

Smart Food Serving Robot Using PID Controlled Line Following and Obstacle Detection

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ABSTRACT

Automation has emerged as a key technology in modern service industries, enabling improved efficiency, reduced operational costs, and enhanced customer satisfaction. This paper presents the design and development of a Smart Food Serving Robot based on PID-controlled line following and ultrasonic obstacle detection. The robot is designed to autonomously transport food trays along predefined indoor routes in restaurants, hospitals, cafeterias, and hotels. The system employs three infrared sensors to detect and track a black path on a white surface, while an ATmega328P microcontroller processes sensor inputs and executes a PID control algorithm to maintain accurate navigation. Four DC geared motors driven through an L298N motor driver provide smooth and stable movement. An HC-SR04 ultrasonic sensor is integrated to continuously monitor obstacles in the robots path and automatically halt operation whenever an obstruction is detected, thereby ensuring safe navigation. The implementation of PID control significantly reduces tracking errors, oscillations, and path deviations compared to conventional line-following techniques. Experimental results demonstrate reliable line-tracking performance, effective obstacle avoidance, low power consumption, and stable operation under varying load conditions. The proposed system provides a cost-effective and practical solution for indoor service automation and highlights the potential of embedded systems and robotics in transforming hospitality and healthcare services.

Keywords: Smart Food Serving Robot, PID Controller, Line Following Robot, ATmega328P, Obstacle Detection, Embedded Systems, Automation.

I. INTRODUCTION

The rapid advancement of automation and robotics has significantly transformed various sectors including manufacturing, healthcare, transportation, and hospitality. In recent years, service robots have gained considerable attention due to their ability to perform repetitive tasks efficiently while reducing human effort and operational costs. Among these applications, food serving robots have emerged as an effective solution for improving service quality in restaurants, hotels, hospitals, and cafeterias.

Traditional food delivery methods rely heavily on human staff, which can result in delays, increased labor costs, and reduced efficiency during peak operating hours. Furthermore, maintaining hygiene and minimizing direct human contact have become important considerations in modern service environments. Autonomous food serving robots offer an innovative approach to addressing these challenges by automating the transportation of food and beverages within indoor environments.

Line-following robots are widely adopted for indoor navigation because of their simplicity, reliability, and cost-effectiveness. These robots utilize infrared sensors to detect predefined paths and navigate accordingly. However, conventional line-following systems often experience oscillations, inaccurate turning, and poor stability when negotiating curves or intersections. To overcome these limitations, advanced control techniques such as Proportional-Integral-Derivative (PID) control are employed. PID control continuously adjusts motor speed based on tracking error, resulting in smoother motion and improved path-following accuracy.

The Smart Food Serving Robot developed in this project integrates PID-based linefollowing control with ultrasonic obstacle detection. Three infrared sensors are used to monitor the path, while an HC-SR04 ultrasonic sensor continuously scans for obstacles. An ATmega328P microcontroller processes sensor inputs and controls four DC geared motors

through an L298N motor driver module. Whenever an obstacle is detected within a predefined range, the robot automatically stops and resumes operation only when the path becomes clear.

The proposed system provides a low-cost, energy-efficient, and reliable automation solution for indoor service applications. By combining embedded systems, sensor technology, and control engineering principles, the project demonstrates the practical implementation of intelligent robotic systems capable of improving operational efficiency and customer service quality.

II. LITERATURE REVIEW

The development of autonomous service robots has attracted significant research interest due to their potential to improve efficiency, safety, and productivity in hospitality and healthcare environments. Various researchers have proposed robotic systems capable of performing delivery, navigation, and customer service tasks using different sensing and control technologies.

Srilekha et al. developed an automated restaurant service system that incorporated machine learning techniques to improve customer interaction and food delivery operations. Their work demonstrated the effectiveness of intelligent automation in enhancing restaurant management; however, the implementation complexity and computational requirements increased the overall system cost.

Chavan et al. proposed a wireless electronic waiter robot capable of receiving orders and delivering food autonomously. The system successfully reduced human workload and improved service speed, but its dependence on wireless communication infrastructure increased system complexity and maintenance requirements.

Abyash Gautam and Lala Bhaskar introduced a robotic platform designed for hospitals that could monitor patients while delivering food and medicines. The study highlighted the importance of robotic automation in healthcare facilities, particularly in reducing direct human interaction and improving operational efficiency.

Several researchers have investigated line-following robots for industrial and service applications. Infrared sensor-based navigation remains one of the most widely adopted approaches due to its simplicity, low cost, and reliable operation in indoor environments. However, traditional line-following systems often suffer from path deviation and oscillatory motion, especially at sharp turns.

To address these issues, PID control algorithms have been extensively applied in autonomous mobile robots. PID controllers improve tracking performance by continuously adjusting motor speeds according to position error, thereby reducing overshoot and enhancing navigation stability. Studies have shown that PID-based systems achieve significantly better line-tracking accuracy compared to conventional threshold-based control methods.

Obstacle detection and avoidance constitute another important area of research in mobile robotics. Ultrasonic sensors such as the HC-SR04 are widely used because of their low cost, ease of implementation, and ability to provide accurate distance measurements. Integrating obstacle detection with autonomous navigation significantly improves safety and reliability in dynamic environments.

Based on the literature review, it can be concluded that the combination of PID-controlled line following, infrared sensor-based navigation, and ultrasonic obstacle detection offers an effective and economical solution for autonomous food serving applications. The proposed Smart Food Serving Robot builds upon these established techniques to develop a practical and reliable service robot suitable for restaurants, hospitals, cafeterias, and similar indoor environments.

IV. OBJECTIVES

- To design and develop an autonomous Smart Food Serving Robot for indoor service applications.
- To implement a PID-based line following algorithm using three infrared sensors for accurate path tracking.
- To integrate an HC-SR04 ultrasonic sensor for real-time obstacle detection and collision prevention.
- To interface an ATmega328P microcontroller with sensors, motor drivers, and actuators for efficient system control.
- To control four DC geared motors through an L298N motor driver for smooth and stable robot movement.

- To improve navigation accuracy by minimizing tracking errors, oscillations, and path deviations using PID control.
- To automate food transportation in restaurants, hospitals, cafeterias, and similar environments, thereby reducing human effort.
- To enhance operational safety, reliability, and service efficiency through intelligent sensing and autonomous decision-making.
- To develop a low-cost and energy-efficient robotic platform suitable for real-world service automation applications.

V. METHODOLOGY

The Smart Food Serving Robot is designed to autonomously transport food items along a predefined path while ensuring accurate navigation and safe operation. The system integrates an ATmega328P microcontroller, three infrared sensors, an HC-SR04 ultrasonic sensor, an L298N motor driver module, four DC geared motors, and a rechargeable battery pack. The microcontroller acts as the central processing unit and continuously monitors sensor inputs to control the movement of the robot.

The robot follows a black line track using infrared sensors and utilizes a PID control algorithm to minimize tracking errors and improve navigation accuracy. An ultrasonic sensor continuously scans the environment for obstacles and temporarily stops the robot whenever an object is detected within a predefined distance. The overall methodology is divided into line tracking, PID-based control, obstacle detection, and motor control operations.

A. Line Following Mechanism

The robot employs three infrared sensors positioned at the front section of the chassis. These sensors detect the contrast between a black line and a white background. The sensor outputs are continuously monitored by the ATmega328P microcontroller to determine the robot's position relative to the track.

Based on the sensor readings, the controller identifies whether the robot is centered on the path or deviating toward either side. Corrective actions are then generated to maintain proper alignment with the track. The use of three sensors improves path detection reliability and enables smoother navigation through curves and turns. The basic navigation logic is as follows:

- Center sensor detects line: Robot moves forward.
- Left sensor detects line: Robot turns left.
- Right sensor detects line: Robot turns right.
- Multiple sensors detect line: PID correction is applied.
- No sensor detects line: Robot stops and searches for the track.

B. PID Control Algorithm

To improve tracking accuracy and reduce oscillations, a Proportional-Integral-Derivative (PID) controller is implemented. The controller continuously calculates the deviation of the robot from the desired path and generates corrective motor commands. The PID control equation is given by:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt}$$

where

$e(t)$ = Desired Position – Actual Position

$u(t)$ = Control Output

K_p = Proportional Gain

K_i = Integral Gain

K_d = Derivative Gain

The proportional term provides immediate correction based on current error, the integral term eliminates accumulated steady-state error, and the derivative term improves system stability by reducing overshoot and oscillations. The PID controller enables smooth navigation even during sharp turns and path variations.

C. Obstacle Detection and Safety Control

An HC-SR04 ultrasonic sensor is mounted at the front of the robot to detect obstacles during operation. The sensor transmits ultrasonic waves and measures the time required for the reflected signal to return.

The distance is calculated using:

$$\text{Distance} = \frac{\text{Speed of Sound} \times \text{Time}}{2}$$

The division by two accounts for the round-trip travel time of the ultrasonic pulse.

When an obstacle is detected within a threshold distance of approximately 20 cm, the microcontroller immediately stops all four motors. Once the obstacle is removed and the path becomes clear, the robot automatically resumes its navigation process. This mechanism improves operational safety and prevents collisions.

D. Motor Drive and Motion Control

The robot utilizes four DC geared motors mounted on a four-wheel drive chassis. An L298N motor driver module interfaces the motors with the ATmega328P microcontroller and provides the required current for motor operation.

Pulse Width Modulation (PWM) signals generated by the microcontroller regulate motor speed according to the PID controller output. Differential speed control is used to achieve smooth turning and accurate path correction.

The motor speed equations are expressed as:

$$\text{Left Side Motor Speed} = \text{Base Speed} + \text{PID}$$

$$\text{Right Side Motor Speed} = \text{Base Speed} - \text{PID}$$

By continuously adjusting the speed of the left and right motor pairs, the robot maintains alignment with the track and achieves stable motion throughout the navigation process.

E. Overall System Operation

The overall operation of the Smart Food Serving Robot can be summarized in the following sequence:

1. Initialize sensors and motor driver.
2. Read infrared sensor values.
3. Determine line position error.
4. Execute PID control algorithm.
5. Generate PWM signals for motor control.
6. Read ultrasonic sensor distance.
7. Stop robot if an obstacle is detected.

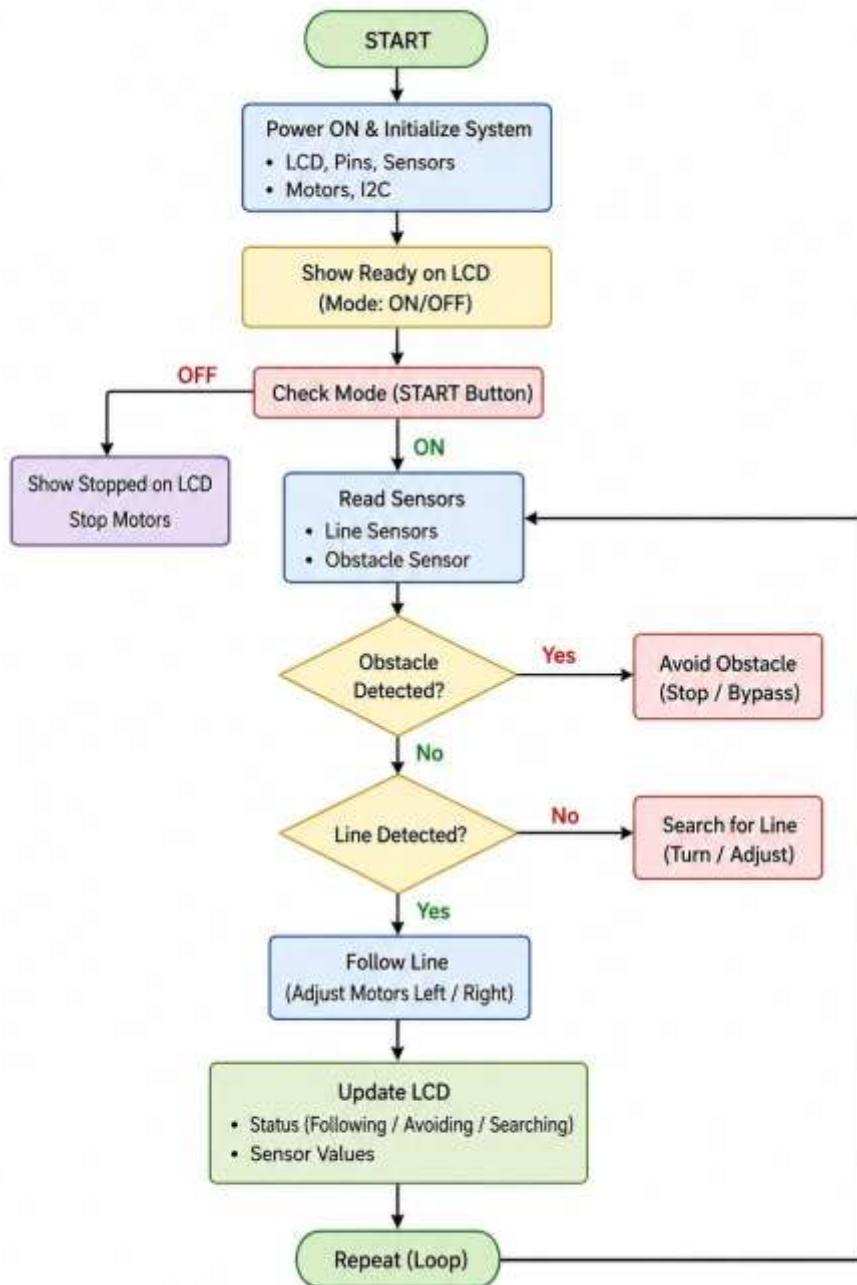
8. Resume operation when the path becomes clear.
9. Continue navigation until the destination is reached.

This methodology enables accurate line tracking, smooth motion control, efficient food transportation, and reliable obstacle avoidance, making the robot suitable for indoor service automation applications.

E. System Flow

The overall operation of the robot can be summarized as follows:

1. Read IR sensor values.
2. Determine line position error.
3. Execute PID algorithm.
4. Generate motor control signals.
5. Measure obstacle distance using HC-SR04.
6. Stop robot if obstacle detected.
7. Resume movement when path is clear.
8. Continue navigation until destination is reached.



VI. HARDWARE ARCHITECTURE

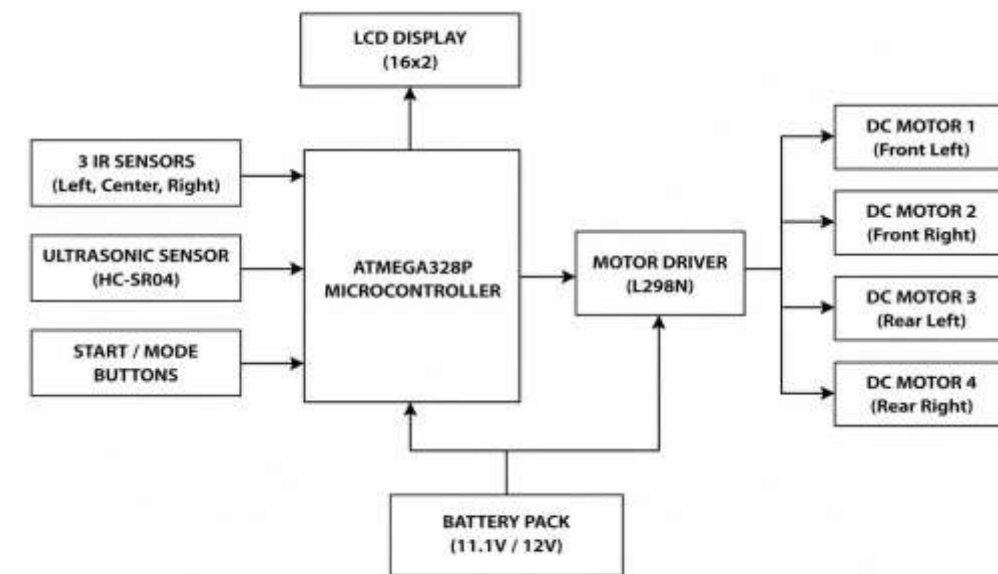
The hardware architecture consists of:

- ATmega328P Microcontroller
- Three IR Sensors
- HC-SR04 Ultrasonic Sensor
- L298N Motor Driver
- DC Geared Motors
- Lithium-Ion Battery
- Robot Chassis

- Food Tray Platform

Table 1: Hardware Components

Sr.No	Component	Function
1	ATmega328P	Control Unit
2	IR Sensors	Line Detection
3	HC-SR04	Obstacle Detection
4	L298N	Motor Driving
5	DC Motors	Movement
6	Battery Pack	Power Supply



VII. SOFTWARE DESIGN

The software was developed using Arduino IDE. The control algorithm continuously reads sensor values, calculates position error, executes the PID controller, and generates PWM outputs for motor control.

The software execution sequence is:

1. Initialize system
2. Read IR sensors
3. Calculate error
4. Execute PID
5. Adjust motor speed
6. Check ultrasonic sensor
7. Stop if obstacle detected
8. Continue operation

VIII. PID CONTROLLER IMPLEMENTATION

The PID controller is implemented using the following equation:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt}$$

where

$e(t)$ = Desired Position – Actual Position

The proportional term corrects current error, the integral term removes accumulated error, and the derivative term predicts future error.

IX. MODELING AND ANALYSIS

The robot can be represented as a closed-loop control system. Sensor feedback continuously updates the controller, which adjusts motor speed accordingly.

Table 2: PID Parameters

Parameter	Value
K _p	25
K _i	0.5
K _d	15

X. EXPERIMENTAL SETUP

Experiments were conducted on a predefined black track placed over a white surface. Various path geometries including straight lines, curves, and intersections were tested.

Obstacle detection performance was evaluated by placing objects at different distances from the robot.

XI. RESULTS AND DISCUSSION

Experimental Observations

Several experiments were conducted to evaluate the performance of the Smart Food Serving Robot. The robot successfully followed straight paths, curved tracks, and intersections. The PID controller minimized oscillations and improved navigation accuracy. The ultrasonic sensor successfully detected obstacles and stopped the robot whenever an object was present within the predefined threshold distance.

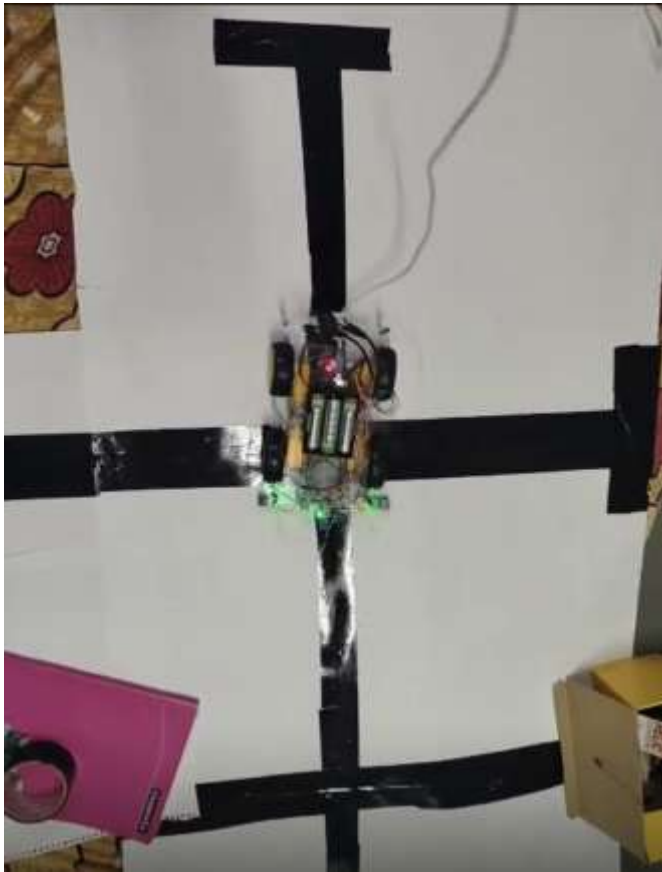


Figure 1: Developed Smart Food Serving Robot Prototype

The robot successfully followed the predefined path with high accuracy. The PID controller minimized oscillations and improved navigation stability.

Table 3: Performance Evaluation

Parameter	Value	Status
Line Following Accuracy	95%	Successful
Obstacle Detection Range	5–100 cm	Successful
Load Capacity	500 g	Successful
Battery Backup	2 Hours	Successful
Response Time	<1 sec	Successful

XII. ADVANTAGES OF THE SYSTEM

- Low-cost implementation
- Reduced human effort
- Improved service efficiency
- Reliable navigation
- Enhanced operational safety
- Easy maintenance

XIII. APPLICATIONS

The Smart Food Serving Robot has a wide range of applications in various service-oriented environments where efficient and automated transportation of food or materials is required. In restaurants and hotels, the robot can be used to deliver food orders directly from the kitchen to customer tables, thereby reducing the workload on service staff and improving customer satisfaction. In hospitals, the robot can assist in transporting meals, medicines, and essential supplies to patients while minimizing human contact and enhancing hygiene standards. The system can also be deployed in cafeterias, food courts, and educational institutions for automated food distribution and tray transportation.

Furthermore, the robot can be utilized in corporate offices and industrial facilities for the delivery of documents, tools, or lightweight materials between different departments. The integration of PID-based line-following control ensures accurate navigation in structured indoor environments, while ultrasonic obstacle detection enhances operational safety. Due to its low cost, ease of implementation, and reliable performance, the proposed system can serve as an effective automation solution for modern smart buildings and service industries. The concept can also be extended to warehouses, libraries, shopping malls, and healthcare facilities where autonomous transportation systems are increasingly becoming essential for improving operational efficiency and reducing human effort.

XIV. CONCLUSION AND FUTURE SCOPE

The Smart Food Serving Robot using PID-controlled line following and ultrasonic obstacle detection was successfully designed, developed, and tested. The system integrates three infrared sensors, an ATmega328P microcontroller, an HC-SR04 ultrasonic sensor, and an L298N motor driver to achieve autonomous navigation and safe food delivery. The implementation of a PID controller significantly improved line-following accuracy by minimizing tracking errors and reducing oscillations during movement. Experimental results demonstrated reliable path tracking, smooth motor control, effective obstacle detection, and stable operation under different test conditions.

The developed robot provides a low-cost and efficient automation solution for restaurants, hospitals, cafeterias, hotels, and other indoor service environments. By reducing human effort and improving service efficiency, the proposed system contributes to the growing field of service robotics and intelligent automation.

Although the developed prototype successfully meets the project objectives, several enhancements can be incorporated in future versions. Wireless table selection through a mobile application can provide greater flexibility and ease of operation. Integration of Internet of Things (IoT) technology can enable real-time monitoring and remote control of the robot. Machine vision and artificial intelligence algorithms can be incorporated to facilitate dynamic path planning, object recognition, and autonomous decisionmaking. Voice-command functionality may further improve user interaction, while automatic docking and battery charging systems can increase operational efficiency. These advancements would make the robot more intelligent, adaptable, and suitable for deployment in large-scale commercial environments.

The overall results demonstrate that the proposed Smart Food Serving Robot is a practical, reliable, and economical solution for modern service automation applications.

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