An-Najah National University

Faculty Of Engineering And Information Technology

Computer Engineering Department

Sparko: Unleashing the Potential of Smart Robotics

PREPARED BY:

Abdallah Khayat

Salahaldin Shehada

SUPERVISED BY:

Dr. Luai Malhis

June 20, 2024

Acknowledgements

"We give our deepest gratitude to Dr. Luai Malhis, our supervisor, for his amazing support during our project journey. His valuable scientific guidance has been inspiring in achieving our great success. We are also thankful to the members of the Department of Computer Engineering for their extensive expertise and assistance. Additionally, we are grateful to our friends and family who have been with us from the beginning of our journey, giving us all the support and encouragement we needed. Their limitless belief in our abilities has been a cornerstone for our achievement."

DISCLAIMER

This report was written by Salahaldin Shehada and Abdallah Khayat at the Computer Engineering Department, Faculty of Engineering, An-Najah National University. It has not been altered or corrected, other than editorial corrections, as a result of assessment and it may contain language as well as content errors. The views expressed in it together with any outcomes and recommendations are solely those of the authors. An-Najah National University accepts no responsibility or liability for the consequences of this report being used for a purpose other than the purpose for which it was commissioned.

Contents

List of Figures

Abstract

This research paper demonstrates the implementation of Sparko showing its design and development. Sparko is smart robot we created to perform several tasks. These tasks include interactive communication. They also involve movement control. It is powered by using a rechargeable 12V lithium battery. Which is regulated to 6V using voltage converter. It is also connected to battery indicator to show the amount of battery left.
Sparko’s main body is built using plastic 3D printed components. It has nine servo motors. Two for each leg. Two for each hand. And one for the head. These allow for flexible and precise movements. Control of Sparko’s movements is conducted through WiFi using a Raspberry Pi Pico W and a servo driver.

To enhance user interaction Sparko features LCD screen on its head. The screen displays various facial expressions. Ultrasonic sensor is integrated. This enables obstacle detection. It also allows avoidance capabilities. Additionally, Sparko possesses advanced speech features using two ESP32 modules. One module converts speech to text using Google Cloud API. The other sends text to ChatGPT API and converts its response to speech. This allows the robot to respond verbally. These modules are connected with microphone and speaker creating complete audio chat interaction system. Infrared sensor is used to activate Sparko's listening mode. This enables it to receive commands to process verbal queries from users, then it responds accordingly.

Testing results has shown Sparko's effective movement control. Reliable obstacle avoidance. The speech-to-text and text-to-speech functionalities showed good level of accuracy with some limitations such as having response with no more than 30 words due to esp32 memory capacity. There is a small error percentage when it comes to recognizing words. This combination of hardware and software makes Sparko valuable advancement in interactive robotics field. Offering great value for future developments.

1 Introduction

1.1 General background

The interaction experience with robots has largely changed due to the possible innovations in the field of artificial intelligence robotics. Application of new ideas within the modern society has already become a normal feature in everyday human life. And the need to make people's life easier is on its highest demand which can normally be achieved through using smart robotics assistants, effective communication has to be established and environments have to be navigated. This paper introduces the Sparko robot which combines advanced motion control with interactive communication in order to achieve the goal of being robot assistant that have integrated AI.

1.2 Objectives

The major objective of this research is to develop Sparko, a smart robot capable of performing multiple tasks. It will be able to communicate through human dialogs using its voice chat feature as well as perform some actions at the same time based on the command given from the controlling device (WEB page). The specific objectives are :-

1. **Movement Control:** To enable Sparko to perform a set of movements using nine servo motors to achieve wide range of flexibility, using a WEB page that have simple interface(buttons) which can be accessed through multiple devices making it easy to control.
2. **Facial Expressions:** To provide Sparko with LCD that can display images as facial expressions to make it more user-friendly.
3. **Obstacle Avoidance:** To provide Sparko with Ultrasonic sensor. This allows it to detect and avoid obstacles based on the location of the obstacle. This improves its ability to interact with different environments safely.
4. **Interactive Voice Communication:** To provide Sparko with the required hardware to have advanced speech recognition and immersive response capabilities, allowing it to understand and respond to human commands naturally.
5. **Complete Integration:** To combine all of these features into a single multitasking robot that effectively integrates hardware and software, achieving the goal of becoming an interactive user friendly robot assistant.

1.3 Significance

Sparko meets the growing needs for robots and AI that can interact with people while benefiting from the latest advanced voice chat AI features. It can be used in many ways, including:

Personal Assistance: Sparko helps with our daily life by offering an easy to use voice assistant that can answer questions via the ChatGPT API. It can also be charged at any time ,while also having the ability to move in wide range of sets that have the potential to do some useful simple tasks. This makes Sparko a helpful assistant for daily tasks.

Education: Sparko works great as a learning tool that encourages students to learn, by having the ability to answer almost any type of questions the user may ask, thanks to its advanced AI database integrated with its micro-controller.

Kids Toy: Sparko is great example of a friendly robot that can help children spell words correctly as well as extending their knowledge by having Sparko as a reverence when ever having a question, additionally, it’s ability to move remotely works great as a way to entertain children.

Obstacles avoiding, WiFi control, speech recognition all together will make Sparko a good qualitative case in robotics, and it will certainly be a meaningful asset for human-robot interaction with its great potential.

1.4 Organization of the report

This report is organized showing a comprehensive overview of Sparko's development and capabilities. It is divided into several chapters, each focusing on different aspects of the project:

1. **Introduction**: This chapter provides the general background, objectives, and significance of the project. To set the context for the reader.

2. **Literature Review**: This chapter reviews existing research related to Sparko. By focusing on interactive robotics, voice interaction technologies, and obstacle avoidance systems. It highlights key contributions in these areas and identifies gaps that Sparko aims to address.

3. **Methodology**: This chapter details the standards and specifications used, as well as the materials and components involved, also the design and construction process, software development, and constraints and considerations. It provides a complete explanation of how Sparko was built and the reasons behind the choices made.

4. **Results & Discussion**: This part presents the results of the project. It discusses the problem resolution, contributions, logical implications, and limitations. It provides an analysis of how well Sparko meets its objectives and the potential impact of the project.

5. **Conclusion & Recommendations**: This final section summarizes the project. It draws conclusions based on the final results. It also offers recommendations for future improvements and work.

By organizing the report in this manner ensures that each aspect of Sparko's development is completely covered. It remains easily accessible to the reader.

2 Literature Review

This chapter reviews existing researches related to Sparko, it focuses on interactive robotics, voice interaction technologies and obstacle avoidance systems. This literature review highlights key contributions, it also identifies gaps in the current research and shows how Sparko is built and how is it different compared to the other existing solutions.

2.1 Interactive Robotics

Smart robots have become very common to server as a personal assistance, as well as in education and entertainment. Research by (Brezeal, Brooks, & et al, 2003)showed the importance of social communication, like body language and facial expressions which makes robots more engaging. Robots like NAO and Pepper by SoftBank Robotics can greet people, answer questions, and provide entertainment, but they are expensive and complex to program. Meanwhile, Sparko aims to be more affordable and easier to use, which can be achieved by using common components like the Raspberry Pi Pico W and ESP32 modules.

2.2 Voice Interaction Technologies

Voice interaction has improved greatly with AI and cloud services. For example, Speech-to-Text and Text-to-Speech API's services from Google Cloud and ChatGPT API from OpenAI enable the system to analysis and generate speech as a response. An example of famous voice assistants is Alexa which have made voice control commonly used in smart homes. Sparko uses Google's and OpenAI's APIs to understand and respond to commands, making it a helpful tool for personal assistance, education and entertainment.

2.3 Obstacle Avoidance Systems

Obstacle avoidance is important for robots to move safely. Components like infrared sensors and ultrasonic sensors can be used for this case. (Broenstein & Koren, 1989) developed the Vector Field Histogram method using ultrasonic sensors to help robots navigate narrow environments. More recent work by (Thrun, Burgard, & Fox, 2005) used LIDAR and computer vision for complex navigation tasks. Sparko uses an ultrasonic sensor for reliable and affordable obstacle detection, allowing it to move safely using simple requirements.

2.4 Gaps and Contributions

Despite progress, high costs and complexity limit access to advanced robots. Integrating multiple functions into a simple user-friendly system is also challenging. Sparko addresses these gaps by:

- Being affordable and having it built using common components.
- Combining voice interaction, movement control, and obstacle avoidance.
- Offering an easy-to-use web interface for control.

Sparko builds on existing technologies and combines different functionalities into one single robot to enhance human-robot interaction, making advanced robotics more accessible. This review highlights the current state for the existing robots and introduces Sparko's unique contributions, explained in the following chapters.

3 Methodology

3.1 Standards and Specifications (Codes)

During the development of Sparko, applying several engineering standards to ensure its functionality, safety and feasibility:

- **ISO 9241-210 Standard**: Applied to ensure a user-centered design approach, enhancing Sparko's usability and user experience.
- **IEEE 802.11 Standard**: Used for the WiFi communication module, enabling Sparko to connect and interact with different devices over a network.

These standards are included in the design process, ensuring that Sparko meets industry models and user expectations.

3.2 Materials and Components

3.2.1 3D Printed Design

We designed the main body of the robot using Fusion application with the help of a professional designer to do some modifications to the original design from (HashRobotics, 2024) make it look like a complete structure for a robot, that have a place for LCD on the head which represents the face of the robots, with a servo motor attached to the head for rotational movements, and going down to the center of the robot we have a large space for the main control components including the voice circuit and the movement circuit, we also designed legs and arms in a way that each leg has two servo motors and each arm has two servo motors which gives it the ability to perform wide set of movements, the figure below shows the full design:-

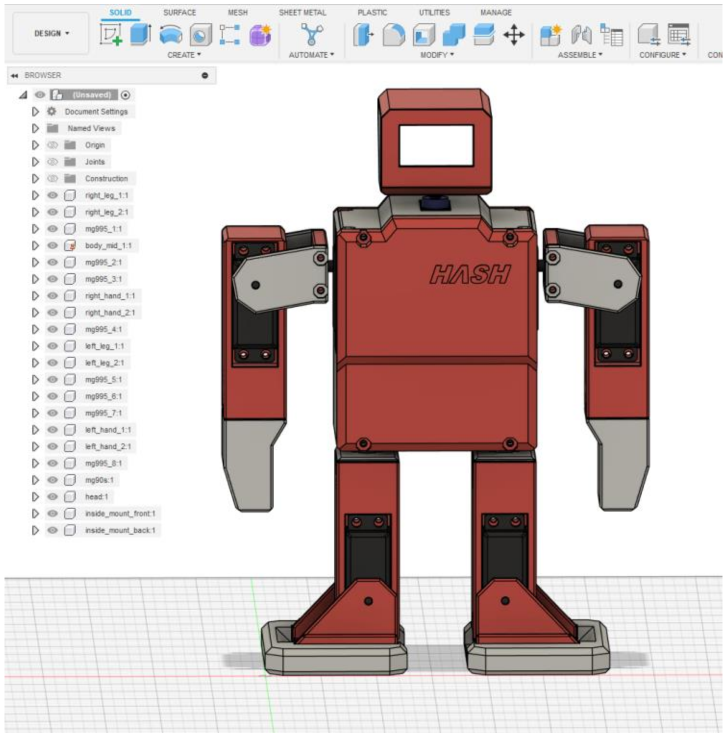


Figure 1: 3D Front Design

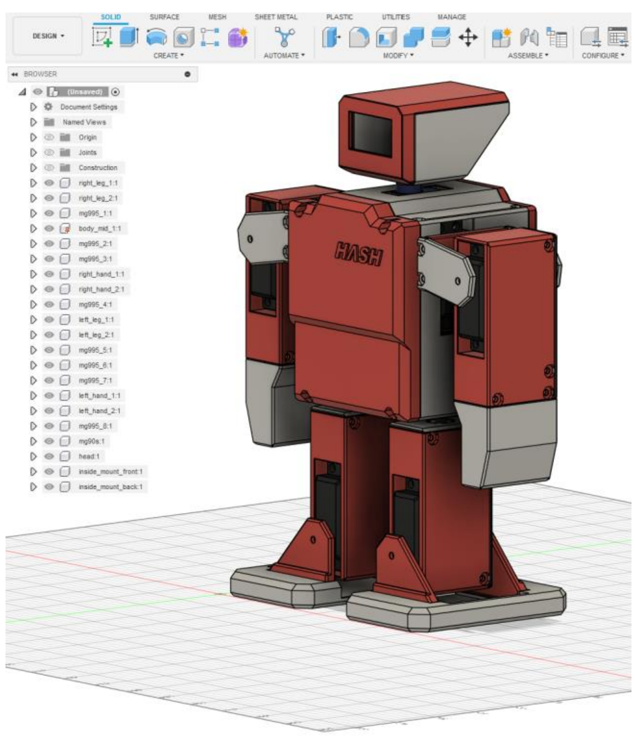


Figure 2: 3D Side Design

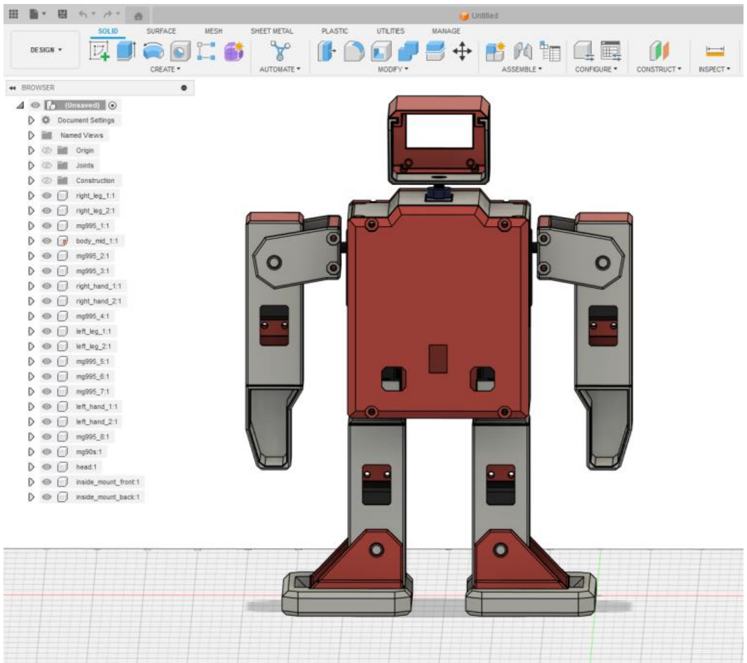


Figure 3: 3D Back Design

3.2.2 3D Printed Horns

A simple 3d printed horn that can be attached to the servo motor, connecting it to the main body.

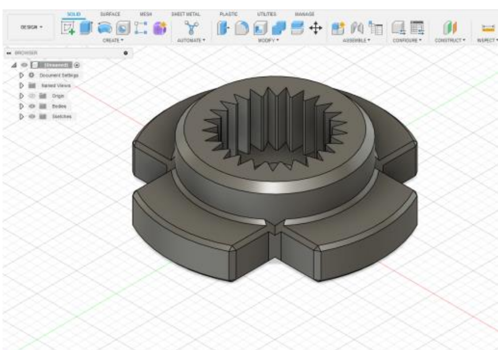


Figure 4: 3D Printed Horn

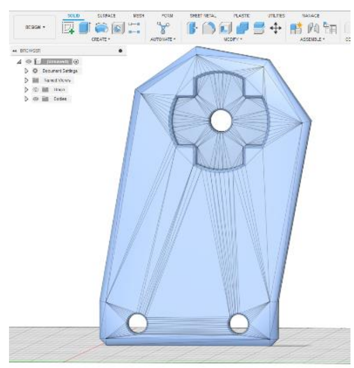


Figure 5: Horn Sample Part

3.2.3 Raspberry Pi Pico W

It’s used as the main microcontroller, we integrated the hardware components with it to manage their operations such as Servo driver which is used to control the movement of the servo motors, it’s also used to control the LCD and the Ultrasonic sensor, all programmed using micropython. Additionally, all the components are controlled in the code through WiFi connectivity which is available in this model.

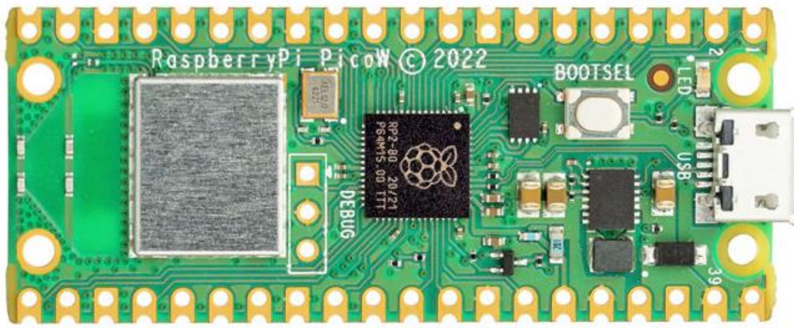


Figure 6: Raspberry Pi Pico W

3.2.4 PCA9685

The PCA9685 is an essential component in our project, providing the capability to control multiple servo motors with precision and ease, and it’s connected directly with Raspberry Pi Pico W

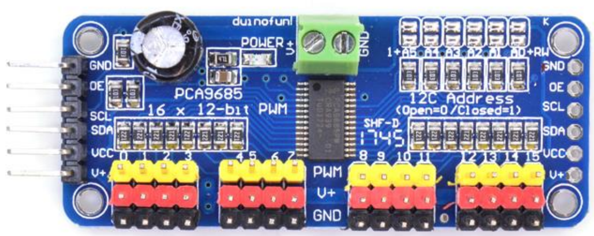


Figure 7: PCA9685 Servo Driver

3.2.5 MG995 (metal servo motor) & SG90 (servo motor)

Mg995:-

- Quantity: 8
- Represents the joints of the robot with two servos for each limb.

Figure 8: MG995 Servo Motor

Sg90:-

- Quantity: 1
- Represents the joint for the head movement in the robot.

Figure 9: SG90 Servo Motor

3.2.6 OLED LCD screen display (128*64)

To view the facial expression of the robot.

Figure 10: OLED LCD

3.2.7 Ultrasonic & IR sensors

- Ultrasonic: it's used to measure the distance and make Sparko avoid obstacles if they are within the distance of the detection.

Figure 11: Ultrasonic sensor

- IR sensor: an infrared sensor used to start the functionality of voice recording when it detects movement in terms of out project.

Figure 12: IR sensor

3.2.8 ESP32 module

A widely used microcontroller which plays a critical role in our project, we used two instances of it, the first one is responsible for the functionality of recording voice and converting it to text via google cloud services and sending it to the second esp32 which uploads the text to ChatGPT Api and returns the response and convert it to actual voice afterwards.

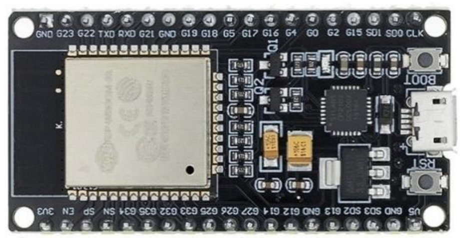


Figure 13: ESP32 Module

3.2.9 Speaker & INMP 441

- INMP441: used as the audio input device(microphone).

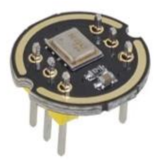


Figure 14: INMP441 microphone

- Speaker: used as an output audio device.

Figure 15: Speaker

3.2.10 MAX98357A

The MAX98357A is a digital-to-analog converter (DAC) and class D amplifier integrated into Sparko to handle audio output.

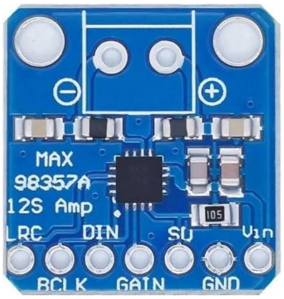


Figure 16: MAX98357A (class D)

3.2.11 Additional Components:

- Battery Indicator.
- Lithium batteries.
- LM2596 (voltage regulator).
- ON-OFF switch.
- 3*10mm Screws.
- Wires.
- PCB boards.
- HT7333-A (3.3v regulator).

3.3 Design and Construction

3.3.1 Building the complete design of Sparko

After printing the complete design mentioned above, we started constructing the robot step by step 3*10 screws and servo motors, the figure below shows all the 3D components used in the robot, and the other figure shows the step by step construction of the robot:

Figure 17: 3D Components

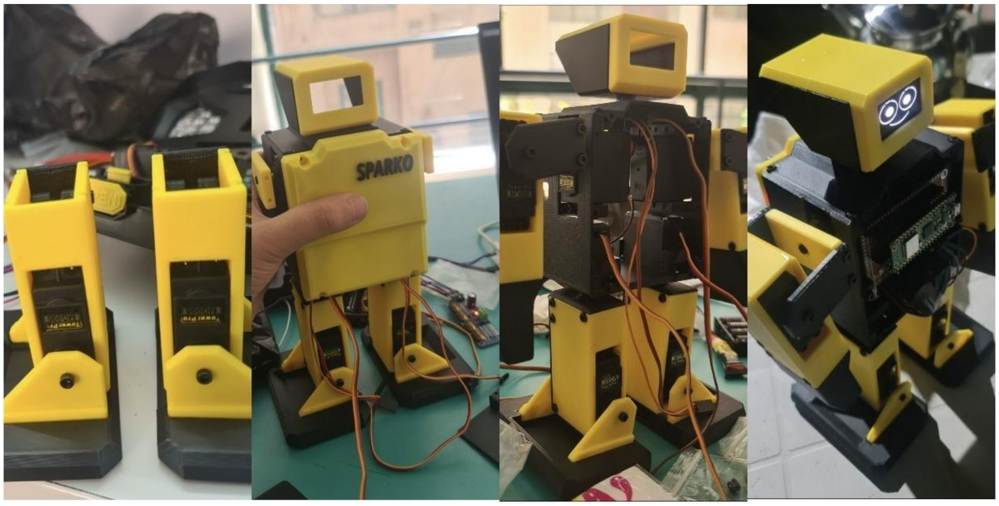


Figure 18: Step By Step Construction

3.3.2 Sparko's Movement Circuit

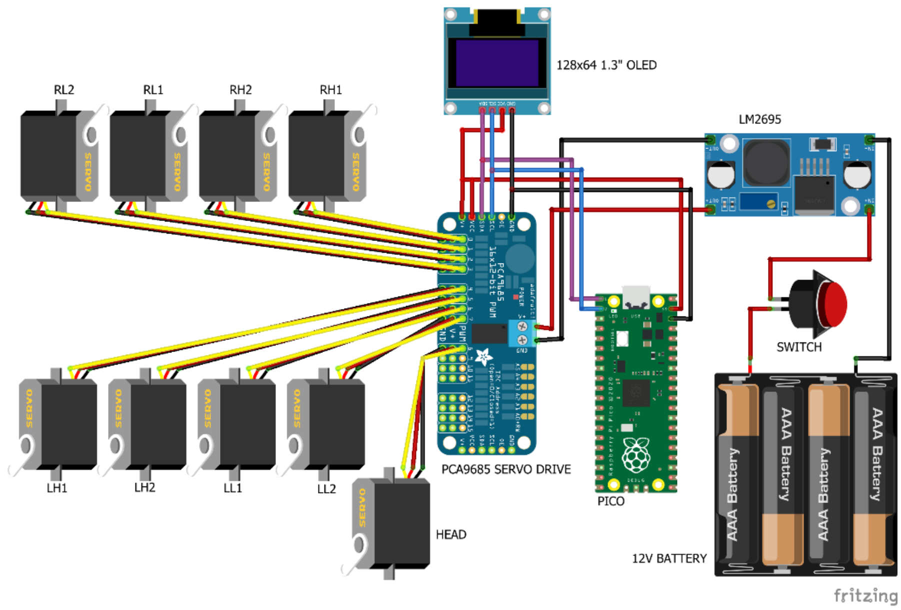


Figure 19: Complete Movement Circuit

The figure above shows the complete connection of movement circuit which includes 9 servomotors, LM2695, 12v battery, PCA9685, Raspberry Pi Pico W, on-off switch and OLED LCD.

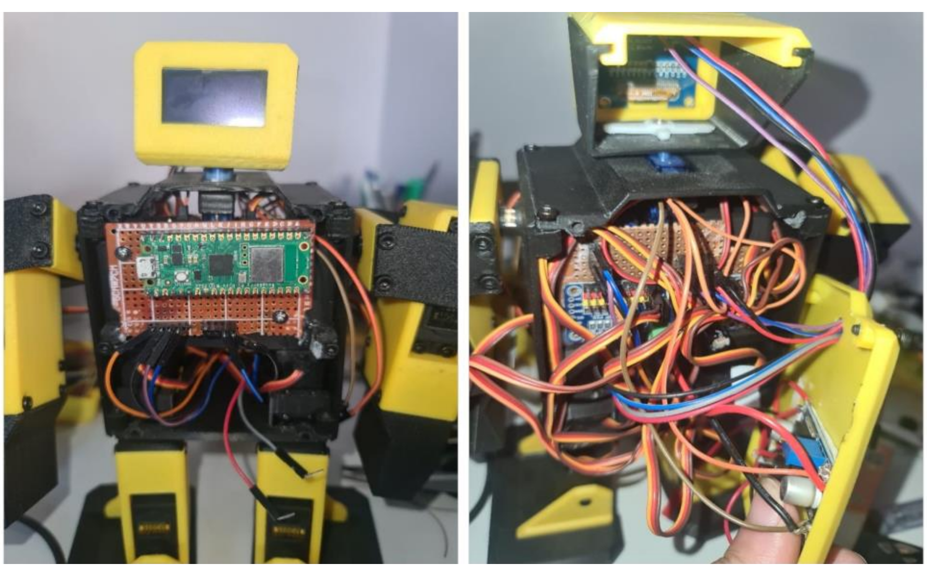


Figure 20: Real design of Movement Circuit

3.3.3 Sparko's Voice Circuit

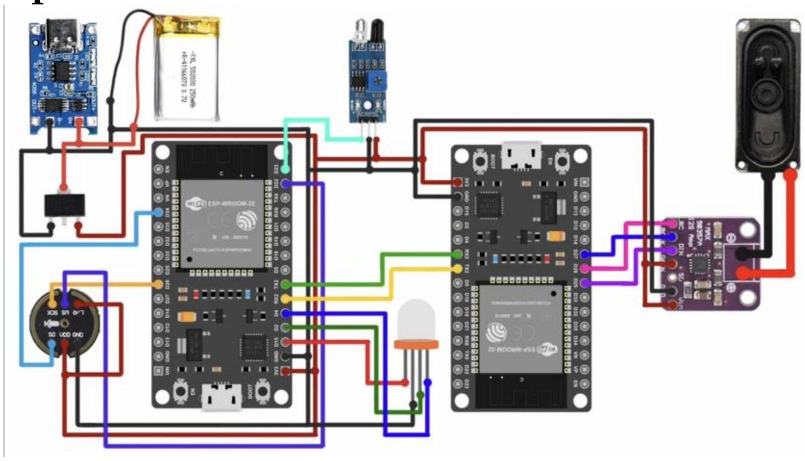


Figure 21: Complete Voice Circuit

The figure above shows the complete circuit which includes 2 ESP32 with all the other components connected as shown to set up the voice chat circuit.

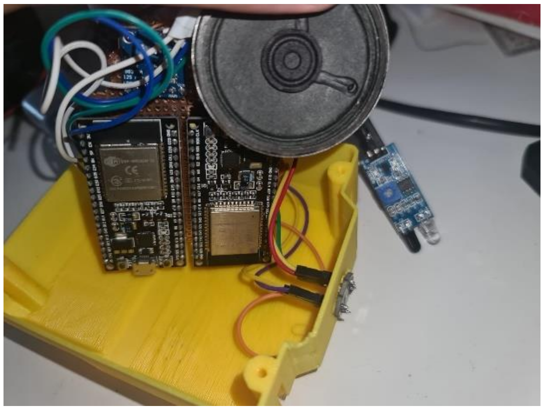


Figure 22: Real Design of Voice Circuit

3.4 Software Development

The software development of Sparko is divided into two main stages:

3.4.1 Movement Control Development

We programmed the Raspberry Pi Pico using micropython in Thonny IDE environment, we first started by creating a connection with local network that we specified and after that we implemented the html web code (simple front-end buttons) to do some simple tasks for example changing face expression and doing some movements based on precalculated servo motors rotations, so that each button represents a simple task.

We used a python code to convert images to hex codes which we implemented in out code to view images on the LCD screen.

We implemented the movement functions by testing the servo motors in different sets of rotations to achieve a realistic movement that makes up Sparko.

We implemented the ultrasonic to detect obstacles and move in the opposite direction by moving backward or rotating to a direction based on the location of the obstacle.

The figures below show the running code with html interface on a laptop and a mobile phone: -

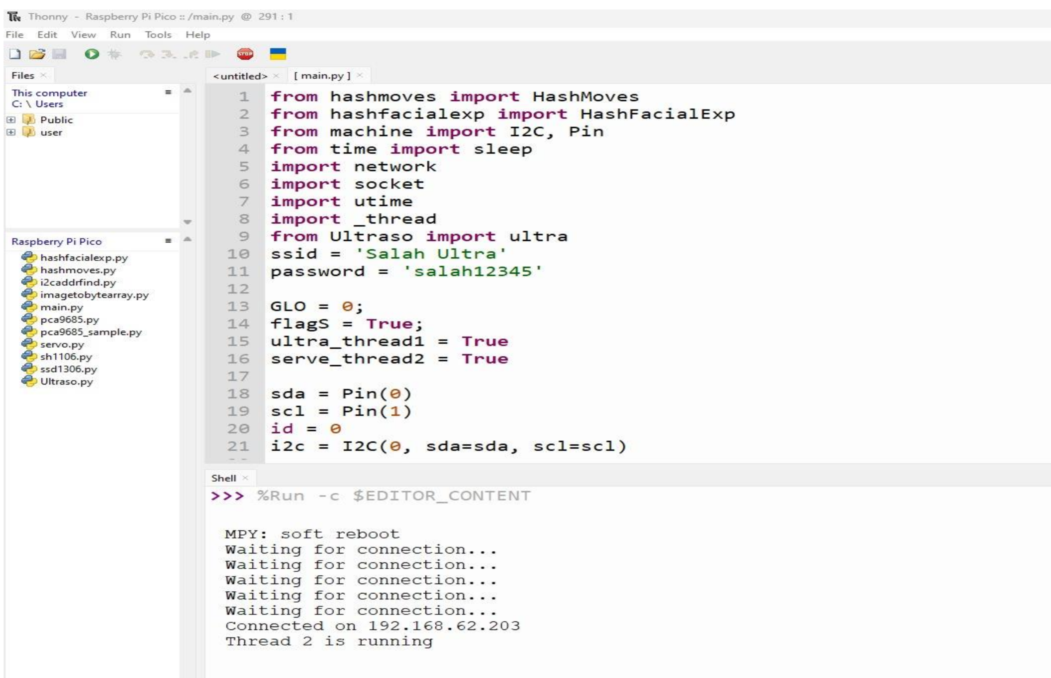
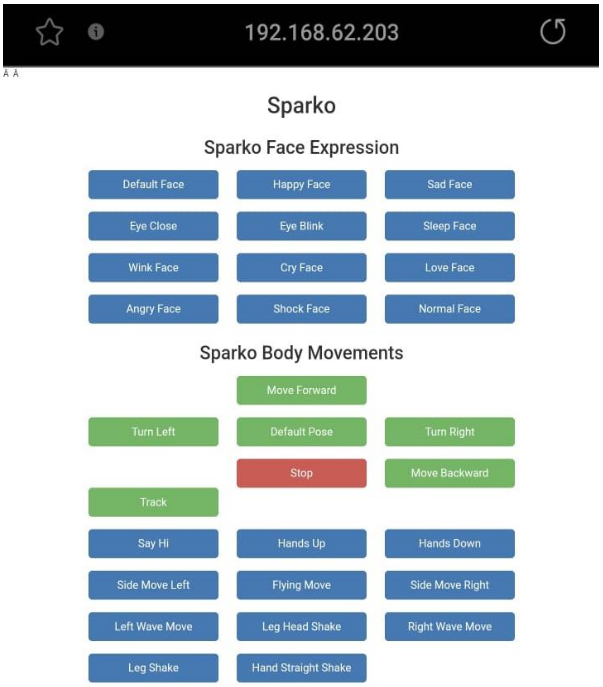


Figure 23: Running the main code



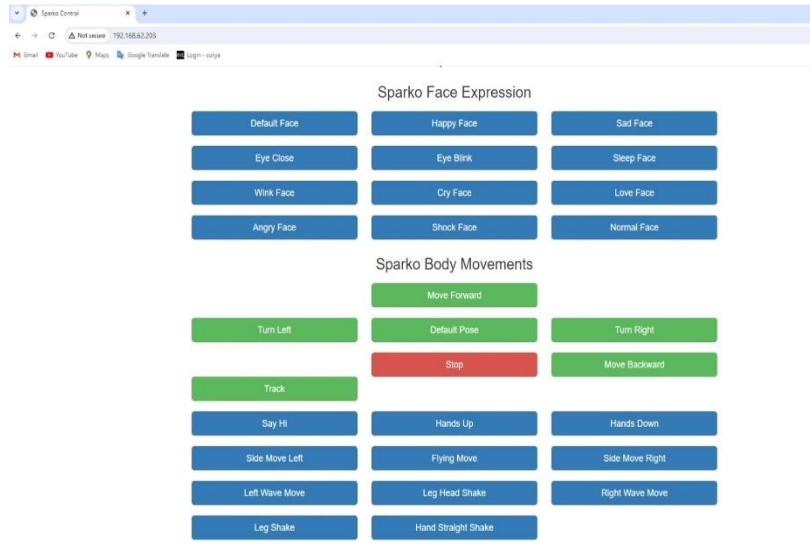


Figure 24: Desktop Interface

Figure 25: Mobile Interface

3.4.2 Voice Development

For this part we used two ESP32 modules instead of using one module; to reduce the complexity of the code and to eliminate errors faster and easily and also to get the maximum memory possible.

Starting with the first ESP32, it's connected with INMP441 digital microphone and the IR sensor, we programmed the code so that it starts by connecting the ESP32 to a mobile phone which has an internet so that Esp32 can access internet services, it works so that when the IR sensor detects motion it gives the ESP32 a signal to start recording the voice for around 3 seconds and after recording it, it uploads the voice to the google cloud (Speech-To-Text) API service which converts the audio signal to text and downloads the converted text to the ESP32 again.

After that the converted text is sent to the other ESP32 (second) via the UART serial port, And when ESP32(second) receives this text signal it uploads the text to ChatGPT Api service which generates a response using OpenAI service, the response again is download to the ESP32(second) and is converted to audio signals using (audio.h) library that is supported in the Arduino IDE, these audio signals afterwards come as an output through the speaker.
The figure below shows the functionality of the voice chat feature integrated in Sparko: -

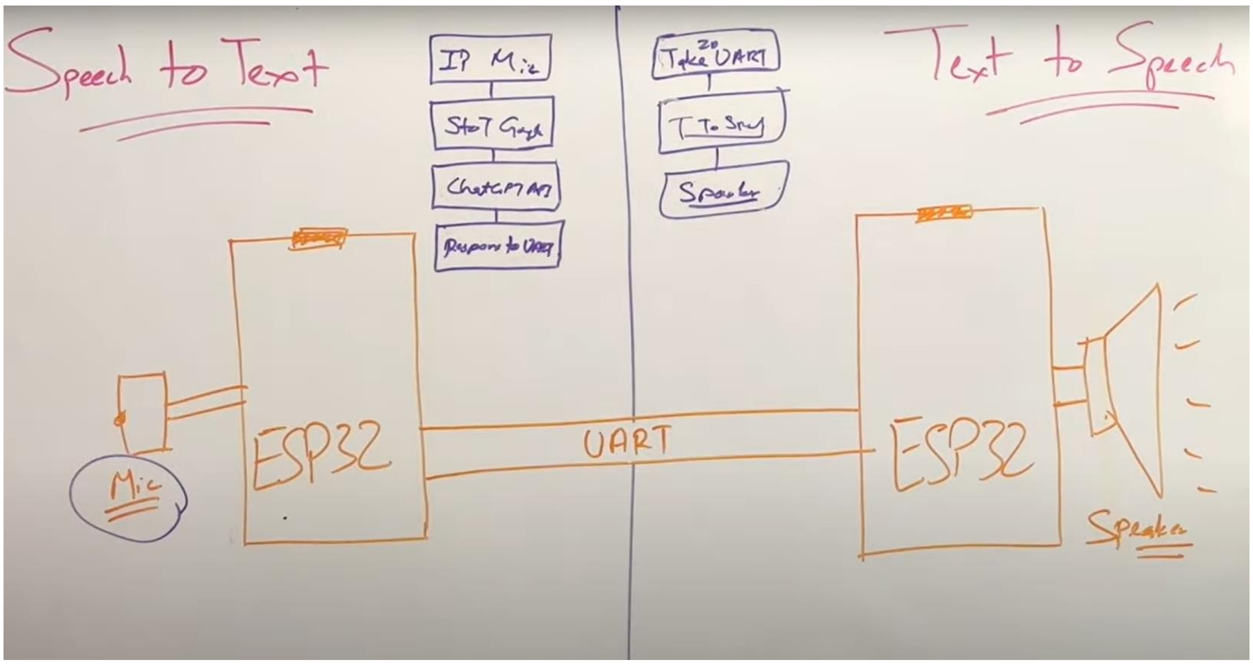


Figure 26: Functionality of Voice Chat Feature

3.5 Constraints and Considerations

- **Economic Constraints**: We used affordable components to make it suitable with the limited budget we had, for example we used simple microcontroller (Raspberry Pi Pico W) instead of the popular Raspberry Pi computer which have much more applications and image processing features.

- **Availability Constraint:** We had some struggles with finding some required components like (INMP441 & HIT7333-A) in our country, so we had to order them from abroad which was time consuming and expensive.

- **Safety and Health**: We implemented a protection circuit connected with the lithium battery to prevent it from over-charging and heating (which can be dangerous sometimes).

- **Manufacturability**: Designing Sparko to be easily assembled and replicated using readily available components at any time giving it the potential for the future upgrades.

- **Sustainability**: A limitation we had in sustainability was the delay that the robot requires from the time of the receiving the voice command until giving the response due to the long process that it goes through, another limitation was that it can't spell more than 30 words for each question due to the flash memory in the ESP32 limited capacity.

- **Time Constraints**: We had limited time to achieve complete project, starting from designing the body of Sparko, as well as waiting for some external components to arrive from abroad, while also considering the complex functionality of the voice chat feature with the web page control panel making it require a long period of time to make and preventing us from adding some other extra features.

3.6 Specifications & Start up

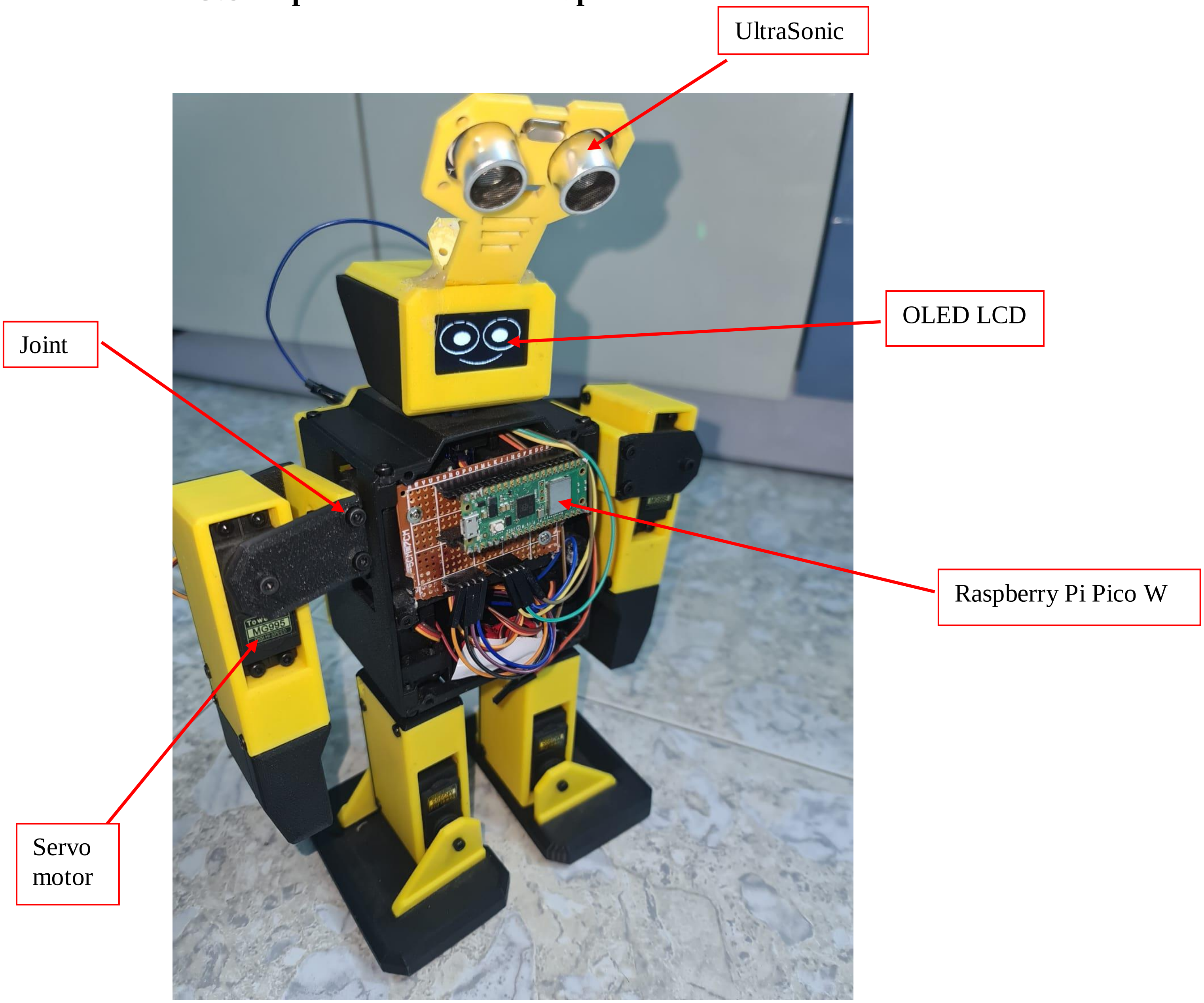


Figure 27: Front Specification

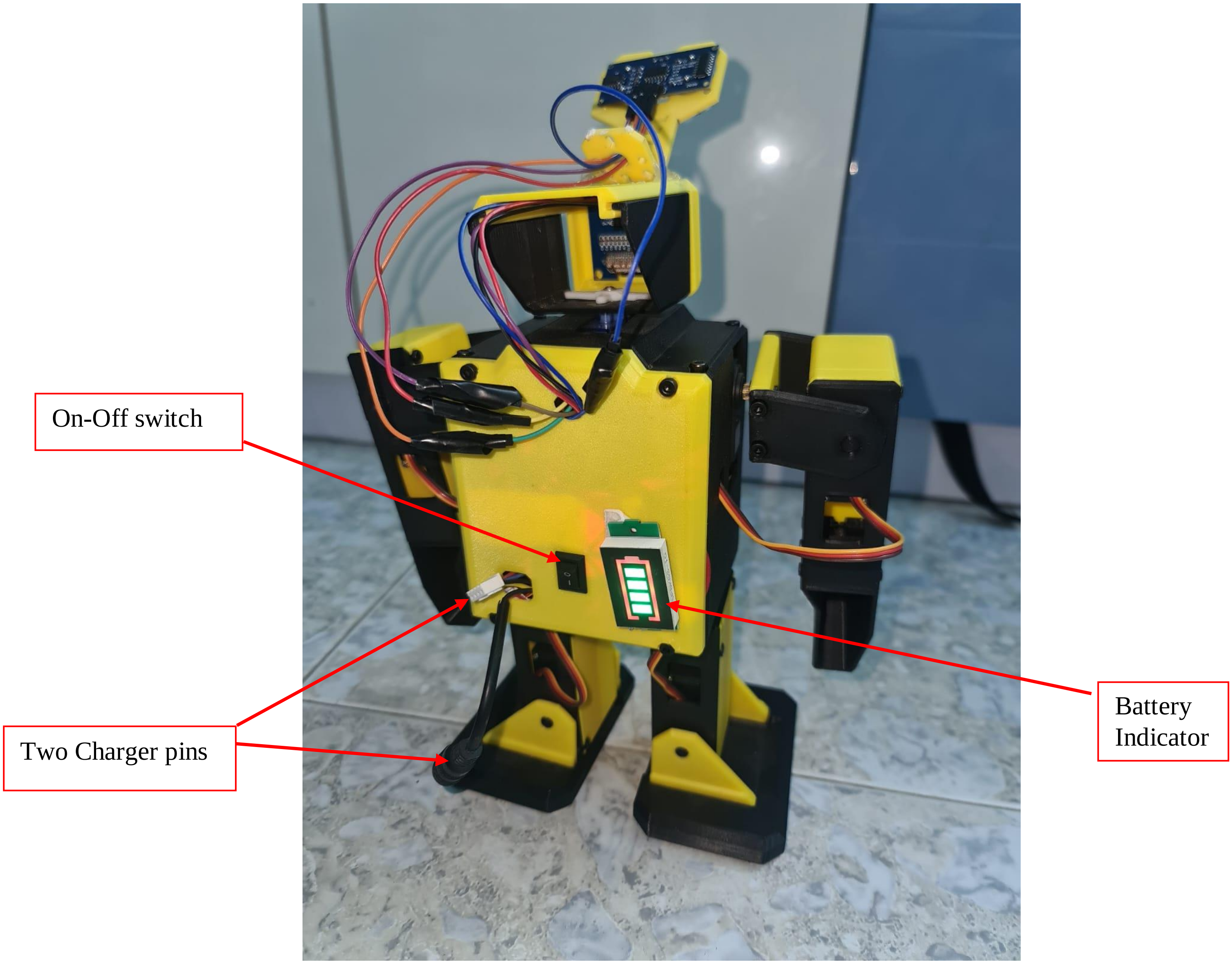
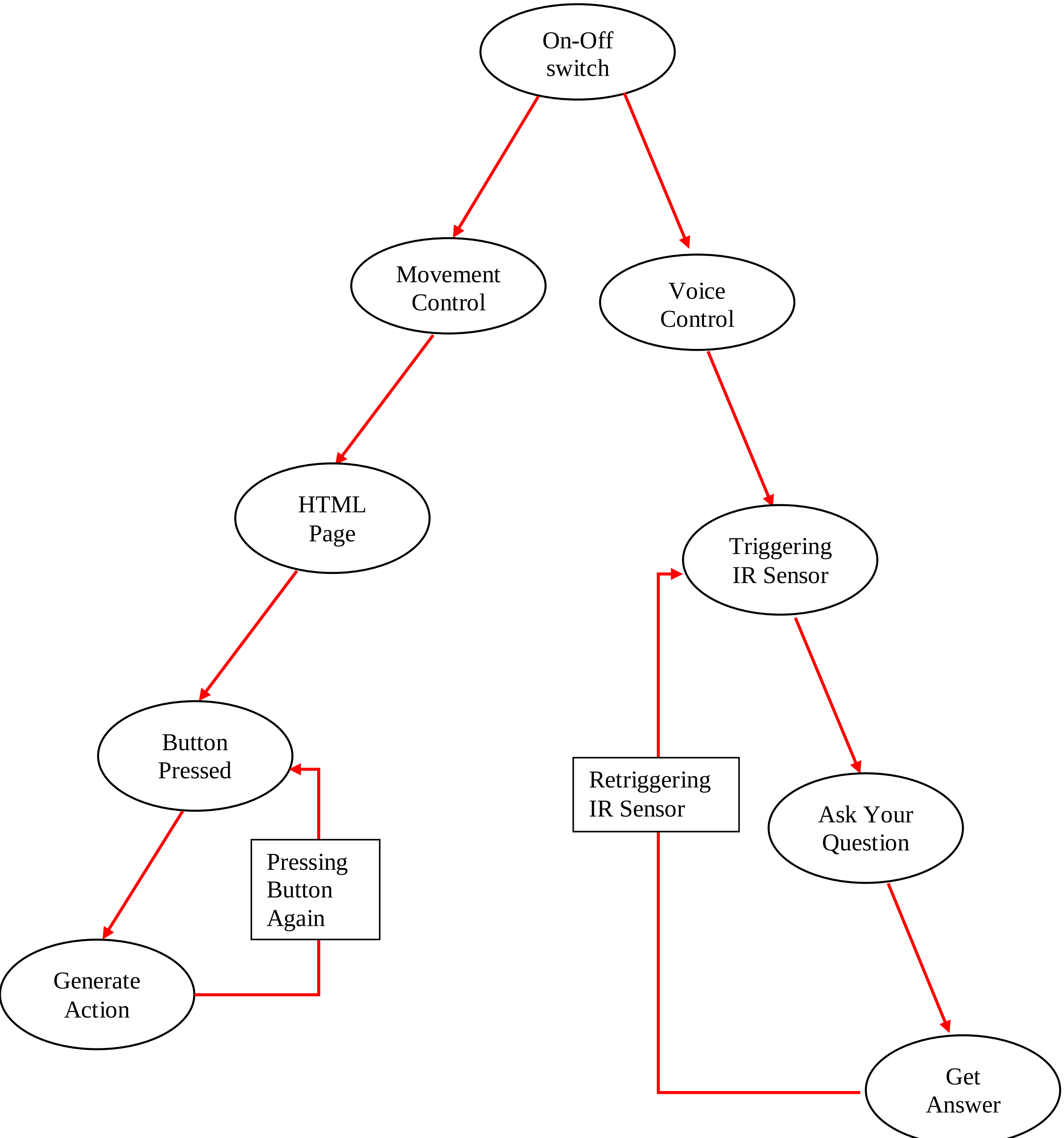


Figure 28: Back Specification

- **Start up**


On-Off switch
Movement Control
Voice Control
HTML Page
Triggering IR Sensor
Button Pressed
Retriggering IR Sensor
Ask Your Question
Pressing Button Again
Generate Action
Get Answer

4 Results & Discussion

4.1 Results

The development and testing of Sparko, a multifunctional robot, came out with significant outcomes:

- **Movement Control:** Sparko successfully used nine servo motors for enhanced flexibility and user interaction. Additionally, it can be controlled using any smart device connected to its local network through user-friendly web page interface.

- **Facial Expressions:** An OLED LCD display enabled Sparko to exhibit various facial expressions, increasing user engagement.

- **Obstacle Avoidance**: The ultrasonic sensor allowed Sparko to effectively detect and avoid obstacles.

- **Voice Interaction**: Advanced speech recognition and response capabilities were achieved via Google Cloud and OpenAI APIs, giving Sparko the ability to answer questions successfully.

- **Complete Integration**: All features were seamlessly integrated, showcasing a functional, interactive robot assistant.

4.2 Discussion

4.2.1 Problem Resolution

The project successfully developed a cost-effective, user-friendly robot capable of interactive movement, facial expressions, obstacle avoidance, and voice interaction.

4.2.2 Contributions

- **Affordability**: Utilized cost-effective components like Raspberry Pi Pico W and ESP32 modules.
- **User Interaction**: Enhanced engagement through voice interaction and facial expressions.
- **Integration**: Demonstrated effective hardware and software integration for improved human-robot interaction.

4.2.3 Logical Implications

- **Educational Tool**: Effective for interactive learning with its ability to answer any question at any time.

- **Personal Assistance**: Versatile tool for personal assistance and entertainment.

4.2.4 Limitations

- **Component Availability**: Sourcing from abroad was time-consuming and costly.
- **Performance Constraints**: Limited memory and response time due to processing delays.
- **Battery Safety**: Additional complexity and cost due to necessary protection circuits.

5 Conclusion & Recommendations

5.1 Conclusion

Sparko successfully integrated movement control, facial expressions, obstacle avoidance, and voice interaction into a cost-effective and user-friendly robot. Its Effective design and integration strategies for interactive robotics can be achieved affordably while maintaining fully working functionality.

5.2 Recommendations

5.2.1 Cost-Effective Improvements:

- **Optimize Processing**: Reorganize processing steps to use multi-threading and consider microcontroller upgrades to enhance response time.
- **Increase Memory**: Implement modules with larger memory capacities to support complex interactions, or add an external memory for the ESP32 module.
- **Component Sourcing:** Identify local suppliers to reduce time and cost associated with required components for Sparko.

5.2.2 Future Work:

- **Advanced Sensors**: Implementing additional sensors for expanded capabilities in navigation and interaction (for example temperature, light sensors).
- **Application Expansion**: giving it the ability to do some simple tasks like carrying items by making minor changes to its design.
- **Image Processing Application**: adding a ESP32 camera module which can give it wide range of capabilities for example image recognition, and answering correctly when being asked “What can you see?”.
- **Interface Enhancement**: Improving the web interface for Sparko, also adding more functionalities that can be done within its capacities.
- **Voice Control**: Giving it the ability to move and change facial expressions using voice commands.

References

1. Brezeal, C., Brooks, R. A., & et al. (2003). Humanoid robots as cooperative partners for people. *International Journal of Humanoid Robotics*, 1-34.
2. Broenstein, J., & Koren, Y. (1989). Real-time obstacle avoidance for fast mobile robots. *IEEE Transactions on Systems, Man, and Cybernetics*, 1179-1187.
3. HashRobotics. (2024, 6 17). Retrieved from GUMROAD: https://hashrobotics.gumroad.com/
4. Thrun, S., Burgard, W., & Fox, D. (2005). *Probabilistic Robotics.* MIT Press.