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Smart Interactive Robot

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Abstract

The "Smart Interactive Robot" project aims to create an IoT-integrated robot named "Ayyash" that will emulate humans in an engaging manner through its capabilities to have intelligent conversations, use nonverbal communication cues, and interact physically with its environment. The project is specific to and serves as a benchmark for creating devices called virtual assistants in Palestine. It also makes things run easier in smart buildings by building interactions through voice commands.

The proposed system combines both AI and IoT technologies to give us a fully developed assistant that can comprehend and respond to complex commands. Ayyash is capable of connecting with users in both verbal and non-verbal ways, thus it is a device that could be used with flexibility for many applications.

The setup consists of sensors, cameras, an AI-based control unit, and mobile software that can be manipulated by the user to shift the robot and communicate with people through the text-to-voice system. The robot is able to look at its surroundings, understand which person is near, and solve problems on its own. The arrangement will be deployed as a scenario, just as a guarantee of the trustworthiness and the way the system works.

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Chapter 1

Introduction

1.1 Preface

The rapid advancement of technology has led to the development of smart assistants and robots that can perform various tasks to assist humans in their daily activities. Despite significant progress in this field globally, there is a noticeable gap in the adoption and implementation of such technologies in Palestine. This project aims to bridge this gap by developing a smart interactive robot named Ayyash.

1.2 Problem Statement

The absence of advanced smart assistants in Palestine limits the efficiency and effectiveness of smart environments. There is a need for a versatile and intelligent system that can understand and execute voice commands, provide nonverbal communication cues, and physically interact with its surroundings to assist users in various applications.

1.3 Aims and Objectives

The primary aim of this project is to develop a smart interactive robot that can integrate into the IoT environment, engage in intelligent conversations, and provide nonverbal communication cues. The specific objectives include:

- Designing and developing the hardware components of the robot.
- Implementing AI-based software for natural language processing and decision making.
- Ensuring the robot can interact with its environment and perform tasks autonomously.
- Developing a mobile phone app to control the robot and send text for speech.

1.4 Requirements

There are several functional and non-functional requirements of the system:

1.4.1 Functional

- The robot should be able to understand and respond to voice commands.
- The robot should provide nonverbal communication cues.
- The robot should interact with its environment and perform tasks autonomously.
- The mobile app should allow users to send text for the robot to speak and control its movements.

1.4.2 Non-functional

- The system should be reliable and efficient.
- The system should be user-friendly and easy to interact with.

1.5 Challenges

1.5.1 Technical Challenges

Natural Language Processing (NLP)

Implementing an effective NLP system capable of understanding and processing a wide range of voice commands in different accents was a significant challenge. The variability in user speech patterns and environmental noise added to the complexity.

Real-Time Face Recognition

Achieving real-time face recognition and processing was critical for the robot's functionality but posed significant computational demands. The system needed to recognize faces quickly and accurately in various lighting conditions and environments.

1.5.2 Logistical Challenges

Hardware Integration

Integrating various hardware components, including sensors, cameras, actuators, and the microcontroller, posed significant challenges in ensuring seamless communication and coordination.

Supply Chain and Component Availability

Sourcing high-quality components within budget constraints and ensuring their timely availability was a logistical hurdle. Delays in component delivery could potentially disrupt the project timeline.

1.5.3 Operational Challenges

User Interaction Design

Designing an intuitive and user-friendly interface for interaction with the robot was essential but challenging. The system needed to accommodate users with varying levels of technical proficiency.

Testing and Validation

Thoroughly testing and validating the robot's performance across different scenarios and environments was crucial to ensuring reliability and effectiveness.

1.6 Conclusion

Addressing the challenges encountered during the development of the "Smart Interactive Robot" required innovative thinking, meticulous planning, and persistent efforts. By leveraging advanced technologies, modular design principles, and user-centric approaches, we were able to overcome these challenges and achieve the project's objectives. The lessons learned and solutions developed during this process have significantly contributed to the robustness and success of the project.

1.7 System Description

The "Smart Interactive Robot" project aims to develop an advanced, human-friendly robot named Ayyash, designed to integrate seamlessly into smart environments and enhance human interactions through intelligent behavior and responsive actions. This innovative project is divided into two main components: the Ayyash Robot and the Smart Environment, each playing a crucial role in creating a cohesive, interactive system. As shown in Figure 1.1.

1.7.1 Human-Friendly Smart Robot (Ayyash):

- **Emotional and Action Mimicry:** Ayyash is engineered to mimic human emotions and actions, creating a more intuitive and engaging user experience. It can display a range of emotions and perform actions that reflect human-like behavior, making interactions more natural and effective.
- **Versatile Assistance:** The robot is equipped to assist in various fields such as customer service, education, and domestic environments. Its capabilities include intelligent conversation, non-verbal communication cues, and physical interactions, providing comprehensive support and enhancing user satisfaction.
- **Advanced Perception and Processing:** Ayyash utilizes high-definition cameras, multiple microphones, and ultrasonic sensors to gather environmental data.
- **Mobile App Control:** The robot can be controlled via a mobile app, allowing users to send text for speech and control the movement of 2 DC motors and a servo motor.

1.7.2 Smart Environment:

- **Voice-Controlled Interaction:** The smart environment is designed to be controlled through voice commands. Users can issue commands to Ayyash. Ayyash processes these commands and communicates with various smart devices within the environment, enabling seamless control and automation.
- **Integrated System Architecture:** The integration between Ayyash and the smart environment is facilitated through standardized communication protocols. This ensures reliable data exchange and real-time processing, allowing for quick and accurate responses to user commands and environmental changes.

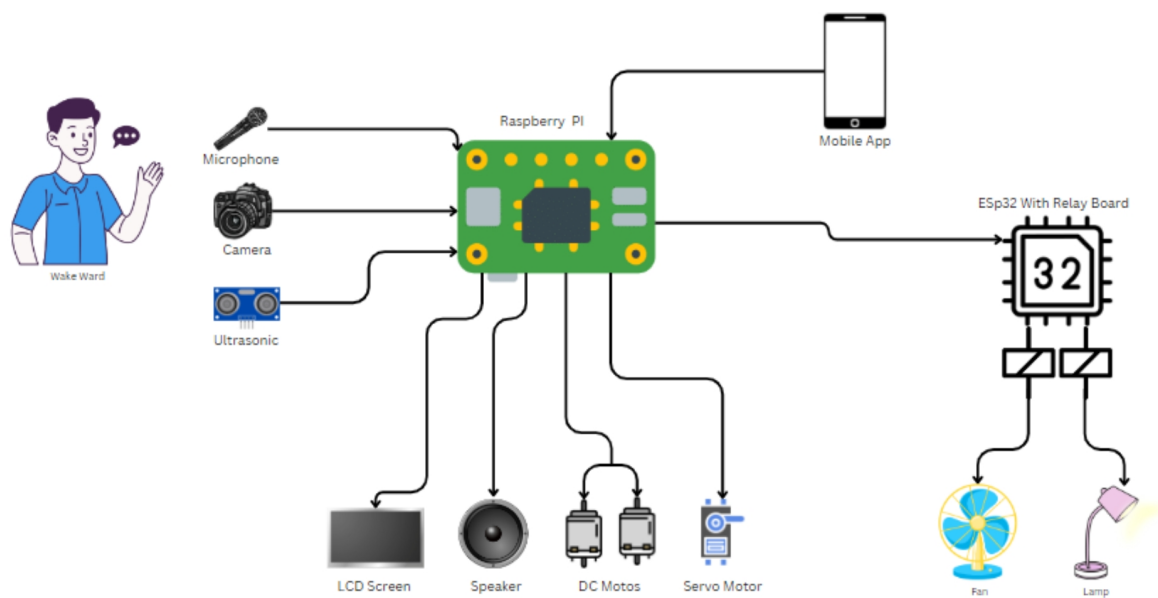


Figure 1.1: System Description

Chapter 2

Background

2.1 Preface

This chapter introduces the theoretical foundation for our project, focusing on smart interactive robots. These robots, enhanced by IoT integration, assist in various tasks, from daily activities to complex problem-solving. We will review previous works, highlighting the unique features and innovations of our project, and positioning it within the existing field of artificial intelligence and robotics.

2.2 Related Work

In the broad domain of robotics, numerous projects have been undertaken to create robots capable of social interaction. These robots are designed to perform impressive functions such as autonomous navigation, understanding spoken commands, and responding to gestures and touches.

2.2.1 Vector Robot

In August 2018, Anki launched Vector. The project involves developing a face recognition system using a Raspberry Pi, a camera, and a neural network. The camera observes the face and then feeds it into a trained neural network for face recognition. This data is then used to adjust the robot's movement toward the user's location. Figure 2.1 shows the Vector Robot.[1]

Features:

- Vector can move around on its own, exploring your space.
- You can talk to Vector, and it understands your voice commands.
- Vector can recognize faces, which allows him to personalize your experience. For example, Vector can greet you by name when you come home.
- Vector has Amazon Alexa built-in, which means you can use it to control your smart home devices, get the news and weather, and play music.

Limitations:

- Vector is not as responsive as other smart assistants, and it sometimes takes a few seconds to process your commands.
- Vector is a relatively expensive smart assistant robot.
- Limited voice control commands.



Figure 2.1: Vector Robot

2.2.2 EMO Robot

EMO Desktop Pet is a cute little robot designed and manufactured by a company called Living.ai. Built with multiple sensors and cutting-edge technologies, Emo is a cool desktop AI robot pet with a character that can self-explore the world and react to you with 1000+ faces and movements. Figure 2.2 shows the EMO Robot.[11]



Figure 2.2: EMO Robot

Features:

- Emo features an HD camera with face recognition that can remember you and your family members. He gets to know you by seeing you every day.

- Emo has a 4-microphone array that can capture sounds and locate the source direction instantly. If you need him, just say “Hey Emo!”.
- Emo is equipped with a touch sensor on its head, which enables it to sense your touch. Like any pet, he likes a nice pat on the head.
- Professional and friendly robot body.

Limitations:

- Limited movement.
- Cannot control any IoT device.
- The product price is very expensive: 700 \$.

2.2.3 Intelligent Personal Assistant

This project has been built in PPU since 2023. The project aimed to improve the ability of officers and disabled individuals to use and interact with various technologies by enabling them to complete tasks using speech commands and creating automation scripts for daily tasks that had faster performance compared to the traditional method. Figure 2.3 shows the Intelligent Personal Assistant.[19]



Figure 2.3: Intelligent Personal Assistant

Features:

- Adding additional mobility to the robot, such as moving its head.
- Creating a GUI to allow users to define new commands and register additional users without modifying the source code.
- Implementing gesture recognition to control the volume.
- Adding an Arabic language version to the system.
- Adding a feature that allows the robot to read screen content loudly to assist blind individuals.

- Adding a feature for controlling house appliances like lights and AC (Air conditioning).

Limitations:

- There is no physical movement.
- The shape is not friendly to humans.
- There is no eye expression.

2.3 Theoretical Background

The development of the "Smart Interactive Robot" project is rooted in several key areas of technology and research, including artificial intelligence (AI), robotics, and the Internet of Things (IoT). This section provides an overview of the theoretical principles and technological advancements that underpin our project.

2.3.1 Artificial Intelligence (AI)

AI is the backbone of our smart interactive robot, enabling it to perform tasks that require human-like intelligence. AI encompasses various subfields, including natural language processing (NLP), and computer vision.

Natural Language Processing (NLP)

NLP allows the robot to understand and respond to human language. By leveraging NLP cloud services like OpenAI, our robot can process voice commands, engage in meaningful conversations, and provide appropriate responses. This capability is crucial for making the robot user-friendly and interactive.

Computer Vision

This field involves the use of cameras and image processing algorithms to enable the robot to perceive and interpret its surroundings. Techniques such as facial recognition, and scene understanding are implemented using tools like Vision API on OpenAI, allowing the robot to recognize users.

2.3.2 Robotics

Robotics is the study of designing, building, and operating robots. Our project draws on several key concepts in robotics, including kinematics, dynamics, and control systems.

Kinematics and Dynamics

These principles govern the movement and behavior of the robot. Kinematics focuses on the robot's motion without considering the forces causing it, while dynamics takes into account the forces and torques. Understanding these principles is essential for designing the robot's physical structure and ensuring smooth and accurate movements.

Control Systems

Control systems are crucial for managing the robot's actions and ensuring it operates as intended. Our robot uses various control algorithms to maintain stability, follow desired trajectories, and interact safely with its environment. These algorithms are implemented on the Raspberry Pi 4, which serves as the central processing unit.

2.3.3 Internet of Things (IoT)

The integration of IoT technology allows our robot to connect with and control other smart devices in its environment. This capability extends the robot's functionality and enables it to operate as a central hub in a smart home or office.

Connectivity

The robot is equipped with wireless communication modules (such as Wi-Fi) to connect with IoT devices. This connectivity allows it to send and receive data, control appliances, and integrate with other smart systems.

Interoperability

To ensure seamless interaction with various IoT devices, our robot supports standardized communication protocols like HTTP. This interoperability is essential for creating a cohesive smart environment where the robot can efficiently manage and control different devices.

2.3.4 Human-Robot Interaction (HRI)

HRI focuses on the communication and collaboration between humans and robots. Our project emphasizes creating a natural and intuitive interface for users to interact with the robot.

Voice Interaction

By integrating advanced speech recognition and synthesis technologies, the robot can understand voice commands and provide spoken responses. This interaction mode is crucial for accessibility and ease of use.

Nonverbal Communication

In addition to voice interaction, the robot uses nonverbal cues such as gestures, facial expressions, and LED indicators to enhance communication. These cues help convey emotions, intentions, and status, making the interaction more engaging and human-like.

User Interface (UI)

A graphical user interface (GUI) is also provided, allowing users to customize the robot's behavior without modifying the source code. This flexibility ensures that the robot can adapt to different user needs and preferences.

2.4 Summary

In summary, the theoretical foundation of our "Smart Interactive Robot" project encompasses AI, robotics, IoT, and HRI. By leveraging advancements in these fields, we aim to create a robot that not only performs tasks efficiently but also interacts seamlessly with users and its environment, providing a comprehensive and innovative solution for smart environments.

Chapter 3

System Design

3.1 Preface

This chapter provides an overview of the essential hardware and software components intended for the "Smart Interactive Robot" project.

3.2 System Design Overview

The system design of the Smart Interactive Robot involves both hardware and software components. The hardware includes sensors, cameras, and actuators that allow the robot to perceive and interact with its environment. The software component involves AI algorithms for natural language processing, decision making, and control of the robot's actions.

The system architecture is divided into several modules:

- **Perception Module:** Responsible for collecting data from sensors and cameras.
- **Processing Module:** Handles data processing, decision making, and command execution.
- **Actuation Module:** Executes physical actions based on processed data.

3.3 Hardware Components

3.3.1 Processing Unit

Raspberry Pi 4 Model B

The central processing unit, a Raspberry Pi 4, handles primary computational tasks. The Raspberry Pi 4 Model B, serving as the central processing unit for our Smart Interactive Robot, boasts a powerful quad-core ARM Cortex-A72 processor and up to 8GB of RAM, providing robust computational capabilities for tasks like image processing and machine learning. Its dual-band Wi-Fi, Bluetooth 5.0, and Gigabit Ethernet ensure seamless connectivity within IoT environments. With multiple USB 3.0 ports and GPIO pins, it easily interfaces with various sensors and actuators, making it ideal for our robotics application. Compact and energy-efficient, the Raspberry Pi 4 enhances the robot's

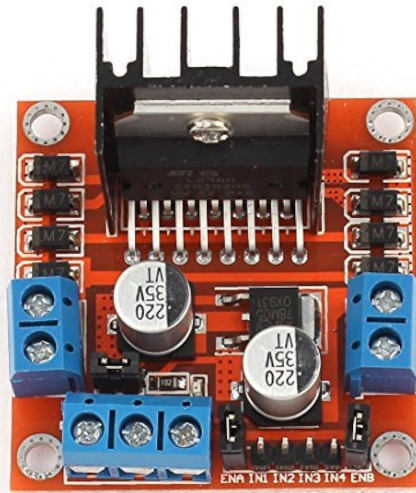


Figure 3.3: Dual H-Bridge Motor Driver L298N

3.3.2 Body and Structural Design

Structure and Chassis

The robot's body structure is designed to house all essential components securely using durable materials for stability and protection, allowing easy access for maintenance and upgrades. Figure 3.4 shows Rover Robot chassis. [4]

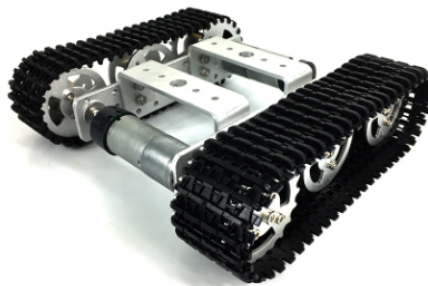


Figure 3.4: Rover Robot chassis

Physical Dimensions

The dimensions are optimized for functionality and portability, ensuring the robot can navigate different environments while maintaining a user-friendly interface.

Mobility Mechanisms

Equipped with wheels and motor systems, the robot ensures smooth movement across various surfaces with stability and precise navigation.

Aesthetics

The exterior design features a friendly and approachable appearance with a sleek finish and human-like features to enhance user interaction.

3.3.3 Mechanical Components

Actuators

For driving the wheels, Dual DC 12V 350rpm motors were selected, providing the necessary torque and speed for stable and efficient movement across various surfaces. These motors are well-suited for applications requiring robust performance and reliable operation. Figure 3.5 shows the Encode Motor. [14]



Figure 3.5: 12V DC Encode Motor

For precise movements, MG996R servo motors were chosen. These high-torque servos offer excellent precision and control, making them ideal for tasks requiring accurate positioning and smooth motion. With their metal gear construction, MG996R servos ensure durability and consistent performance in demanding applications. Figure 3.6 shows the MG996R servo motors. [17]



Figure 3.6: MG996R servo motors

Power System

A rechargeable battery pack and power management circuits provide stable and sufficient energy, ensuring efficient usage. Figure 3.7 shows lithium Ion Cells, [18] Figure 3.8 shows the BMS for three cells. [2]



Figure 3.7: lithium Ion Cells

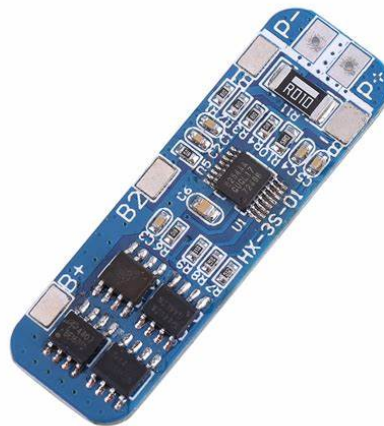


Figure 3.8: BMS for three cells

Cooling System

Heat sinks and fans maintain optimal operating temperatures, ensuring components operate within safe ranges. Figure 3.9 shows the Cooling System of the Robot. [3]



Figure 3.9: Cooling System of the Robot

3.3.4 Sensors and Perception

Vision System

The vision system of our Smart Interactive Robot incorporates a PlayStation Camera, which plays a crucial role in object recognition and environment mapping. This camera provides high-resolution video capture, enabling the robot to accurately detect and identify objects in its surroundings. The PlayStation Camera's USB interface ensures seamless connectivity and compatibility with the Raspberry Pi 4, allowing for efficient data transfer and real-time image processing. With its wide-angle lens and adjustable focus, the PlayStation Camera enhances the robot's visual perception, making it capable of performing complex tasks such as facial recognition, obstacle detection, and navigation. Figure 3.10 shows the Sony USB Camera. [15]



Figure 3.10: Sony USB Camera

The vision system also includes a Raspberry Pi screen, which serves as an interactive interface for users. This display allows for real-time visualization, providing an intuitive way for users to interact with the robot. The Raspberry Pi Screen supports high-resolution graphics, ensuring clear and vibrant visuals. It is designed to be energy-efficient and compact, fitting seamlessly into the robot's body structure. Figure 3.11 shows the LCD Raspberry Pi screen. [7]



Figure 3.11: LCD Raspberry Pi screen

Audio System

The audio system comprises a Kisonli USB speaker and an integrated microphone. The USB speaker delivers high-quality sound, ensuring clear and audible communication. The integrated microphone, part of the USB camera setup, captures voice commands and environmental sounds, enhancing the robot's interaction capabilities. Figure 3.12 shows the Kisonli USB Speaker. [10]



Figure 3.12: Kisonli USB Speaker

Proximity Sensors

For obstacle detection and distance measurement, ultrasonic sensors are employed. These sensors emit ultrasonic waves and measure the time taken for the echoes to return, providing accurate distance readings. The sensors are strategically placed to cover a wide area, ensuring the robot can navigate safely and avoid collisions. Figure 3.13 shows the Waterproof Ultrasonic Sensor Module. [16]



Figure 3.13: Waterproof Ultrasonic Sensor Module

3.4 Software Components

3.4.1 AI Modules

The Smart Interactive Robot incorporates advanced AI modules to enhance its interaction capabilities. The integration of OpenAI's GPT-4 and Picovoice's Rhino Speech-to-Intent technology allows the robot to understand and respond to natural language commands accurately. The AI modules enable the robot to engage in intelligent conversations, interpret user intents, and execute appropriate actions. Figure 3.14 shows Picovoice Launches Speech-to-Text Platform. [13] Figure 3.14 shows OpenAI API and GPT 3.15. [12]



Figure 3.14: Picovoice Launches Speech-to-Text Platform



Figure 3.15: OpenAI API and GPT

3.4.2 Speech Recognition

The robot uses advanced speech recognition algorithms to convert spoken language into text. This technology allows the robot to understand and process voice commands, enhancing its interactivity.

3.4.3 Natural Language Processing (NLP)

NLP algorithms enable the robot to comprehend and generate human language. This capability allows the robot to engage in meaningful conversations, understand user queries, and provide relevant responses.

3.4.4 Vision Processing

Computer vision algorithms process the data from the vision system, enabling the robot to recognize faces. This capability is essential for tasks such as navigation and interaction.

3.4.5 Control Algorithms

Control algorithms manage the robot's movements and actions. These algorithms ensure smooth and precise operation of the actuators, enabling the robot to perform tasks such as navigation, and interaction.

3.4.6 Remote Control

The Smart Interactive Robot includes a mobile app for remote control, enhancing its versatility and user convenience. The app allows users to send text for speech synthesis, and control two DC motors, and a servo motor. With an intuitive interface, the app enables seamless interaction with the robot, providing users the ability to operate the robot remotely, execute commands, and monitor its status in real-time. This remote control feature significantly enhances the robot's functionality and user experience.

3.4.7 Firebase Cloud Service

The Smart Interactive Robot utilizes Firebase as a cloud service to manage and synchronize data across devices in real-time. Firebase provides a robust and scalable backend, enabling seamless communication between the robot and the mobile app. This cloud service is essential for handling data storage, user authentication, and real-time database updates, ensuring that the robot can process commands, update statuses, and interact with users efficiently. By leveraging Firebase, the project benefits from enhanced reliability, security, and scalability, making it easier to manage and expand the system's capabilities in the future. [6] Figure 3.16 shows Firebase Cloud Service.



Firebase

Figure 3.16: Firebase Cloud Service

3.5 System Architecture

The system architecture of our smart interactive robot project shows the entire design and structure of the system, thus highlighting the fact that different hardware and software components collaborated to accomplish the desired function. This consists of both a general block diagram, a schematic diagram, and a flowchart diagram which together depict the interconnection and communication pathways between different modules. The architecture makes sure that every component, which includes sensors, actuators, microcontrollers, and cloud services, work in tune to give a smart and reactive robotic system.

3.5.1 General Block Diagram

In our project, the general block diagram provides a high-level overview of the Smart Interactive Robot's architecture, illustrating the key components and their interactions. This diagram is designed to showcase the modular structure of the system, where each block represents a crucial element of the robot's functionality. The diagram includes inputs such as microphones, cameras, and ultrasonic sensors, which feed data into the central microcontroller. The microcontroller, acting as the brain of the system, processes this information using AI modules like OpenAI and Picovoice to interpret and generate appropriate responses. Outputs from the microcontroller are directed towards various actuators, including motors and a speaker, to perform physical actions and communicate with users. Additionally, the integration of cloud services via Firebase allows for remote control and real-time status updates through a mobile app, enhancing the robot's interactivity and connectivity. This block diagram serves as a visual summary of the complex interactions within the robot, providing a clear understanding of how the different components work together to achieve the desired functionality. As shown in Figure 3.17.

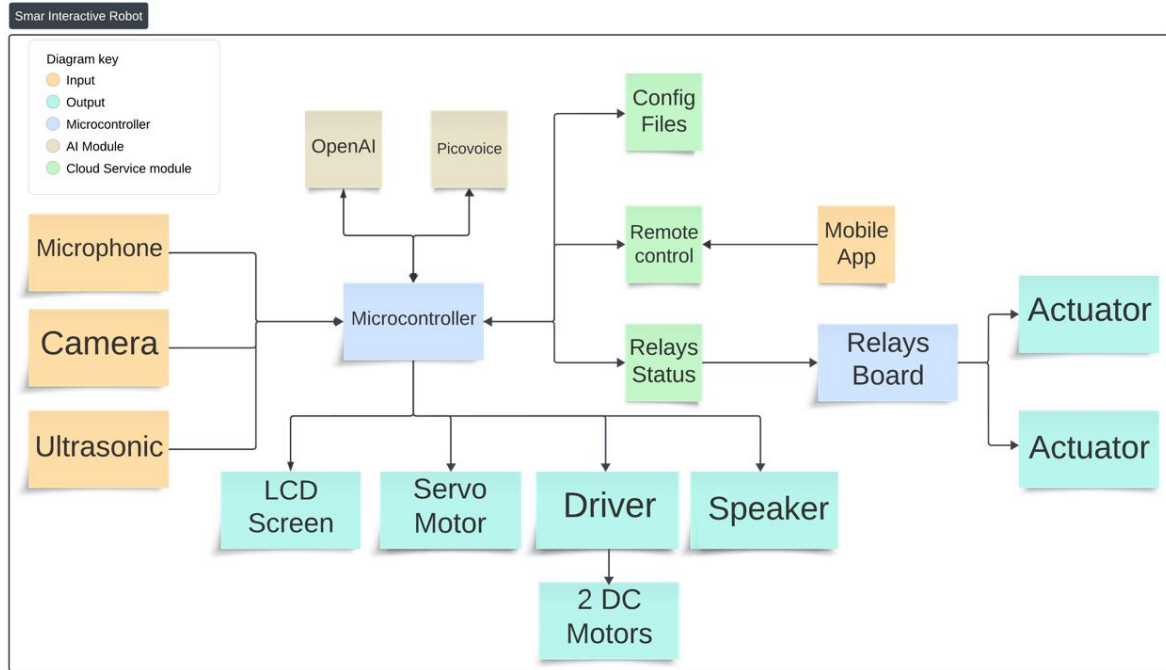


Figure 3.17: General Block Diagram

3.5.2 Flowchart Diagram

The flowchart for our Smart Interactive Robot project provides a visual representation of the sequence of operations within the system. It maps out the logical flow of data and control between different components, showcasing the decision-making processes and interactions that occur as the robot performs various tasks. This includes the flow of information from sensors to the microcontroller, the execution of control commands, and the response actions carried out by actuators. The flowchart ensures clarity in understanding the operational logic and helps in identifying potential areas for optimization or troubleshooting within the system.

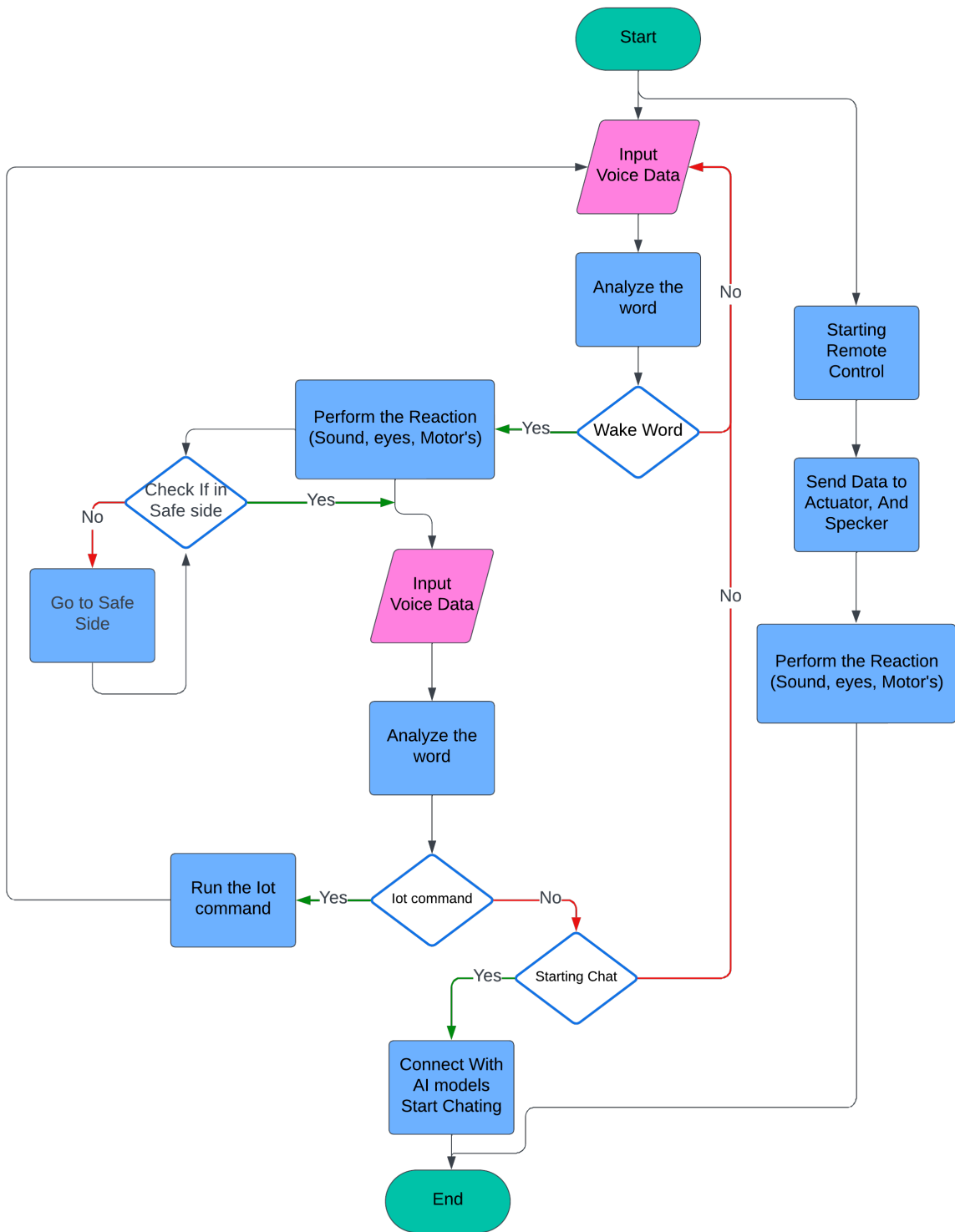


Figure 3.18: Flowchart Diagram

3.6 Summary

This chapter provided an in-depth overview of the system design for the Smart Interactive Robot. It covered the essential hardware and software components, their functionalities, and the interactions between different modules.

Chapter 4

Implementation

4.1 Preface

This chapter details the implementation of the Smart Interactive Robot, Ayyash. The implementation phase involves assembling the hardware components, integrating the software systems, and configuring the communication protocols.

4.2 Hardware Assembly

The hardware components are assembled following the modular system architecture outlined in the design phase.

4.2.1 Microcontroller

Raspberry Pi 4 Model B

We connected the Raspberry Pi 4 Model B as the central processing unit of the robot, interfacing it with various sensors and actuators. The GPIO pins of the Raspberry Pi were utilized for connecting the ultrasonic sensors, motor drivers, and relay modules. The USB ports were used to connect peripheral devices such as the Sony USB Camera and Kisonli AUX Speaker, ensuring robust data handling and peripheral support. As shown in Figure 4.1.

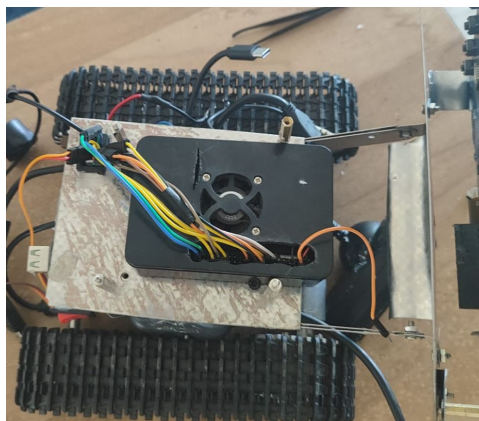


Figure 4.1: Raspberry Pi 4 Model B Connections

Esp32 with relay board

We integrated the ESP32 microcontroller with the KC868-A8 relay board to manage and control high-power components. Each relay channel was connected to a specific component like the cooling system or external actuators, providing efficient and reliable control. The ESP32 was programmed to communicate with the Raspberry Pi via Wi-Fi, ensuring seamless data transmission and control over the connected devices. As shown in Figure 4.2.

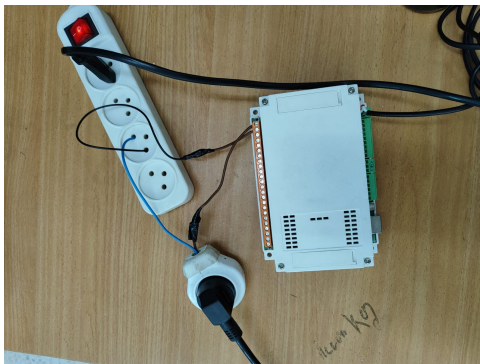


Figure 4.2: ESP32 with the KC868-A8 relay board Connections

H-Bridge Motor Driver

The Dual H-Bridge Motor Driver L298N was connected to the Raspberry Pi to control the robot's motors. We connected the input pins of the motor driver to the GPIO pins of the Raspberry Pi and the output pins to the motors. This setup allowed for precise control of the motor's speed and direction, enabling smooth and accurate movement of the robot. As shown in Figure 4.3.

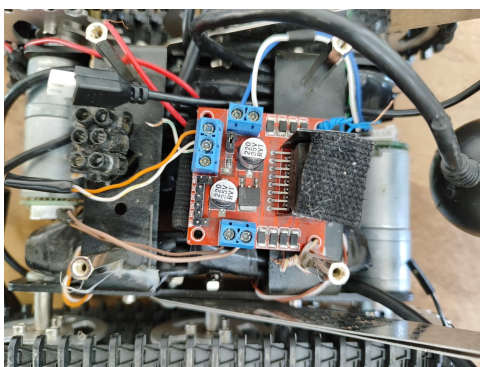


Figure 4.3: Dual H-Bridge Motor Driver L298N Connections

4.2.2 Cooling System

We installed a cooling system to maintain optimal operating temperatures for the robot's components. The cooling fans were connected to the relay board, which was controlled by the ESP32. The relay board was programmed to activate the cooling system based on temperature readings from sensors placed within the robot, ensuring efficient heat dissipation and component longevity. As shown in Figure 4.4.

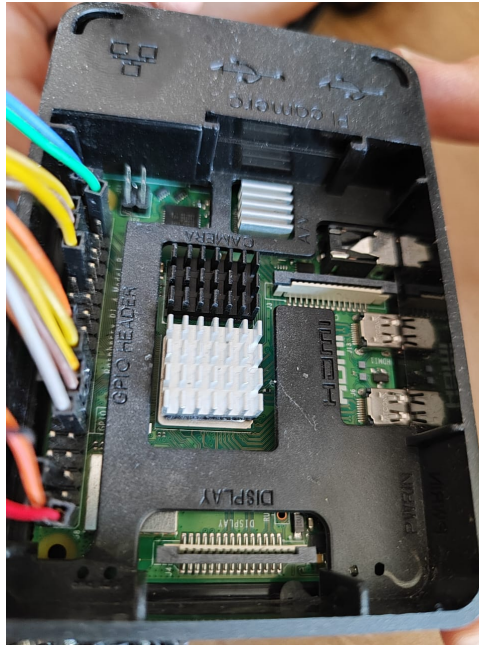


Figure 4.4: Cooling System of the Robot Connections

4.2.3 Vision System

Camera

The Sony USB Camera was connected to the Raspberry Pi via a USB port, providing high-definition video input for object recognition and environment mapping. The camera's drivers were installed on the Raspberry Pi, and it was configured to work with OpenCV for real-time image processing and analysis. As shown in Figure 4.5.



Figure 4.5: Sony USB Camera Connections

LCD Raspberry Pi screen

We connected the LCD screen to the Raspberry Pi using the HDMI port and configured it to display the robot's interface and visual feedback. This screen was essential for debugging, providing status updates, and enhancing user interaction by displaying real-time data, system status, and visual cues. As shown in Figure 4.6.



Figure 4.6: LCD Raspberry Pi screen Connections

4.2.4 Audio System

Kisonli AUX Speake

The Kisonli AUX Speaker was connected to the Raspberry Pi's audio jack to provide high-quality sound output. This speaker was used for voice interactions, audio feedback, and alerts. The audio output was managed by the Raspberry Pi's sound system, ensuring clear and responsive audio communication. As shown in Figure 4.7.

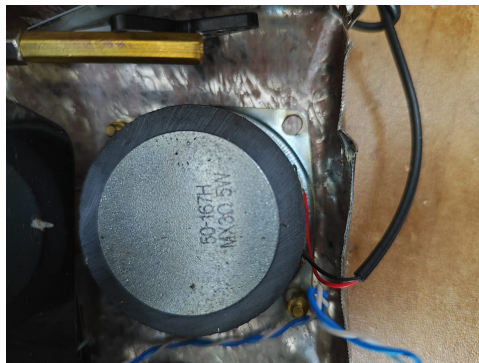


Figure 4.7: Kisonli AUX Speaker Connections

Microphone Array Connections

We integrated a microphone array, which is integrated into the PlayStation Camera, into the robot to capture voice commands and environmental sounds. As shown in Figure 4.5.

4.2.5 Proximity Sensor

We connected the waterproof ultrasonic sensor modules to the GPIO pins of the Raspberry Pi. These sensors were strategically placed around the robot to detect obstacles and measure distances, providing crucial data for navigation and collision avoidance. The waterproof design ensured reliability and accuracy in various environmental conditions. As shown in Figure 4.8.

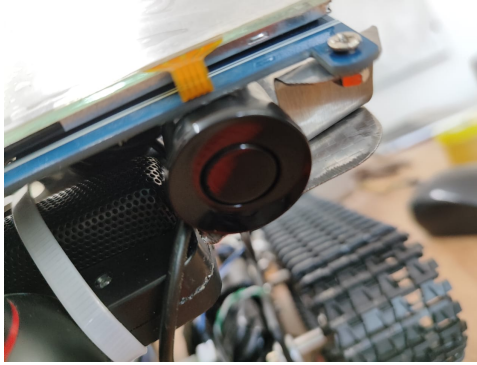


Figure 4.8: Waterproof Ultrasonic Sensor Module Connections

4.2.6 Actuators

We connected Dual DC 12V 350rpm motors to drive the wheels, providing the necessary torque and speed for stable and efficient movement across various surfaces. These motors were mounted securely on the chassis to ensure robust performance and reliable operation in diverse environments. As shown in Figure 4.9. We integrated MG996R servo motors for

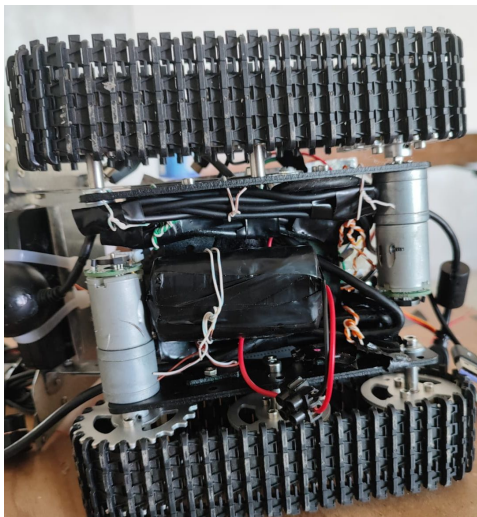


Figure 4.9: 12V DC Encode Motor Connections

precise movements, ensuring accurate positioning and smooth motion. These high-torque servos, with their metal gear construction, were connected to the robot's framework to guarantee durability and consistent performance in demanding applications. Each servo was carefully calibrated to achieve optimal precision and control, making them ideal for tasks requiring meticulous movement. As shown in Figure 4.10.

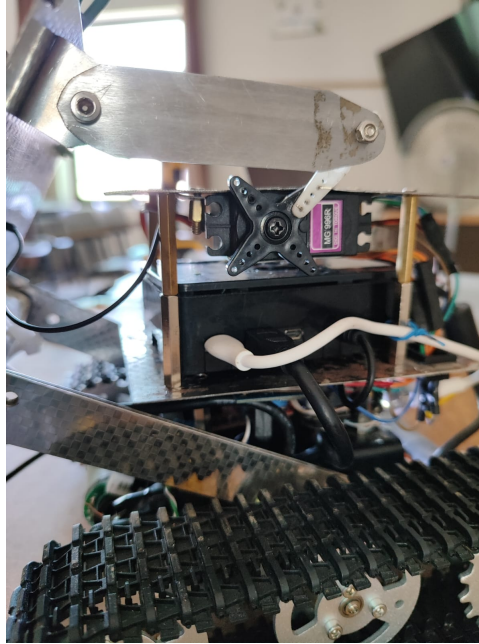


Figure 4.10: MG996R servo motor Connections

4.2.7 Power System

We connected a high-capacity lithium polymer (LiPo) battery to serve as the primary power source, ensuring ample power for the robot's extended operation. The battery was connected to a power distribution board, which regulated and distributed power to all components, including the Raspberry Pi, ESP32, motor drivers, cooling system, sensors, and peripheral devices. As shown in Figure 4.11. We employed step-down (buck) converters to regulate voltage, supplying 5V to the Raspberry Pi and ESP32 microcontroller, while the motor drivers and other high-power components received 12V. This setup ensured that each component received the appropriate voltage and current for optimal performance. As shown in Figure 4.12.

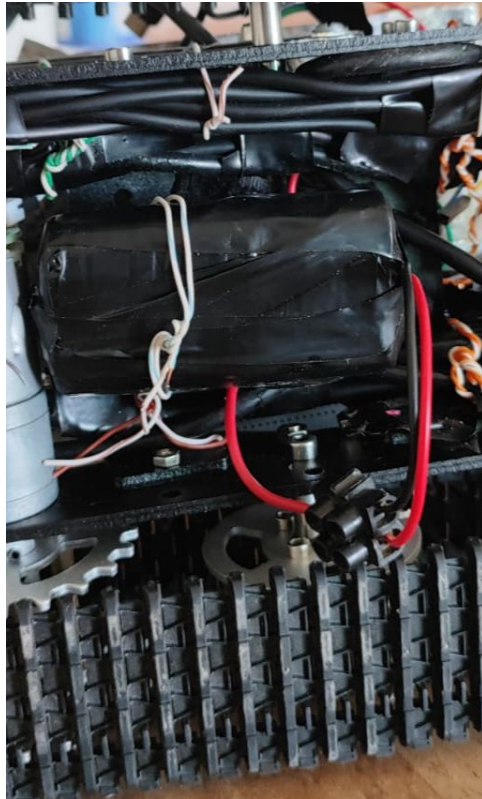


Figure 4.11: Three lithium Ion Cells with BMS for three cells Connections

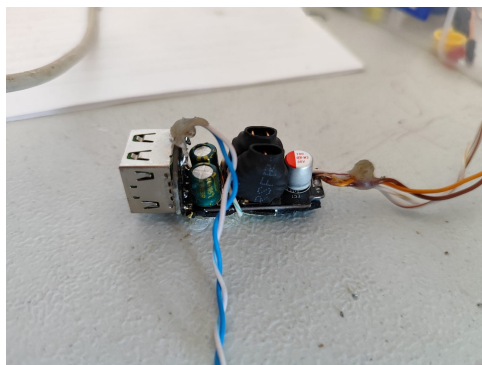


Figure 4.12: Buck Converter Regulator 12V/24V to 5V 5A USB Car Power Adapter Connections

4.3 Software Integration

In our Smart Interactive Robot project, several advanced software components are integrated to enable intelligent functionality and seamless connectivity. These components include OpenAI for natural language processing, Picovoice for offline speech recognition, Firebase for cloud-based data storage and real-time communication, and a custom-built mobile app for user interaction and control.

4.3.1 OpenAI and GPT Integration

OpenAI's powerful natural language processing models are utilized to enhance the robot's conversational abilities. By connecting to OpenAI's API, the robot can understand and generate human-like text, enabling it to engage in intelligent and context-aware conversations with users. The integration involves setting up secure API keys, sending user inputs to the API, and processing the responses to drive the robot's behavior and dialogue. As shown in Figure 4.13.

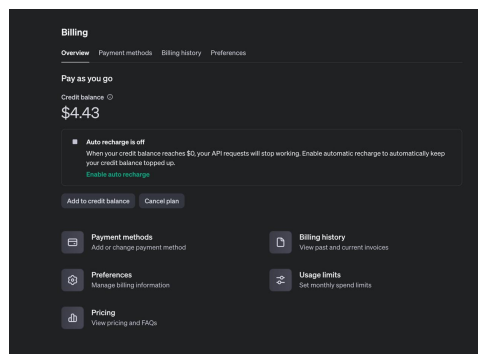


Figure 4.13: OpenAI API and GPT Integration

4.3.2 Picovoice Integration

To enable offline voice recognition, Picovoice's cutting-edge technology is employed. Picovoice allows the robot to process voice commands locally without requiring an internet connection, ensuring fast and reliable performance even in areas with limited connectivity. The integration process includes configuring Picovoice's wake word and command recognition models, as well as linking the recognized commands to the robot's actions.

4.3.3 Firebase Integration

Firebase is used to provide real-time database capabilities, allowing the robot to store and retrieve data efficiently. This cloud service also supports real-time communication between the robot and the mobile app, enabling features such as remote control and status monitoring. The integration includes setting up Firebase Authentication for secure access, configuring Firestore for structured data storage, and implementing Firebase Cloud Messaging (FCM) for sending notifications to the mobile app. As shown in Figure 4.14

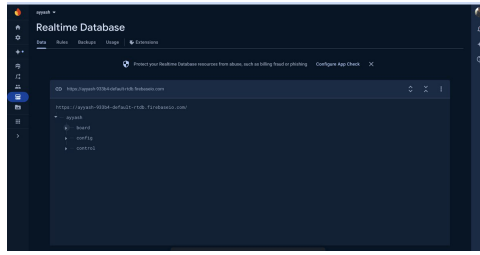


Figure 4.14: Firebase Cloud Service Integration

4.3.4 Mobile App Integration

A custom mobile app is developed to serve as a user-friendly interface for controlling the robot and monitoring its status. The app connects to the robot via Bluetooth and the internet, allowing users to send text commands, control the robot's movements, and receive real-time feedback. Integration involves ensuring compatibility with the robot's hardware components and software systems, as well as providing intuitive controls and clear visualizations for user interaction. As shown in Figure 4.15 4.16



Figure 4.15: Mobile App Interface Integration

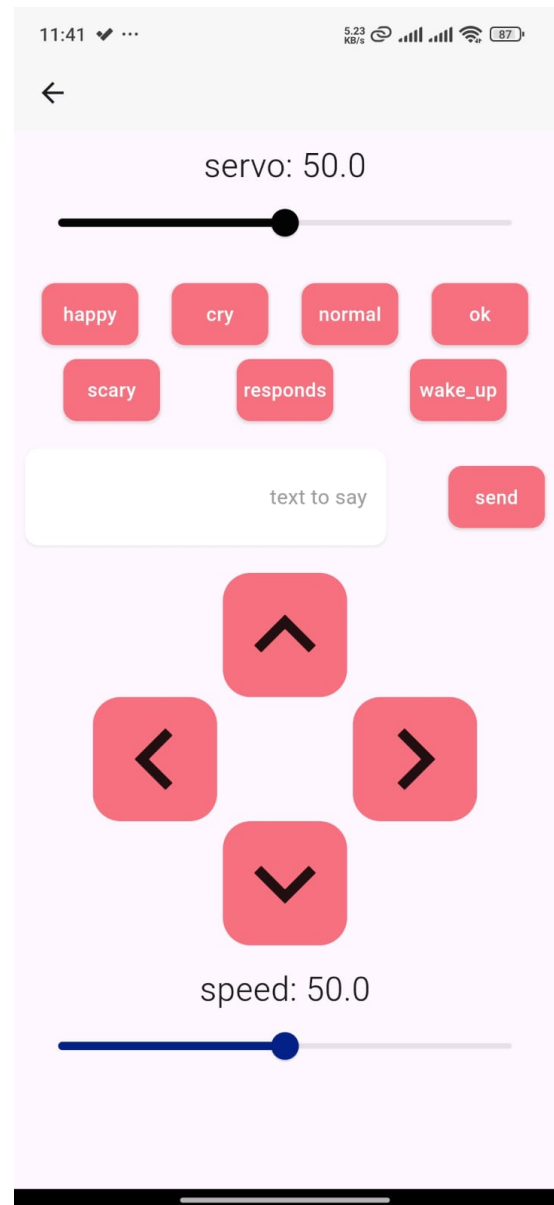


Figure 4.16: Mobile App Control Integration

4.4 Software Design Architecture and patterns

The software integration of our project is divided into several key processes, each responsible for specific functionalities. These processes are illustrated in the following block diagrams to provide a clear understanding of their roles and interactions.

Part 1: Main and Wake Word Detection Processes

This figure 4.17 illustrates the main process and the wake word detection process. The main process imports necessary modules and initializes various components such as the speech recognizer and logging. The wake word detection process listens for a specific wake word to trigger subsequent actions.

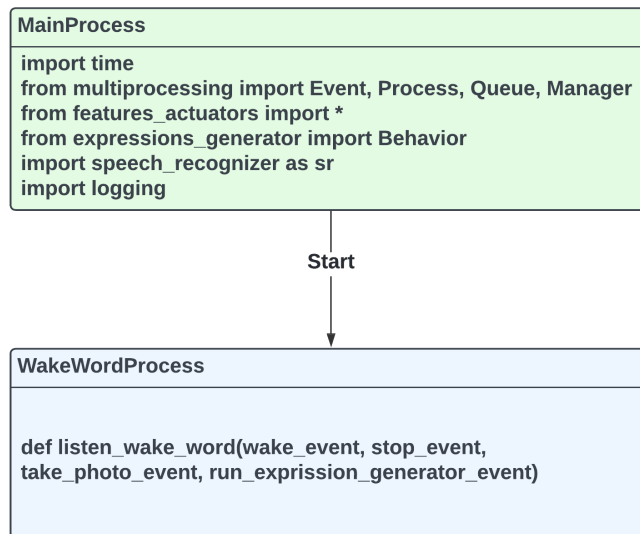


Figure 4.17: Main and Wake Word Detection Processes

Part 2: Controller Process with its Sub components

This figure 4.18 depicts the controller process and its various sub-components. The controller manages the overall system, coordinating between different sub-components such as the queue manager, queue receiver, and various controllers for sensors, servos, sound, motors, and screen.

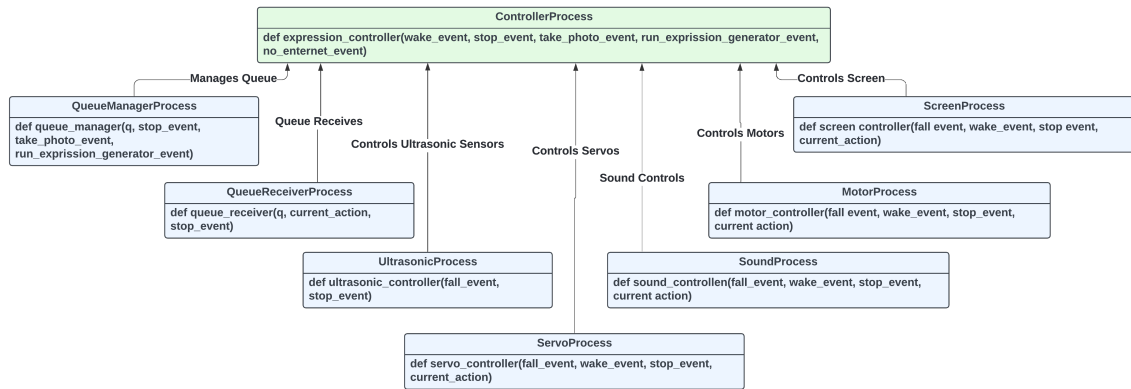


Figure 4.18: Controller Process with its Sub components

Part 3: Expression Controller and Behavior Module

This figure 4.19 shows the expression controller and the behavior module. The expression controller manages various events such as wake, stop, take photos, and run expression generator. The behavior module generates the necessary actions based on the inputs from the queue manager and other processes.

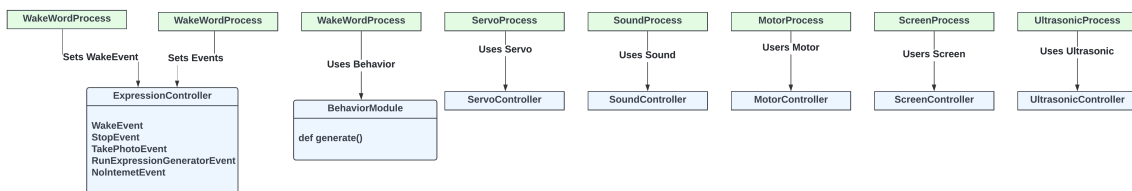


Figure 4.19: Expression Controller and Behavior Module

Part 4: Software Architecture for ESP32 with 8-Relay Board

This figure 4.20 shows the software architecture for the ESP32 with an 8-relay board. The ESP32 runs firmware that handles GPIO operations and relay control. The firmware reads data and sends commands to the relay control module, which in turn controls the 8 relays. The software components include the firmware, relay control module, which work together to manage the connected devices.

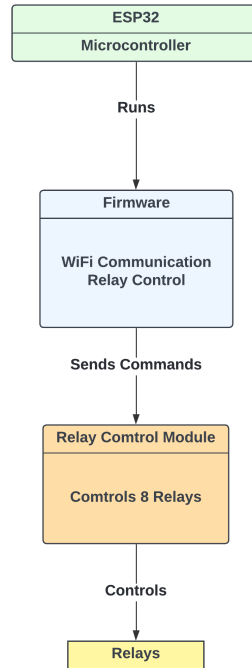


Figure 4.20: Software Architecture for ESP32 with 8-Relay Board

Part 4: Remote Control via Mobile App

The mobile app serves as a crucial interface for remote control and monitoring of the Smart Interactive Robot. This app allows users to interact with the robot in real time, providing commands and receiving feedback directly from a mobile device. The app is designed with a user-friendly interface, enabling easy control of the robot's movement, speech, and other functionalities. Through the app, users can send text-to-speech commands, control the two DC motors and servo motor, and receive live updates on the robot's status. This integration ensures seamless communication between the robot and the user, enhancing the robot's interactivity and functionality.

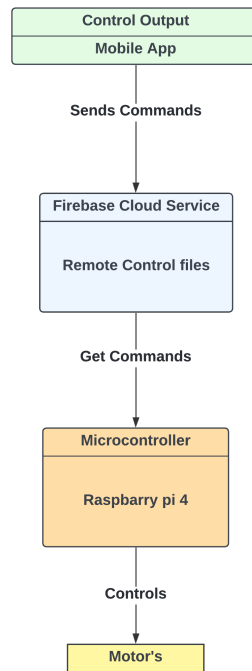


Figure 4.21: Software Architecture for emote Control via Mobile App

4.4.1 Communication Protocols

Ayyash uses HTTP (Hypertext Transfer Protocol) for communication within the IoT environment. This protocol is widely used and supported, ensuring compatibility and ease of integration with various devices and services. HTTP provides a reliable and straightforward means for real-time interactions, allowing Ayyash to effectively communicate with other components in the IoT ecosystem.

Chapter 5

Results and Testing

5.1 Preface

This chapter details the testing procedures and results of all system components within the Smart Interactive Robot project. Each hardware component underwent rigorous testing to ensure functionality and reliability, and the outcomes of these tests are discussed in the following sections.

5.2 Hardware Testing

Raspberry Pi 4 Model B Connections

We connected the Raspberry Pi 4 Model B as the central processing unit, interfacing it with various sensors and actuators. The GPIO pins, USB ports, and HDMI output were tested for functionality. The Raspberry Pi successfully communicated with all connected devices and displayed system outputs on the LCD screen.

ESP32 with the KC868-A8 Relay Board Connections

The ESP32 microcontroller was integrated with the KC868-A8 relay board to manage high-power components. We verified the ESP32's ability to control each relay, ensuring reliable switching of the connected devices. The ESP32 maintained stable communication with the Raspberry Pi, providing efficient control over the power system and actuators.

Dual H-Bridge Motor Driver L298N Connections

The Dual H-Bridge Motor Driver L298N was tested by connecting it to the Raspberry Pi and the motors. We verified the correct functioning of motor control, ensuring that the robot's wheels moved as intended. The driver provided precise control over speed and direction, enabling smooth and responsive navigation.

Cooling System of the Robot Connections

The cooling system, including fans and heat sinks, was connected to the Raspberry Pi 4 Model B and tested for temperature regulation. The system successfully activated

the cooling components based on temperature readings, maintaining optimal operating conditions for the robot.

Sony USB Camera Connections

The Sony USB Camera was connected to the Raspberry Pi via a USB port and tested for image capture and video streaming. The camera provided high-definition video input for Face recognition, integrating seamlessly with the robot's vision system.

LCD Raspberry Pi Screen Connections

The LCD screen was connected to the Raspberry Pi using the HDMI port and tested for display functionality. It successfully showed the user interface and visual feedback, enhancing user interaction with the robot.

Kisonli AUX Speaker Connections

The Kisonli AUX Speaker was connected to the Raspberry Pi's audio jack and tested for sound output. It provided clear and high-quality audio feedback, supporting the robot's voice interactions.

Waterproof Ultrasonic Sensor Module Connections

The waterproof ultrasonic sensors were connected to the GPIO pins of the Raspberry Pi and tested for obstacle detection and distance measurement. The sensors accurately measured distances and detected obstacles, contributing to the robot's navigation and collision avoidance system.

Microphone Array Connections

The microphone array was connected to the Raspberry Pi via a USB port and tested for voice command capture. It effectively captured voice inputs for processing by the robot's natural language processing system, facilitating smooth human-robot interaction.

Power Management System Connections

The power management system, including the high-capacity lithium polymer (LiPo) battery and power distribution board, was tested for stable power supply to all components. Voltage and current sensors were integrated and monitored to ensure safe and efficient power management.

Each hardware component of the Smart Interactive Robot underwent rigorous testing to ensure functionality and reliability. These comprehensive tests confirmed that all components performed as expected, providing a solid foundation for the overall system's performance.

5.3 Software Testing

In this section, we detail the testing procedures and results for the software components integrated into the Smart Interactive Robot. These components include OpenAI and ChatGPT for natural language processing, Picovoice for offline speech recognition, Firebase for cloud services, and the custom-built mobile app for user interaction and control.

OpenAI and ChatGPT Integration

The integration of OpenAI's ChatGPT model was tested to ensure the robot's capability to engage in intelligent and context-aware conversations. The testing involved sending various user queries to the robot and evaluating the relevance, accuracy, and responsiveness of the generated responses. The results showed that the OpenAI API performed consistently, providing coherent and contextually appropriate responses across a range of conversational topics. Latency was minimized, ensuring real-time interaction, which enhanced the robot's conversational abilities.

Picovoice Integration

Testing for Picovoice involved evaluating the robot's ability to recognize and process voice commands locally, without relying on an internet connection. The Picovoice engine was tested for accuracy in recognizing predefined wake words and commands in different environments and noise levels. The results indicated high accuracy and responsiveness, even in noisy settings, ensuring reliable voice command processing. The integration was further validated by ensuring that the recognized commands were correctly executed by the robot, confirming the robustness of the offline speech recognition system.

Firebase Integration

Firebase was tested for its role in managing real-time data communication between the robot and the mobile app, as well as storing critical system data. The testing process involved verifying real-time synchronization of data, such as sensor readings and command responses, between the robot and the cloud. Firebase Authentication was tested to ensure secure access control, and Firestore was evaluated for its ability to handle data storage and retrieval efficiently. The results confirmed that Firebase provided a reliable and secure cloud-based solution, enabling seamless real-time communication and data management.

Mobile App Integration

The mobile app was tested to ensure smooth user interaction and control over the robot's functionalities. The testing involved checking the app's connectivity with the robot via the internet, verifying that the app could successfully send commands, receive real-time feedback, and display the robot's status. User interface elements were tested for responsiveness and ease of use, ensuring that users could intuitively control the robot's movements, and monitor its operations. The app performed reliably across different devices and network conditions, providing a user-friendly interface for interacting with the robot.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The Smart Interactive Robot project, named Ayyash, has successfully demonstrated the integration of various hardware and software components to create a versatile and interactive robotic system. Ayyash is capable of engaging in intelligent conversations, providing non-verbal communication cues, and physically interacting with its environment, making it a significant step towards advanced human-robot interaction in IoT environments.

Throughout the project, we meticulously designed and tested each component to ensure reliable performance. The use of the Raspberry Pi 4 as the central processing unit, along with the integration of ESP32 microcontrollers with relays board, high-definition cameras, ultrasonic sensors, and various actuators, has allowed Ayyash to perform a wide range of tasks effectively. The power management system, cooling system, and robust control algorithms have further ensured the robot's stability and longevity.

Overall, Ayyash has met the project's goals of creating an intelligent, interactive, and user-friendly robot that can serve in various fields, demonstrating the potential of advanced robotics in enhancing daily life and work environments.

6.2 Future Work

To further enhance the capabilities of Ayyash, we aim to incorporate features found in advanced consumer robots. These features include:

- **Emotional Intelligence and Expressions:** Developing advanced algorithms to enable Ayyash to recognize and respond to human emotions. This includes facial expressions, voice tone analysis, and adaptive responses to create a more engaging and empathetic interaction experience.
- **Autonomous Navigation and Mapping:** Implementing advanced SLAM (Simultaneous Localization and Mapping) techniques to allow Ayyash to navigate autonomously in complex environments. This includes obstacle avoidance, path planning, and real-time environment mapping to enhance mobility and usability.
- **Advanced AI and Machine Learning:** Integrating cutting-edge AI and machine learning models to improve Ayyash's conversational abilities, decision-making processes, and personalization. This includes natural language understanding, context-aware responses, and continuous learning from interactions.

- **Enhanced Connectivity and IoT Integration:** Expanding Ayyash’s connectivity to seamlessly integrate with a broader range of IoT devices and services. This includes voice-controlled home automation, real-time data synchronization, and enhanced interoperability with other smart systems.
- **Interactive Display and User Interface:** Upgrading the LCD screen to provide a more interactive and visually appealing user interface. This includes touch-screen capabilities, dynamic animations, and customizable user experiences to enhance user engagement.
- **Integration of Robotic Arm:** Incorporating a robotic arm to enable Ayyash to perform more complex tasks that require physical manipulation. This includes picking up objects, interacting with the environment, or assisting users in daily activities. The arm will be designed to work seamlessly with the existing hardware and software architecture, ensuring smooth operation and integration.
- **Expansion of Sensor Array:** Enhancing the robot’s perception capabilities by including a broader array of sensors in future versions. This includes adding sensors such as touch sensors, motion sensors, and more advanced proximity sensors for better navigation and interaction with the surroundings. These enhancements will allow Ayyash to collect more data from its environment, leading to improved decision-making and interaction efficiency.

By integrating these advanced features, we aim to elevate Ayyash to the level of sophistication seen in advanced robots, making it an even more powerful and versatile companion for users. These enhancements will not only improve the robot’s functionality but also broaden its applications and impact in both personal and professional settings.

6.3 Limitations

6.3.1 Hardware Constraints

- **Processing Power:** The Raspberry Pi 4, while powerful, has limited processing capabilities compared to more advanced computing systems. This may impact performance, especially with complex AI tasks.
- **Sensor Limitations:** The quality and accuracy of sensors (e.g., cameras, microphones) can affect the robot’s ability to interact effectively. Limitations in sensor resolution or range might impact performance.

6.3.2 Software Challenges

- **Real-Time Processing:** Managing real-time interactions and processing multiple streams of data (e.g., from cameras and microphones) simultaneously can be challenging. This might affect responsiveness and accuracy.
- **Complexity in AI:** Implementing sophisticated AI and NLP algorithms may require extensive fine-tuning and optimization to achieve the desired performance.

6.3.3 Integration Issues

- **IoT Compatibility:** Ensuring seamless integration with various IoT devices and platforms can be complex. Compatibility issues might arise, affecting functionality.
- **Inter-Component Communication:** Coordinating communication between different components (e.g., sensors, actuators, software modules) might introduce delays or synchronization issues.

6.3.4 User Interaction

- **Natural Interaction:** Ensuring natural and intuitive interactions between users and the robot can be challenging, particularly with non-verbal communication and context understanding.
- **Customization:** Adapting the robot's behavior to different users' needs and preferences might require additional development and customization.

6.3.5 Scalability and Upgrades

- **Modularity:** Expanding or upgrading hardware components (e.g., adding new sensors or actuators) might require redesigning parts of the system.
- **Software Updates:** Keeping the software up-to-date with the latest advancements in AI and robotics may require ongoing maintenance and development.

6.3.6 Cost and Resources

- **Budget Constraints:** Developing and maintaining advanced robotics projects can be expensive. Cost management is crucial, especially if scaling up or adding new features.
- **Resource Availability:** Access to high-quality components and development tools might be limited depending on your location and budget.

6.4 Final Remarks

The development and successful implementation of Ayyash mark a significant achievement in the field of smart interactive robots. This project serves as a foundation for future innovations, contributing to the advancement of technology in Palestine and beyond.

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