity measurements. The microcontroller reads the outputs of these sensors, converts them into meaningful electrical values, and processes the data for display and transmission.

The measured parameters are displayed locally on a 16×**2 LCD display**, allowing operators near the robot to observe real-time readings. To enable remote monitoring, the processed data is transmitted using a **GSM module**, which sends the sensor readings as an SMS message to a registered mobile number. This wireless communication capability ensures that industrial parameters can be monitored from a safe location without requiring personnel to enter restricted areas. The overall operation of the proposed system follows a sequential process. Initially, the robot starts from its base position and begins following the predefined path using the line sensors. As it moves along the track, the microcontroller continuously corrects the robot's direction to maintain accurate navigation. When the robot reaches a monitoring station, it temporarily stops, activates the sensing modules, collects the required parameters, displays them on the LCD, and transmits the data through the GSM module. After completing the data transmission process, the robot resumes movement along the path until the next monitoring point is reached. The integration of autonomous navigation, electrical parameter monitoring, and wireless communication makes the proposed system an effective solution for automated inspection in industrial environments. By enabling continuous monitoring and remote data transmission, the system significantly reduces the need for manual inspection and enhances operational safety in hazardous areas.

VI. RESULTS AND DISCUSSION

The developed prototype of the autonomous line-following monitoring robot was tested under controlled experimental conditions to evaluate its navigation performance, sensing accuracy, and wireless communication capability. The experiments were conducted using a predefined track where monitoring stations were placed at specific locations to simulate industrial inspection points. The prototype consisted of the microcontroller unit, line tracking sensors, sensing modules, GSM communication module, and the robotic drive mechanism mounted on a compact platform. During the experiments, the robot successfully followed the predefined path using the infrared line sensors without significant deviation. The microcontroller continuously processed sensor signals and adjusted the speed of the DC motors through the motor driver to maintain stable navigation. The differential drive mechanism allowed smooth directional correction when the robot encountered curves in the track. This ensured reliable path tracking throughout the experiment.

At each designated monitoring point, the robot automatically stopped and initiated the sensing process. The **voltage sensor module** measured the voltage level of the monitored circuit, while the **ACS712 current sensor** provided load current measurements. The **DHT11 sensor** was used to measure humidity in the surrounding environment. The collected sensor data was processed by the microcontroller and displayed on the **16×2 LCD display**, enabling local observation of the measured parameters. The GSM communication module successfully transmitted the measured parameters to a registered mobile number in the form of a text message. The received message included values of voltage, current, and humidity obtained from the monitoring station. The transmission was successfully completed during each test cycle, demonstrating reliable remote monitoring capability. The experimental results confirm that the proposed system is capable of performing autonomous navigation, accurate sensor data acquisition, and wireless data transmission. The integration of line-following navigation with industrial parameter monitoring provides an efficient approach for automated inspection in restricted environments. The system effectively reduces the need for manual monitoring and ensures that critical parameters can be observed remotely in real time.

Overall, the developed prototype demonstrated stable operation, reliable sensing performance, and successful communication with external monitoring devices. These results validate the feasibility of using autonomous line-following robots for industrial monitoring applications, particularly in environments where human access is limited or hazardous.

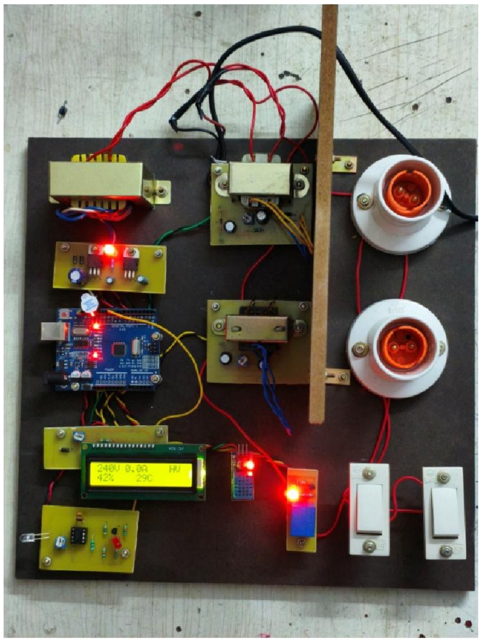

Fig. 3. Monitoring Station for Electrical Parameter Measurement

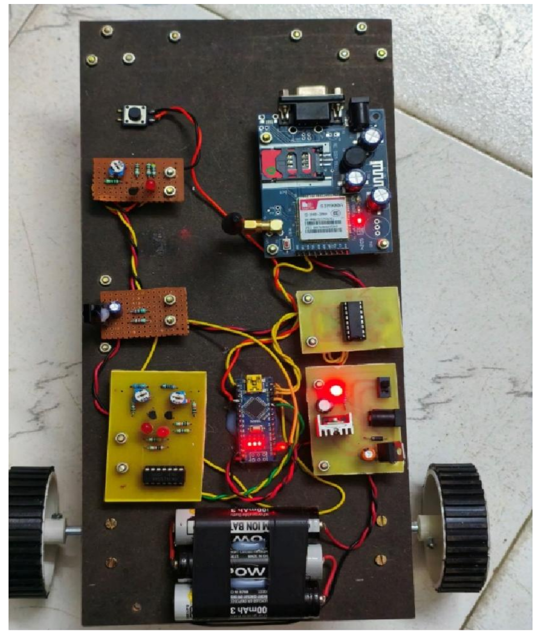

Fig. 4. Hardware Prototype of the Autonomous Line-Following Monitoring Robot

Fig. 5. Experimental Setup Showing Robot Stoped at the Station

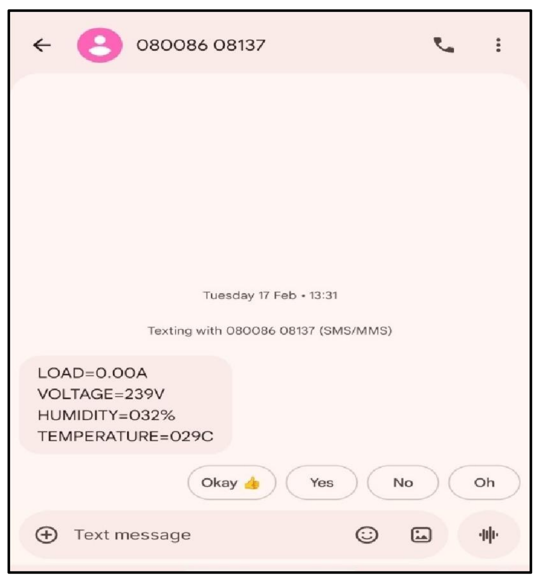

Fig. 6. SMS Data Received from GSM Module on Mobile Device

VII. FUTURE SCOPE

The proposed autonomous monitoring robot demonstrates a reliable approach for industrial parameter monitoring using line-following navigation and GSM-based communication. However, several enhancements can be implemented in future developments to improve the system's capabilities and performance.

One potential improvement is the integration of IoT**-based cloud monitoring platforms**, which would allow the collected sensor data to be stored and visualized in real time through web dashboards or mobile applications. This would enable continuous monitoring of industrial parameters from any location rather than relying only on SMS-based communication.

Another important enhancement involves incorporating advanced **navigation techniques** such as computer vision or AI-based path planning. This would allow the robot to navigate dynamically without relying on a predefined line track and improve its ability to operate in complex industrial environments.

Additional sensing modules such as **gas sensors, radiation detectors, and temperature sensors** can also be integrated into the system to expand its monitoring capabilities for nuclear plants, chemical industries, and hazardous manufacturing facilities.

Future versions of the system can also improve energy efficiency by integrating **solar charging systems and advanced battery management techniques**, enabling longer operational duration and reduced maintenance requirements.

Furthermore, the robot could be enhanced with **wireless camera modules for live video monitoring**, allowing operators to visually inspect equipment and surroundings along with sensor data. These improvements would significantly increase the effectiveness of the system for industrial safety, predictive maintenance, and remote inspection applications.

VIII. CONCLUSION

This paper presented the design and implementation of an autonomous line-following robot developed for industrial parameter monitoring and remote data transmission. The system utilizes infrared line sensors for navigation, enabling the robot to follow a predefined path and stop at designated monitoring stations. At these locations, the robot measures important electrical and environmental parameters including voltage, load current, and humidity using dedicated sensing modules.

The sensed data is processed by the ATmega328P microcontroller and displayed locally on a 16×2 LCD display. Additionally, the measured parameters are transmitted to a registered mobile number through a GSM communication module, enabling real-time remote monitoring of industrial conditions. The experimental results demonstrate that the robot successfully follows the predefined path, accurately collects sensor data, and reliably transmits monitoring information via wireless communication.

The developed prototype provides a **cost-effective, portable, and reliable solution for automated industrial monitoring,** particularly in hazardous or restricted environments where human access is limited. By reducing the need for manual inspection and enabling real-time monitoring of critical parameters, the proposed system contributes to improved safety and operational efficiency in industrial facilities.

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