A Multilingual Restaurant Serving Robot Request Management System

Abimbola R. Iyanda, Toheeb A. Azeez
Department of Computer Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

ABSTRACT

The Multilingual Request Management Restaurant Serving Robot was developed as a solution for revolutionizing the restaurant industry by addressing language barriers and improving customer service through the application of advanced robotics and language processing technologies. The implementation phase involved the development of a web-based ordering system that allowed customers to place orders from their tables via a web interface. This system was hosted on an Espressif32 (ESP32) microcontroller, acting as a hotspot. Customers connected to it and placed orders through a web page. The ESP32 served as a web server, processing requests and communicating them to an Arduino mega, which controlled the robot's actions. Performance evaluation included testing the system's accuracy, efficiency, and overall effectiveness in handling multilingual customer requests. Various real-world scenarios were simulated to test the robot's performance in different situations. This included testing for handling customer orders with various language selections, obstacle avoidance during navigation, and successful delivery of food. Users' feedback was collected to assess performance and identify areas for improvement. The potential impact of this work on the restaurant industry is significant, as it demonstrates the potential for wide acceptance of multilingual restaurant serving robots. The Multilingual Request Management Restaurant Serving Robot can enhance customer experiences, streamline restaurant operations, and promote cultural inclusivity. It represents an innovative solution to language barriers in customer service, contributing to the advancement of robotic technology and its applications in the service sector.

KEYWORDS

Request Management
Service Robots
Restaurants
Multilingual
Order
Customer

1. INTRODUCTION

Robotic advancements have given rise to innovative designs and systems capable of understanding human actions and even thoughts. Some robots are designed for social and physical interactions, particularly in assisting and serving people. Robot waiters, for example, address the challenges of serving in restaurants, where they significantly enhance service efficiency. These robots can take orders, move within the restaurant, and serve customers. They outperform human waiters by serving up to 400 meals daily compared to an average of 200. This technology is revolutionizing the food and beverage industry, improving service quality and efficiency (Garcia-Haro *et al.*, 2021).

Modern culture is increasingly shaped by technological progress, influencing all aspects of daily life. The field of robotics is rapidly expanding worldwide, offering new opportunities and breaking down technological barriers (Aydin, 2021). This trend extends to the hospitality industry, traditionally known as a people-centric sector. However, technological innovations such as self-service kiosks, augmented and virtual reality, chatbots, and blockchain are now being employed in the hotel industry, including restaurants. A notable addition to this technological toolkit is the integration of robots, reflecting a broader shift towards automation and enhanced guest experiences (Israel *et al.*, 2019).

Robots and automation are being employed by businesses to optimize processes, increase competitiveness, deliver better service, and reduce expenses. The COVID-19 pandemic has further fueled the adoption of contactless services, allowing remote delivery of services. However, the long-term use of robots and automation will face challenges related to demographic shifts and labor shortages in developed economies (Ivanov, 2021). Robots offer the advantage of continuous 24-hour work, which humans cannot match, contributing to labor reduction in various fields, and ultimately saving time and costs. The widespread adoption of robots in restaurants is a recent development driven by a shortage of human waitstaff. Rapid advancements in robotics technology have introduced innovative approaches, including reading human thoughts, benefiting not only the elderly, ill, and injured but also the military, where robots serve as luggage carriers (Newaz *et al.*, 2020). These robots, often referred to as social robots, play a crucial role in recognizing social cues, engaging in conversations, and integrating into various aspects of society. Their adaptability and ability to comprehend human thoughts and actions make them versatile in assistive robotics. While robots currently learn from humans, the future envisions robots as instructors, marking a transformative shift in human-robot interaction (Yanmida *et al.*, 2020).

Robots are evolving to seamlessly blend into human environments, serving roles in entertainment and assistance, particularly in industries like hospitality where robotic waiters are gaining prominence. Researchers are innovating with technologies such as wireless call systems, waiter robots, self-service ordering systems, and menu recommenders to enhance efficiency. Ensuring natural and intuitive human-robot communication is critical as robots increasingly engage intimately with people in common settings. These developments reflect a broader trend in robotics, where machines aim to become more integrated into everyday life, assisting with laborious tasks and providing entertainment (Kamruzzaman & Tareq, 2017).

Modern production methods rely on machine vision and Global Positioning System (GPS) technologies. The agricultural sector has been profoundly impacted by advancements in electronics, smaller computers, and smarter chips, leading to processes that are more efficient. The growing interest in autonomous vehicles stems from improved data transfer, enhanced computing power, and rapid data processing, promising increased accuracy and productivity. Path planning is a central challenge in robotics, with two distinct approaches: reactive, relying on sense-act couplings for autonomous behavior with low-level control, and deliberative, using a top-down strategy to detect key environmental aspects, plan actions, and execute them efficiently (Akhshirsh *et al.*, 2021).

Corresponding Author: A.R. Iyanda (*abiyanda@oauife.edu.ng*)
Received 7 March 2024 | **Received in revised form** 24 May 2024 | **Accepted** 2 June 2024 | **Available online** 7 September 2024
The editor responsible for coordinating the review of this article and approving its publication was *I. P. Gambo*.
1115-9782

The traditional restaurant service model faces difficulties in handling customer requests in a multilingual context, leading to miscommunication and subpar dining experiences. Current solutions like bilingual staff or translation apps are often inefficient. Hence, a Multilingual Request Management Restaurant Serving Robot is needed to overcome language barriers, ensuring smooth dining experiences. This robot must accurately interpret diverse customer requests and understand regional dialects and nuances as achieving natural, friendly interactions with customers is crucial (Zhang, 2022). This is in line with the outcome of the pretest carried out. Addressing these challenges requires research in natural language processing, machine learning, robotics, and human-robot interaction. Such a robot will enhance customer satisfaction, streamline restaurant operations, and create an inclusive dining environment. Therefore, in harmony with these opinions, the study develops a Multilingual Request Management Restaurant Serving Robot using three indigenous Nigerian languages (Hausa, Igbo and Yoruba) in addition to English, the lingua franca in Nigeria that can be used by vast majority in request management.

Section 2 presents a comprehensive review of the relevant literature, exploring existing research, technologies, and methodologies related to multilingual communication, robotics, natural language processing, and human-robot interaction in the context of restaurant service. Section 3 describes the research methodology, including the design process, and system architecture employed in the study. Section 4 presents the system implementation. Section 5 discussed the conclusion and recommendation.

2. THEORETICAL FRAMEWORK

The study stands on well-established theories interpreted within the context of the ubiquity of modern technologies. Business transactions and economic growth between people of diverse language and cultural backgrounds have become widespread in today's globalized world, whether through physical mobility or technical means of communication, and appear to be a driving factor in the global economy. However, language barriers often exclude individuals and groups, emphasizing the importance of effective communication in both political and corporate spheres. This is particularly relevant in multilingual countries like Nigeria, where linguistic skills are essential for seamless business and social interactions. Multilingualism has gotten significant attention. Given that a unified country necessitates persons with linguistic skills, residents must be able to do business and carry out their social and economic responsibilities without being hindered by communication barriers (Aronin and Singleton, 2012). The theory of multilingualism in e-commerce suggests that incorporating multiple languages in electronic transactions can enhance user experience. Multilingual devices enable businesses to reach diverse prospects cost-effectively. Jake (1998) emphasized the importance of interacting with customers in their native language for market success.

Technology Acceptance Model (TAM) is an information systems theory that models how users come to accept and use a technology (Davis, 1989). Through the use of TAM, users' attitude or behavior across a broad range of technologies and user population is explained. The Application Framework (TAM) is a sub-component of the Open Digital Framework, TM Forum's blueprint for enabling successful business transformation. It provides a common language and means of identification for patrons and staff all software application areas.

The Diffusion of Innovation (DOI) Theory (Rogers, 2003) elucidates how an idea, behavior, or product gradually gains traction and spreads within a specific population or social system over time. Adoption involves individuals embracing new behaviors or products, perceiving them as novel or innovative. DOI facilitates adoption by highlighting perceived benefits over traditional methods, alignment with existing operations and cultural norms, and the ability to trial the innovation before widespread adoption. Visibility of benefits to stakeholders also plays a pivotal role. This theory underscores the importance of perceived novelty and value in driving the diffusion process, shaping the acceptance and integration of innovations like the restaurant serving robot into societal contexts.

The Unified Theory of Acceptance and Use of Technology (UTAUT) examines the acceptance of technology, determined by the effects of performance expectancy, effort expectancy, social influence and facilitating conditions (Venkatesh *et al.*, 2016). The effect of predictors is moderated by age, gender, experience and voluntariness of use. Performance Expectancy is the belief that using the robot system will lead to better performance in restaurant service. Effort Expectancy: is the ease of use associated with the robot system. Social Influence is the degree to which peers, customers, and industry standards influence the acceptance of the robot system. Facilitating Conditions is the availability of resources, support, and infrastructure to support the use of the robot system.

Human-Robot Interaction (HRI) is the science of studying people's behavior and attitudes towards robots in relationship to the physical, technological and interactive features of the robots. This is with the goal to develop robots that facilitate the emergence of human-robot interactions that are at the same time efficient (according to original requirements of their envisaged area of use), but are also acceptable to people, and meet the social and emotional needs of their individual users as well as respecting human values (Dautenhahn, 2013). This theoretical framework provides a comprehensive understanding of the factors influencing the adoption and successful integration of Multilingual Restaurant Serving Robot Management Systems. By considering technological, organizational, and environmental factors, along with key theories of technology acceptance and human-robot interaction, restaurants can strategically plan and implement these systems to maximize benefits and address potential challenges.

3. LITERATURE REVIEW

The field of robotics has garnered significant attention in recent years, finding applications in various sectors like healthcare, education, elderly care, and automotive industries. Robotics is seen as a transformative technology with immense potential to shape daily life. Understanding its future impact is crucial. Researchers believe that robotics will continue to evolve, offering endless possibilities and innovations (Matthew *et al.*, 2022). This technology's growth and adaptability promise to influence and improve numerous aspects of our lives in the near future.

The term "robot" was coined in 1920, introducing the concept of artificial workers devoid of emotions. Since then, the world of robotics has evolved immensely. Today, robots powered by AI are transitioning into digital citizens. They play an integral role in modern life, revolutionizing industries and enhancing convenience. Early industrial applications of robots included unloading components in die-casting facilities, with Japan pioneering robotic production lines in the 1940s.

Advancements in artificial intelligence and robotics have not only influenced industries but also led to the establishment of ethical guidelines, known as the "laws of robotics." These laws aim to prevent misuse of the technology. Robots are now widely used in maritime exploration, manufacturing, the military, agriculture, space exploration, and more, performing repetitive tasks efficiently.

Furthermore, robotics has given rise to software capable of identity theft prevention and generating relevant content for search engine queries. Sentiment analysis software is employed by businesses to understand public perception, enabling improved marketing and prompt response to negative feedback. The future holds increasing utilization of robots beyond traditional industries and businesses.

3.1. Types of Robots

Robots come in various types, each serving specific purposes. Industrial robots are used in factories for tasks like welding, painting and assembly tasks (Arents, 2022; Evjemo *et al.*, 2020). Service robots aid people with tasks like vacuuming and medical procedures (Wirtz *et al.*, 2018). Military robots, including drones and underwater vehicles, assist in surveillance and bomb disposal (Szegedi, 2017). Educational robots are employed in schools to teach students (De Cristoforis *et al.*, 2013). Entertainment robots provide amusement in theme parks and toys (Bogue, 2022). Medical robots, especially in rehabilitation and prosthetics, enhance the quality of life for disabled patients (Bucolo *et al.*, 2020). These diverse robot types cater for different industries and applications, demonstrating the versatility and significance of robotics in today's world.

3.2. Application of Robotics in the Industry

The field of robotics encompasses the development of machines capable of replicating human behavior, finding applications in diverse sectors. Presently, robots play pivotal roles in hazardous environments, such as bomb detection, radioactive material inspection, and hazardous material containment, as well as in manufacturing processes where human involvement is unfeasible. Diverse in form, robots may resemble humans to facilitate acceptance in roles mirroring human actions like thinking, lifting, speaking, and walking. A notable trend is the emergence of bio-inspired robotics, drawing inspiration from nature.

While some robots operate autonomously, others require user input to function. The idea of autonomous robots has existed for centuries, but significant progress in understanding their capabilities and potential uses emerged in the 20th century. Throughout history, many scholars, inventors, engineers, and technicians have envisioned robots eventually performing tasks in a human-like manner and replicating human behavior. As robotics technology advances, its applications continue to expand, ranging from hazardous tasks to manufacturing and even mimicking human actions. The trajectory of robotics suggests a promising future, positioning robots as versatile tools across diverse industries, contributing to increased efficiency and safety.

In contemporary times, robotics finds extensive utilization, particularly in sectors such as healthcare, agriculture, education, manufacturing, military, and food processing. The food processing industry assumes a pivotal role in converting agricultural raw materials into consumable products, emphasizing customer satisfaction through enhanced distribution, quality, and convenience. Historically dominated by manual methods, the industry has transitioned to fully or partially automated solutions, driven by population growth, evolving customer preferences, heightened demand, and technological advancements (Iqbal *et al.*, 2017). These technologies have enabled the industry to enhance supply chain performance, ensure efficient food supply management, and improve overall operational efficiency. As a result, automation has become an indispensable part of the food processing sector, providing a wide range of benefits that contribute to its competitiveness and safety.

The impetus for automation in the food industry emanates from diverse factors, including fluctuating demands, process modifications, internal organizational challenges, human resource considerations, and external factors. Automation is prominently evident in tasks such as seeding, harvesting, cutting, processing, and packaging within the food processing sector. Furthermore, these robotic applications extend to industries such as beverage, dairy, and chocolate, encompassing activities like bottle cleaning, container filling, and product arrangement on conveyor belts (Iqbal *et al.*, 2017).

The adoption of robotic systems in food processing offers numerous advantages, including increased productivity, enhanced product quality, improved profitability, heightened cleanliness and safety standards, and enhanced worker safety. Additionally, the use of robotic systems reduces labor costs and minimizes workplace injuries. The integration of automation in the food industry has revolutionized its operations, ensuring efficiency, safety, and quality throughout the production process.

Restaurant automation has evolved to encompass comprehensive operational systems, transforming how restaurants operate. The concept of automation in restaurants dates back to the 1970s when some eateries, known as automats, served food through vending machines, allowing customers to place orders directly. Modern automation integrates technology in various aspects, from food preparation to billing. Some establishments have embraced full automation, utilizing robots to supplement or replace human roles like waiters and chefs. This shift not only enhances efficiency but also introduces a higher level of customization, empowering customers to personalize their orders. The ongoing evolution of restaurant automation highlights the pivotal role of technology and robotics in shaping the dining experience, offering convenience and efficiency. The continuous advancements in this field display a trajectory towards a more streamlined and customer-centric approach to restaurant operations.

3.3. Related Works

A series of studies that contribute to the evolving landscape of service robots in the hospitality industry were examined, each presenting unique approaches, innovations, and insights. Acosta *et al.* (2006) initiated their exploration by focusing on creating a specialized service robot tailored for restaurant duties. The primary tasks targeted were gathering and cleaning objects, employing an object-matching strategy to proficiently identify and collect various items, including dishes, glasses, bottles, spoons, forks, and knives. Despite the robot's adeptness in classifying and collecting items, the study highlighted a significant limitation in that it lacked customer interaction and food service capabilities, emphasizing a deficiency in communication aspects within its design.

Jang and Lee (2020) took a different perspective, delving into the impact of characteristics exhibited by serving robots on customers and their dining experiences. The identified attributes (anthropomorphism, intimacy, likability, intelligence, and safety) became the focal points of investigation. The study aimed to explore the correlation between these robot attributes and various customer-related metrics, including happiness, perceived advantages and risks, perceived value, and the likelihood of customers returning. Significantly, the research underscored the importance of employing goal-oriented robots without human errors, collective consciousness, and genetic memory in the restaurant industry. It emphasized the interconnectedness between robot attributes and customer perceptions and behaviors, shedding light on the complex dynamics shaping the human-robot interaction landscape.

Yanmida *et al.* (2020) contributed to the discourse by developing an autonomous transport robot specifically tailored to address food service challenges in traditional cafe settings. Their innovative methodology introduced a model delivery robot integrated with a remote order placement system. A novel RFID-based method for table detection and mobile robot localization in indoor settings was proposed, highlighting efficiency in the robot's ability to navigate to tables, take customer orders, and return to the kitchen by following a designated blackline path on the floor. Despite these achievements, the study highlighted a potential enhancement area in that the system's computational power, relying on the Arduino Mega, could benefit from a more robust microcontroller to enhance RFID tag detection accuracy.

Thanh (2019) introduced an eatery-serving robot employing a line-following method, programmed to navigate specific tables by following marked lines on the floor. Equipped with ultrasonic sensors to detect obstacles, the robot demonstrated its ability to issue a warning signal when necessary. Notably, the robot exhibited multilingual communication capabilities, addressing customers in Korean, English, and Vietnamese, offering greetings and messages. Despite these capabilities, areas for improvement were identified, such as the need for a tuning algorithm controller to enhance the robot's turning motion and the potential for expanding its language capabilities.

Naidu and Srinivasa (2023) developed a prototype for a Smart Restaurant Multi-Purpose Serving Robot, aimed at enhancing service delivery in restaurant settings. The robot employs advanced technologies including remote sensing, a USB camera, Kinect V2 sensor, and the SLAM algorithm for precise navigation. It is equipped with a robotic arm featuring a soft gripper and speech capabilities in English, enabling it to perform a variety of tasks. During testing, the robot successfully navigated to designated tables, avoided obstacles, and interacted with customers effectively. It also possesses additional functionalities, such as floor cleaning. The study demonstrates the feasibility of implementing such multi-functional robots in real-world restaurant environments, showing significant potential for improving operational efficiency and customer service. The results underscore the benefits of integrating robotics into restaurant operations, making a strong case for their practical application in the industry.

Yang and Chew (2021) delves into the incorporation of intelligent robots in the hospitality sector, addressing issues in human-robot interaction, user experience, data confidentiality, and service intelligence. The iRCXM model, combined with a decision tree algorithm, is introduced to enhance human-robot interactions by categorizing users and facilitating smooth transitions. The model offers strategies for issue resolution, aiding companies in timely adjustments. A robot user interaction system, utilizing Android, face recognition, and robot control through Baidu Cloud AI API and Sanbot-OpenSDK, validates the model's feasibility. Future research focuses on refining the iRCXM model with AI techniques, incorporating visual, image, and tactile sensors for automatic satisfaction and emotion analysis. The study advocates for more natural language conversations between service robots and customers, suggesting the use of 5G communication for real-time interactions. Multilingual robot development is proposed to address diverse consumer backgrounds and language challenges in the global hospitality landscape. The study recommends adopting frameworks like Tokku RT Special Zones in Wales to obtain customer consent for robot-collected data.

These studies highlight diverse approaches to integrating service robots into restaurant environments, each addressing specific challenges and highlighting successes and areas for improvement in design and implementation. However, there is a noticeable gap in research involving African languages, especially Nigerian languages. Highlighting the potential for developing a multilingual restaurant serving robot request management system will enhance customer satisfaction, streamline restaurant operations, and create an inclusive dining environment that transcends language barriers.

4. METHODOLOGY

The Methodology adopted for this work is the System development life cycle (SDLC), which provides the method, structure, controls, and checklist needed to ensure successful system development. The basic activities of the game development process employed in this work include requirement gathering, design, implementation, testing.

Requirement gathering is a critical phase in system development that involves collecting and documenting the needs and expectations of stakeholders for a new or modified product or system. The stakeholders were identified. The internal stakeholders (staff, management, IT team). The external stakeholder (customers). Surveys/Questionnaire was distributed to the customers to gather feedback on language preferences and user experience.

The 14-item questionnaire was used for pretest as shown in Figure 1. Face validity was used to validate the survey given the questionnaire to people who understand our topic read through and make comments until the final one was agreed upon

4.1. System Design

The restaurant serving robot study aims to develop an autonomous robot capable of taking customer orders, delivering food to designated tables, and providing multilingual voice feedback. The study seeks to enhance the dining experience in restaurants by automating the ordering and food delivery process, reducing customer waiting times, and providing a seamless and interactive dining experience.

The System Analysis and Requirement Gathering Phase focuses on collecting and validating user requirements to create a specification for the proposed system. The goal is to support three entities: customers placing orders, kitchen staff preparing food, and the delivery robot. The system aims to serve customers efficiently, as illustrated in Figure 2. Three main components, work together to ensure efficient order processing, food delivery, and customer communication.

- Sex
- Marital status
- Age
- Did you find the restaurant/Café family-friendly?
- How do you prefer getting your meals?
- How often do you visit restaurants?
- How do you prefer visiting a restaurant?
- How often did you visit a robot service restaurant/café outside Nigeria?
- With whom did you visit the restaurant/café?
- How would you feel if you found out your waiter/waitress is a robot?
- How confident are you interacting with a service robot in a restaurant/café? (If you are chanced to have one)
- Which languages will you prefer when interacting with a service robot in a restaurant/café (Select all that apply)?
- Have you used a robotic machine before? (e.g. Sanitizer dispenser)
- Do you feel a robot service restaurant/café will increase the output of a restaurant?

Figure 1: Questionnaire items

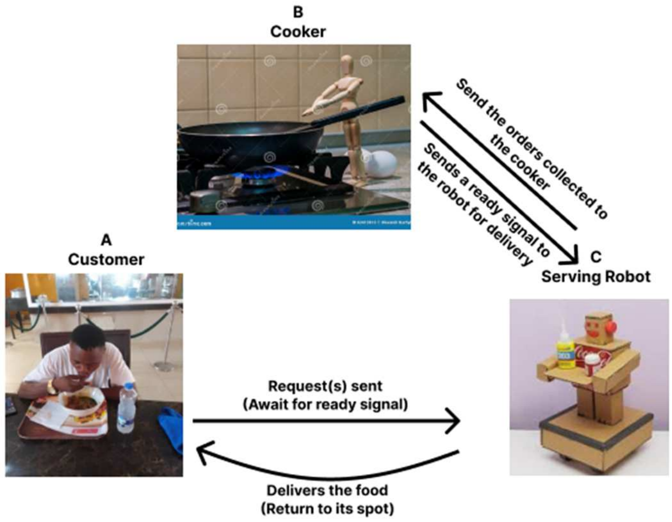


Figure 2: Proposed model of the restaurant serving robot

The hardware aspect of the work is essential for understanding the system's physical components and their relationships. This information is crucial for software development and integration. Figure 3 illustrates the study's overall architecture, providing a comprehensive view of the hardware setup. The system architecture and design of the restaurant serving robot are integral to its seamless operation.

The web-based customer ordering system facilitates customer interactions. It allows patrons to connect to the robot's ESP32 web server and place orders from their tables. A user-friendly web interface permits language selection, table number input, and food type selection. The ESP32 acts as a hotspot, providing Wi-Fi access for customers to connect to the system and place their orders. ESP32 offers considerable processing power and versatility, which are essential for implementing advanced features like real-time data processing and remote updates

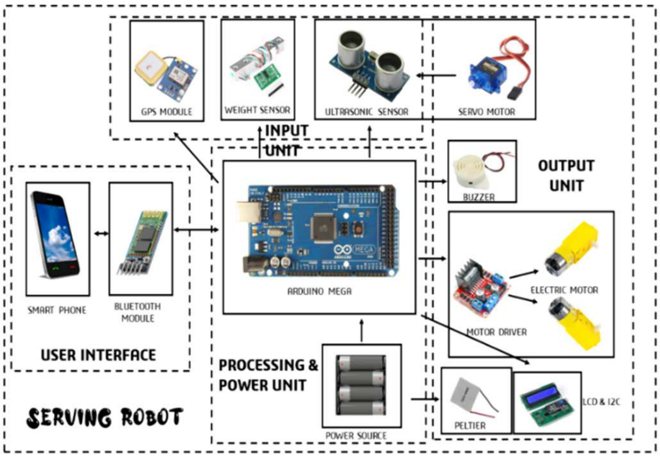


Figure 3: System Architecture

The robot's control and navigation system utilizes an Arduino Mega microcontroller as the brain of the robot, receives and processes orders from the ESP32 web server. It manages navigation and obstacle avoidance, calculating distances and directions to reach tables while considering potential obstacles. Ultrasonic sensors detect obstructions, and the robot adjusts its route accordingly. A weight sensor (HX711) ensures accurate food weight detection, and a servo motor places the food on the table. Arduino Mega is chosen for its extensive I/O pins, large memory capacity, and robust processing power compared to other microcontrollers in the Arduino family. This makes it ideal for handling multiple sensors and actuators simultaneously in a complex system like a restaurant serving robot. The HX711 weight sensor is chosen for its high precision and reliability in measuring weights, which is crucial for ensuring accurate portion control and load management when the robot carries food items

The multilingual voice feedback system enhances customer interaction. It includes a RedMP3 speaker and voice files in multiple languages. Based on the customer's language selection during ordering, the robot plays the corresponding voice file. The RedMP3 speaker communicates with the Arduino Mega via software serial communication. It provides feedback upon successful order placement and announces the robot's arrival at the designated table.

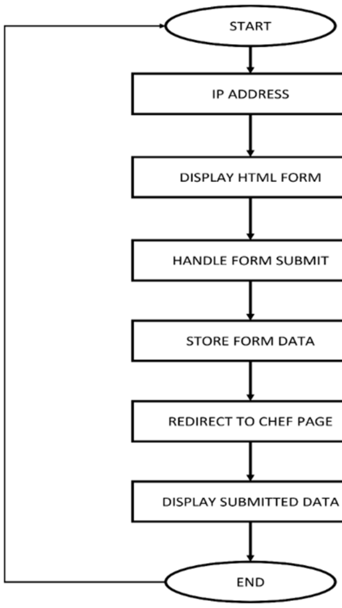


Figure 4 Flowchart for Ordering Form

This system design ensures efficient, customer-oriented service, addressing the challenges of language barriers in restaurant settings. Figure 4 shows the ordering form, allowing customers to place orders in their chosen language. The ordering form is managed by the robot for effective and proper request handling. The sequence diagram that provides a standard way to visualize the design and how the request being made from the interface gets delivered to the robot is shown in Figure 5.

5. SYSTEM IMPLEMENTATION AND TESTING

5.1. Technologies and Tools

The robot's hardware components include an Arduino Mega for control, an ESP32 for customer connectivity, an HX711 Weight Sensor for accurate food weight detection, an Ultrasonic Sensor for obstacle avoidance and distance measurement, a Servo Motor for precise food placement, Electric Motors for wheel movement, and a Buzzer for audio feedback and alerts. These components work together to create a functional and interactive robot capable of processing orders, navigating obstacles, and delivering food to customers.

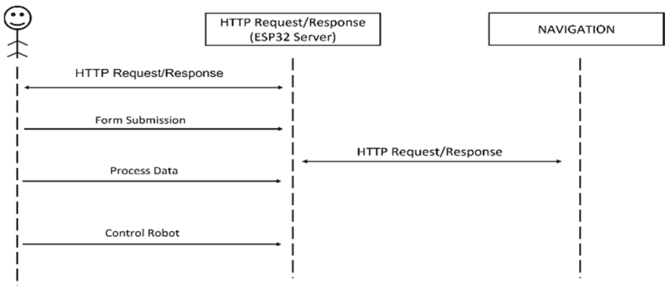


Figure 5: Sequence diagram for the Ordering interface

The software setup for the restaurant serving robot study involved three main tools:

i. Arduino IDE: This Integrated Development Environment was essential for programming the Arduino Mega and ESP32 microcontrollers. It enabled the development of code to control hardware components and manage system communication.

ii. RDworks: RDworks software was used for laser cutting the acrylic materials used in constructing the robot's frame. It provided a user-friendly interface for precise pattern creation based on Solidworks CAD designs.

iii. Solidworks: Solidworks was employed for Computer-Aided Design (CAD) modeling of the robot's frame, serving as the blueprint for laser cutting the acrylic material to construct the physical structure.

Figure 6 shows the prototype of the design.

Figure 6: Prototype design of the robot

Web Technologies, including HTML, CSS, and JavaScript were used to build the web-based ordering system on the ESP32 server. AJAX enabled dynamic order handling without page reloading, improving user experience. The implementation phase involved hardware integration, programming, and extensive testing to ensure reliable robot performance, addressing unique challenges posed by combining hardware and web components with innovative solutions.

5.2. Integration and Connection of Hardware Components

The integration and connection of hardware components in this study involved several key steps to ensure proper functionality and communication between the various parts of the system:

Serial communication was established between the Arduino Mega and ESP32, where the Arduino Mega acted as the host, communicating with the ESP32 as the client. This connection facilitated the exchange of order data between customer devices and the robot. The ultrasonic sensor was connected to the Arduino Mega using digital pins for trigger and echo signals. The sensor emitted ultrasonic waves, and the Arduino Mega measured the time taken for the waves to bounce back, allowing it to calculate the distance to obstacles.

The HX711 weight sensor was connected to the Arduino Mega through data pins and a clock pin. These connections enabled data communication and power supply to the weight sensor, allowing accurate measurement of the food's weight. A servo motor was connected to the Arduino Mega using a PWM (Pulse Width Modulation) pin. The Arduino Mega generated PWM signals to control the servo motor's angle, which, in turn, controlled the movement of the robot's arm for food delivery.

Electric motors were connected to a motor driver, which was then connected to the Arduino Mega. The motor driver allowed the Arduino Mega to control the direction and speed of the electric motors, enabling forward, backward, and turning movements of the robot. The buzzer was connected to one of the digital pins on the Arduino Mega. The Arduino Mega controlled the buzzer to produce audio feedback and alerts as needed, enhancing the user experience.

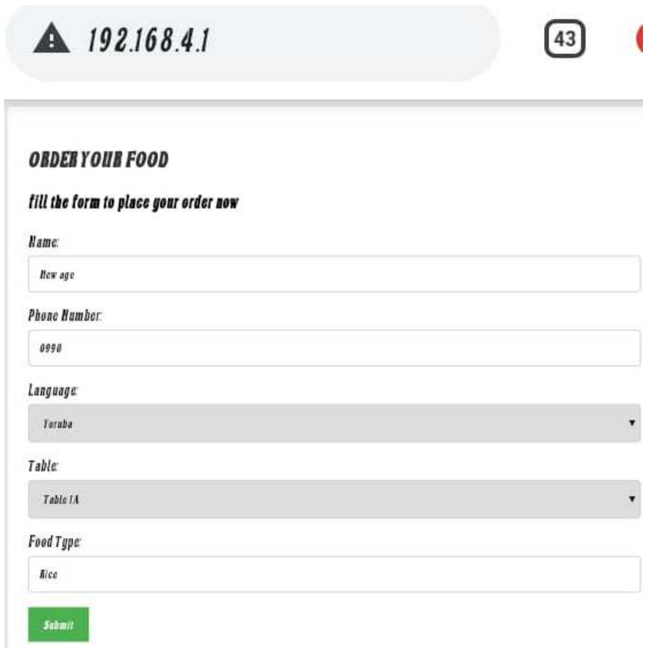
The integration process ensured that each hardware component was properly interfaced with the Arduino Mega, and the ESP32 facilitated seamless communication between the web-based ordering system and the robot's control and navigation system. The software code running on both the Arduino Mega and ESP32 played a vital role in interpreting sensor inputs, processing customer orders, and executing the robot's movements and actions. This successful integration of hardware and software components resulted in an operational restaurant serving robot capable of providing a delightful dining experience for customers.

5.3. Implementation of the Web-Based Ordering System

The web-based ordering system allows customers to place orders from their tables via a web interface hosted on the ESP32 microcontroller, which acts as a hotspot. Customers connect to this hotspot, access a web page provided by the ESP32, and place orders. The ESP32, functioning as a web server, processes these requests, extracts order details, and communicates them to the Arduino Mega, which controls the robot's actions based on the orders received.

The web page for customer orders was designed to be user-friendly and responsive. It featured a form with dropdown menus and an input field. Customers could choose their preferred language, select a table number, and enter the type of food they wanted to order (Figure 7). The page had a clear heading, and basic CSS was used for styling. Users could select languages like Yoruba, English, Igbo, or Hausa, pick their table number (e.g., table 1a, table 1b), and input their food choices. A submit button allowed customers to confirm their orders easily. This structure aimed to provide a straightforward and efficient ordering experience for restaurant patrons.

The ESP32 was configured to act as an access point, creating a Wi-Fi hotspot for customers. It established a web server on port 80 to handle incoming client connections. When customers send HTTP requests, the server accepts the connections and processes the requests. These requests contained information about language, table number, and food type. The ESP32 then responded based on the request URL. If it was an order request, it extracted order details and communicated them to the Arduino Mega through serial communication. This setup allowed customers to connect to the robot's hotspot, place orders through a web interface, and have their requests processed by the ESP32, facilitating seamless communication between customers and the robot's control system.



(a) The ordering page

(b) The list of the menu received by the robot

***Figure 7**: Screenshot for restaurant order form*

5.4. Implementation of the HX711 Weight Sensor for Food Detection

The HX711 weight sensor was employed to accurately measure the weight of customer-ordered food. Connected to the Arduino Mega, it utilized the HX711 library to ensure precise reading of weight values, enhancing the food detection capabilities.

To enable the robot to sense the weight of ordered food, a two-step process is employed. First, the weight sensor is calibrated by measuring known objects and adjusting its scale factor for accuracy. Then, when the chef places food on the robot, the calibrated weight sensor, working in tandem with the load cell, accurately measures the weight of the food, ensuring precise food detection. This calibration step is crucial to ensure reliable weight readings.

Upon detecting the weight of the food, the robot takes several actions. It continuously monitors the weight sensor and, when a significant increase above a predefined threshold is detected, it considers the food weight as detected. Subsequently, the robot initiates the food delivery process, following a predefined path while avoiding obstacles. At the customer's table, language selection is prompted via the web-based ordering system. Based on the chosen language, the robot utilizes the RedMP3 module to play a corresponding voice message, notifying the customer that their food is ready for pickup. Finally, the robot returns to its base station, ensuring readiness for the next order. This streamlined process enhances the efficiency and user experience of the food delivery system.

5.5. Implementation of Multilingual Voice Feedback

The robot employs the RedMP3 speaker module to offer multilingual voice feedback, playing pre-recorded audio files in various languages. This feature enhances customer experience and facilitates clear communication during food delivery. The RedMP3 speaker module connects to the Arduino Mega via SoftwareSerial communication, with designated TX and RX pins. Voice files, stored on a micro-SD card, are linked to specific languages (e.g., English, Yoruba, Igbo, and Hausa). A defined communication protocol enables the Arduino to play the desired voice files. This setup facilitates multilingual voice feedback, allowing the robot to communicate with customers in their preferred languages by selecting and playing the corresponding voice files stored on the SD card.

The robot implements multilingual voice feedback using the RedMP3 speaker module, enabling clear communication with customers in their preferred language. The hardware setup involves connecting the RedMP3 speaker to the Arduino Mega through SoftwareSerial communication. Pre-recorded voice files in various languages are stored on a micro-SD card within the RedMP3 speaker, each associated with a specific language. The Arduino communicates with the speaker using a defined protocol to play the desired voice files.

When a customer places an order, they select their preferred language for voice feedback. The Arduino maintains a mapping between language options and corresponding voice file numbers on the SD card. For example, "English" might map to voice file number 1, "Yoruba" to number 2, "Igbo" to number 3, and "Hausa" to number 4. The chosen language code is included in the response sent to the web-based ordering system.

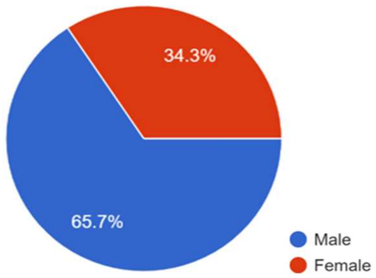
When the robot arrives at the customer's table for food delivery, it reads the language code from the response. It then selects the appropriate voice file number based on the language code and plays the corresponding voice file through the RedMP3 speaker. This implementation ensures that customers receive voice feedback in their chosen language, enhancing their overall dining experience and facilitating effective communication with the robot.

The request management restaurant serving robot integrates advanced hardware, software, and web technologies to optimize restaurant service. These components collectively enhance the robot's functionality, ensuring efficient, accurate, and interactive service delivery

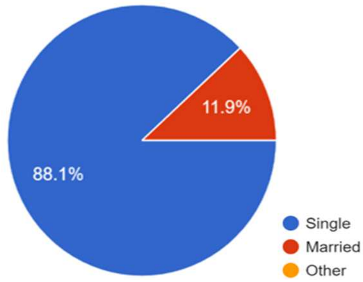
5.6. Testing and Validation

A pretest survey was carried out first to justify the need for providing the proposed solution. A questionnaire designed using Google Forms comprising 14 items was used to gather information from the respondents. Out of the 67 responses received, 34.3% and 65.7% were female and male respectively (Figure 8a). The respondents that were married are 11.9% while 88.1% were single (Figure 8b).

Those range between 18 to 30 years of age are 85.1%, 9% range between 31 to 45 years, 3% for age range between 46 to 60 and none for 60 or above (Figure 9a). Those that find restaurants family-friendly are 86.8% while 13.4% do not (Figure 9b), which means most people prefer going to a restaurant to making homemade food.

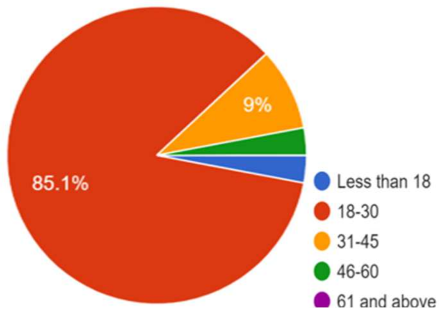


(a) Sex

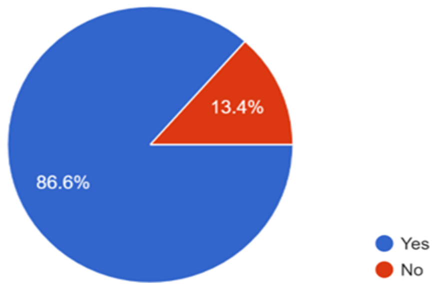


(b) Marital status

*Figure 8: **Illustration for sex and marital status***



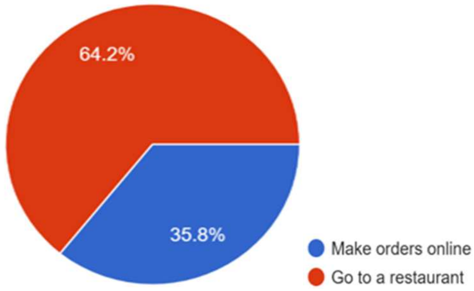
(a) Age



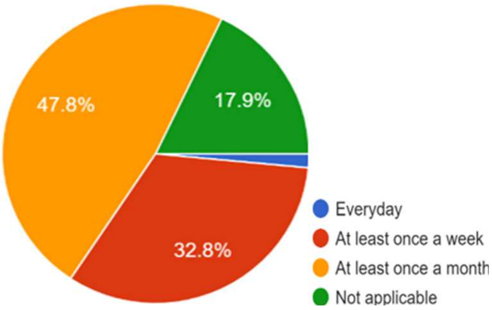
(b) Feedback on whether the restaurant was family-friendly

Figure 9: Illustration for age distribution and Feedback on whether the restaurant was family-friendly

Those who prefer to go to a restaurant are 64.2% while 35.8% prefer making orders for their meal online (Figure 10a). Those who prefer a visit to the restaurant at least once a month, or at least once a week, everyday respectively are 47.8%, 32.8%, and 1.5% respectively while 17.9% do not visit restaurants (Figure 10b).



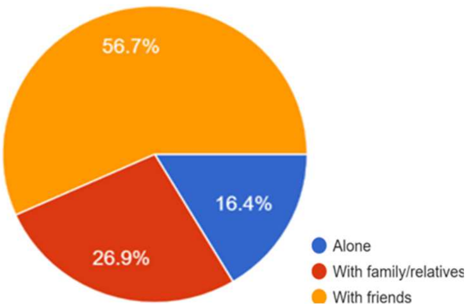
(a) Response to preference for how the meal is received



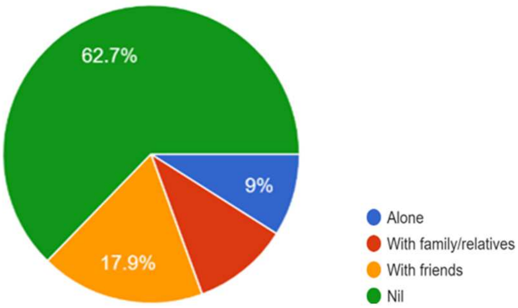
(a) (b) Response to Frequency of visits to restaurants

Figure 10: Illustration for response to preference for how meal is received and restaurant visits

Those who like to visit restaurants with friends, family/relatives and alone are 56.7%, 26.9% and 16.4% respectively (Figure 11a). Those who have visited restaurants with friends, family/relatives and alone are 17.9%, 10.4% and 9.0% respectively and those who have never visited with any are 62.7% (Figure 11b).



(a) People who like visiting restaurants with friends, family, and alone



(b) People who have visited restaurants with friends, family, and alone

Figure 11: Illustration for response to people who like visiting and who have visited restaurants with friends, family, and alone

Those who have visited a robotic café once and more than twice outside Nigeria are 1.5% and 3% respectively while those who have never visited a robotic café outside Nigeria are 95.5% (Figure 12). This shows nearly most all who have visited the restaurants had not visited a robotic restaurant before.

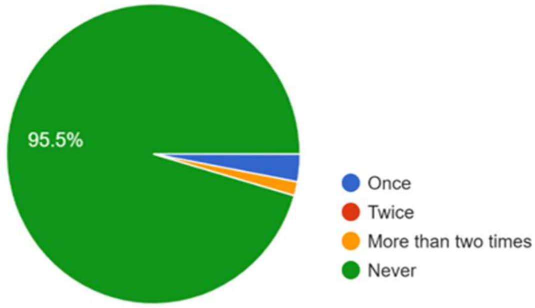
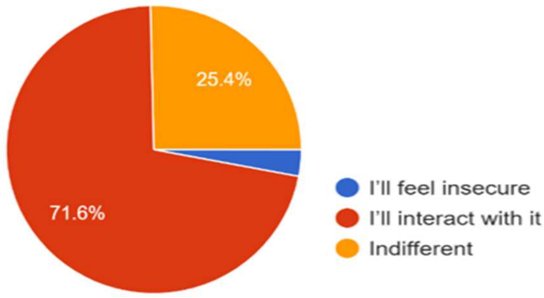
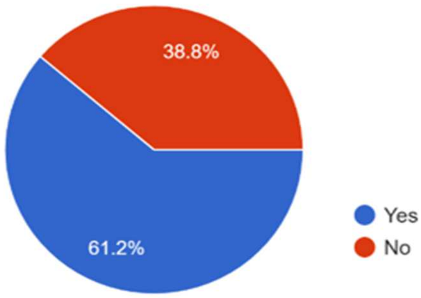


Figure 12: Illustration for robot service restaurant visit outside Nigeria frequency

Those who stated that if they found out that a waiter/ waitress is a robot they would like to interact with it are 71.6%, 3% stated that they would feel insecure and 25.4% were indifferent (Figure 13a). Those who have interacted with other robotic machines before are 61.2% while 39.8% have never interacted with any (Figure 13b).



(a) Response to finding out the waiter/waitress is a robot



(b) Response to the use of robotic machine

*Figure 13: **Illustration for Response to finding out the waiter/waitress is a robot and the use of robotic machine***

Those who stated that they have not engaged physically with any robot before but are confident to interact with it if any are 88.1%, 9% stated that they had no confidence in interaction with a robot service restaurant while less than 3% stated that they have confidently engaged physically with robots service restaurant before (Figure 14).

Those who prefer interacting with service robots with native language and lingual Franca are 59.7% and 52.2% respectively (Figure 15). This shows more people prefer to interact with the robot in their native than in the English language.

Those who feel that a robot service restaurant will increase the output of a restaurant are 55.2%, 37.3% feel it may be, while 7.5% feel it would not (Figure 16). This shows more people reasoned that using a serving robot in restaurants will effectively increase the output of a restaurant in terms of multilingual interaction with customers, enhancing customer experience, increasing efficiency and productivity, and Sanitation and Hygiene.

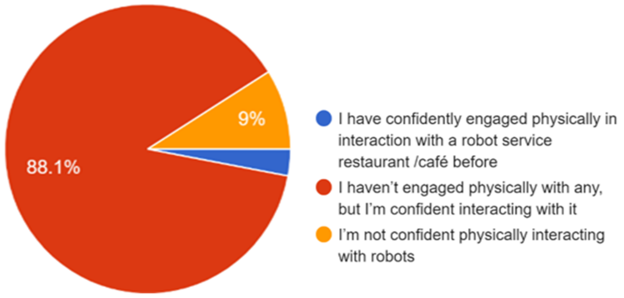


Figure 14: *Illustration for user confidence with interacting with service robot*

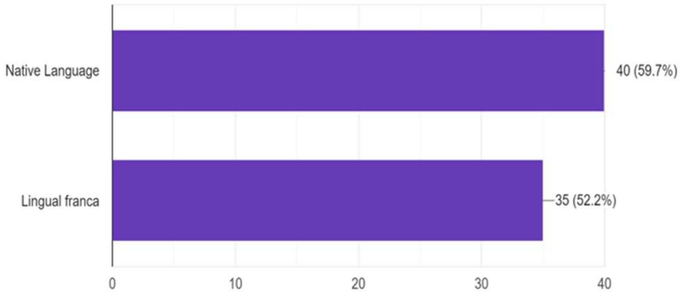


Figure 15 *Illustration for language preference*

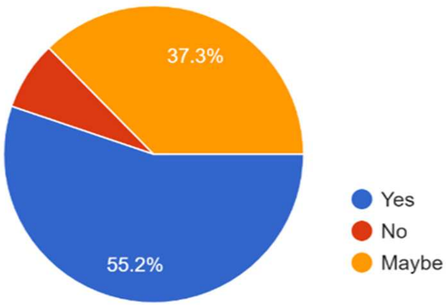


Figure 16: Illustration for increase in restaurant efficiency and productivity

In the implementation phase, testing and validation were conducted to ensure the restaurant serving robot management system's functionality, performance, and reliability. This testing approach included unit testing and integration testing, verifying individual components and their interactions in the system.

Testing and validation encompassed several key methodologies:

i. Unit Testing: Each hardware element underwent independent testing to confirm its proper operation. For instance, the weight sensor (HX711) was verified with known weights for accurate measurements. Similarly, the motor driver and servo motor were assessed to ensure correct movement and control.

ii. Integration Testing: Following component validation, integration testing ensured smooth interactions between different modules and components. These tests encompassed scenarios where multiple elements collaborated to execute tasks like navigation, order reception, and food delivery.

iii. Scenario-based Testing: Various real-world scenarios were simulated to assess the robot's performance across different situations. This included testing for multilingual order handling and obstacle avoidance during navigation ensuring robust functionality.

5.6.1. *Test cases and scenarios for the restaurant serving robot testing*

i. Customer Order Submission
Test Case: Customer orders via web system with language, table, and food selection.
Scenario: Verify correct order reception and chef view update.

ii. Navigation and Obstacle Avoidance
Test Case: Robot navigates to the table while avoiding obstacles.
Scenario: Introduce obstacles, confirm successful detection and avoidance.

5.6.2. *Test results and issues*

The testing phase generally produced favorable outcomes, with the robot performing well. Nevertheless, a few challenges arose during testing:

i. Obstacle Detection Delay: The ultrasonic sensor exhibited a slight delay in detecting obstacles, resulting in minor delays in avoidance maneuvers.

ii. Voice File Compatibility: Certain voice files experienced playback issues on the RedMP3 speaker due to format compatibility problems.

iii. Weight Sensor Calibration: Calibration of the HX711 weight sensor demanded meticulous adjustment to achieve precise weight measurements, involving trial and error during testing. These issues were addressed to enhance the robot's performance.

Future plans include expanding the system to support additional languages, broadening its applicability. The robot will cater for diverse linguistic groups, enhancing service quality and customer satisfaction. It is also of note that implementing Multilingual Restaurant Serving Robot Management Systems in a commercial setting presents several operational challenges that must be carefully addressed for successful deployment and long-term viability. Effective implementation requires careful planning, substantial investment, and ongoing management. By proactively addressing maintenance needs, managing costs, ensuring long-term reliability, seamlessly integrating with existing operations, prioritizing safety and compliance, and enhancing customer acceptance and experience, restaurants can maximize the benefits of these systems while mitigating potential operational risks. This approach ensures that the technology not only enhances service but also supports sustainable business operations.

6. CONCLUSION

The successful development of a multilingual request management restaurant serving robot has resulted in an interactive and efficient food delivery system. The web-based ordering system, path navigation, weight sensing, and multilingual voice feedback components work harmoniously to provide a seamless dining experience for customers. The primary goal was to create a multifunctional robot that could manage requests from customers in various languages, optimizing service efficiency and enhancing customer satisfaction. By integrating natural language processing (NLP) algorithms and language translation capabilities, the robot effectively bridges language barriers, ensuring a smooth dining experience for all patrons. The acceptance of Multilingual Restaurant Serving Robot Management System technology by both restaurant patrons and staff is pivotal for its successful adoption and integration into restaurant operations.

Future enhancements for the restaurant serving robot include implementing autonomous mapping using advanced sensors like LIDAR for improved navigation, integrating object recognition technology for personalized service, developing a mobile application for customer convenience, enhancing the voice feedback system for voice interaction, optimizing energy efficiency for extended operation, and integrating cloud services for remote monitoring and centralized control in restaurant chains. These improvements can make the robot more versatile, interactive, and energy-efficient while providing better customer experiences and management capabilities. Attention will be give to this in our future work. However, this is an ongoing study which is expected to produce a full-fledged multilingual restaurant serving robot for Nigerian and

African people. Expansion to other languages is also part of the future plan. Implementing Multilingual Restaurant Serving Robot Management Systems in a commercial setting presents operational challenges. Successful deployment requires careful planning, investment, and ongoing management. Addressing maintenance, costs, reliability, integration, safety, compliance, and customer acceptance maximizes benefits while mitigating operational risks.

REFERENCES

Acosta, L., González, E., Rodríguez, J. N., & Hamilton, A. F. (2006). Design and implementation of a service robot for a restaurant. International Journal of Robotics & Automation, 21(4), 273.

Akhshirsh, G. S., Al-Salih, N. K., & Hamid, O. H. (2021). A cost-effective GPS-aided autonomous guided vehicle for global path planning. Bulletin of Electrical Engineering and Informatics, 10(2), 650–657. https://doi.org/10.11591/eei.v10i2.2734

Arents, J., & Greitans, M. (2022). Smart industrial robot control trends, challenges and opportunities within manufacturing. Applied Sciences, 12(2), 937.

Aronin, L., & Singleton, D. (2012). Multilingualism (Vol. 30). John Benjamins Publishing.

Aydin, İ. (2021). Investigation of the effect of robot waiter usage desire on word of mouth communication and robot waiter usage attitude in restaurants. Turkish Business Journal, 2(4), 93-105.

Bogue, R. (2022), "The role of robots in entertainment", Industrial Robot, Vol. 49 No. 4, pp. 667-671. https://doi.org/10.1108/IR-02-2022-0054

Bucolo, M., Buscarino, A., Spinosa, A., Stella, G. & Fortuna, L. (2020). "Human machine models for remote control of ultrasound scan equipment," in Proceedings of the IEEE International Conference on Human-Machine Systems (ICHMS), pp. 1–6, Rome, Italy.

Dautenhahn, K. (2013). 38. Human-robot interaction. The encyclopedia of human-computer interaction.

Davis, F. D. (1989). Technology acceptance model: TAM. Al-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption, 205, 219.

De Cristoforis, P., Pedre, S., Nitsche, M., Fischer, T., Pessacg, F. & Di Pietro, C. (2013). "A Behavior-Based Approach for Educational Robotics Activities". IEEE Transactions on Education. 56 (1): 61–66.

Evjemo, L. D., Gjerstad, T., Grøtli, E. I., & Sziebig, G. (2020). Trends in smart manufacturing: Role of humans and industrial robots in smart factories. Current Robotics Reports, 1, 35-41.

Garcia-Haro, J. M., Oña, E. D., Hernandez-Vicen, J., Martinez, S., & Balaguer, C. (2021). Service robots in catering applications: A review and future challenges. Electronics (Switzerland), 10(1), 1–22. https://doi.org/10.3390/electronics10010047

Israel, K., Tscheulin, D. K., & Zerres, C. (2019). Virtual reality in the hotel industry: Assessing the acceptance of immersive hotel presentation. European Journal of Tourism Research, 21, 5–22. https://doi.org/10.54055/ejtr.v21i.355

Iqbal, J., Khan, Z. H. & Khalid, A. (2017). Prospects of robotics in food industry. Food Sci. Technol. Vol: 37, pg: 159–165.

Ivanov, S. (2021). Technology in Society Robots as restaurant employees - A double-barrelled detective story. 67(October). https://doi.org/10.1016/j.techsoc.2021.101779

Kamruzzaman, M., & Tareq, M. (2017). Design And Implementation of A Robotic Technique Based Waiter. International Conference on Electrical Information and Communication Technology (EICT), 3rd (December), 7–9.

Jake, V. T. (1998). Global electronic commerce through localization and multilingualism. Computer standards & interfaces, 20(2-3), 101-109.

Jang, H. W., & Lee, S. B. (2020). Serving robots: Management and applications for restaurant business sustainability. Sustainability, 12(10), 3998.

Matthew N. O. Sadiku, Kirtikumar K. Patel & | Sarhan M. Musa (2022). Future of Robotics. International Journal of Trend in Scientific Research and Development, 6 (4). pp. 1805-1810. ISSN 2456-6470 URL: https://www.ijtsrd.com/papers/ijtsrd50259.pdf

Naidu, R. & Rao, S. S. (2023). Smart restaurant multi-purpose serving robot. In AIP Conference Proceedings (Vol. 2788, No. 1). AIP Publishing.

Newaz, N. T., Siddik, A. B., Hossain, R., Rahman, M., Newaz, N. T., & Saifuzzaman, M. (2020). IoT Waiter Bot : A Low Cost IoT based Multi Functioned Robot for Restaurants. International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO) Amity University, Noida, India., 8th, pg: 1174–1178.

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.

Szegedi, P., Koronvary, P., & Bekesi, B. (2017). The Use of Robots in Military Operations. Scientific Research & Education in the Air Force-AFASES, 1.

Thanh (2019): Development of a Line-Following Method-Based Eatery Serving Robot Methodology. Journal of Science and Technology Issue on Information and Communications Technology 17(12.1):1

Venkatesh, V., Thong, J. & Xu, X. (2016). Unified Theory of Acceptance and Use of Technology: A Synthesis and the Road Ahead. Journal of the Association for Information Systems, 17 (5), 328-376

Wirtz, J., Patterson, P. G., Kunz, W. H., Gruber, T., Lu, V. N., Paluch, S., & Martins, A. (2018). Brave new world: service robots in the frontline. Journal of Service Management, 29(5), 907-931.

Yanmida, D. Z., Alim, S. A., & Imam, A. S. (2020). Design and Implementation of an Autonomous Delivery Robot for Restaurant Services. Journal of Electrical Engineering, 19(3), 66–69.

Zhang, X., Balaji, M. S., & Jiang, Y. (2022). Robots at your service: value facilitation and value co-creation in restaurants. International Journal of Contemporary Hospitality Management, 34(5), 2004-2025.

Yang, J., & Chew, E. (2021). The design model for robotic waitress. International Journal of Social Robotics, 13(7), 1541-1551.,.