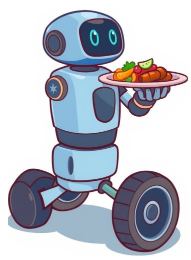
AN-NAJAH NATIONAL UNIVERSITY

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

COMPUTER ENGINEERING DEPARTMENT

Hardware Graduation Project: WAIRO



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Acknowledgment

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Abstract

With the increasing demand for efficient service solutions in the hospitality industry, there is a growing need for automation to enhance customer experience while optimizing restaurant operations. The WAIRO project aims to develop an autonomous robot system that streamlines food ordering and delivery processes within restaurant environments.

The key aspects of this project include creating a dual-mode robotic platform that seamlessly handles both order-taking and food delivery tasks. The system will support wireless table identification, automated navigation, and interactive customer engagement through audio feedback.

Our primary objective is to develop a reliable robot that enhances restaurant efficiency by autonomously managing customer interactions and food delivery.

The implementation of WAIRO is expected to yield significant benefits for restaurant stakeholders, including reduced operational costs, decreased wait times, and minimized human error in order processing.

1 Introduction

1.1 Background

Restaurants and cafés continuously aim to provide better customer service, reduce waiting times, and manage operational efficiency. Human waiters perform repetitive tasks like taking orders and serving food, but during busy periods, service quality and accuracy might decline.

To address this, robotic waiter systems have emerged, providing automated solutions to improve service efficiency and customer satisfaction. Such robots streamline restaurant operations by:

- Quickly and accurately delivering food
- Taking orders from customers
- Reducing human errors and delays
- Offering a unique, interactive experience for diners

The WAIRO robot is an innovative automated waiter designed to enhance restaurant service. It uses simple yet effective technologies like line-following sensors, obstacle detection sensors, and RFID for navigation, ensuring precise delivery and safety.

The robot communicates wirelessly with kitchen staff, who input commands indicating which table the robot should serve. Once instructed, WAIRO autonomously navigates using infrared sensors for path-following and ultrasonic sensors to avoid collisions. Upon reaching the designated table identified by RFID tags, the robot can accept customer orders through either voice or keypad input, then communicate these orders instantly back to the kitchen.

WAIRO leverages cloud technologies to interpret customer voice commands accurately, using Speech-to-Text (STT) and natural language processing through Large Language Models (LLMs). This approach provides a friendly, conversational experience, improving customer interactions.

This project highlights a practical application of robotics and cloud technology, emphasizing efficiency, accuracy, and enhanced customer engagement, marking a step forward in modernizing restaurant operations.

2 Constraints and Standards

2.1 Standards

Safety Standards:

- **Obstacle Avoidance:** Ultrasonic sensors are used to detect and respond to obstacles, ensuring the robot stops safely to prevent collisions, protecting both customers and restaurant staff.
- **RFID Tagging:** RFID tags guarantee that the robot accurately identifies tables, ensuring orders and deliveries always reach the correct destination.
- **User Interaction Safety:** Clear and simple voice and keypad commands are implemented to prevent miscommunication, enhancing operational safety and reliability.

Electrical Standards:

- **Reliable Wiring:** Standardized electrical connections ensure all sensors, motors, controllers, and communication modules function reliably without risks of short circuits or electrical failures.
- **Component Compatibility:** All electronic components, including sensors, Arduino Mega, ESP modules, and motor drivers, are selected and connected according to established electrical safety and reliability standards.

Mechanical Standards:

- **Durable Chassis:** The robot chassis is designed based on mechanical engineering guidelines for stability, durability, and ease of movement within restaurant environments.

2.2 Constraints

Voice Processing Dependency:

The robot relies heavily on cloud-based Speech-to-Text (STT), Large Language Model (LLM) processing, and Text-to-Speech (TTS) for customer interaction, requiring stable and fast internet connectivity to maintain real-time and seamless communication. Delays or disruptions in internet connectivity can affect user experience and operational efficiency.

3 Literature Review

The integration of robots into service sectors, especially the restaurant industry, has become increasingly common due to their ability to enhance customer experiences, improve efficiency, and reduce operational costs. Robotic waiters and service robots offer practical solutions to automate repetitive tasks, such as order-taking and food delivery, resulting in smoother restaurant operations.

Robotics in Restaurant Services: Several robotics solutions, such as the popular Pudu Robotics series, already operate in restaurant settings, successfully navigating crowded areas to deliver food. These robots typically use combinations of IR sensors, ultrasonic sensors, and cameras for navigation and obstacle detection. However, ensuring accurate table localization and seamless customer interaction remains a key challenge in dynamic environments.

Line-following Navigation: Line-following methods using infrared (IR) sensors are frequently employed to guide robots on predetermined paths. This approach simplifies navigation in structured environments like restaurants. Previous research indicates that IR-based line-following robots achieve high accuracy in controlled environments, although they can face issues with sensor misalignment or variations in lighting conditions.

Obstacle Detection and Avoidance: Ultrasonic sensors have proven effective for real-time obstacle detection and avoidance. These sensors measure distances using sound waves, allowing robots to safely navigate around objects and people. Research highlights ultrasonic sensors as reliable and cost-effective solutions for maintaining safe operation in crowded spaces.

RFID for Accurate Localization: Radio Frequency Identification (RFID) technology is widely recognized for its precision in marking specific locations within environments. Applying RFID tags at key points, like restaurant tables, helps robots confirm arrival accurately. Studies support RFID's effectiveness in reducing navigational errors and ensuring precise robot positioning, thus improving delivery reliability.

Voice Interaction and Cloud Integration: Recent advancements in cloud computing and speech recognition have enabled more sophisticated robot-human interactions. Speech-to-Text (STT), Text-to-Speech (TTS), and cloud-based Large Language Models (LLM) facilitate conversational interactions, enhancing user engagement. Despite this, maintaining fast and reliable internet connections remains essential to prevent delays and maintain a natural interaction flow.

User Interface Simplicity: Easy-to-use interfaces, such as voice input or simple keypad commands, are critical for ensuring seamless integration of robots into restaurant workflows. Studies suggest intuitive designs significantly improve adoption rates among both customers and restaurant staff, reducing training needs and operational errors.

The WAIRO robot integrates these proven technologies—IR sensors for line-following, ultrasonic sensors for collision prevention, RFID for precise location tracking, and voice-based interactions via cloud computing—to provide efficient, reliable, and user-friendly automated waiter service in restaurant environments.

4 Methodology

4.1 System Workflow

One of the key features of the system is the robot's ability to automatically respond to customer requests based on table interaction. When a customer presses the order button at their table, the robot is immediately dispatched to that specific table. Upon arrival, it initiates the order-taking process through voice interaction or another interface.

Figure 1: Table Order Button Interface

Once the customer places the order, it is registered along with the corresponding table number and sent to the chef's interface. The chef can view incoming orders in real-time and update the order status accordingly.

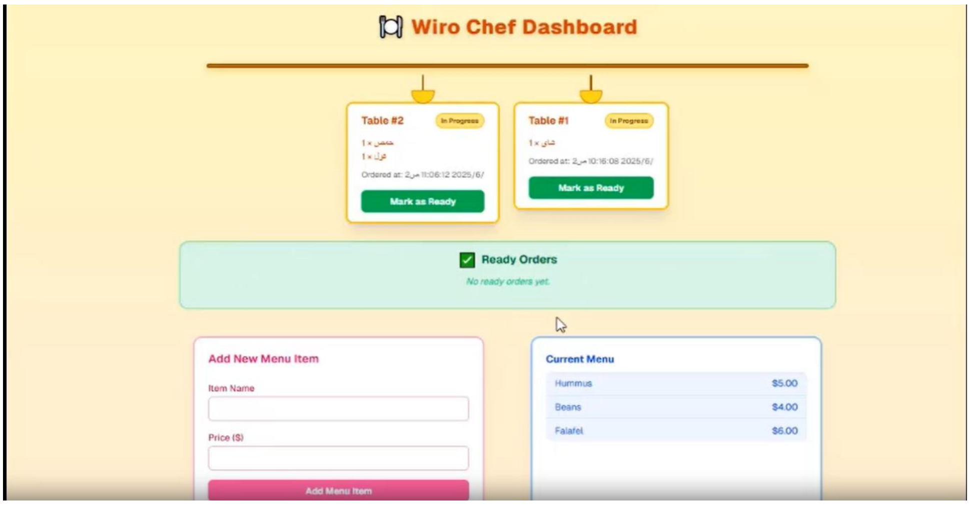

Figure 2: Chef's Order Management Interface

When the chef marks the order as "Ready," the robot is notified, returns to the kitchen, picks up the prepared meal, and delivers it directly to the same table that initially made the request—ensuring a smooth and autonomous service cycle.

4.2 Hardware Parts

- Arduino Mega 2560
- 2 power banks
- Battery 12V 9A
- Connecting wires
- 2 H-Bridge Motor Driver L298N
- Keypad
- 2 Ultrasonics
- RFID
- ESP32
- NFC tags
- 2 IR sensors
- 2 Breadboards
- 4 DC motors
- Amplifier
- Speaker

- INMP441 Microphone
- Logic level shifter

4.3 Description

In this section, we will discuss each of the hardware components that we used.

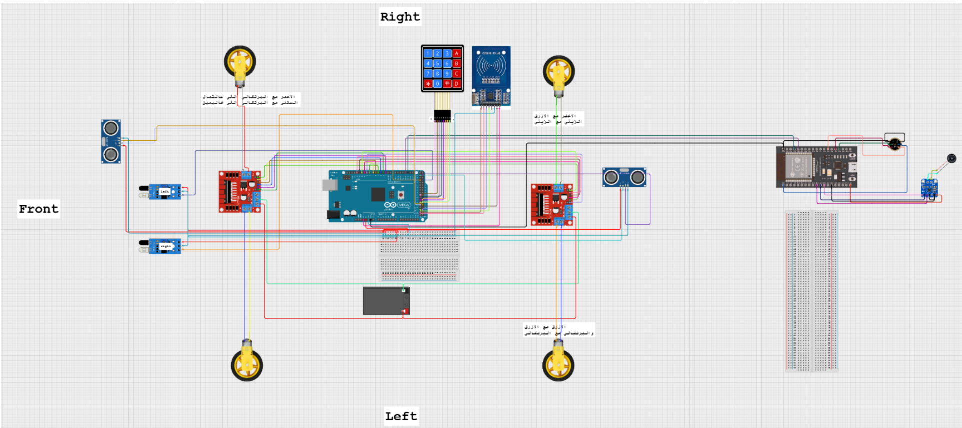

Figure 3: System Architecture Overview

4.3.1 Arduino Mega 2560

Figure 4: Arduino Mega 2560

The Arduino Mega 2560 serves as the central controller for WAIRO, managing sensor data, controlling motors, and coordinating all robot operations. It handles inputs from the keypad for table selection, processes readings from IR sensors for accurate line-following, and communicates with ultrasonic sensors to detect and avoid obstacles. It also interacts with the RFID module to confirm accurate table positioning and communicates with the ESP32 module for voice processing, ensuring seamless robot operations in restaurant environments.

4.3.2 Power Banks

Figure 5: Power Banks

Two power banks supply stable power to critical low-voltage components such as the Arduino Mega and ESP32 module, ensuring consistent and uninterrupted operation. These dedicated power supplies enhance reliability and prevent power fluctuations from affecting sensitive electronics.

4.3.3 Logic Level Shifter

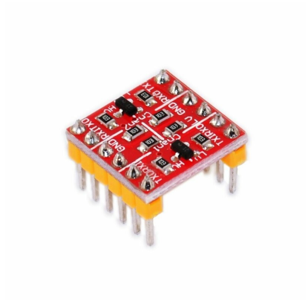

Figure 6: Logic Level Shifter

A logic level shifter ensures safe communication between components operating at different voltage levels, specifically enabling reliable interaction between the 3.3V ESP32 module and the 5V Arduino Mega. It prevents damage due to voltage mismatches and maintains stable communication throughout robot operation.

4.3.4 RFID and NFC Tags

Figure 7: RFID Module

The RFID module, coupled with NFC tags, ensures the robot reliably identifies its target locations. As the robot approaches a table, the RFID module reads the NFC tag, allowing precise positioning and verification that the robot has reached the correct table.

4.3.5 Keypad

Figure 8: 4x4 Matrix Keypad

A 4x4 matrix keypad provides a simple and intuitive interface for customers, allowing them to input what they want to order. This straightforward interaction streamlines order management.

4.3.6 DC Motor

Figure 9: DC Motor

The four DC motors power the robot's wheels, converting electrical signals into mechanical energy to drive its movements. Controlled by motor drivers, these motors enable precise and responsive motion essential for accurate navigation within the restaurant.

4.3.7 H-Bridge Motor Driver L298N

Figure 10: L298N Motor Driver

The L298N H-Bridge motor drivers control the robot's four DC motors, enabling precise movement forward, backward, and stopping actions. They translate signals from the Arduino Mega into mechanical movements, allowing the robot to navigate accurately along its designated paths.

4.3.8 Speaker

Figure 11: Speaker

A speaker translates electrical audio signals into clear audible sound, enabling WAIRO to verbally communicate with customers. This capability enhances interaction, providing an engaging and user-friendly customer experience.

4.3.9 Ultrasonic HC-SR04

Figure 12: Ultrasonic Sensor HC-SR04

Ultrasonic sensors detect obstacles in real-time by emitting and receiving sound waves. Mounted strategically on the robot, these sensors continuously monitor the environment, ensuring the robot pauses movement immediately upon detecting any obstacle, thus avoiding collisions.

4.3.10 IR Sensor

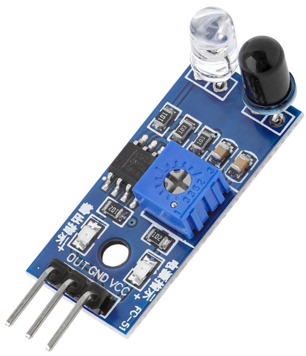

Figure 13: IR Sensor

Infrared (IR) sensors detect and follow the black line path laid out in the restaurant. By sensing reflected infrared light from the line, these sensors provide critical feedback to the Arduino Mega, ensuring the robot stays accurately aligned on its intended path.

4.3.11 Rubber Wheels

Figure 14: Rubber Wheels

We used solid rubber wheels that move steadily on the ground. A custom coupler was designed to securely connect the motor to the wheel, ensuring smooth and stable movement for the robot.

4.3.12 ESP32

Figure 15: ESP32 Module

The ESP32 module provides wireless connectivity and handles voice processing tasks by interfacing with cloud services. It receives audio inputs from customers via the microphone, sends these inputs to cloud-based Speech-to-Text (STT) and Large Language Model (LLM) services, and retrieves processed responses for audio output.

4.3.13 Amplifier

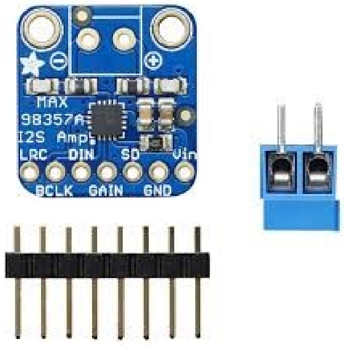

Figure 16: Audio Amplifier

An audio amplifier enhances the strength and clarity of audio signals sent from the ESP32 module, ensuring the robot's voice outputs are audible to customers. The amplified signals are then output through a speaker for effective communication.

4.3.14 Microphone

Figure 17: INMP441 Microphone

The INMP441 microphone captures customer voice commands clearly, converting sound waves into electrical signals. These signals are transmitted to the ESP32 module and processed by cloud-based speech recognition services, enabling effective and natural interaction between the robot and customers.

5 Results and Discussion

The waiter robot, WAIRO, successfully achieved its primary objectives, effectively demonstrating navigation within the restaurant environment. Utilizing two IR sensors, the robot consistently followed the predefined black-line paths forward and backward.

The RFID module performed effectively, accurately identifying tables via NFC tags. The robot successfully stopped precisely at the intended tables. This accurate RFID identification contributed significantly to reliable deliveries and customer interaction.

Ultrasonic sensors were critical in obstacle avoidance, consistently detecting objects or customers within the robot's path. Upon detecting obstacles, the robot effectively paused its movement, resuming only when the path was clear, ensuring safety within the busy environment.

Voice interactions, enabled by the ESP32 module and cloud-based Speech-to-Text (STT) and Large Language Models (LLM), significantly improved the customer experience. Customers could smoothly communicate their orders verbally through the microphone, and responses were clearly delivered through the integrated speaker. This functionality provided an engaging and efficient interaction, enhancing overall customer satisfaction. Nevertheless, maintaining smooth real-time communication was dependent on stable and fast internet connectivity, presenting occasional challenges in network-dependent operations.

Moreover, the keypad provided a straightforward and efficient interface for customers, simplifying their interaction with the robot.

Integrating multiple hardware components, including the Arduino Mega, ESP32 module, DC motors, motor drivers, IR sensors, ultrasonic sensors, RFID module, and audio components, required substantial testing and debugging. Ensuring stable, error-free operation between these components was critical, and the system eventually achieved a high degree of reliability after thorough adjustments.

In summary, WAIRO successfully integrated various hardware and software components, effectively automating the waiter functions within a restaurant environment. Despite minor challenges related to turning movements and network stability, the robot demonstrated considerable potential for practical, real-world applications in restaurant service automation.

6 Conclusion and Recommendation

In conclusion, the WAIRO waiter robot successfully demonstrates the integration of robotics and communication technologies to automate service tasks within a restaurant environment. The project effectively implemented IR sensors for accurate line-following navigation, ultrasonic sensors for obstacle detection, and RFID for precise table identification. The robot successfully managed voice interactions through cloud-based Speech-to-Text (STT) and Large Language Models (LLM), significantly enhancing customer experience by allowing natural, conversational ordering.

Despite successful implementation, the project encountered minor challenges, including occasional navigation stalls during turning maneuvers and reliance on stable internet connectivity for real-time voice interaction. Overall, WAIRO effectively demonstrates significant potential for practical applications in automating restaurant services, improving customer interactions, and optimizing staff workflow.

6.1 Recommendations

For future development and enhancements, the following improvements are recommended:

- **Enhanced Navigation:** Develop more robust turning mechanisms or consider alternative navigation algorithms to address current stalling issues during turns.
- **Network Reliability:** Explore incorporating offline speech recognition capabilities or more stable communication protocols to reduce dependency on constant internet connectivity.
- **Load Handling:** Optimize the robot's physical design to comfortably handle heavier or multiple trays, expanding its delivery capabilities.
- **Extended Interaction:** Integrate additional interactive features, such as touch-screen interfaces or advanced voice recognition capabilities, to further enhance user-friendliness.
- **Operational Analytics:** Incorporate data logging systems to collect operational metrics, helping restaurants analyze performance and further optimize service efficiency.

Implementing these enhancements would significantly improve WAIRO's reliability, flexibility, and overall functionality within dynamic restaurant environments.

7 Future Work

The WAIRO waiter robot successfully demonstrated practical capabilities for automated navigation, obstacle avoidance, and voice-based customer interaction in a restaurant environment. To enhance WAIRO's functionality, flexibility, and user-friendliness, the following areas are suggested for future development:

Advanced Navigation: Incorporating camera-based visual navigation systems powered by AI to enable the robot to operate without relying solely on black-line tracking. This improvement would allow more adaptive navigation within dynamic restaurant layouts.

Offline Voice Processing: Implementing local voice recognition and response systems to reduce dependence on internet connectivity, ensuring reliable and uninterrupted customer interaction even in the absence of stable network connections.

Improved Customer Interface: Adding interactive touchscreens or advanced voice assistants to offer enhanced user engagement, collect direct feedback, and simplify ordering processes.

By addressing these areas, the WAIRO robot can become more intelligent, adaptable, and efficient, significantly enhancing its practical value and usability within the restaurant industry.

8 Limitations

Despite our initial plans, certain features that were intended to be part of the final implementation could not be completed due to unforeseen challenges and unfavorable conditions during the final stages of development. These features include:

- **RFID Payment System:** A system that would enable customers to pay using RFID cards, allowing for a seamless and contactless payment experience.
- **Manual Control Mode:** A functionality allowing manual control of the robot, enabling it to move in all directions (forward, backward, left, and right) for testing and troubleshooting purposes.
- **Kitchen RFID Tag:** An RFID tag placed at the kitchen station to help the robot accurately identify and navigate to the kitchen.

Unfortunately, access to the university facilities has been limited recently due to poor road conditions, which significantly hindered our ability to finalize and test these features. These limitations present opportunities for future work to enhance the robot's capabilities and functionality.

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