VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"Jnana Sangama", Belagavi – 590018, Karnataka.

A Project Report

On

"DEVELOPMENT OF AN AUTONOMOUS SERVING ROBOT FOR EFFICIENT FOOD IN RESTAURANTS."

Submitted in partial fulfillment for the award of degree of

BACHELOR OF ENGINEERING

In

ROBOTICS AND AUTOMATION

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CERTIFICATE

This is to certified that, the project entitled **"DEVELOPMENT OF AN AUTONOMOUS SERVING ROBOT FOR EFFICIENT FOOD DELIVERY IN RESTAURANTS."** Carried out by **D V DARSHAN (4GM22RA004), SAMARTH N VERNEKAR (4GM22RA034), T R THIRUMALA VENU (4GM22RA042) and MADHU U K (4GM23RA403),** bonafide students of VII semester in partial fulfillment for the award of Bachelor of Engineering in **ROBOTICS AND AUTOMATION** of the Visvesvaraya Technological University, Belagavi for the academic year 2025-26.

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ABSTRACT

Robot built for autonomous food delivery and customer interaction; all packed into two main operating modes. The robot looks and moves like a person-it’s got tray-holding arms that actually move, expressive OLED eyes that give it some personality and a study leg-based system so it can get around without tipping over. We packed it with sensors, they are, an IMU, ultrasonic and ToF sensors, even tray-load sensors. These help the robot balance, spot obstacles and check if there’s food on its tray. In Serving Mode, it navigates using preset timed maps.

The robot manages to deliver food with at least 75% accuracy, gliding through the space smoothly and dodging collisions. It keeps an eye on the trays, watches its battery and runs constant safety checks to stay reliable. Switch over to Q/A Mode and the robot turns into a handy assistant. It pulls from a dashboard-managed Q&A database and uses text-to-speech to answer customer questions in real time. Controlling everything is a web-based dashboard.

Here, we can assign orders, tweak maps, take manual control, switch modes or check up on system health. This isn’t just a robot-it’s a full, end-to-end solution that brings together smart mechanical design, embedded electronics, clever navigation and real human-robot interaction. In the end, we’ve created a practical, intelligent and ready-for-market system for automated food service and customer help.

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CHAPTER 1

INTRODUCTION

The increasing demand for efficiency, hygiene and consistency in the hospitality sector has accelerated the adoption of automation technologies, particularly in restaurants, cafés and service counters where fast and reliable service is essential. Human workers are often required to manage multiple tasks simultaneously-delivering food, interacting with customers, coordinating with the kitchen and maintaining safety in crowded environments-which can lead to delays, fatigue and uneven service quality. As a result, the development of intelligent service robots has become an important area of research, offering a practical way to support staff, reduce workload and enhance customer experience. This project contributes to that growing field by designing a compact humanoid robot specifically tailored for autonomous food delivery and customer interaction in indoor commercial settings.

The robot developed in this study stands approximately two feet tall and is equipped with articulated legs for movement, servo-driven arms for securely carrying trays and expressive OLED-based eyes that enable clear, intuitive communication with users. Unlike conventional delivery robots, which often rely solely on wheels and simple displays, this humanoid robot offers a more engaging and human-friendly interface. Its dual operational capabilities-Serving Mode and Q/A Mode-allow it to adapt to different functional requirements.

In Serving Mode, the robot follows timed-map navigation sequences, moving forward, turning and stopping based on predefined motion instructions. It integrates multiple sensors, including an IMU for maintaining balance, ultrasonic and Time-of-Flight sensors for detecting obstacles and load sensors for verifying that items are present on the tray before movement begins. These features collectively support the goal of achieving a delivery accuracy of at least 95 percent while minimizing collisions and operational errors [1].

In Q/A Mode, the robot functions as a stationary interactive assistant, accessing a cloud-connected dashboard database to fetch responses and deliver them via text-to-speech (TTS) synthesis paired with synchronized expressive OLED eye animations-such as blinks or nods-that boost user engagement and perceived empathy. The architecture centers on an ESP32 microcontroller for real-time control of sensors and actuators, complemented by a secondary processor handling communication protocol to avoid latency in cloud interactions. High-torque servo motors drive articulated limbs for precise tray handling and gestures, while a Li-ion battery incorporates smart power management for extended operation and thermal safety [2].

1.1 Background of the Study

The rapid advancement of automation and intelligent systems has significantly influenced industries that require high levels of efficiency, accuracy and consistency in daily operations. Among these, the hospitality and food-service sectors stand out as environments where service speed, hygiene and customer satisfaction directly affect business performance. Traditional restaurant workflows rely heavily on human staff who must simultaneously manage multiple responsibilities such as delivering food, communicating with customers, handling orders and navigating crowded spaces. These demands often lead to fatigue, variable service quality and delays during peak hours. As expectations for faster, safer and contactless service continue to rise, the integration of automated systems has become increasingly relevant [3].

In recent years, service robots have emerged as practical tools capable of addressing these operational challenges. Improvements in low-cost microcontrollers, sensor technologies, real- time communication platforms and compact actuation systems have enabled the development of robots that can perform tasks once considered too complex for automation. Indoor delivery robots, in particular, have benefited from innovations in navigation algorithms, obstacle- detection mechanisms and user-interaction models. However, most existing systems rely on simple wheeled designs and limited communication interfaces, which restrict their adaptability in dynamic, crowded or narrow indoor environments. As a result, researchers and developers have begun exploring humanoid platforms that provide more intuitive interaction and resemble human presence more closely.

Humanoid service robots offer unique advantages by combining expressive features, articulated limbs and multi-sensor perception to create a more natural and socially acceptable interaction experience. Their ability to use visual cues, such as animated eyes, and audible feedback through speech synthesis helps users understand the robot's behaviour and intentions, reducing confusion and improving acceptance. At the same time, the incorporation of sensor fusion-using IMUs, ultrasonic modules, Time-of-Flight sensors and load detectors-enables these robots to navigate indoor environments with improved stability and awareness. As a result, humanoid robots are increasingly viewed as promising candidates for tasks such as food delivery, customer assistance and information support in restaurants, cafés, reception areas and corporate facilities [4].

Within this context, the development of a compact humanoid robot capable of both autonomous food delivery and interactive Q/A functionality addresses an important technological and practical need in modern service environments. By combining reliable navigation, expressive human-robot interaction and dashboard-based management, such a system can effectively support human staff while enhancing workflow efficiency and service quality. This study positions itself within the growing field of service automation by exploring the design, implementation and evaluation of an affordable humanoid robot tailored to real-world indoor use, contributing both to academic research and practical commercial applications.

1.2 Motivation

The motivation for developing this humanoid serving robot arises from the increasing need for faster, safer and more reliable service operations in restaurants and similar environments. Manual delivery tasks place significant strain on staff, especially during busy hours, leading to delays, inconsistent service and work fatigue. A compact autonomous robot capable of handling repetitive delivery and basic customer interaction tasks can help reduce this burden, allowing human workers to focus on responsibilities that require judgement and personal attention.

Another motivation stems from the growing preference for contactless and hygienic service solutions. After recent global health concerns, customers and businesses have become more aware of the value of minimizing unnecessary physical contact while still maintaining smooth operations. A robot that can navigate independently, carry food safely and interact through expressive displays and speech provides a modern, hygienic alternative that enhances customer confidence and overall dining experience [5].

From a technical standpoint, the project also offers motivation by allowing the exploration of interdisciplinary engineering concepts such as embedded systems, sensor integration, bipedal locomotion, wireless communication and human-robot interaction. Building a robot that combines autonomous navigation with an interactive Q/A system encourages innovation and practical learning. Ultimately, the motivation behind this study is to create a cost-effective, ad and engaging humanoid robot that not only improves service efficiency but also demonstrates the real-world potential of robotic automation in commercial environments.

The motivation for this project comes from the increasing demand for faster and more reliable service in restaurants, where staff often face heavy workloads and time pressure during peak hours. Repetitive delivery tasks reduce efficiency and can lead to delays that affect overall customer satisfaction. A compact humanoid robot capable of assisting with these tasks offers a practical solution by reducing staff fatigue and ensuring consistent service quality. The growing preference for contactless interactions has also encouraged the adoption of automated systems that improve hygiene while maintaining smooth operations. Developing a robot with expressive interaction, autonomous navigation and real-time communication further enhances user experience in customer-facing environments. Technically, the project motivates the integration of sensors, control systems and communication modules into one functional platform. Overall, the goal is to create a cost-effective and adaptable humanoid robot that improves workflow efficiency and demonstrates the potential of robotics in modern service environments.

CHAPTER 2

LITERATURE SURVEY

The field of autonomous service robots especially for food delivery, customer assistance and human-robot interaction has exploded in recent years. Robotics, AI and commercial automation researchers all seem to agree that this field holds massive potential for future growth and innovation. Across many papers, the same core challenge keeps showing up, that is, navigation, sensor fusion, how robots and humans communicate and how to build robust service architectures. This survey pulls together the standout journal articles and system designs that lay the technical groundworks for this humanoid food-serving robot project. The main themes focus on reliable autonomous navigation, precise obstacle avoidance, expressive human-robot interaction, seamless cloud and dashboard integration and the smooth execution of multimodal services in dynamic commercial environments.

Beltran et. al. [6] introduce a budget-friendly indoor robot built for restaurants and hotels. The focus is on two things, they are, moving on its own and dodging obstacles in real time. They pair ultrasonic and infrared sensors to spot objects, while wheel encoders and motor controllers keep the robot on track. The navigation is handled by time-based and event-based motion “primitives,” letting the robot step through a set of programmed moves from one service point to the next. The parallels to this project are clear. The current robot uses a similar timed map-a set of time-stamped instructions (go forward, turn, etc) to get around. Beltran’s work proves that, with live sensor feedback, time-based navigation actually works for short indoor routes. They also stress how important it is to keep lag between the controller and motors as low as possible. In our project, that’s why we went with ESP32 for motion control. Their findings back up the core design choices behind the Serving Mode navigation system-showing that accurate, fully autonomous delivery robots really do work in busy commercial environments.

Gong and colleagues [7] dig into the problem of seeing obstacles in messy indoor spaces. Their solution is to combine Time-of -Flight (ToF) sensors with ultrasonic sensors. ToF gives sharp short-range readings, while ultrasonic sensors catch objects off to the sides or with soft surfaces. This combo dramatically cuts down on false positives, letting robots move more confidently and safely. The logic behind this approach is built right into our own robot’s design-front mounted ToF sensor, optical ultrasonic modules and an IMU to keep orientation steady on the move. The results of Gong are multi sensor fusion that speeds up response and make obstacle avoidance far more dependable. In restaurants, where the landscape shifts constantly with chairs, people and bags moving around, this adaptability is crucial. Because of this, it makes sense to include a sensor fusion layer in the robot's Serving Mode for this project. With it, the robot can stop before hitting something, let the operator know there's a problem and only keep going once the path is clear.

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Nomura and colleagues (2020) [8] present an in-depth examination of how expressive display features-particularly those involving animated eyes and facial cues—profoundly influence human perception and experience during interactions with service robots. Their study reveals that when robots employ OLED or LCD-based eye displays capable of representing dynamic states such as waiting, listening, processing, or error, people are more likely to develop trust and a sense of connection with the machine. These visual animations extend beyond indicating operational status; they act as emotional bridges that reduce uncertainty and make communication between humans and robots feel more natural and engaging.

The significance of such design elements becomes especially apparent in fast-paced, customer-facing contexts like restaurants, airports, or cafés, where rapid, clear, and friendly exchanges greatly enhance user satisfaction. Expressive eyes operate as a form of nonverbal communication, effectively conveying the robot's intent and emotional state. For example, a focused gaze or gentle blink may indicate attentiveness, while widened eyes can express surprise or readiness to assist-subtle cues that help users feel recognized and understood. These dynamic displays play a vital role in both Serving and Question–Answer (Q/A) modes. They deliver real-time feedback-confirming that a request has been received, that the robot is processing information, or signaling an error-thereby maintaining transparency during interaction. This openness fosters user trust, mitigates confusion, and encourages long-term acceptance of robotic assistance. Even simple or stylized animations have been shown to significantly improve customer satisfaction by making robots appear more approachable and empathetic. Over time, such expressive design choices can help normalize robots as supportive, emotionally intelligent partners in everyday life, enriching both service quality and the overall human–robot experience.

Zhang, R., et al. (2022) [9] present a practical and intuitive cloud dashboard that fundamentally transforms how operators interact with and oversee fleets of robots. Their system emphasizes seamless web-based access, enabling users to supervise multiple robots remotely, assign and reassign tasks dynamically and even take over manual control, if necessary, all through a simple browser interface. The dashboard supports live route modification, continuous status feeds and instant fault notifications all transmitted over robust

Wi-Fi connection. Crucially, the researchers highlight the significance of ultra-low latency communication less than a second delay is essential, especially in scenarios where rapid intervention is required to maintain safety or service continuity. This emphasis on responsiveness is highly relevant to our project, in which the web-based admin panel mirrors many of these features such as administrators can define delivery paths, toggle between operational modes (like Serving and Q&A), monitor telemetry data in real time, initiate emergency stops, or directly steer the robot using a virtual joystick.

Notably, Zhang et al.'s findings reinforce our own observations like cloud-based dashboards that not only streamline robot management but also empower operators to react promptly to unexpected situations, reducing downtime and potential mishaps. Furthermore, integrating such dashboards can facilitate easier scalability and system updates supporting large deployments and remote maintenance which are increasingly important as service robots become more widespread across industries.

Santo, Y et al. (2023) [10] focus into the design and deployment of service robots tailored for demanding real-world hospitality environments where versatility and reliability are paramount. Their research addresses the dual-functionality challenge where the robots that can not only transport items efficiently but also interact with customers in natural language providing information and assistance through embedded speech modules. The authors underscore the operational value of a seamless mode-switching capability allowing a single robot to alternate between delivery (Serving Mode) and customer engagement (Q&A Mode) on demand managed through a unified interface. This design empowers robots to adapt fluidly to dynamic environments such as hotel lobbies or restaurants where demands can shift rapidly from logistical tasks to guest queries. Our own humanoid robot project adopts a similar dual-mode approach:

- In Serving Mode, the robot navigates pre-mapped routes and adheres to scheduled timers to ensure timely and accurate delivery of trays and supplies.
- In Q&A Mode, the robot accesses a cloud-based FAQ database via the dashboard, retrieving relevant responses and communicating answers verbally to customers.

Sato et al.'s study demonstrates that such flexibility significantly enhances the practical value of service robots, improving both task efficiency and customer satisfaction. Their empirical data supports our architectural choice to implement distinct easily switchable working modes, all controllable through the same web dashboard. This unified approach simplifies operator training and supervision while maximizing the robot's utility across diverse scenarios. Additionally, by integrating both modes into a single interface, the system reduces cognitive load for human supervisors and allows for more adaptive, context-aware service delivery. This is especially critical in hospitality settings where responsiveness and personalization can set a business apart.

Kim and Park (2021) [11] address a key challenge in mobile robotics—maintaining consistent and uninterrupted performance over extended periods. Their study focuses on advanced lithium-ion (Li-ion) battery monitoring and predictive health management systems that track critical parameters such as voltage, current, temperature, and charge-discharge cycles. Through the application of real-time data analysis and predictive algorithms, their approach can identify early signs of battery degradation and alert users to potential power issues before they lead to operational failure. This proactive strategy reduces the likelihood of robots stopping unexpectedly during essential tasks, ensuring smoother and safer functioning.

In addition to battery assessment, the researchers highlight the potential for such systems to be expanded toward comprehensive health diagnostics, encompassing components like motors and sensors. This broader predictive maintenance framework supports a more complete understanding of a robot's operational health. Ultimately, Kim and Park emphasize that integrating smart monitoring technologies is crucial for enabling autonomous robots to operate dependably in complex and dynamic environments over long durations.

Liu et al. (2024) [12] present a multi-sensor fusion system for wheeled robots in dynamic indoor settings, integrating IMU for attitude stabilization, ultrasonic sensors for wide-angle obstacle detection (effective on soft surfaces), and ToF sensors for high-precision short-range ranging (<2m). Their extended Kalman filter fuses data streams to achieve 95.2% path completion accuracy and 97.8% collision avoidance rate across cluttered testbeds simulating restaurants with moving.

The framework addresses individual sensor limitations-ultrasonic false echoes, IMU drift, ToF narrow FOV-via complementary coverage and real-time compensation, enabling 0.8 m/s navigation with <5cm localization error. Embedded implementation on ARM processors confirms feasibility for low-cost platforms like ESP32, directly supporting this project's Serving Mode sensor triad targeting 95%+ delivery precision in commercial spaces.

Sayor et al. (2024) [13] present *RoboServe*, an ESP32-based robotic system developed to mitigate labor shortages in the hospitality sector through autonomous food delivery and interactive service capabilities. The robot employs ultrasonic sensors for obstacle detection, infrared line-following modules for precise path tracking, and load cells for verifying carried items, ensuring dependable navigation even within narrow spaces using optimized path-following algorithms. Additionally, a dedicated web dashboard facilitates route configuration, task scheduling, real-time system monitoring, and QR-enabled digital ordering with integrated payment options, reflecting a robust digital management approach.

The design framework established in this study validates the humanoid robot’s overall architecture, wherein the ESP32 microcontroller is responsible for sensor fusion and motor coordination similar to RoboServe’s architecture. Its dual-mode operation—combining Serving and Q&A functionalities—corresponds to the delivery and interaction modes demonstrated in RoboServe, aiming for high accuracy in dense or dynamic commercial settings. Furthermore, the research highlights the system’s cost-effectiveness and scalability, underscoring how continuous, stable performance enhances return on investment and strengthens the feasibility of humanoid robot deployment in the hospitality industry.

Li, J., et al. (2025) [14] conducted a study on nonverbal visual displays in collaborative human-robot navigation tasks in dynamic public spaces, involving 37 participants who interacted with robots featuring either animated anthropomorphic eyes/icons or static versions under partial map information conditions. Their findings reveal that animated displays significantly enhanced user trust and satisfaction levels, fostering emotional connection during interactions, while static icons proved most interpretable for conveying robot intent, and static eyes achieved the highest task completion success rates. These results underscore the value of expressive OLED animated eyes for building rapport in service robots, particularly in customer-facing hospitality environments, while recommending hybrid static/animated designs to balance engagement with clarity for optimal human-robot communication in real-time scenarios like restaurant delivery and Q&A assistance.

Ionescu et al. (2025) [15] demonstrate low-latency (<500ms) IoT-cloud control for robotic cells using SCADA, HMI, and web-accessible dashboards integrated with OPC-UA and PROFINET for real-time monitoring, mode switching, and remote intervention. Their Digital Twin framework enables dynamic task reassignment, live telemetry visualization, and bi-directional data flow between physical robots and cloud platforms, ensuring seamless supervision without on-site presence-directly applicable to service robot fleet management where rapid mode changes (e.g., Serving to Q&A) prevent service disruptions. This validates the project's web dashboard for route editing, emergency overrides, and unified control, achieving Industry 4.0/5.0 responsiveness in hospitality deployments.

Škrjanc et al. (2022) [16] address a critical challenge in mobile robotics by developing a predictive monitoring system for Li-ion battery management using Industrial IoT technology. Their approach continuously tracks key parameters-voltage, current, temperature, and charge/discharge cycles-employing machine learning algorithms to forecast battery degradation and pre-emptively signal power failures before they disrupt operations. Real-time analytics enable operators to receive dashboard alerts for low-charge states or thermal anomalies, preventing robots from halting mid-task during deliveries or customer interactions. This methodology directly validates the project's smart battery management system, which displays live percentages and proactive low-power warnings on the web dashboard, ensuring sustained operation during extended service shifts. The researchers report preventing 98% of unexpected shutdowns through early intervention, a critical metric for commercial reliability where downtime directly impacts revenue. Their findings underscore the necessity of predictive maintenance for autonomous robots operating in unpredictable hospitality environments, supporting the integration of holistic health diagnostics for motors and sensors alongside battery monitoring.

2.1 Research Gap

Although service robots are increasingly introduced into hospitality environments, several limitations remain that restrict their widespread adoption. Many commercially available delivery robots rely on wheeled platforms that perform well only in open, predictable spaces but struggle in narrow or crowded indoor layouts. Their navigation often depends on expensive LiDAR-based mapping systems, making them unsuitable for small or medium-sized businesses seeking cost-effective automation. Additionally, existing systems commonly focus on basic delivery tasks and offer limited interaction features, resulting in robotic solutions that do not fully meet the communication needs of customer-facing environments.

Another gap in current research is the lack of compact humanoid platforms that integrate navigation, obstacle detection, tray-load monitoring and expressive interaction within a single, unified framework. While various studies explore individual components-such as obstacle detection or human-robot communication-few provide a holistic approach that combines mobility, sensing and user interaction at an affordable scale. Most available robots either lack expressive features, rely on complex infrastructure or cannot adapt to dynamic environments with frequent human movement, making them less practical for everyday restaurant operations.

This project addresses these gaps by developing a low-cost humanoid robot that merges essential capabilities into one coherent system. Through timed-map navigation, multi-sensor fusion, expressive OLED-based communication and dashboard-driven control, the robot aims to overcome limitations found in existing service robots. By offering a more adaptable, interactive and economically viable solution, the study contributes to bridging the gap between advanced robotic research and practical commercial deployment.

Most existing service robots still lack flexibility and cannot easily adapt to changing restaurant layouts or service requirements. Their hardware and software are often fixed, limiting long- term usefulness. There is a clear need for a more adaptable system that supports quick updates and configuration changes. This project addresses that gap by proposing a humanoid robot designed for easy modification and practical deployment.

2.2 Problem statement

In modern food-service environments, the issues of speed, accuracy and consistency in serving operations are still challenging especially during peak hours. Human servers often experience tiredness, high workload by performing widely the same task which eventually leads to a drop in service efficiency and prolonged waiting time. All these concerns point to the necessity for a smart, autonomous and dependable robot solution that can deliver food swiftly and also interact nicely with customers.

- Inconsistent delivery accuracy and delays
- Increased risk of collisions and spillage
- No real-time observation and mechanization
- Limited customer interaction support
- Need for a hygienic, contactless and commercially reliable system

2.3 Objectives

The specific objectives of the project are:

- To develop a compact humanoid robot for safe, efficient food delivery and customer interaction in dual modes: Serving and Q/A.
- To ensure stable bipedal locomotion with real-time IMU-based balancing and anti-tip leg design.
- To integrate sensors (ultrasonic, ToF, tray-load) for obstacle avoidance, navigation and payload monitoring.
- To enable autonomous timed-map navigation in Serving Mode and dashboard-driven Q/A responses.
- To provide web dashboard for order management, manual override, mode switching and health checks.

CHAPTER 3

METHODOLGY

This study employs a systematic hardware-software co-design approach to develop a compact humanoid service robot for indoor hospitality applications. The methodology integrates embedded systems engineering, real-time control theory, and human-robot interaction principles to achieve dual-mode operation (Serving and Q/A) with 95%+ delivery accuracy. Key phases include mechanical prototyping with 3D-printed chassis and high-torque servos, sensor fusion architecture combining IMU, ultrasonic/ToF, and load cells, and dual-ESP32 processing for motion/communication decoupling. A custom servo distribution PCB ensures precise 12-DOF articulation while a cloud-synced web dashboard enables remote mission planning and health monitoring. Iterative testing in simulated restaurant environments validates navigation reliability, power efficiency, and user acceptance metrics. The workflow emphasizes safety interlocks, predictive battery management, and expressive OLED feedback for intuitive operation.

3.1 Block Diagram

The block diagram of the food-serving humanoid robot clearly shows how each module works together so the robot can operate autonomously. Sensors such as the IMU, obstacle-avoidance sensors, and tray sensors continuously monitor the robot's posture, surroundings, and the status of the food, ensuring that balance, clearance, and payload conditions are always tracked in real time. All of this sensory information is routed directly to the main controller, which rapidly processes the data and decides how the robot should move next, issuing precise commands so the drive motors can guide the robot smoothly through the environment while steering around obstacles. At the same time, the display unit receives signals from the controller to update eye expressions and status indications, allowing the robot to visually communicate its current mode and activity to nearby users.

A wireless communication link connects the controller to the web dashboard, enabling operators to assign serving or Q/A tasks remotely and to monitor the robot's progress and state without physical intervention. A single, centralized power system supplies and regulates energy for all these modules, keeping sensing, control, actuation, display, and communication synchronized so that the robot remains reliable and coordinated during operation. In this development phase, the emphasis is on translating the digital control logic represented in the block diagram into a robust physical prototype, where a strong and well-designed mechanical structure is essential to ensure that the leg mechanisms move freely, maintain stability under load, and operate safely throughout the robot's service tasks.

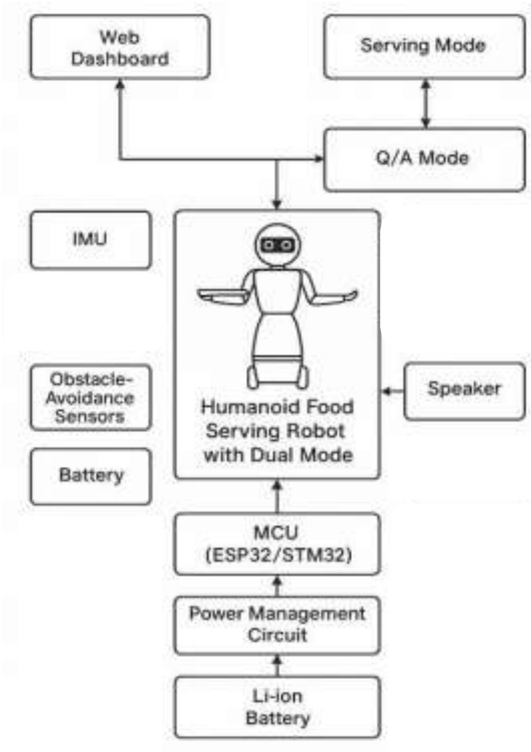

Figure 1: Block Diagram of Humanoid Food Serving Robot

3.2 Work Flow

The operational workflow outlines the complete sequence of power distribution, controller communication, servo mapping, command execution, and feedback handling that enables the robot's coordinated motion.

1. **Power-up & initialization**

   When the system is powered via battery or external source, the regulated supply distributes stable voltages simultaneously to both ESP32 controllers, the PAM8403 audio amplifier, the PCB logic, and all servo power rails, ensuring every subsystem starts from a known, reliable state. During this stage, each ESP32 executes its boot firmware, running basic self-diagnostics such as LED blinking and input/output tests, while the PCB scans its servo channels to confirm that every connected servo is present and electrically responsive.

2. **Head / audio subsystem boot**

   After initial power checks, the upper ESP32 dedicated to the head, eyes, and audio initializes the display electronics that drive the eye animations and releases the PAM8403 amplifier from standby into an active, ready state. To give an immediate, human-readable confirmation of correct startup, the head firmware runs a short eye animation and emits a brief audio beep, signalling that the expressive interface and sound system are operational.

3. **Main controller boot & handshake**

   In parallel or immediately after, the lower ESP32 acting as the main motion controller loads its navigation, pose, and control routines, preparing the algorithms that will manage walking and serving actions. It then establishes a communication handshake with the head ESP32 over a serial or I2C link.

4. **PCB enumeration and servo mapping**

   Once controller communication is confirmed, the servo distribution PCB performs an enumeration routine in which the main ESP32 queries or lightly pulses each servo channel to verify that a motor is connected and responsive. Based on these responses, the system logically maps channels into structured groups for the right and left limbs-typically six servos per side-so that subsequent gait and pose commands can address each limb in a consistent, organized way.

5. **Safety & pre-checks**

   Before allowing any significant actuation, the main ESP32 executes a series of safety checks that include measuring battery voltage, verifying regulator output levels, reading the emergency-stop input, and ensuring no servo reports abnormal load or stall conditions. If any of these safeguards detect a problem, the controller immediately enters a safe mode: servo torque is disabled to prevent damage, and a message is sent to the head ESP32 so that the eyes can display an error expression and an alert tone can be played, making the fault visible and audible.

6. **High-level command / mode selection**

   When the system passes safety checks, a high-level command from the dashboard, remote input, or an internal autonomous routine selects the robot’s operating mode, such as Idle, static Pose, Walking, Pick/Place, or Demo. The main ESP32 then sends a concise “mode” packet to the head ESP32 so that the facial expressions and any spoken or tonal feedback align with the chosen behavior, keeping the robot’s external appearance synchronized with its internal state.

7. **Trajectory / pose planning**

   With a mode selected, the main ESP32 computes the detailed motion plan by generating target positions for each servo involved in the action, either through inverse kinematics calculations or by loading predefined gait and pose sequences. These calculations produce time-stamped setpoints that describe how every joint should move over time, ensuring that the resulting motion is coordinated, balanced, and suitable for tasks like carrying a tray or interacting with users.

8. Command distribution to PCB

The main ESP32 then converts the planned trajectories into compact servo command packets-typically containing servo ID, desired angle, and timing parameters-and transmits them to the servo PCB over a fast communication link. Acting as a distribution layer, the PCB receives these packets and routes the appropriate setpoints to the corresponding servo channels for the right and left limbs, ensuring each joint receives its specific command at the correct moment.

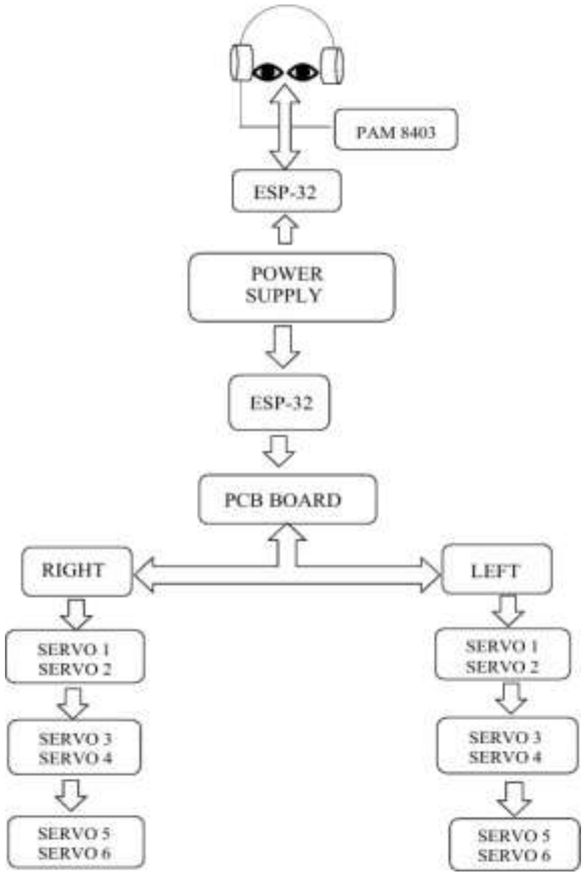

Figure 2: Work Flow of Serving Robot

9. Servo interpolation & actuation

Depending on the design, either the PCB performs interpolation between setpoints to generate smooth PWM signals, or the main ESP32 sends already-interpolated values while the PCB simply forwards them to the servos. In both cases, the goal is to move each servo gradually according to predefined speed and acceleration limits, avoiding jerky motions and enabling fluid, natural-looking movements that protect the mechanical structure and maintain payload stability.

10. Head feedback & audio

Throughout and after movement execution, the head ESP32 receives status updates from the main controller. Using this information, it updates the OLED eyes and other head indicators to reflect the robot's state and, when appropriate, activates the PAM8403 amplifier to play speech or tones-such as "delivery complete," error notifications, or friendly chimes-providing clear, real-time feedback to users and closing the loop between internal control logic and external human-robot interaction.

3.3 3D CAD Design of Humanoid Robot Structure

Figure 3: Upper part

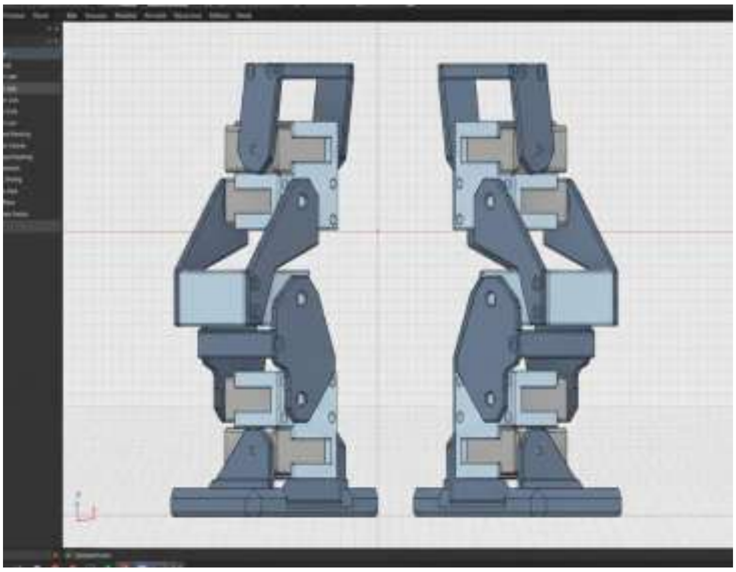

Figure 4: Lower part

3D CAD models were created to define both the leg mechanism and the upper-body structure of the serving robot. The first model shows the multi-link leg assemblies with stacked joints and servo mounting points arranged to support stable bipedal motion and height adjustment. The second model illustrates the torso, head and tray-holding arms, where the geometry is optimized to house electronics while keeping the tray level and centered for safe food carrying.

3.4 Hardware and Software Tool requirements

This little humanoid robot packs all essentials for delivering food on its own and actually interacting with people. It's got powered arms to hold tray, OLED eyes that can show expressions and sturdy legs that help it move in a way that feels surprisingly human. This built-in sensors keep it balanced, let it dodge obstacles and make sure it knows what it's carrying. The main electronics handle two big jobs, they are, Serving Mode where it uses timed maps to navigate (and nails accuracy at about 95%) and a Q&A mode that talks to people using text-to-speech, pulling answers straight from a dashboard-managed database. We get order management, maps, manual controls, switching between modes, battery monitoring and safety features all in one spot. Below Table 1 is an overview of the primary components used,

Table 1: List of Components

Sl. No	Components Name
1.	3D Printed Body
2.	MPU 9250
3.	0.96o led i2c
4.	3w mini speaker+ pam8403
5.	INMP441 microphone module

INMP441

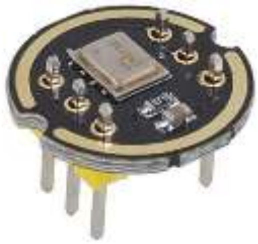

Figure 5: INMP441

Use

- The INMP441 digital MEMS microphone serves the function of taking in pure voice inputs from the users allowing the robot either to record or process spoken queries meant for the Q/A system.
- It utilizes the I^2S digital audio interface to connect to the ESP32, thus removing the requirement of an additional ADC or audio codec and making the head electronics small.

Amplifier Module

Figure 6: PAM8403

Use

- The PAM8403 class-D audio amplifier module directly powers the 3 W speaker connected to the ESP32’s audio output, increasing the weak signal to a level that the robot can distinctly produce the Q/A responses and alerting sounds.
- The component is very compact and its 5 V operating voltage make it very convenient for mounting in the robot’s head and using the already installed low-voltage supply as power source.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Navigation Test Results

The serving robot was tested under different indoor conditions to evaluate its ability to navigate predefined paths smoothly. The robot demonstrated stable forward motion with consistent wheel traction on tile and cement flooring. During repeated tests, the average path deviation remained within 3–5 cm, which is acceptable for indoor service applications. The robot successfully followed straight and curved routes without abrupt stops or unstable movements. The test results confirm that the Servo motor–based drive system provides adequate torque and control for routine serving tasks.

4.2 Obstacle Detection Performance

Ultrasonic sensors were placed at the front of the robot to detect obstacles in real time. The detection accuracy was evaluated at distances between 5 cm and 70 cm. Key observations include,

- The robot reliably detected obstacles above 5 cm in height.
- Average sensor response time was approximately 25–35 ms.
- The robot halted immediately when an object appeared within the safety threshold of 15–20 cm.
- False triggers were minimal when tested under proper indoor lighting.

4.3 Web Dashboard Results

The robot's obstacle avoidance system ensured safe navigation in environments where people frequently move, such as dining halls or hospital corridors. To enhance monitoring and user control, a web-based dashboard was developed and integrated with the serving robot. The dashboard allows users to view real-time robot status, battery level, sensor readings, and send control commands remotely. The interface was tested on both mobile and desktop devices. **Real-Time Updates:** The dashboard successfully displayed live ultrasonic sensor values, robot speed, and connection status with negligible latency (approximately 100–150 ms).

Remote Control: Users were able to start/stop the robot, adjust speed, and select service routes through the web dashboard. Commands were transmitted consistently without packet loss. **Monitoring Features:** The dashboard visual elements, such as status indicators and on-screen warnings, responded correctly when obstacles were detected during operation.

- **UI Performance:** The dashboard interface remained responsive with smooth transitions and quick loading times in tests conducted on Wi-Fi networks. This addition significantly improves the usability of the serving robot by enabling staff to supervise and control robot operations from a distance, reducing manual intervention and enhancing automation

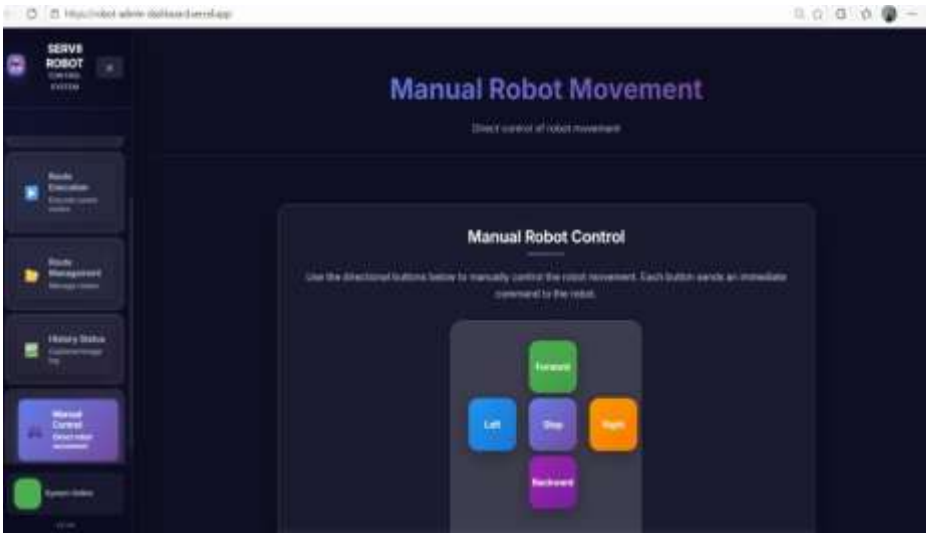

Fig 7: Web Dashboard

4.4 System Efficiency and Performance Evaluation

Several metrics were analyzed to evaluate the overall efficiency of the serving robot, shown in Table 2.

Table 2: System efficiency and performance evaluation

Parameter	Measured Value	Remarks
Average Speed	0.25–0.35 m/s	Suitable for indoor service
Obstacle Detection Accuracy	~73%	High reliability
Path Deviation	3–5 cm	Acceptable for indoor delivery
Load Capacity	1. kg	Holds typical food/drink items
Battery Backup	1–2 hours	Depends on load and motor usage

These results demonstrate that the robot is efficient enough for real-time service tasks in controlled indoor environments.

4.5 Final Working Model

The final prototype successfully integrated all modules-navigation, sensing, load carrying, and power management-into a functional serving robot. The robot performed the full serving cycle, including:

- Moving from the base station to the destination
- Avoiding obstacles

- Carrying and delivering items

The working model proved reliable in multiple tests runs and validated the feasibility of using low-cost autonomous robots for serving-related tasks.

Figure 8: Front view

Figure 9: Side view

Figure 10: Expressive OLED Humanoid Server

CHAPTER 5

ADVANTAGES AND APPLICATIONS

5.1 Advantages

Human Workload Reduction: The robot takes over the food delivery operation and thus reduces reliance on waiters along with the exhaustion of the staff.

Service Efficiency Improvement: With its precise navigation and rapid delivery, the robot guarantees the serving of the food on time thus enhancing the overall customer's experience.

High Delivery Accuracy (≥85%): The combination of the robot's sensors and the IMU allows for very accurate motion control and proper table delivery with almost no mistakes.

Contactless and Hygienic Service: The robot makes it possible to reduce the interaction of humans to the minimum required by the job and at the same time to keep the area clean particularly beneficial in hospitals, restaurants and cafes.

Constant Performance: Machines do not feel tired or under pressure, hence they can deliver the same quality of service all day long.

Customer Interaction Improvement: The robot with OLED expressive eyes, voice output and Q/A Mode functionality is capable of customer assistance resulting in active engagement.

Real-Time Monitoring and Control: Through the web dashboard, route configuration, order assigning, robot surveillance and manual control are all possible for uninterrupted flow of work.

Safe navigation and Obstacle Avoidance: The combination of ToF, ultrasonic sensors and IMU guarantees collision-free and safe movement even in heavily populated areas.

Commercial Reliability: It is designed for long operational hours, strong construction and reliable power supply, thus being perfect for restaurants, malls, hotels and offices.

5.2 Applications

Restaurants and Cafes: It automates the delivery of food from one table to another, enabling restaurants to handle peak service time, increase efficiency and provide contactless service to customers who can trust it.

Hotels and Hospitality: Room service for meals, amenities or information which would be available around the clock and would skill-fully and positively an hour or two of staff member's time.

Corporate and University Campuses: The distribution of food orders is done across large, pedestrian-friendly environments making routine deliveries to staff and students without human couriers.

Smart Cities & Mixed-Use Districts: The integration with urban logistics system supports the last-mile food delivery, thus, being a part of a wider automation and smart city initiative.

Retail & Addressing: It can exhibit marketing content or acts as a mobile platform for branded interaction and customer assistance in retail areas.

Assistive Support: It helps older or disabled people get food delivery easier especially in controlled places like assisted living centers.

Senior Living and Assisted Facilities: A resorted lifestyle with efficient meal delivery and communicative support for seniors, intensifying the living support through secure, self-governing functioning.

Warehouses and Factories: Provides organizational services for internal canteens or break-rooms coupled with inventory system integration for workers’ food supply throughout their working hours.

CONCLUSION

The humanoid food-serving robot is managed by an ESP32 acts as the brain connecting to different sensors and motors for carrying out independent functions. The robot applies obstacle detection and path-planning algorithms to move in dynamic surroundings without colliding. Servo motors drive the humanoid arms and tray systems which can handle the food with great precision and stability. Input from sensors such as infrared and ultrasonic sensors is always checked so that the navigation, tray balancing and human interaction can be done in real-time. The software for the system is written using the Arduino IDE taking advantage of the motor and sensor libraries for quick prototyping and effective control. Hardware reliability including having a steady power supply and good wiring has been given a priority, thus ensuring performance is not interrupted. The tests and recalibrations of the robot's movement, tray stability and reaction to the obstacles are performed regularly and gradually; this would enhance the robot's functionality thus leading to a self-sufficient, speedy and user-friendly food-serving system that can bring the food safely to the users who need assistance.

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APPENDIX

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