OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

Exploration of Robotic Waiter System Design and Implementation

Prof.P.S.Togrikar[1], S.B.Nadaf[2], T.D.Galande[3], P.S.Ghadage[4]

[1]Assistant Professor, *E & TC Engineering Department, S. B. Patil College of Engineering, Indapur (MH), India,*

[2 3 4] Student, *E & TC Engineering Department, S. B. Patil College of Engineering, Indapur (MH), India,*

pradeep.togrikar@gmail.com[1], sahilnadaf@gmail.com[2], tejasvipatil979@gmail.com[3], pratikghadage20@gmail.com[4]

Abstract: This project focuses on the Development of a Robotic Waiter System, an intelligent solution aimed at mitigating critical shortcomings in the traditional hospitality sector, namely manpower shortages, service delays, and high operational expenditure. The core intelligence is cantered on the STM32 Microcontroller, which is programmed to manage all sensor inputs and motor controls in real-time. It employs line-following and multi-sensor fusion (IR/Ultrasonic) for precise navigation and safe, autonomous delivery. A key safety feature is the integration of Ultrasonic and IR sensors for robust, real-time obstacle avoidance. Orders are initiated via a table-specific interface, and the robot completes the cycle by confirming successful food collection with an Order Detection Sensor. By automating this demanding delivery task, the system offers a tangible return on investment through superior service consistency, reduced human error, and a demonstration of practical embedded system deployment for commercial automation.

Keywords: STM32 Microcontroller, IR Line Following, Ultrasonic Sensors, Order Detection Sensor, Embedded Systems, Real-Time Control, Service Consistency, Intelligent Robotics, Path Tracking.

I INTRODUCTION

A. Background and Motivation

The contemporary hospitality sector is confronted by a formidable challenge: maintaining high-quality, consistent service for a growing customer base [1] amidst the constraints of rising labour costs, high staff turnover, and the necessity for hygienic, non-contact service [3, 10]. Traditional restaurant service paradigms, often characterized by heavy reliance on human waitstaff, are proving economically burdensome and susceptible to operational failures, such as delays and congestion during peak hours, which leads to customer dissatisfaction [1, 2]. This has catalysed the emergence of Service Robotics as a data-driven service management concept that leverages advanced technologies to automate routine delivery tasks. The fundamental goal is to optimize operational efficiency, enhance customer experience, and maximize profitability by reducing dependence on manual labour [6]. With the rise of IoT-enabled smart homes, diverse communication standards have caused compatibility challenges. The *Matter* protocol simplifies integration by offering a common framework for seamless device interaction[11].

At the core of efficient service delivery are two fundamental robotic practices: reliable autonomous navigation and precise object handling. Autonomous navigation, as demonstrated using IR Line-Following [7] and advanced UWB/EKF fusion [5], is renowned for its high accuracy in indoor environments. By delivering items along a defined or mapped path, it minimizes losses attributable to human error and ensures that the delivery is timely [7]. Concurrently, the use of dedicated embedded controllers, such as the STM32 Microcontroller utilized in similar systems, is essential for orchestrating motor control, sensor readings, and real-time safety functions, as seen in various designs employing Ultrasonic and IR sensors [4, 8].

The synergistic combination of precise navigation and automated handling constitutes a powerful strategy for modernizing restaurant operations. However, the manual or semi-mechanized process of delivery is labour-intensive, time-consuming, and frequently lacks the consistency required for optimal service results. The repetitive and physically demanding nature of food delivery contributes to escalating labour costs, and the human element is inherently susceptible to fatigue and error. Our project, the "Development of a Robotic Waiter System," is thus motivated to provide a practical, STM32-based solution that effectively integrates these core robotic practices to streamline the service chain [10].

II LITERATURE SURVEY

The technological trajectory of automated mulching and drip irrigation systems has demonstrated significant evolution over the past decade. This review synthesizes and critically analyses key research contributions, categorizing them based on their technological approach, level of autonomy, and system integration.

Comparative Navigation Techniques and Control

The reviewed literature presents two primary navigation strategies: infrastructure-dependent and flexible free-roaming. Line-following robots, such as those detailed by Divyashree L. K. et al., achieve smooth, efficient movement by employing an array of IR sensors to detect and follow a marked line on the floor, controlling DC gear motors precisely [4]. Conversely, researchers focusing on flexible, non-rail solutions, including Chin S. Chen et al., implement SLAM (Simultaneous Localization and Mapping) combined with sophisticated sensory fusion to construct a composite 3D point cloud and 2D occupancy grid map (PC-OGM), enabling reliable navigation through complex restaurant environments with narrow aisles [3].

Embedded Platforms and IoT Integration

The choice of the central control platform dictates the robot's functionality and scalability. Foundational waiter-bots commonly utilize the Arduino Uno due to its development simplicity and effectiveness for basic tasks like motor control and line-following [4, 8]. The increasing need for remote monitoring and commercial application has pushed designs toward IoT-based robots [10]. Luthfi Arifandi et al. specifically utilized the ESP32 microcontroller, integrating it with smartphone applications to allow the delivery robot to be controlled and monitored remotely over a network, showcasing an Automated Delivery Robot System [9]. This shift enhances functionality, enabling remote order management and real-time status updates for commercial applications [10]. The Matter protocol can be embedded in IoT controllers like STM32 to enable secure, interoperable smart device communication. It ensures real-time data exchange between sensors and cloud services efficiently[11].

Localization and Sensor Fusion Techniques

Precise localization without physical tracks is a major challenge addressed through sensor fusion. Yunlong Sun et al. proposed fusing Ultra-Wide Band (UWB) positioning technology with data from an odometer and a low-cost gyroscope/accelerometer [5]. The information from these disparate sensors is combined using an Extended Kalman Filter (EKF) algorithm, which effectively reduces positioning error to approximately 15 cm, making it commercially acceptable for non-rail movement in restaurants [5]. This contrasts with the simpler IR sensor arrays used in line-following systems by Sucheta Raut et al., which define a virtual path for the robot to follow for service efficiency [8].

Operational Challenges and Commercial Utility

The primary goal of these systems is to automate service and overcome issues like long wait times and inconsistent quality [10]. M. Asif et al. noted that using waiter robots with electronic menu bars can handle shortcomings like congestion and manual order processing [1]. The commercial viability is contingent on the system's reliability, which is why Chin S. Chen et al. evaluated their non-contact service robot based on three categories: availability, reliability, and satisfaction [3]. Prof. (Dr) Vinodpuri R. Gosavi et al. highlight that the development of IoT-based waiter robots provides a viable, hygienic alternative for automated food delivery, especially in the post-pandemic era [10].

Synthesis and Identification of Research Gaps

The survey reveals a clear technological dichotomy: simple, low-cost systems versus complex, high-cost autonomous platforms. This synthesis identifies critical gaps that your project is specifically designed to address:

A. Limitations in Current Embedded Platforms and Complexity

- **Focus on Low-Performance Microcontrollers**: Several systems, such as those by Divyashree L. K. et al. [4] and Sucheta Raut et al. [8], rely on Arduino-based designs. This simplicity inherently limits the processing power required for advanced sensor integration, complex control algorithms, and sophisticated real-time decision-making.
- **Overly Complex Infrastructure:** The Non-Rail Navigation proposed by Yunlong Sun et al. [5] requires an intricate setup, including external Ultra-Wide Band (UWB) infrastructure and computationally heavy Extended Kalman Filter (EKF) algorithms, which increases deployment complexity and cost.
- **Computational Intensity:** Solutions involving multi-sensor fusion and mapping, like the non-contact robot by CHIN S. CHEN et al. [3], are highly

computationally intensive, demanding powerful processors (e.g., Jetson/PC-based platforms) that are not cost-effective for typical restaurant automation.

- **IoT Focus, Limited Actuation:** Research like that of Luthfi Arifandi et al. [9] focuses heavily on ESP32 IoT control, often simplifying the core robotic actuation, navigation, and robust safety protocols necessary for commercial service.

B. Gaps in Integration and Commercial Viability

- **Absence of Integrated STM32 Solution:** A significant gap exists in the development of a fully integrated, cost-effective service robot utilizing the STM32 Microcontroller. The STM32's balance of high performance, rich peripheral set, and power efficiency is ideal for managing the robust line-following, multi-sensor safety (Ultrasonic/IR), and precise delivery confirmation (Order Detection Sensor)—a holistic combination currently lacking in the literature.
- **High-Cost Barrier:** The general consensus, noted by Jackson Lee Jian Soon et al. [2] and others, is that the implementation of intelligent service robotics remains prohibitively expensive, limiting commercial adoption to a simple concept level [1, 6].
- **Lack of Task-Specific Confirmation:** Most systems focus on general navigation, failing to detail the crucial final step of a service robot: precise delivery confirmation. Our project explicitly addresses this with the Order Detection Sensor, a function often absent in the reviewed designs.

III .METHODOLOGY

The reviewed papers detail two main system methodologies for service robots. The first is the Low-Cost Line-Following Approach [4, 7, 8]. This method typically employs an Arduino Uno [4] or similar microcontroller and an array of IR sensors to detect a black line on a surface of a contrasting colour [4, 8]. Raut et al. utilized this for a "Virtual Path Following Smart Waiter-Bot" implemented with an Arduino-based design [8]. The second, more advanced method, is the Non-Rail Navigation with Sensor Fusion [3, 5, 9]. This approach aims to eliminate the need for physical guidance strips. Sun et al. positioning with an odometer and a low-cost gyroscope/accelerometer using an Extended Kalman Filter (EKF) to achieve a positioning error of about 15 cm [5]. Similarly, Luthfi Arifandi et al. designed an automated delivery robot using ESP32 technology for IoT integration and remote monitoring in an office setting [9]. Advanced systems, like those developed by Chen et al., also integrate 3D point cloud maps with 2D occupancy grid maps for better localization [3].

IV .SYSTEM DESIGN AND IMPLEMENTATION

The development of the Robotic Waiter System is guided by a robust, modular design philosophy that prioritizes cost-effectiveness, navigational precision, and real-time safety. This section details the hierarchical system architecture, the selection criteria for core hardware components, and the implementation of the control algorithms.

A. Overall System Architecture

The robotic system is functionally partitioned into four primary interconnected modules, as illustrated in the system block diagram: the Control Unit, the Sensory Unit, the Actuation Unit, and the Power Management Unit.

- **Control Unit:** This is the brain of the system, cantered on the STM32 Microcontroller. Its function is to process incoming data from the Sensory Unit, execute the path-finding and obstacle-avoidance algorithms, and generate Pulse Width Modulation (PWM) signals to control the Actuation Unit. It also manages the interface for table-destination input and coordinates the final delivery confirmation.
- **Sensory Unit:** This module provides the robot with real-time awareness of its environment. It comprises the IR Line-Following Array for path detection, Ultrasonic Sensors and IR Sensors for obstacle and proximity detection, and the Order Detection Sensor for verifying food pickup/delivery status.
- **Actuation Unit**: This unit translates the control signals into physical motion. It consists of DC Gear Motors paired with a Motor Driver (e.g., L298N or similar H-bridge) to manage direction and speed, ensuring precise movement along the defined path.
- **Power Management Unit**: This unit supplies regulated power to all components, typically using a high-capacity battery pack and appropriate voltage regulators to ensure stable power delivery to both the motor drivers (high current) and the low-power control electronics (STM32, sensors).

B. Hardware Implementation

Control Core: STM32 Microcontroller

The STM32 Microcontroller (STM32F401RE or similar family) is selected as the main processor, offering a superior balance of performance and peripheral richness compared to simpler platforms like the Arduino [4, 8]. The STM32's higher clock speed and numerous GPIO pins facilitate the simultaneous management of the multi-sensor array and the rapid execution of the navigational algorithms, ensuring a faster and more reliable response in dynamic restaurant environments.

Navigation Sensors

- **IR Line-Following Array**: A set of 5-8 Infrared (IR) sensors is mounted on the underside of the robot. These sensors detect the contrast between the black guideline and the floor, providing a digital or analog input that determines the robot's deviation from the central path. This method is favoured for its consistency and low cost [7].
- **Ultrasonic Sensors:** At least one HC-SR04 Ultrasonic sensor is positioned at the front of the robot. It is used for long-range obstacle detection (e.g., 5 cm to 400 cm), providing crucial advance warning of large static or moving obstacles like tables, walls, or customers.
- **IR Proximity Sensors:** These are often smaller and faster than the Ultrasonic sensor and are strategically placed on the sides and front for short-range, rapid proximity detection. They serve as an immediate safety trigger to halt or adjust motion if an object comes too close, preventing minor collisions.

Actuators and Mechanisms

- **DC Gear Motors:** Two high-torque DC gear motors are used for differential drive, allowing the robot to execute sharp turns by adjusting the speed difference between the two wheels. The torque provided by the gear mechanism ensures the robot can carry food loads stably.
- **Order Detection Sensor:** A simple mechanical or optical limit switch is integrated into the food tray. This switch detects the presence of an order tray/plate at the beginning of the journey and the absence of the plate (i.e., customer has taken the food) at the destination. This provides crucial task-specific delivery confirmation, a feature often overlooked in general navigation systems.

Navigation and Control Algorithm

The robot's software utilizes a multi-layered control system to achieve both efficient movement and safety.

Line-Following Algorithm (Core Control)

The navigation relies on a Proportional (P) or Proportional-Integral-Derivative (PID) control scheme executed on the STM32.

1. **Error Calculation:** The input from the IR sensor array is processed to calculate an Error Value, representing the robot's deviation from the centre of the black line (zero error).
2. **Correction:** The STM32 uses the Error Value to calculate the necessary motor speed adjustments. If the robot drifts left, the right motor speed is increased proportionally (P-control) to steer it back onto the line.
3. **Execution:** The calculated speeds are sent as PWM signals to the motor driver. This continuous closed-loop feedback allows the robot to follow the path smoothly and accurately, even around curves.

Safety and Obstacle Avoidance Logic

Safety takes precedence over navigation. The control flow incorporates an interrupt-driven hierarchy for immediate obstacle response:

Continuous Monitoring: The STM32 constantly monitors data from the Ultrasonic and IR Proximity sensors while executing the line-following routine.

Obstacle Detected:

- If the Ultrasonic Sensor detects an obstacle within a predefined safety threshold (e.g., 50 cm), the robot begins to decelerate.
- If any IR Proximity Sensor is triggered (indicating a very close object, e.g., <10 cm), the robot initiates an immediate emergency stop.

Resumption: After a brief pause, the robot checks if the path ahead is clear. If the obstacle has moved

(e.g., a person walking past), the robot safely resumes the line-following algorithm from its current position. This ensures the robot handles dynamic restaurant congestion effectively [2]

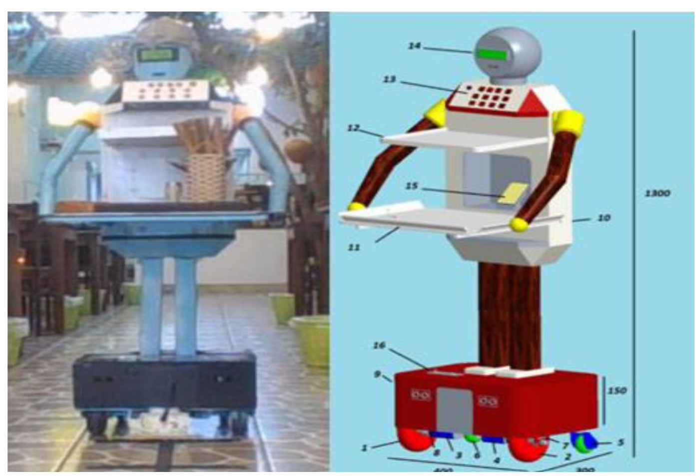

Fig .1: Waiter Robot [2]

Flowchart

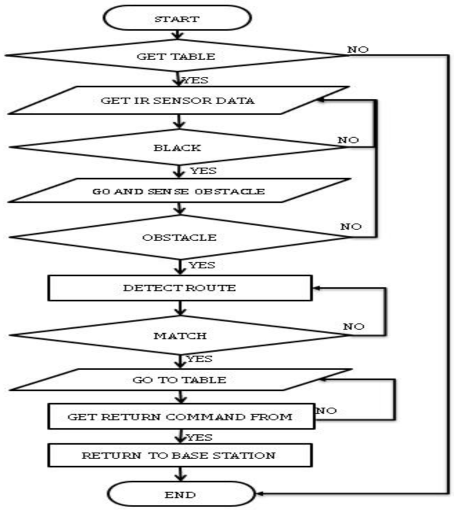

Fig. 2:Flowchart

V CONCLUSION AND FUTURE RESEARCH DIRECTIONS

A. Conclusion

This survey confirms the critical role of autonomous service robots in addressing systemic challenges within the hospitality sector, specifically mitigating high labour costs, staffing issues, and service inconsistencies [1, 2]. The literature reveals a clear technological spectrum, ranging from cost-effective, infrastructure-dependent solutions like IR Line-Following [4, 7] to highly advanced, non-rail systems utilizing complex Ultra-Wide Band (UWB) and Extended Kalman Filter (EKF) sensor fusion for superior localization [5]. While advanced solutions offer high flexibility, they often introduce complexity and cost that act as barriers to commercial adoption.

The analysis highlighted a significant gap: the need for an integrated, high-performance, yet cost-effective platform optimized for structured environments. Our project, the STM32-based Robotic Waiter System, is positioned to bridge this gap by demonstrating that a mid-range, powerful microcontroller can effectively manage robust line-following, multiple safety sensors (Ultrasonic/IR), and task-specific confirmation (Order Detection Sensor) without relying on expensive external infrastructure. Ultimately, the successful development of such integrated systems solidifies the vision of streamlined, hygienic, and efficient automated food delivery for commercial applications [10].

B. Future Research Directions

Based on the synthesis of the current state-of-the-art and the limitations observed, future research in robotic waiter systems should concentrate on the following areas:

1. **Dynamic Environment and Human-Aware Navigation:** The most critical challenge is achieving seamless navigation in highly dynamic, unstructured environments. Future work must focus on developing robust, low-latency motion planning algorithms that can predict and react to complex human movement (e.g., crowded peak hours) to ensure safety and avoid the computational intensity associated with current multi-sensor SLAM systems [3].

2. **Cost Reduction for Advanced Localization:** While non-rail navigation (UWB/EKF) offers superior flexibility, its high deployment cost remains a constraint [5]. Research should explore more economical alternatives, such as fusing low-cost visual odometry or enhanced Wi-Fi/Bluetooth Low Energy (BLE) localization techniques, to achieve commercially acceptable positioning accuracy without expensive external systems.

3. **Enhanced Scalability and Fleet Management (IoT):** As restaurants adopt multiple robots, the focus must shift to centralized fleet management. Future research should leverage advanced IoT architectures (beyond simple ESP32 control [9]) to handle simultaneous task assignment, real-time traffic control, and efficient battery management across an entire robotic fleet, ensuring optimal service uptime and maximizing resource utilization [10].

4. **Haptic and Interaction Sophistication:** To truly replace human labour, robots need improved capabilities for human-robot interaction (HRI) and advanced dexterity. This includes developing safer, more intuitive interfaces, and implementing sophisticated object handling mechanisms that can safely deliver diverse items (e.g., glassware, soup) with high stability.

REFERENCES

[1] M. Asif, M. Sabeel, Mujeeb-ur-Rahman, Z. H. Khan. (2015). Waiter Robot - Solution to Restaurant Automation. *MDSRC-2015 Proceedings*.

[2] Jackson Lee Jian Soon, Abdul Rahim bin Abdullah. (2021). Development of Restaurant Waiter Assistant Line Follower Robot. *Article, September 2021*.

[3] CHIN S. CHEN, CHIA J. LIN, CHUN C. LAI. (2022). Non-Contact Service Robot Development in Fast-Food Restaurants. *IEEE Access*, vol. 10.

[4] Divyashree L. K., Keerthana K. V., Vyshnav E. (2025). Line Following Food Serving Robot. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, Vol. 13, Issue 2.

[5] Yunlong Sun, Lianwu Guan, Zhanyuan Chang, Chuanjiang Li, Yanbin Gao. (2019). Design of a Low-Cost Indoor Navigation System for Food Delivery Robot Based on

Multi-Sensor Information Fusion. *Sensors (MDPI)*, vol. 19, no. 22.

[5] Dele Z. Yanmida, Sabur A. Alim, Abubakar S. Imam. (2020). Design and Implementation of an Autonomous Delivery Robot for Restaurant Services. *ELEKTRIKA Journal of Electrical Engineering*, Vol. 19, No. 3.

[6] Risa Aisyah, Ayu Latifah, Nurhidayat, Jalaludin Kifti, Bintang Nur Alfiyah. (2024). Implementation of Line Follower Robot for Food Delivery Robot. *Article, November 2024*.

[7] Sucheta Raut, Samruddhi Randive, Prajwal Kamdi, Yogesh Khadse, Dushyant Sahare. (2020). VIRTUAL PATH FOLLOWING SMART WAITER-BOT. *International Journal of Creative Research Thoughts (IJCRT)*, Volume 8, Issue 4.

[8] Luthfi Arifandi, Endah Setyaningsih, Yohanes Calvinus. (2023). AUTOMATED DELIVERY ROBOT SYSTEM DESIGN FOR OFFICE USING ESP32 TECHNOLOGY. *International Journal of Application on Sciences, Technology and Engineering (IJASTE)*, Volume 1, Issue 3.

[9] Prof. (Dr) Vinodpuri R. Gosavi, Sayali Darade, Komal Mahandule, Gayatri Ghotekar, Anushka Kokare. (2025). DESIGN AND DEVELOPMENT OF IOT BASED ROBOT FOR COMMERCIAL APPLICATIONS. INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH AND ENGINEERING TRENDS, Volume 9, Issue 1.

[10] P. S. Togrikar, Shashikant Patane, Pratik Phase, and Harshada Baravkar, "*Matter the New Way in IoT*," in *Proc. International Conference on Engineering, Science and Technology (ICEST-2K24),* Indapur, Maharashtra, India: SPVP's S. B. Patil College of Engineering, 2024