UCF ECE SENIOR DESIGN PROJECT
ION

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Group 11:

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1.0 Executive Summary

Working at a desk for long hours can get boring and monotonous. Whether it be writing a paper for a high-school history class or working a forty-hour week as a software engineer, many people are overworked and quickly become unproductive when sitting at a desk for hours. The group hopes to combat this with the introduction of Ion - an interactive personal robot-assistant. Ion can bring some fun and entertainment to the desktop to provide some relief to hours of coding or researching for a paper. By being able to connect to the internet and a multitude of application, Ion can provide entertainment by playing some music, telling jokes, or even provide some support in your tasks by searching the internet for any questions you may have. By doing this, Ion aims to integrate all your needs into a cute, amusing little robot who can be both your aide and your companion.

Voice-recognition assistants have taken storm on the market with huge companies such as Apple, Amazon, and Google participating. With IoT (Internet of Things) becoming a big phenomenon, it is becoming a necessity to have a way to connect everything and control them through a single application. For many companies, voice-recognition assistants are the answer to connect all these products that they could potentially put out onto the market and create a new craze around. Internet searches, weather, traffic, phone control, TV control, and house control can all be controlled through a single voice-recognition application.

Other than a personal project, Peeqo, that is described later in section 3.1.4, many of the voice-recognition personal assistants are all software-based smart-speakers and don't have a physical embodiment which can be more interactive with users. With inspiration from Peeqo, the group wanted to build a project that has that physical embodiment and can use that to its advantage to better portray emotion and reaction to the user. Rather than being a faceless app, Ion aims to be a step more innovative and a step closer to the user by having face-tracking so that it seems like it is fully engaged in conversation and aware of your presence, voice recognition and machine learning technologies to have intelligent conversations, and servos motors to be able to move fluidly and portray some more human-like characteristics.

2.0 Project Description

The section serves to provide an understanding of the group's motivation and goals in choosing the project and in heading into development of the project. These motivations and goals helped shape the design of the project by drawing out the requirements that will also be specified in this section.

2.1 Project Motivation, Objectives, and Goals

The main motivation is to deliver a product that both serves a realistic purpose and demonstrates our abilities and the knowledge the group have gained through their education in the College of Electrical Engineering and Computer Science at UCF. While the group is aiming to complete the course, they also want to deliver a product that they are proud of, meets all their expectations, and can match up to the products and projects that inspired theirs. Those products and projects that inspired this project are given more attention in section 3.1.

Many of the goals for the project relate to what the group wanted to learn while working on it and what they want to deliver with their project. Coming into the process, the group didn't want to be constrained by keeping to topics that they already knew - they wanted to learn new skills in this process. A few of these new skills include UX design for the menu system, PCB design, mechanical engineering for the servos motors, 3D printing for the body and miscellaneous pieces, 3D modeling to design the device, and character design to create the personality of Ion. As you can see by the length of this list, the group didn't want to focus in one area or only stick to what they already knew - the group wanted to branch out and push themselves to deliver a great project.

2.2 Requirements Specifications

The requirements specifications included below are important to note because they severely influenced and constrained how the project was designed. By noting and keeping to these specifications, it was much easier to shape the project from the beginning and know what the group could work with when delivering their project

2.2.1 Size, Weight, and Dimensions

Most of the requirements relating to the size, weight, and dimensions of the project stem from the user experience expectations. The group's goal for this product is for it to be a small, interactive robot that can sit on a desk or countertop to be used by the customer. The product should be mobile enough to move from room to room or from home to office. The product should also be small enough to carry in one hand and not take up too much table space. This limits the size, weight, and dimensions requirements specifications regarding size, weight, and dimensions, which are specified below.

- The device shall weigh less than five (5) lbs.
- The device shall have dimensions less than 7" by 7" by 15".

2.2.2 Software Speed and Efficiency

The speed at which the software will run greatly affects user experience. The group wants a product which will have a short start-up time and, when being used, will not show any signs of lag or loading. The product needs to be very responsive to give the impression that it is actively interacting with the user and portray more of a human-like personality. As far as software efficiency, it is very important to limit errors and time spent 'thinking' as, again, the group is making it as human as possible and giving the impression that it is an intelligent, sentient being. When a user interacts with the device, the device should be able to realistically interact back with the user through speaking, expressing emotion, and through tracking the user's face with sight. As such, this restricts the software speed and efficiency requirements specifications to the ones stated below.

- The device shall have a boot-up time of less than thirty (30) seconds.
- The device shall have an initial setup time of less than fifteen (15) minutes.
- The device shall respond to voice commands within two (2) seconds of being spoken to by the user.
- The device shall understand 80% of what is spoken to it.
- The device shall be able to fully understand and process the English language.
- The device shall be able to recognize faces 80% of the time under normal lighting conditions.

2.2.3 Power Consumption

Power consumption is one of the more important aspects of the requirements specifications especially since the device should be able to work wirelessly when being moved around the house, office, or wherever used. The requirements specifications for power consumption are as follows:

- The device shall be powered by a rechargeable battery.
- The device shall have an average power consumption of 50 watts or less.
- The device shall have a power switch to turn the device on or off.
- The device shall have a battery life of at least an hour.

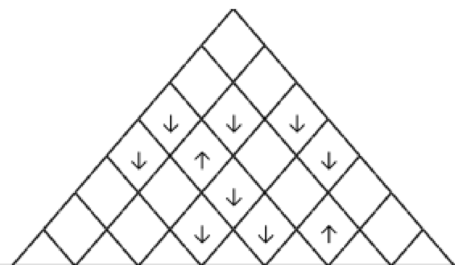
2.2.4 Costs

Users, competitor costs, and personal budget are the main concerns in relation to cost of the product. Through research, the group found that competitors have products available to purchase at an approximate cost of around $100-150. Considering the extra capabilities that the group's product will have with using servos to move and have an interactive personality, the fact that the product is only a prototype, and the fact that the group is competing with major companies who have access to premium supply, they thought it was fair to aim for an approximate cost of $500. If they did move forward will full production of the device, they could hypothetically cut the production costs and, since they will know what components they will need and could streamline production, it should cut the cost significantly. With that in mind, the group is aiming for a component cost of $120 as stated below. The group goes more in depth with the specific budget in section 9.2 of this document.

- The component cost of the device shall be less than $120.

2.3 House of Quality Analysis

In order to better understand the impacts of constraints on another, a "house of quality" analysis was conducted shown below in Figure 1. It shows that the constraints with the highest impacts are cost, power consumption, and display size. Display size is important because it directly affects user experience. A larger display not only makes it more enjoyable to view content, it also makes it easier to navigate the configuration menu because the device's setup relies on touch input. While the size of the display is somewhat restricted to the available space, the more impactful constraints are cost and power consumption. A larger display is more expensive and requires more power to run.



		Dimensions	GUI Functions	Power Consumption	Cost	Display Size	Setup Time	Voice recognition speed and accuracy
		-	+	-	-	+	-	+
Cost	-	↓		↓	↑↑	↓↓		↓
Weight	-	↓			↓			
Battery life	+	↓		↓↓	↓	↓↓		
Power consumption	-				↓	↓↓		↓
Sound quality recording and playback	+	↓		↓↓	↓			↑↑
CPU power	-		↓	↓↓	↓↓		↑	↑↑
Display size	+	↓↓	↑	↓↓	↓↓	↑↑	↑	
Targets for Engineering Requirements		< 7x7x15"	Change settings, user profiles, interaction with	< 50 watts average	< $120 component cost	maximize	less than 15 minutes	understand %80 with < 2 second reaction

Figure 1: House of Quality

Power consumption is such an impactful constraint because the device is intended to run on battery power. The more power is consumed, the shorter the battery life will be. To reduce power consumption, the most efficient components must be chosen to perform their tasks according to the specifications. Cost correlates negatively with every specification because to improved performance almost always relies on higher quality components which in turn are often more expensive. The impact of weight is not as high as other components because the device is intended to be stationary. If necessary, it is possible to sacrifice the weight constraint to buy a bigger battery to reduce the impact of higher power consumption, therefore allowing a less power efficient processor to save cost to buy a larger display.

3.0 Project-Related Research

This section details the research that went into planning the development of the project. This includes similar projects and products that are on the market and helped influence the requirements and features of the project as well as research for the different features and technologies that went into the device.

3.1 Similar Projects and Products

The group drew a lot of inspiration from products already on the market or from personal projects found on the internet. Through research, knowledge was gained on what types of features to include in the product and how to innovate from those products already on the market. More in-depth analysis of the major products on the market and projects that influenced Ion in the sections below.

3.1.1 Amazon Echo

Amazon's Echo can be considered the leader among home control smart speakers with its voice assistant counterpart, Alexa. Amazon Echo, seen in Figure 2, is a smart speaker that also holds access to Amazon's intelligent virtual assistant, Alexa, who can respond to voice commands, check the weather, play music through Bluetooth, and set alarms among a multitude of other things. This product is on the market for $100. With Amazon's huge influence on the market and their strong marketing tactics, Amazon and Echo are a leader in their industry.

Figure 2: Amazon's Echo – Image Credits to WikiMedia

Housing an array of seven (7) microphones that give the Echo 360° omni-directional voice control, the Echo gives both a wide and long range for the user to interact through voice. It is connected to an outlet through an AC power adaptor, so it does have to stay put in one place and have an outlet available. Coming in at 3.3" by 3.3" by 9.3" and 2.3 lbs., it is a great size, but does not house an LCD with touch capability like Ion does. This must be considered when planning for size and dimensions.

A very cool feature that the Amazon Echo holds is the ability to learn, in addition to its dozens of base features, skills from a library of tens of thousands of skills that are being added daily by both professionals and by the community. These skills can connect to almost any app or smart product, allowing the customer to order a pizza from Dominos or control your TV with dish. Amazon is very educating on how customers can develop their own skills, and this provides great comfort in knowing the support that Echo will keep receiving from both Amazon and from the community.

Amazon does have an Echo product, the Echo Show, that houses dual 2.0” speakers and a 7.0” screen but isn’t as popular and isn’t exactly what the group is going for in innovating their design. Their goal in providing a screen is to provide a way for the user to watch videos or have their skills be more visual-based, while the group wants to portray more emotion and interaction with the user in using the screen.

The group drew inspiration from the Echo, drawing its home and skill features such as checking weather, setting alarms, and responding to other voice commands with omni-directional voice control. The group looks to innovate this design by creating a more interactive visual interface in a robot that gives reactions and feedback instead of just being a hands-free smart speaker.

3.1.2 Apple HomePod

The HomePod, in Figure 3, is Apple’s attempt at producing a smart speaker like the Amazon Echo or Google Home. It’s a great concept but it came about two years late and it showed as they had poor sales and recently stopped production in April 2018, a mere three months after release in February 2018. Priced at almost $350, it is no wonder sales didn’t pick up. Housing seven tweeters and a four-inch subwoofer, as well as six microphones and a touchscreen on the top, it is a top-level smart speaker with Siri integration. The major downside is the price and the fact that it is two years late to doing exactly what Amazon and Google did. It has the basics you’d expect from an Apple smart speaker but didn’t bring anything to the table and was overall a disappointment for many consumers.

Figure 3: Apple HomePod – Image Credits to WikiMedia

3.1.3 Google Home

Google Home, seen in Figure 4, is Google's response to Amazon Echo. Released in late 2016, it aimed to compete with Amazon Echo, with an emphasis on home automation. Along with the normal features of music playback, weather, etc., Google Home has the ability to sync with home automation products including the Nest, SmartThings, and Philips Hue. Google comes with Google's version of Siri or Alexa, called Google Assistant. Google Assistant is a virtual personal assistant that uses natural language processing and machine learning technologies and carries many of the same features as the previous two competitors.

Figure 4: Google Home – Image Credits to WikiMedia

3.1.4 Peeqo

Peeqo, the GIF bot, was the main inspiration behind Ion and most-closely relates to the idea that was aimed for with this project. Peeqo, seen in Figure 5, is a personal project developed by Abhishek Singh for a thesis project at NYU. He had an idea of an interactive personal assistant which mainly communicated through gifs while helping the user complete tasks in a fun, cute way while providing some entertainment to brighten their day. Abhishek describes Peeqo as 'the love child of Amazon Echo and a Disney Character' which perfectly blends the roles of functionality with bringing amusement. Peeqo is shown in Figure 5.

Figure 5: Peeqo – Image Credits to WikiMedia

Using a Raspberry Pi 3 as the brain and Arduino minis to control the 3D-printed plastic body, Peeqo can see the user using a built-in camera and play sounds and music through a built-in speaker. Also housing a crisp 5.6” 1080p LCD screen, Peeqo can draw gifs from a library on the internet to communicate its emotions and responses to the user.

On the software side of the device, the main program written to run on the Pi was written using Electron and uses HTML, CSS, and JS. To store user preferences, a server was written in Node. Peeqo uses Google Speech API for voice recognition and pulls from a library of GIFs to respond to the user. This feature of responding in GIFs and moving fluidly to emulate human emotion had a huge influence on the goals and designs of the project.

3.1.5 Product Comparison

Shown below in Table 1 is the comparison done between all the four different devices in terms of price, size, weight, speakers, microphones, smart assistant, WiFi, and Bluetooth.

	Amazon Echo	Apple HomePod	Google Home	Peeqo
Price	$85	$350	$129	N/A
Size	9.3” x 3.3” by 3.3”	6.8” x 5.6” x 5.6”	5.6” x 3.8” x 3.8”	9” x 5” x 5”
Weight	2.35lb	5.5lb	1.05lb	
Speakers	One tweeter, one woofer	Seven tweeters, one 4-inch subwoofer	Two tweeters, two subwoofers	USB speaker
Microphones	Seven	Six	Two	
Smart Assistant	Amazon Alexa	Siri	Google Assistant	Google Speech
Wifi	Yes	Yes	Yes	Yes
Bluetooth	Yes	No	Yes	No

Table 1: Product Comparison

3.2 Relevant Technologies

This section aims to provide a description of the major technologies that went into the development of Ion and includes face detection and recognition, voice recognition, signal processing, and user-device interaction among others.

3.2.1 Face Detection and Recognition

One of the major planned features of Ion is the ability to detect and recognize faces.

3.2.1.1 Face Detection

Face detection is the ability to recognize whether there is a face or not. Ion is supposed to know when there is a human face within view. Because the only sensor that provides the necessary input to recognize a face is the camera, Ion will rely on computer vision software for this task. A generic approach to detect faces is to recognize features (eyes, nose and mouth) and correlate their relative position with the average setup of a human face. This is done by taking a capture with a camera, optimizing the image by reducing noise and enhancing edges, and finally detecting the features based on templates from known examples shown below in Figure 6.

The math behind this process is complicated and would be a big undertaking for such a small part of the project but OpenCV, an open source program library, includes many image processing capabilities and provides a simple API to facilitate programming of this function. It is very likely that OpenCV will be used in this project not only because it facilitates programming, but also because the functions contained in the library have been optimized over the years. Ion will rely on facial detection to turn towards the user, so any lag in the program will make Ion's movement more sluggish.

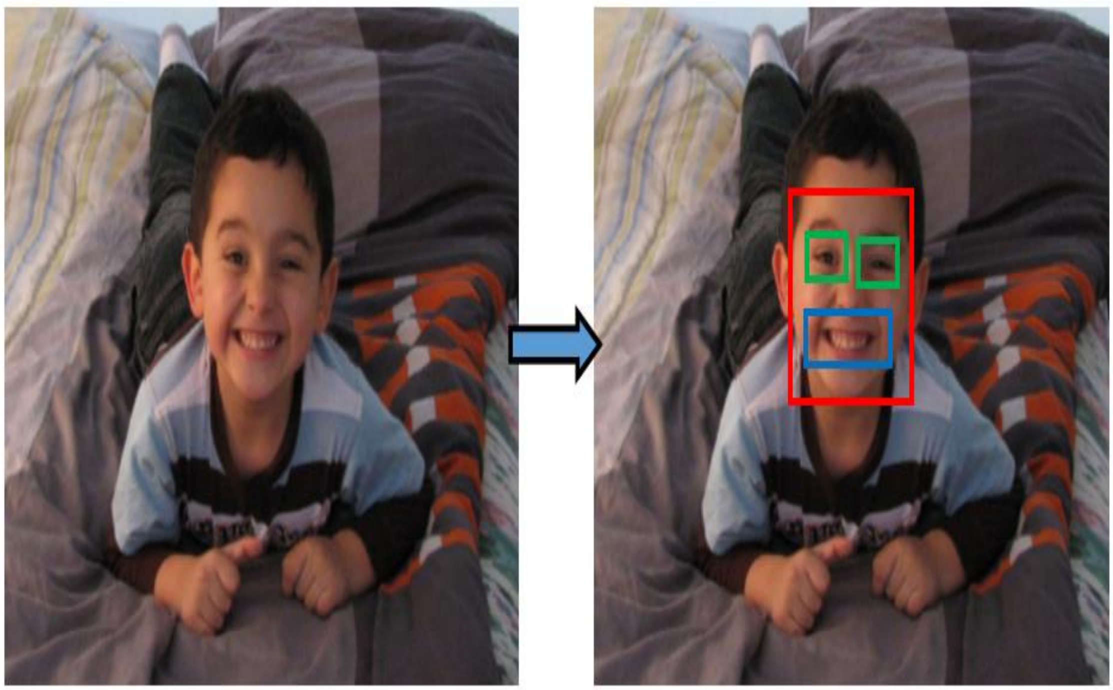


Figure 6: Facial detection. The modified photo on the right shows that the eyes (green boxes) and mouth (blue box) were detected as features and as a result, the face (red box) was detected. This picture is a mockup, simulating facial detection software.

3.2.1.2 Facial Recognition

Facial recognition is one step further from facial detection. Once a face has been detected by the facial detection software, a secondary process is planned to recognize the face. This is done by comparing the features and geometry of the recognized face to a user database of familiar faces. There are several techniques to do this including: Eigenfaces, Fisherfaces, and histograms. These techniques will be further discussed in the software design portion of this document. OpenCV is also the most likely library that will be used for this task. The scope of this project is too broad to develop a proprietary facial recognition algorithm.

3.2.2 Voice Recognition

Voice recognition technologies are starting to be included in a lot more products with the emergence of hands-free devices, virtual assistants, and home automation. Transforming analog sound waves into digital commands. Ion will rely on the microphone to take in the sound waves which will be translated to a digital form which can be understood by speech recognition software, Google Speech API in this case. A standard approach to voice recognition is to listen for keywords in a sentence and then guess the sentence or command with a certain amount of confidence. Higher-level systems utilize artificial intelligence and machine learning to better guess the command and to raise the confidence that it is correct. With this sentence, the software can then decide which command to start or task to complete.

3.2.3 Signal Processing

Another critical relevant technology related to the project would be signal processing, since the device would be receiving and sending lots of signals. Those signals should be processed accurately and fast enough in order to be understandable by both the user and the device while at the same time preventing wait time.

3.2.3.1 User-Device-User Interaction

One of the interactions requiring signal processing related to the device would be the user-device-user interaction. When the user speaks, analog signals are being produced, while the device, being a computer, can only understand and produce digital signals. To get around that, the analog signals produced by the user should be processed and converted into digital signals for the device to understand them and act accordingly. After that, the device produces new digital signals, which sometimes are sent back to the user. So, the digital signals should then get processed and converted into analog signals for the user to understand them.

There should be six components involved in the process; a microphone to receive the analog signals from the user, an analog to digital converter (ADC) to convert the analog signals, a digital to analog converter (DAC) to convert the digital signals, an audio amplifier to amplify the analog signal to be more accurate, speakers to send out the analog signals to the user, and the CPU to process the signals. All those components will then be further explained in section 3.3 of the document. The user-device-user process can then be better illustrated in a figure as shown below in Figure 7.

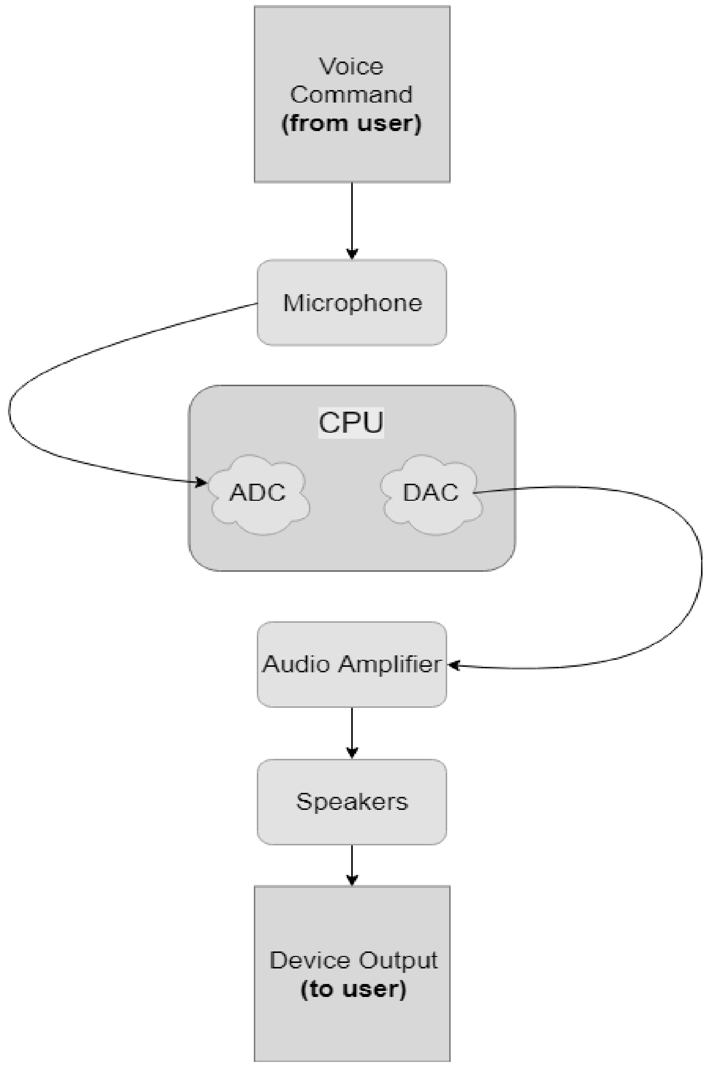


Figure 7: User-Device-User Interaction Flowchart. Example: User asks a question and the device answers back.

3.2.3.2 User-Device Interaction

The user-device interaction would be a simpler process than the user-device-user interaction. The difference between the user-device and the user-device-user is that the device no longer has to convert its own digital signals to analog signals for the user. So, the device still has to convert the analog signals from the user into digital signals, process them, and then send the output digital signal to wherever appropriate based on the command. An example of that would be when the user issues the device a command but is not expecting an answer back.

Components involved in the user-device interaction include the microphone, an analog-to-digital converter, the CPU, and whatever other component that performs the task issued by the CPU output as a digital signal. This process is illustrated below in Figure 8.

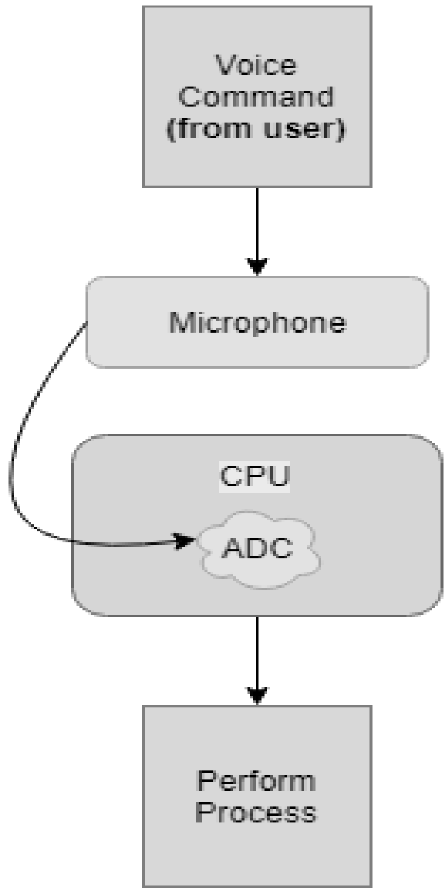


Figure 8: User-Device Interaction

3.2.4 Circuit Protection Device (CPD)

A circuit protection device might be necessary to protect the battery and the device components from an electrical surge. Since the individual circuits are protected by voltage regulators, the only thing left is the battery. There are multiple types of CPDs, including circuit breakers, electronic fuses, diode arrays, and so on. Since the battery is the component that should be protected, the area of concern would be having too much current drawn from it or device failure, and the best candidate for a CPD would be an electronic fuse.

An electronic fuse is basically a resistor with a low resistance made of metal that melts in high temperature caused by a high amount of current. So, in a case of too much current draw from the battery, the fuse would absorb that overdrawn current and melt; therefore, breaking the circuit and shutting the device down before frying the device components and the battery altogether. The right electronic fuse can be picked based on the desired maximum working voltage rating and current rating.

3.3 Strategic Components

3.3.1 Microcontrollers

3.3.1.1 PWM

Pulse width modulation (PWM), for the purpose of this project, means to create an electrical signal in the form of a square pulse with a fixed amplitude and frequency, but with a varying length of that pulse (duty cycle). It will be used to provide the servos with a signal based on which they will alter their position. In theory, a typical servo expects a 5 volt signal every 20 milliseconds and will adjust its position according to the length of that signal. The duration of the pulse can be anywhere between 1 and 2 milliseconds, where 1 ms sets the servo to 0 degrees, 2 ms set the servo to 180 degrees and anything in between those values adjust the servo continuously in a linear matter as shown in Figure 9.

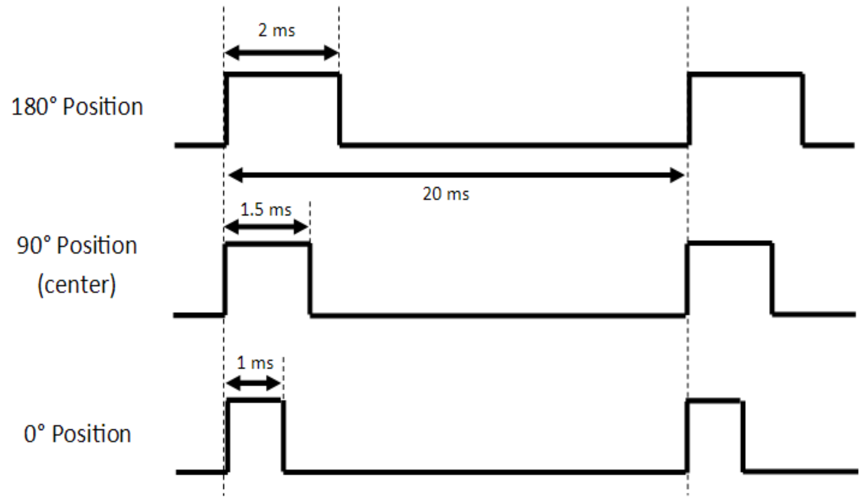


Figure 9: PWM signal for varying positions. The y-axis is the voltage of the signal and the x-axis is time.

While this describes a typical servo, there are other models that use a different timing scheme; and there are models that are able to rotate 360 degrees or more (continuous servos). Furthermore, in Ion's design the width of the pulse is not set to a specific position, but rather increased or decreased incrementally to mimic slow movement towards a direction. Figure 10 shows how PWM will be used for this design. Servo selection for Ion is discussed in more detail in a later section.

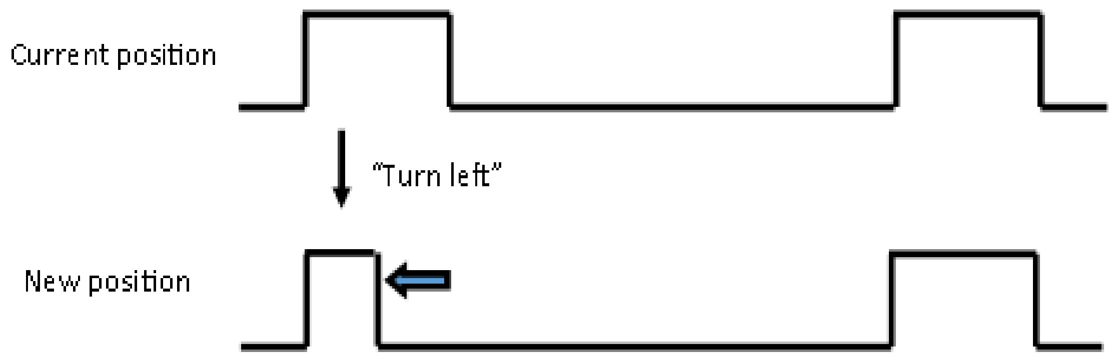


Figure 10: Adapted use of PWM signal to create a "movement" effect.

It is essential that the signal is as accurate or more accurate as the integrated controller of the servo motor. Accuracy refers to the length of the pulse that is generated. If continuous pulse of 1.5 ms is required to hold the servo in center position, but the pulse generated varies by a slight threshold that is picked up by the servo control, the motor will continuously adjust instead of remaining stationary. This unwanted motion not only looks bad in a finished design, it also uses up unnecessary energy. The generated pulse needs to be accurate. However, it does not have to be able to provide enough current to move the servo. This can be done by a separate power connection.

3.3.2 Processors

The design of Ion calls for a central processing unit (CPU) with sufficient processing power to handle facial detection, facial recognition, feedback for motor control, multimedia playback (audio and video), graphical user interface (GUI) with touchscreen input, and other general-purpose inputs and outputs. Preferably, this CPU would come with pulse width accurate modulation (PWM) for two separate outputs to drive two servos. The SBC should also support an operating system like Linux where all necessary coding libraries can be installed successfully. During the prototyping phase, the SBC will be used as generally available, but a final version of Ion would require it to be incorporated into the custom PCB. Therefore, the design of the SBC should also be open source, or it should be somehow possible to integrate it into a PCB design.

3.3.2.1 BeagleBone

The BeagleBone Black is an SBC based on the AM3358 ARM Cortex-A8 with a 1Ghz frequency. It has all necessary Peripherals and an ARM Cortex-A8 can be integrated into the final PCB design. However, with only one processing core running at a maximum frequency of 1Ghz, it is substantially less powerful than the Raspberry Pi 3 and might not suffice to run the required software without noticeable latency.

3.3.2.2 Asus Tinkerboard

The Asus Tinker Board SBC is based on an ARM RK3288 (Cortex A17) with 4 processing cores running at 1.8Ghz. All required peripherals are available, and it has more than enough processing power to handle the more intensive parts of Ion’s processes such as facial recognition. The drawback of this design is the price at almost double the cost of the Raspberry Pi and the availability of the SoC it is based on. Initial internet searches have not provided a source for the necessary hardware to reconstruct this SBC as part of the final PCB.

3.3.2.3 PINE A64

The Pine 64 is a SBC based on the ARM Cortex A53 64-Bit processor with four cores running at 1152Mhz. It is comparable to the Raspberry Pi in almost every way. It’s main difference is the availability of a low cost prototyping board for $35 that would include the chip used in the final PCB design (“Sopine A64”, connected to PCB via SODIMM).

3.3.2.4 Raspberry Pi

The Raspberry Pi 3B is a popular Single Board Computer (SBC) with a low price of $35 and good functionality. It has a 1.2Ghz quad core Broadcom CPU that would be able to handle the required workload, and most other necessary components required for prototyping. Another benefit of the Pi is a large support community and many helpful tutorials for implementations similar to its intended purpose for Ion. Its only drawback is that it only has one PWM output which, according to several user forums, lacks in precision, creating unwanted jitter in the servo. The Raspberry Pi 3B could be used for prototyping and a final PCB implementation could use the Raspberry Pi Compute Module 3 in Figure 11 below, which would be attached to the PCB via a fixed SODIMM connector.

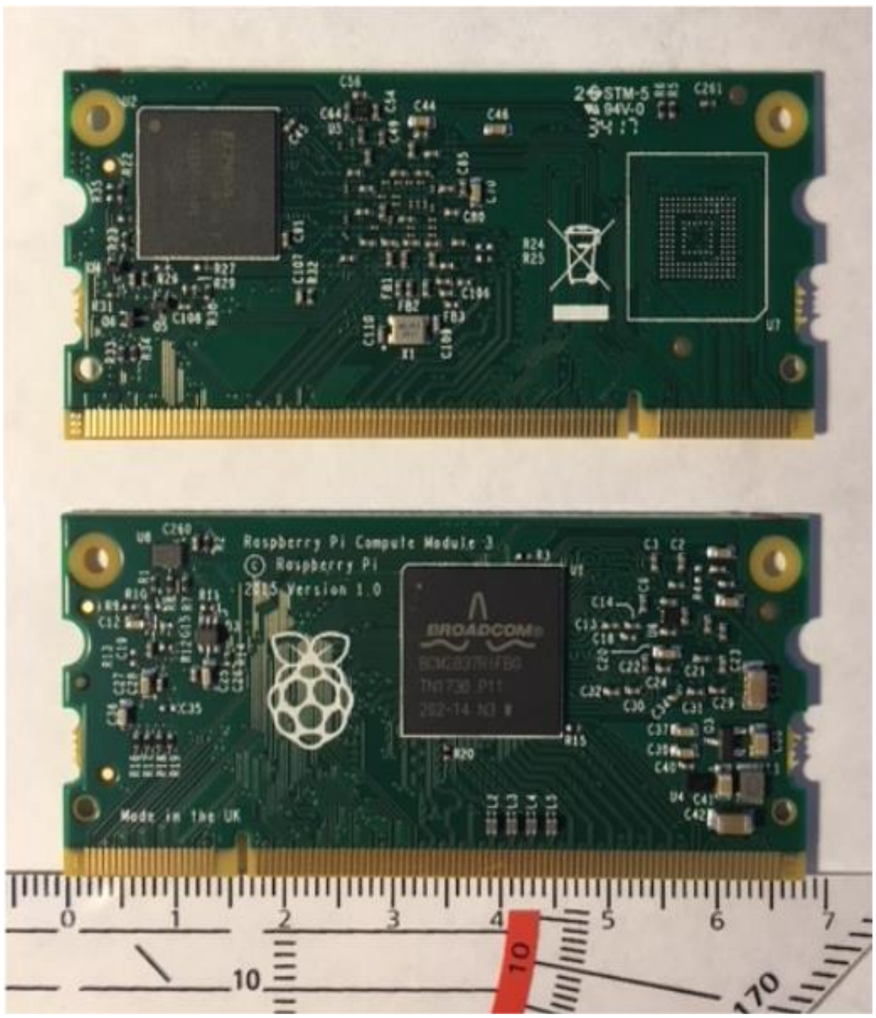


Figure 11: Raspberry Pi Compute Module 3L back and front with cm measure for scale

3.3.2.5 Overall Comparison

The table below, Table 2, shows an overview of the features that are of importance in selecting the prototyping board. The two most plausible contenders are the Raspberry Pi because of its abundance of tutorials and the Sopine A64 because of its similarities to the Raspberry Pi. Although the Sopine and Pi cost the same amount of money, the Sopine chip can be used in the final design, reducing the overall cost of the project.

	Raspberry Pi	BeagleBoard	Asus Tinkerboard	Sopine A64
CPU/SOC	4-core 1.2Ghz	1-core 1.0Ghz	4-core 1.8Ghz	4-core 1.152Ghz
Price	$ 35.00	$ 49.00	$ 55.44	$ 35.00
Component Availability	Readily available	Readily available. CPU can be bought directly for $20.	Prototype board available on Amazon. Components for final design not found yet.	Readily available
Peripherals	Everything necessary, except 2nd PWM output. Also, PWM does not seem to be accurate enough.	All necessary peripherals available.	All necessary peripherals available.	Everything necessary, except 2nd PWM output.
Final Implementation	Connect Raspberry Compute Module 3 via fixed SODIMM connector to PCB.	SBC design to be used as reference to add CPU directly to final PCB.	Currently not possible because components have not yet been found.	Connect Sopine A64 via fixed SODIMM connector to PCB.
Notes	Abundand information andtutorials available on cummunity forums and other websites.	Too expensive and the CPU is not powerful enough.	Too expensive but powerful. This might only become an option if it turns out that more processing power is needed.	Relatively new product but based on a known processor design. The processor used for prototyping can be used for the final product, thus reducing cost.

Table 2: Processor comparison

3.3.3 Audio Components

3.3.3.1 Mono-Audio Amplifier

The mono audio amplifier's main goal is to basically amplify the signals being output by the device in case they were too weak or not clear enough to be understood. The mono audio amplifier receives the output signals from the device, which should have already been processed and converted into analog signals then amplify them to be better understood by the user, then send the amplified signals through the speakers.

The audio amplifier the group decided to go with is a class-D amplifier called SparkFun Mono Audio Amp Breakout - TPA2005D1 for prototyping. This specific mono audio amplifier's features include a volume control potentiometer, where the user can control the volume output by reducing the input signal from 100% to 0%, and a shutdown pin, where the amplifier shuts down to save power when it is not being used. The shutdown pin shuts off the amplifier if the input voltage were either less than 2V or connected to ground, or does nothing otherwise. The mono audio amplifier also has two gain resistors with a resistance of 150kΩ that provide a gain of 2 V/V. The gain resistors can then be changed to different values to further increase the gain of the amplifier. The gain is defined by the equation G=2*150kΩ/Ri, where G is the gain and Ri is the through-hole resistance that can be added to increase the gain. The smallest value for Ri that should be used is 15kΩ to generate a gain of 20. Those features are very convenient for the group's device since it saves power by shutting off the amplifier given that the device could be run wirelessly by a battery. The amplifier can also be powered by an input voltage that ranges from 2.5V to 5.5V DC. [1]

3.3.3.2 Speakers

The speakers are mainly used to output analog signals to the user, whether they were replies from the device or music being played by it. The speaker being for this device is an 8-ohm speaker with a power rating of 0.5 watts. [2] So far only one speaker was enough for the device since it was already loud enough to be heard properly in an average-size room. The speaker is directly connected to the mono audio amplifier to receive the final, processed analog signals to be output to the user. In case the group decided that one speaker was not enough for the final completed device, another speaker could be added in parallel or in series with the first speaker.

If the two speakers were put in parallel with each other, they would both share the same amount of voltage from the source. The only downfall of that is that now the source supplying the voltage must supply greater current to be divided across the two parallel speakers which leads to more heat in the wires. But, in this case, the speakers each can take a maximum voltage of 2V and current of 0.25A. So, in total the source must supply a current of 0.5A which is not a problem at all temperature-wise.

If they were to be connected in series, which is possible as well, the voltage source must supply a greater voltage, meaning a stronger amplifier, but less current, meaning less heat. In total, the voltage source would be supplying a voltage of 4V and a current of 0.25A.

In conclusion, the better option was to go with speakers in parallel in case more speakers were needed, since the voltage being supplied stays the same and the current is too small to worry about heat.

3.3.3.3 Microphones

The microphone is mainly used to pick up analog signals from the user and then send them to the analog to digital converter, so the device can process the voice signals. The microphone being used by the group for the device would be a simple Electret Microphone, shown below in Figure 12, which will be used for prototyping and the final design.

Figure 12: Electret Microphone – Image credits to Sparkfun™ Electronics

The microphone operates with a voltage range of 1VDC to 10VDC, a frequency range around 100Hz to 10KHz, and a maximum current of 0.5mA. [3] The issue with the microphone the group will be using is that it is cheap and poorly filtered, so it is susceptive to noise. To fix that, the microphone might need to be filtered to reduce noise. Once the noise is filtered out, the analog to digital converter can now work with a better signal. A low-pass filter would be the best fit to filter out the noise since human voice is transmitted at low frequencies while noise is considered high frequency. The cutoff frequency for the filter should then be around 2KHz to include all human voice frequencies. After that, using an RC circuit to build the filter, the values for the resistor and capacitor could be calculated using the cutoff frequency equation $f_c = 1/2\pi RC = 2KHz$ where there could be infinite combinations of resistor and capacitor values to be chosen from. The best combination would be to pick low capacitor and resistor values for less size and cost.

3.3.4 Camera

Ion is slated to have one camera that will face the user. Whether it will be embedded in Ion's housing or attached in a different manner will ultimately depend on the design of

Ion’s body and the camera’s design and size. The purpose of the camera is mainly to provide images used in facial detection and recognition. Because of this, the image resolution will likely not need to exceed 640x480 pixels. Should the need arise to also capture video for multimedia playback purposes, this might change. There are several options that would work in the design of Ion in its current state: Pixy, generic webcams, Pi-compatible cameras.

3.3.4.1 Pixy Camera

CMUcam5 (aka. Pixy) is a camera produced by Charmed Labs with an embedded computer vision processor. It can detect objects and relay just basic information to a CPU while processing images on-board. This would greatly reduce the strain on the CPU, making it possible to reduce the power specification of the processor, therefore possibly reducing its cost and power consumption. Because of the camera’s specific purpose, it is also very fast and easy to program. However, after some basic research about the pixy cam, it was determined that it would not be a viable option because it cannot detect or identify faces. Furthermore, at a cost of $69, the Pixy camera is more than double the cost of its alternatives.

3.3.4.2 Open MV M7 Camera

Like the Pixy camera, the Open MV camera has an embedded system that is specifically designed to provide the camera with computer vision. The main difference to the Pixy cam is that it supports facial detection. That, along with available I/O pins for servo control would make the camera a great match for the need that it should fulfill. However, at $65 it is considerably more expensive than a “plain” camera without embedded features. Furthermore, part of the reason to include computer vision in this project was interest in the subject. While it is likely that this camera may be used in a refined version of the design, a self-designed algorithm will be used to further the understanding gained of computer vision from EEL 4660 “Robotic Systems”.

3.3.4.3 Webcams

The selection of available webcams is large. Cheaper models with sufficient capabilities start at $7. The added benefit of a webcam would be that most models include a microphone, making the need for an external microphone obsolete. The drawback would be that a USB port would need to be added to the final PCB design in order to connect it to the SoC.

3.3.4.4 Pi-Compatible Cameras

In case the Raspberry Pi is chosen as the SoC, a pi-compatible camera would facilitate design greatly. Instead of the USB connection necessary for webcams, the Camera Serial Interface (CSI) bus would be used. A basic model, capable of capturing 640x480 video at 90 frames per second is available for $10.99. These cameras are also not limited specifically to the Raspberry Pi. Any SoC with a CSI bus would be able to connect to it.

3.3.5 WiFi Components

3.3.5.1 Sparkfun ESP8266 Thing Dev Board

The Sparkfun ESP8266 Thing Dev Board is a WiFi microcontroller that can enable a device to connect to the internet wirelessly. It can be used for prototyping how the device would react once connected to the internet and what functions it can perform. The ESP8266 Thing is very convenient for testing since it is breadboard compatible, can be powered and programmed through a micro-B USB cable, has a built-in voltage regulator, a built-in USB-to-serial converter, an ON/OFF switch to conserve power, and the list goes on. The ESP8266 Thing is shown below in Figure 13. [4]

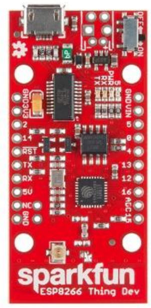


Figure 13: Sparkfun ESP8266 Thing Dev Board – Image credits to SparkfunTM ElectronicsSparkfun ESP8266 WiFi Module

The ESP8266 WiFi Module is a system-on-chip (SoC) that can give a microcontroller the ability to connect to the internet wirelessly. Since the ESP8266 Thing can only be used for prototyping and testing the device with internet, the ESP8266 can be replaced by the ESP8266 SMT module, the ES-12S chip, and used in the final design then connected to the device microcontroller on the PCB. The ESP8266 WiFi Module would be convenient for use since it has a built-in 1MB flash memory, power management units, and an integrated TCP/IP protocol stack. The module also works in almost all operating conditions. The only issue with the ESP8266 WiFi Module is that it is not breadboard friendly but could be converted if needed. The ESP8266 WiFi module is shown below in Figure 14. [5]

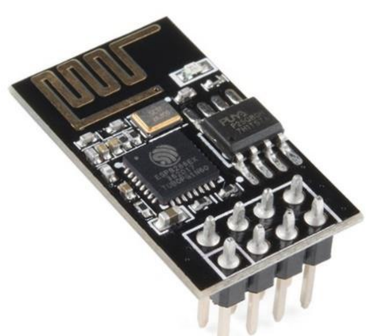


Figure 14: ESP8266 WiFi Module – Image credits to SparkfunTM Electronics

3.3.6 LCD

There was a long list of attributes that had to be kept in mind when looking for a LCD. The LCD is a huge chunk of the budget, being up to $100. The LCD's main purpose is to display visuals including the GUI, YouTube videos, and GIFS, so a decent size screen was needed - between 5" and 7" and having 480p resolution at a minimum. Those qualities should be decent enough to display what the group needs to. The touch screen will be the secondary interaction with the device, behind voice control, and needs to have touchscreen capabilities so that the user can interact with it and navigate the menu system.

3.3.6.1 Option 1: Pi Foundation 7" Display w/ Touchscreen

This screen, shown below in Figures 15 and 16, is more than what is needed for the scope of this project. Being 7", it is a bit larger than what is needed and may be hard to integrate into the design since the aim is to keep the body small. It is 800x480, the same resolution as our other options. It has touchscreen capability - 10-finger touch capability, in fact, which may be too much for the scope of this project. It also comes with an adaptor board that would handle all power and conversions. It includes two connections, a power connector and ribbon cable. The cost of this LCD is $79.95. This option seems viable but may be too much for the scope of the project and budget may be wasted on the extra features of this LCD which aren't necessary.

Figure 15: 7" LCD – Image Credits to Adafruit

Figure 16: 7" LCD – Image Credits to Adafruit

3.3.6.2 Option 2: 5" HDMI Display - 800x480 w/ Touchscreen and Mini Driver

This option, shown below in Figures 17 and 18, is a technical downgrade, being only 480p and 5" in size. The price of this LCD is $79.95. It does include resistive touchscreen capabilities as well as a USB-powered driver board which would save a lot of time if one doesn't need to be developed. It has a 40-pin connector with 24-bit color capability but also an HDMI connection which would be the best option to use, especially with the Raspberry Pi which supports HDMI. For power, this requires 5V and 500mA. This is a great option if the goal is the have a decent screen without putting resources into developing a driver.

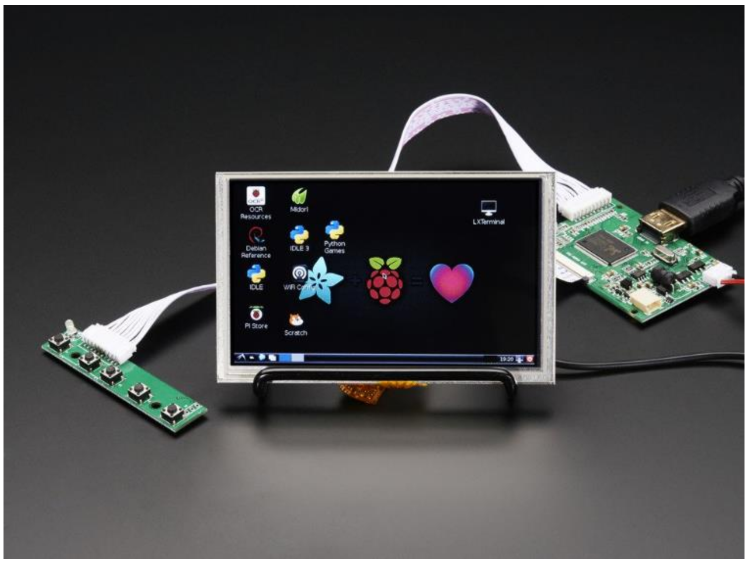


Figure 17: 5" LCD – Image Credits to Adafruit

Figure 18: 5" LCD – Image Credits to Adafruit

3.3.6.3 Option 3: 5.0" 40-pin TFT Display - 800x480 w/ Touchscreen

This option, shown below in Figures 19 and 20, seems like a good fit, having a 800x480 5.0" TFT display and touch capabilities. It is priced slightly higher at $39.95, which makes it much more appealing, as the project budget is only a couple hundred dollars. Coming with an LED backlight and a resistive touchscreen overlay, this can perform all the functions that will be asked of it, including having the GUI interface and playing videos and GIFs. The connectors include a 40-pin which has 24-bit color capability. Some issues for this display includes having a high-refresh rate which requires a powerful processor which don't come with many microcontrollers. The backlight also requires a constant-current mode boost converter which go as high as 24V and will be difficult to integrate into the design of the project. All these issues will probably call for buying their recommended driver board that goes hand-in-hand with this LCD. If this option is chosen, the group would most likely have to design their own driver board which would be a huge undertaking and take a lot of resources and time. The final LCD comparison is shown in table 3 below.

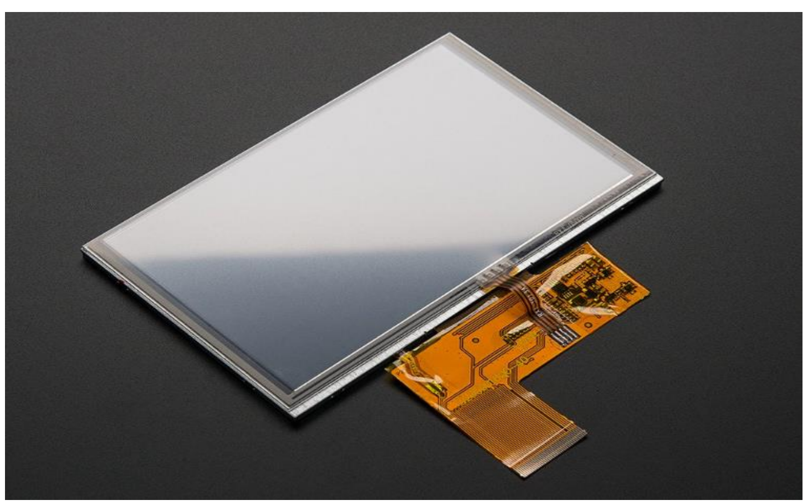


Figure 19: 5" TFT – Image Credits to Adafruit

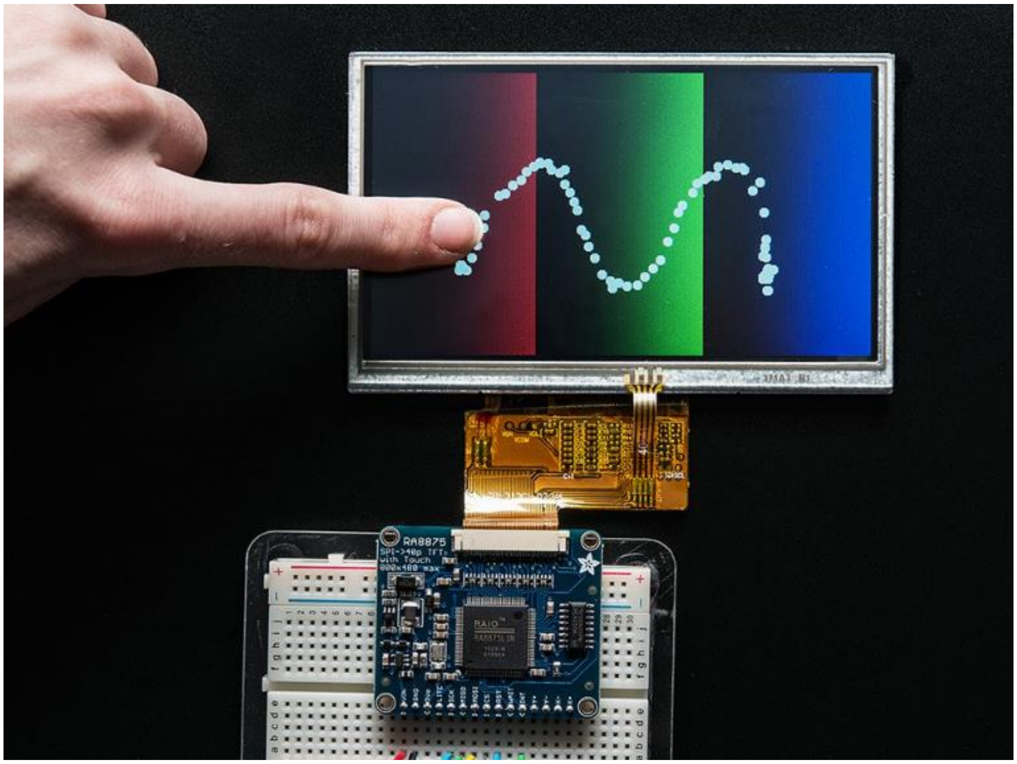


Figure 20: 5" TFT – Image Credits to Adafruit

	7" Pi Foundation LCD	5" LCD	5" TFT
Size	7"	5"	5"
Resolution	800x480	800x480	800x480
Display Type	LCD	LCD	TFT
Driver board?	Yes	Yes	No
Cost	$79.95	$79.95	$39.95
Connectors	Ribbon (DSI)	HDMI	Ribbon (DSI)
Touch capability	Capacitive	Resistive	Resistive

Table 3: LCD Screen Comparison

By looking at the comparison in Table 3 above, the best option for the functionalities that Ion has would be option 1, the 7" Pi Foundation LCD. This screen has everything Ion would need include a large, clean display and touch capability. The biggest factor in choosing this LCD is the inclusion of a driver so that one will not have to be developed.

3.3.7 Motors

Ion is supposed to have four degrees of freedom, or two axes of movement. This requires at least two motors that need to be controlled by the CPU and powered by the battery. The required torque generated by the motors depends heavily on the design of Ion's casing, what kind of bearings, gears weight they need to move. Since the idea is to rotate Ion to face the user, it is necessary when, how fast, in which direction and how far the motor is supposed to turn. Initial research showed two types of motors that would be able to provide the necessary torque and precision: DC motors and servos.

3.3.7.1 DC Motors

A standard DC motor generates torque from DC power. There are two main types: Brushed and Brushless. A brushed DC motor is cheaper to construct and simpler to control. In the case of Ion, some sort of feedback would be required to position the motor according to the signal from the CPU (contributors, 2018). One of the options would be to use a rotary encoder to translate the amount of movement to a position. This type of closed loop system is also referred to as a servomotor (contributors, 2018).

3.3.7.2 Servomotors

As described in the previous paragraph, servo motors are electrical motors that are capable of moving to a specific position via the help of a control system. There are two types of servos that would be useful for Ion's design: Positional rotation, and continuous rotation servos. Positional rotation servos can rotate on one axis by about 180 degrees. The position is dictated by a PWM signal as described in detail in another section of this document. Continuous servos can rotate indefinitely in either direction at a varying speed.

3.3.7.3 Conclusion

DC motors will definitely be used in the design of Ion, but since it is simpler to purchase motors that come with an integrated control system, servo motors will be used. Both types of servo motors described here would work in the design. It is more likely that positional rotation servos will be used because continuous rotation would require a more complicated approach to cable management within the device because over-rotating in one direction could cause cables to wind themselves up and damage the system. A range of motion of more than 180 degrees is also not necessary as Ion is supposed to be a stationary unit on a desk.

3.3.8 Light Emitting Diodes (LEDs)

The main purpose for the LEDs would be to make the device express itself even further with different lighting. There were two options for the RGB LEDs; clear and diffused LEDs. They were both similar in price even though usually diffused is cheaper, but clear provides a much better lighting than diffused. One LED would not be enough, so multiple LEDs will be used but programmed to work in unison. The group will be using RGB clear LEDs to reduce the number of LEDs, compared to using multiple LEDs that produce one color each, while still achieving the same result. The LEDs being used have an internal frequency of 800KHz and require a power supply of 4.5V-6V DC. Shown below in Table 4, the different LED colors are illustrated along with what they are supposed to mean.

Color	Meaning
Yellow	The device is listening to the user.
Green	The device understood the command.
Red	The device did not understand the command.
Orange	The device is currently powering on.

Table 4: LED Colors and Functions

3.3.9 Batteries

Picking the right battery was the tricky part, since batteries can be found in a very large range of options; chargeable or nonchargeable, different nominal voltage ratings, different capacities, and the list goes on. The one certain thing the group has decided to go with is that the battery must be a rechargeable battery for reasons including economic and environmental. The economical side of it would be that the user does not have to worry about replacing the batteries as often by having to buy new ones; so, cheaper for the user. The environmental side of it would be that the batteries will be reused many times rather than discarding the batteries after every use; better for the environment.

Next, the nominal voltage rating would be determined by looking at the components being used for the device and determining what is the maximum voltage required for each component, and the highest would determine the nominal voltage for the battery. Then, a voltage bus can be created to supply the DC voltage to all the circuits in the device. But, a voltage regulator would be needed to regulate the amount of voltage being supplied to each circuit at a constant rate. Since the nominal voltage rating is expected to be low based on the components used for the device, cost might not be too much of an issue to be included as a parameter.

After that, it is important to determine the energy capacity of the battery; too much current being drawn from the battery might cause damage to it or the circuits. To prevent damage to the battery, a circuit protection device can be implemented, just in case. So, in conclusion, it is important to make sure the battery provides the right amount or excess amounts of current.

Finally, another parameter that should be considered is charge cycles; the amount of times the battery can be recharged and discharged before being discarded. Having an extremely low amount of recharge cycles would not be too smart since it defeats the original purpose of picking a rechargeable battery for the device. That means, a decent range of recharge cycles should be around 500-1,000 cycles.

Now that the parameters have been defined, the next thing to look at would be the different types of rechargeable batteries, illustrated below in Table 5, along with their advantages and disadvantages to decide which would be the perfect fit for the project.

Battery Type	Advantages	Disadvantages
Nickel-Metal Hydride (NiMH)	• Recharge cycles between 150-500. • Delivers current at a more constant rate. • Has a self-discharge rate of only 1% per day. • It is best when it is used frequently.	• If idle, self-discharge rate can increase up to 5% per day. • Current rate supply can drop by 15% after 100+ charges. • Batteries should be handled properly, or performance might diminish. • Not good in high temperatures.
Nickel Cadmium (NiCd)	• Up to 1,500 recharge cycles. • Good for high temperatures and rugged. • Steady voltage throughout a charge cycle.	• Cadmium is a highly toxic component. • Low energy capacity compared to NiMH.
Lithium-Ion (Li-ion)	• Recharge cycles between 500-1,000+. • Lowest self-discharge rate between rechargeable batteries.	• Highly impacted by aging. • Can be expensive.

Table 5: Different Battery Types Comparison

3.3.10 Power Switch

Since almost all electronic devices usually have a manual power switch, the group figured that one was needed for the device to save power when the device is not in use or for an emergency shutdown. Given that the battery might supply a voltage around 3.3V-5V and a current around 5000+mAh, it was a bit tricky to pick the right power switch that can handle that much current without getting fried. The power switch's main goal was to break the circuit connecting the battery to the device when needed. The best fit the group found was an ON/OFF SPST rocker switch that has a blue LED rated at 12V and 16A, shown below in Figure 21. It is 20.2mm in diameter and could also be run at a voltage rating of 5V. The blue LED turns on to signal that the device is on or it is off otherwise. [6]

Figure 21: Rocker Switch w/ Blue LED – Image credits to Sparkfun™ Electronics

3.3.11 MicroSD Card Reader

The microSD card reader will be mounted on top of the PCB to hold a microSD card that should have the device's operating system along with on-board storage. However, it was complicated to find the right microSD card reader, so a breakout board will be used for prototyping, then using its schematics, the group will create their own microSD card reader mounted on their PCB. The microSD card reader schematic will be created by following a microSD card breakout board schematic found on *Adafruit*. Some of the components, like the internal voltage regulator, were removed since they are not needed, and only required components were kept. The microSD card reader requires a 5V DC input supply along with 100mA of current. [7]

3.3.12 Digital-to-Analog Converter (DAC)

The digital-to-analog converter is required to convert the digital signals being output by the microprocessor to analog signals for the mono audio amplifier and speaker. There are lots of different options for DACs, many of which include through-hole components. The through-hole components are decent but look unprofessional on a PCB. So, the group researched DAC's that can be mounted on top of the PCB without any through-holes. The best fit that the group has found was the MCP4725 12-bit DAC provided by *Adafruit*. Once again, a breakout board can be used for prototyping then following its schematics, the group should be able to come up with their own DAC using the MCP4725 but without the board. [8]

3.4 Possible Architectures

3.4.1 Overall System Design

3.4.1.1 Powerful vs. Simple CPU

The selection of the CPU depends on the overall design of the architecture. The two extremes considered were:

1. A powerful CPU that handles everything to control passive components.
2. A simple CPU that ties together a system of smart components.

3.4.1.1.1 Powerful CPU

In this type of architecture, the CPU must calculate, control and time everything including:

- Activate, dim and power LEDs
- Generate PWMs for servos
- Calculate positioning of servos based on feedback
- Calculate feedback for servos based on processed images from camera
- Process images from camera (facial detection and recognition)
- Power and control camera
- Process audio received from microphone
- Generate audio signal for amplifier/speakers
- Provide power and data to LCD
- Receive and process touch input from LCD
- Run OS and main program (GUI)

See Figure 22 below for a visual representation of this system. Arrows show the flow of data and power.

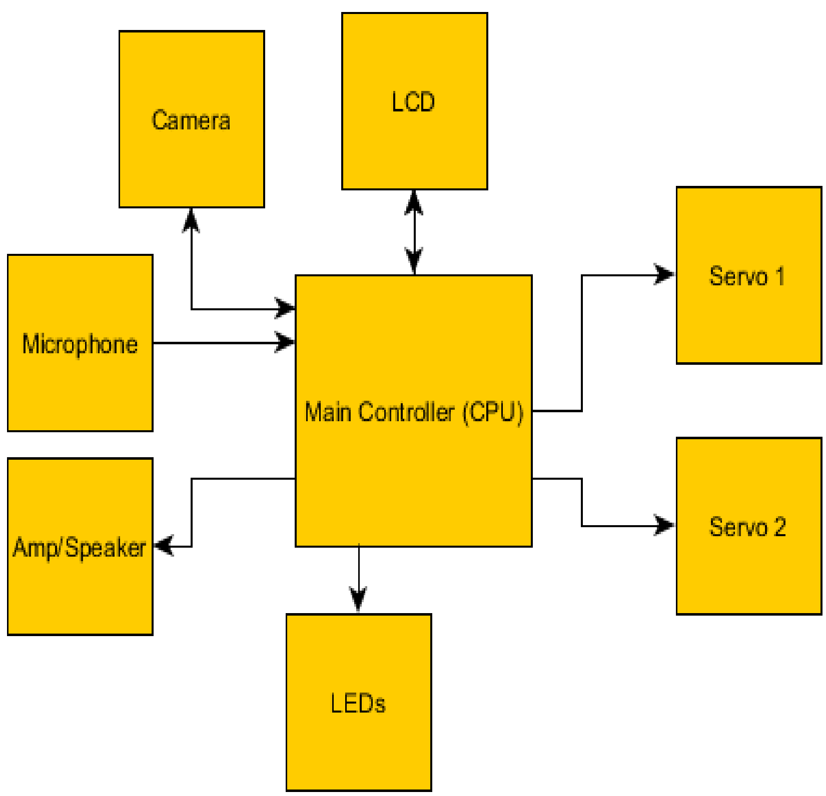


Figure 22: Architecture based on a powerful CPU

The benefit of this architecture would be the low cost of components because “smart” components come at a premium price. The drawbacks would be the price of the CPU and the complexity of the main program. The main routine of the program would have to account for all components on top of the image processing. This may lead to lag problems such as a delayed response of the servos because the processor is busy processing images.

3.4.1.1.2 Simple CPU

The opposite of the architecture described above would be a simple CPU that only needs to run the OS and GUI (from the list of functions outlined in the powerful cpu section above). All other processing would be done by the components themselves. For example, the camera would have an embedded system that automatically focuses and adjusts its gain. Images would be processed and only the necessary data, such as position of users face relative to image center, would be transmitted to the cpu. See Figure 23 below for a visual representation of this system. Arrows show the flow of data and power. The obvious benefit of this architecture is the relief on the CPU, which would only have to act as a scheduler apart from running the OS and GUI. The main drawbacks would be the price of “smart” components and also their availability. Currently, a cost effective (project budget is $500 for the whole system) face-recognition camera for small systems does not exist on the market.

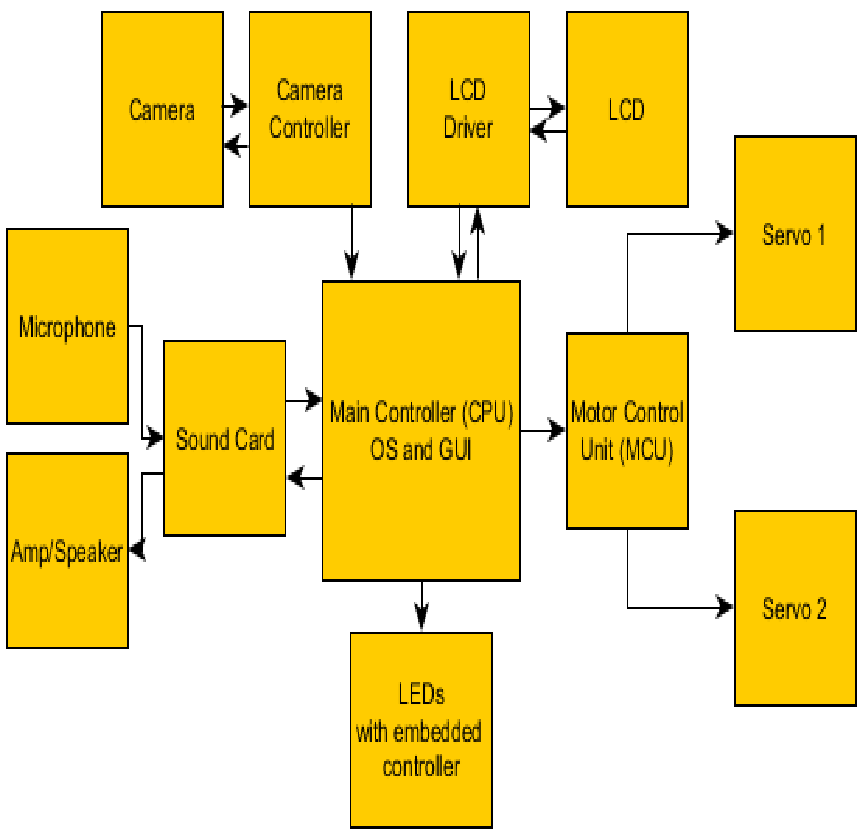


Figure 23: Architecture based on simple CPU and “smart” components

3.4.1.1.3 Conclusion

Both architectures provide considerable benefits over one another and also have considerable drawbacks. Since these architectures are extremes, a good solution would be to implement a hybrid architecture that focuses on taking advantage of readily available and inexpensive "smart" components, such as a dedicated MCU, and compensating for lack of available components by having the CPU to process images. See Figure 24 below for the planned hybrid architecture.

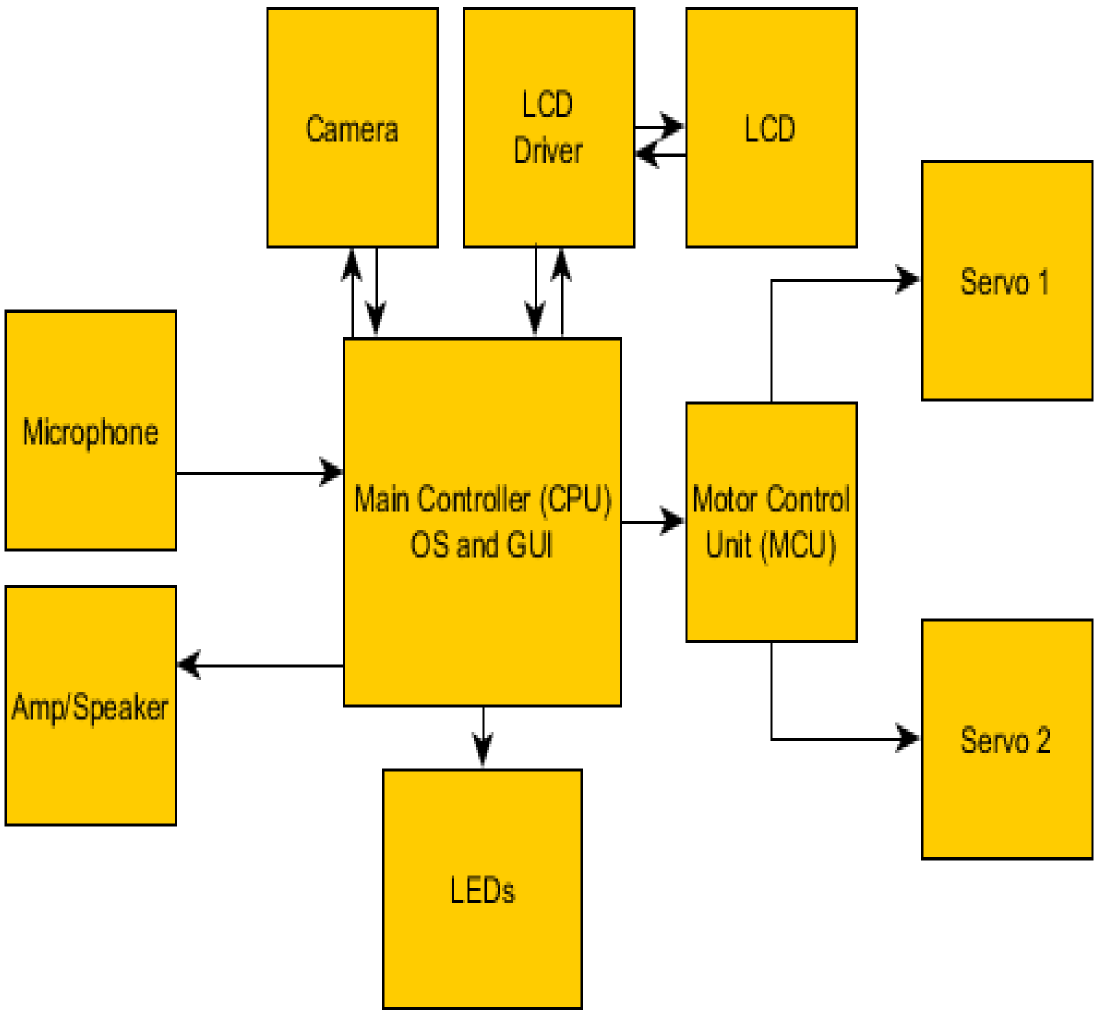


Figure 24: Hybrid Architecture

3.4.1.2 CPU Choice

Because of the high processing requirements of Facial recognition/detection and OpenCV's capability to leverage multiple CPU cores, only 4-core CPUs were considered. The main driver in CPU selection past the 4-core requirement was the cost and availability of prototyping boards. As discussed in section 3.3.2.5, the Raspberry Pi 3B has been chosen as the reference SBC, and therefore the CPU choice is an ARM cortex A53 based microprocessor.

3.4.2 MCU

3.4.2.1 Controller vs. Dedicated MCU

Most SoC and therefore SBCs (used for prototyping) are able to put out two or more PWM signals as is required in this project. However, some SoC are not able to provide an accurate signal in this frequency because PWM is also used to dim LEDs. An inaccurate signal will cause to much variation in a duty cycle that is supposed to be of fixed length. This will lead the motor to move (jitter) when it is supposed to remain at its current position. Furthermore, the SoCs should be dedicated to run the main program, so the burden of generating the pulse should be delegated to a different piece of hardware. To solve these problems, an appropriate solution seems to be a dedicated motor control unit (MCU) that will generate two accurate PWM signals that can be varied by simple signals from the main controller.

3.4.2.2 MCU Considerations

The requirement of the MCU is to provide two independent 4.8V PWM signals that can be varied by the main system controller.

A 556 timer would be the most basic approach to generating a PWM and by far the cheapest option. However, it would require a separate control unit such as a digital potentiometer to vary the width of the pulse. Instead of using several components to achieve the goal of a variable PWM source, it makes more sense to use a chip that has these capabilities integrated. Two cost effective chips have been identified for review because of their available prototyping boards: Texas Instruments M430 (Prototyping board: LaunchPad) and Atmel MEGA328 (prototyping board: Arduino Uno).

The M430 is a little easier to program through the Texas Instruments LaunchPad. However, the native output voltage of the M430 is 3.3V vs. 4.8V for the Atmel chip. Since servos usually require a PWM signal of 4.8V, it is more convenient to use the MEGA328 because there is no need to amplify the control signal, resulting in a simpler circuit. Programming of the MEGA328 will have to be done through either in system programming (ISP) or in circuit serial programming (ICSP).

3.4.3 Mechanical Components

3.4.3.1 Body

Ion’s body will house all of the mechanical and electrical components that make him work while presenting him as a clean, human-like device that can smoothly interact with the user. Many of the main pieces including the base and head will be modeled in Autodesk Fusion 360, a 3D CAD program, and printed using a 3D printer. The head will house the LCD screen, speakers, and microphones. The base will house the power supply. Inside the rest of the body will be the other electronics including the PCB and Raspberry Pi Compute module as well as the servos components which will control Ion's movement. The connecting 'tissue' between the head and base of Ion will be made of a flexible cloth or spandex which will allow him to tilt and move fluidly.

3.4.3.2 Moving Parts

3.4.3.2.1 Cabling

For the choice of cabling, maximum current draw, available space, and flexibility have been taken into consideration. The most common gage for breadboards is 22AWG, which is rated for up to 7 A. While flexibility will at last depend on the coating, 22AWG tends to be flexible enough to be used in limited motion range applications such as Ion's. With the likely exception of PWM cables, all cables will be unshielded. Cables for prototyping will be different than that of the final build in terms of termination, see figure 2, for ease of use and cost saving but the final choice in cabling will depend on how well the equipment performs with the cabling of the various prototype builds.

Figure 25: Pre-terminated cabling used for prototyping

3.4.3.2.2 Gears and Bearings

Ion will only have two servos. One will rotate it on a horizontal plane within 180 degrees and the other one will either bend it to point the camera up and down or just move the camera; see Figure 26. The current design of Ion does not require any gears to leverage or transmit the power of the servos. To facilitate the rotation on the horizontal plane, a "lazy

Susan" style turntable bearing (Figure 27) will be used. This will reduce the torque requirement, and therefore the physical size and power draw of the servo.

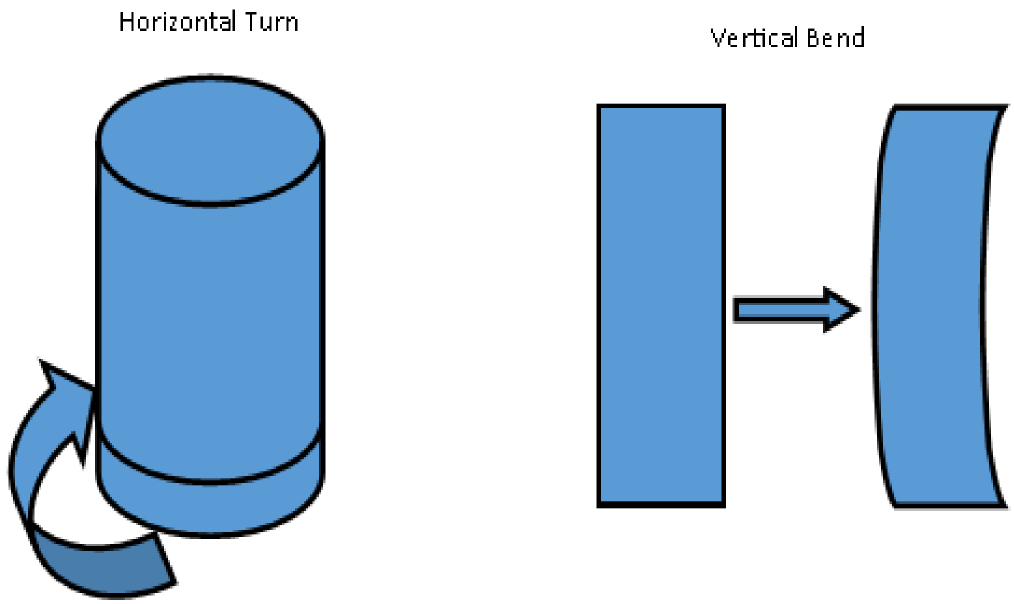


Figure 26: Ion's motion

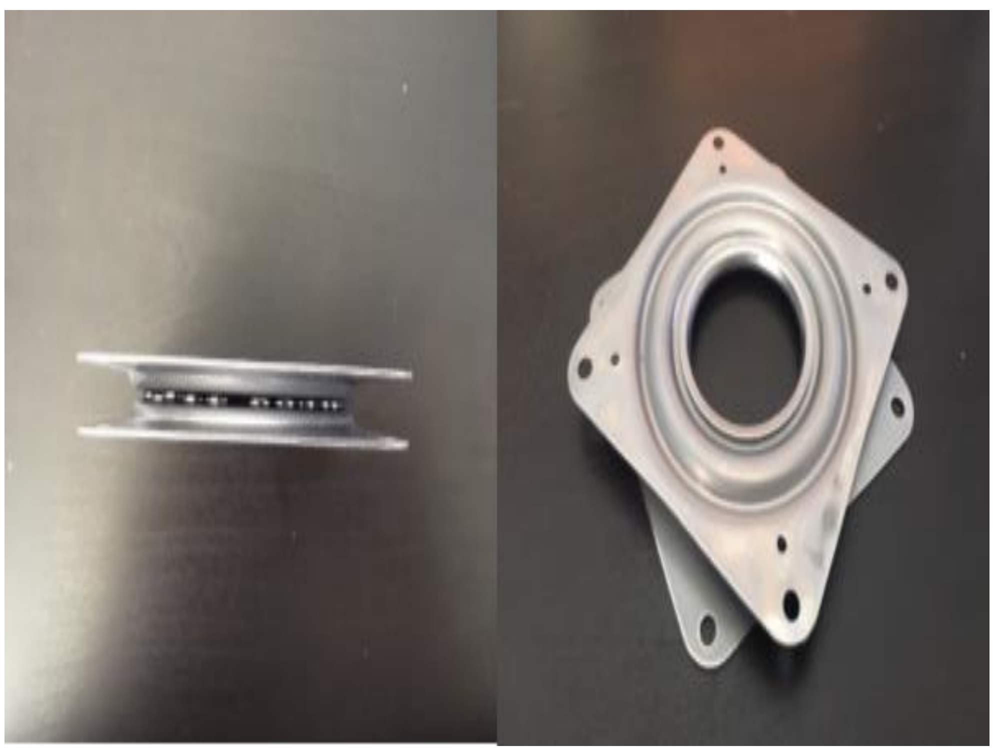


Figure 27: Turntable Bearing. Side view (left) and top view.

4.0 Applicable Standards

4.1 Standards and specification research

Since Ion is meant to be a prototype and not a finished consumer product, no consumer safety standards such as IEC 60950 apply to this design. Because of the wi-fi module, the IEEE 802.11 specification applies but the wi-fi module used already complies with this standard. Other pre-manufactured modules and peripherals are either certified or tested according to, but not limited to the standards listed in Table 6.

Standard	Description
ANSI C63.4-2014 (Revision of ANSI C63.4-2009)	American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9kHz to 40GHz
FCC 47 CFR Part 15, Subpart B	Subpart B deals with unintentional radiators – devices for which the purpose is not to product radio waves, but which do anyway, such as computers

Table 6: Applicable Standards

4.2 Design impact

The impact of these standards on this design is minimal since most standards apply to peripherals and pre-manufactured modules as mentioned above. Unless the design changes or is developed further for sale and consumer use, no standard affects the design in its current stage.

5.0 Design Constraints

Mentioned below are all the Accreditation Board for Engineering and Technology, Inc. (ABET) design constraints that influenced the design of Ion. These include ethical, environmental, economic, time, health and safety, manufacturability and sustainability, as well as social and political. All these constraints put a limit on our designs in ways which will be described in this section.

5.1 Ethical Constraints

Because the product is being used directly by the user, there are many ethical constraints that come along with it. With use of a camera and microphone, there is an ethical standard that must be followed in relation to privacy and securing data. It is understood that those components won't be used without the user's permission or be used in ways that aren't already specified or make sense for the device. Also, with an 'intelligent' two-way conversation system like the one at hand, it is important to make it appropriate for the audience. The project's audience includes anyone who can make use of the device - from a young toddler to an older person. Because small toddlers may use it, it is necessary to make sure that the device doesn't say profane words or access inappropriate content.

5.2 Environmental Constraints

As far as environmental constraints, the product is meant to be used in a dry, indoor room in which it won't be subject to abnormally high heat or humidity. High heat or humidity could cause the device to overheat or malfunction. The microprocessor and CPU need a relatively low heat to keep cool and function properly. Humidity and precipitation can also cause the system to overheat or malfunction. The device is also meant to sit on a flat surface on which it can move around and tilt. Using the servos motors, the device can tilt and turn to convey its emotions and responses and needs a large enough space to be able to do this.

5.3 Economic Constraints

The group didn't have many economic constraints besides what individual members could afford. Being college students with limited budgets, the group's members could only put in around $200 each, for a total project budget of $600. This amount was more than enough to do research, order parts, and develop a fully-working prototype. Other than the personal budgets, the only other constraint that was considered was the price of similar products on the market. The group wanted to provide a decent product for a competitive price, so they had to take that into account. Similar products on the market go for $100-150, but the companies that produce and manufacture them are major powerhouses in the industry and have supply accesses and more resources than the group does.

5.4 Time Constraints

There are multiple time constraints for the design that should be dealt with. The first time constraint would be that the group has only two semesters to finish the design; one to research and the other to build it. Since the group has decided to finish in the Summer semester, the time constraint becomes an even bigger factor, given that the Summer semester is a few weeks shorter than other semesters. To deal with that, the group came up with milestones, further illustrated in section 9.1 of this document, that should be achieved to keep a better track of the group's progress, while also making sure the design is being completed in a sound manner, not all crammed in one week.

Another time constraint would be scheduling. It is known that the group members each have their own busy schedules of school and work together, so each member has limited time to meet up and discuss the design with the rest of the group.

5.5 Health and Safety Constraints

There are several health safety constraints for the device. One of them would be that the device should not produce electrical surges, especially not while the user is near and ends up getting shocked or zapped. Another one would be that the device should not heat up to a point where components would melt or break. Also, the device should not behave unexpectedly and blow up if anything in the circuits goes wrong. The device should be accessible by children as well, so, it should not consist of any small or loose parts that children can swallow.

5.6 Manufacturability and Sustainability Constraints

The main constraint for manufacturability is the available equipment for 3D printing. The PCB and other internal components could become too big to fit into the maximum sized housing that can be produced with the available equipment. Another constraint would be moving mechanical parts. The design team consists of only electrical- and computer engineers, so custom designed moving parts such as gears and bearings would be outside the scope of this project. This constraint limits the design to components readily available on the market.

The sustainability of the device depends mostly on the life and support for the electrical components. Most components, such as the MCU chip have been available for a long time and are mostly guaranteed to be available for the next five years by their manufacturer. Other components, such as the servos are interchangeable and can be replaced with equivalent parts if necessary. Should any of the electrical components be discontinued, a new design may be necessary if there is no available alternative.

As far as the body, we are planning to use a 3D printer, specifically the MakerBot Replicator+. This 3D printer can print up to 11.6” by 7.6” by 6.3”, which meets the requirements of the product. It can use the Tough PLA Filament Bundle, which is more durable and high-impact, which helps our product in case of damage or dropping. This fits the product requirements in terms of printing size, printing material, and printing cost. The group is using an acquaintance's 3D printer as opposed to a professional 3D printer as it is cheaper and easier to work with. If the time did come to mass-produce, the group would have to think about going elsewhere for manufacturing. As for the prototype, this 3D printer is a great option for manufacturability and sustainability.

5.7 Social and Political Constraints

A large constraint created by society includes the negative outlook on data privacy and AI. With the recent data breaches hitting huge companies such as Facebook and Equifax, it is no wonder that consumers are becoming very skeptical of giving their personal information to companies. Many are beginning to realize how much information is given to big companies and is on the internet in general and it is becoming a huge issue when these same big companies who throw millions into security are being hacked or misusing data that gets it in the hands of someone who can call you as a tele-marketer or use it to gain political edge. The group can curb this worry by only collecting the necessary information and informing the user of what their data will be used for and sticking to that promise. Another large social stigma, at least in technology, is the use of artificial intelligence, or AI. Many people are becoming skeptical of the use of AI for many reasons. From the old mindset that AI could take jobs, to the newer big-news stories like Tesla's AI auto-pilot having some technical issues and crashing – AI is a huge social speedbump that will have to be overcome in the coming years. While using AI, the group can calm that worry by making sure the user knows what functions the AI can do and the fact that it is a fun, interactive form of AI will certainly make it easier.

6.0 Project Hardware and Software Design

6.1 Hardware Design

6.1.1 Wireless System

6.1.1.1 WiFi Chip

For the groups final design, a WiFi chip must be used rather than an entire WiFi microcontroller board to reduce the number of PCBs used. The group decided to go with the ESP8266 SMT Module, the ESP-12S, as a WiFi chip that can be mounted on their own PCB. Advantages the ESP8266 module provides are that it has a 4MB flash chip, an integrated analog-to-digital converter, and an antenna on-board that are already pre-programmed. It also has an integrated TCP/IP protocol stack and supports 2.4GHz WiFi with WPA/WPA2 security. The ESP8266 SMT module also features three different power saving modes: deep sleep mode, sleep mode, and active mode. In the sleep modes, the operating current can be reduced to around 12µA or 0.5mA. The ESP8266 SMT module is shown below in Figure 28, it is small in size and should fit well on a PCB. [9]

Figure 28: ESP 8266 SMT Module/ESP-12S - Image credits to Adafruit

6.1.1.2 Circuit Design

Circuit design for the ESP 8266 SMT module was simple since Adafruit provides the schematic and board layout that you need to make it work. The ESP8266 SMT module board layout is shown below in Figure 29 that illustrates all the inputs and outputs for the module along with its pins. This schematic will be very important for building and testing the WiFi chip for the final design and will be further discussed in the PCB schematics section.

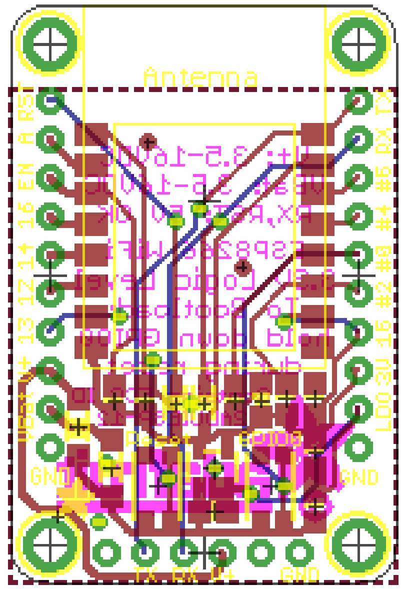


Figure 29: ESP8266 WiFi SMT Module Board – Board credits to Adafruit

6.1.2 Motor Control Unit

The motor control unit (MCU) is responsible for taking instructions from the CPU and positioning the servos accordingly.

6.1.2.1 Design Considerations

Ion will have two servos that need to be controlled by the MCU, so the minimum number of PWM outputs of the MCU chip must be 2. It must also be able to receive commands via I2C.

6.1.2.1.1 PWM Source

As outlined in section 3.4.2.2 “MCU Considerations”, it was determined that the source of the PWM signals should be an external component. Among the two options researched, the Atmel MEGA328 stood out as the better option because of its native output voltage of about 5V, which reduces the voltage control components required on the PCB.

6.1.2.1.2 Power Source

The PWM source itself will be powered through the main controller because the current of the signals is very low. The Servos will be powered directly from Ion’s power source because of the motor’s required higher and varying current. The high current could not only damage the PWM source, variations in the high current could generate noise that interferes with more sensitive components on the PCB.

6.1.2.1.3 Servo Specifications

The required specifications for the two servos are listed in Table 7 below.

Specification	Up/Down Servo	Rotational Servo
Operating Voltage	5V +- 10%	
Torque (kg/cm)	At least 1.5	At least 3
Size (cm, w l h)	Less than 2.5 x 1.5 x 2.5	Less than 3 x 2 x 3
Speed (s)	Less than 1	
Weight (g)	9	
Gear Material	Plastic	

Table 7: Servo Specifications

6.1.2.1.4 Feedback System

The purpose of the feedback system is to create a closed loop control system for the camera movement. The servos, if properly calibrated, can move to a designated position based on the given control signal but there needs to be a way to determine the relation of the motor position to the focal point of the camera to ensure that the camera is properly centered on the user's face.

6.1.2.1.4.1 Position Based Adjustment

The facial detection software will provide the position of the detected face relative to the center of the captured frame. The focal point of the camera is the center of the frame, so the distance of movement necessary to position the face in the center can be calculated. Based on that calculation, the position for the servos can be updated (see Figure 30).

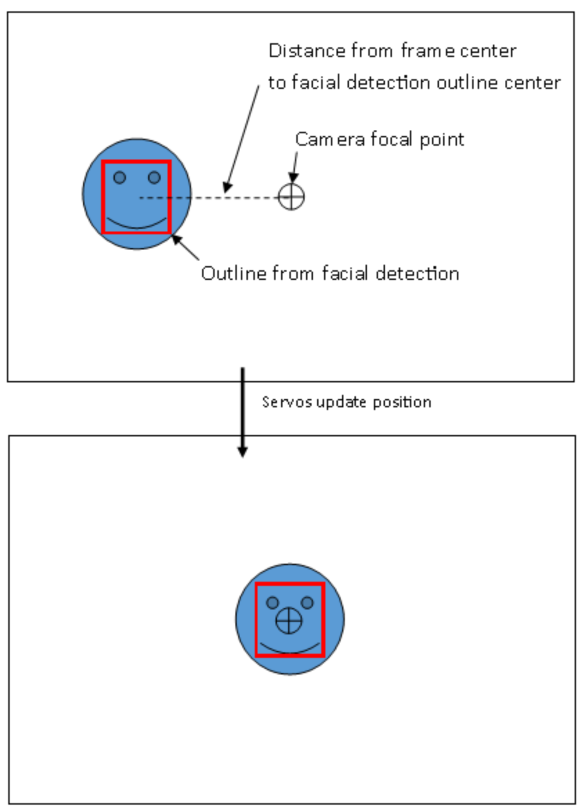


Figure 30: Camera position update based on calculated distance from center.

However, because of possible inaccuracies in facial detection, wrong calculations may lead to unwanted over- or under-correction in position. The position of the face is based on the center of the rectangle drawn around the detected face. The perceived center of the face may be wrong and an overestimated (or underestimated) distance from frame center to face center could be calculated. As a result of an overestimated distance, the position of the camera could overshoot at first and then correct itself to the opposite direction. This could be perceived as jitter. Furthermore, small movements by the user, or turning of the face could lead to many minor corrections of the camera position. This would not only be annoying but also draw more power from the battery than necessary.

This feedback design also relies on proper estimation of distance from face to center. For this, the distance on the frame needs to be translated into rotational distance. To accurately do this translation, the distance from the face to the camera must be known. Figure 31 shows a bird's eye view of the camera and two heads. Note that the two heads are the same person but at different distances from the camera.

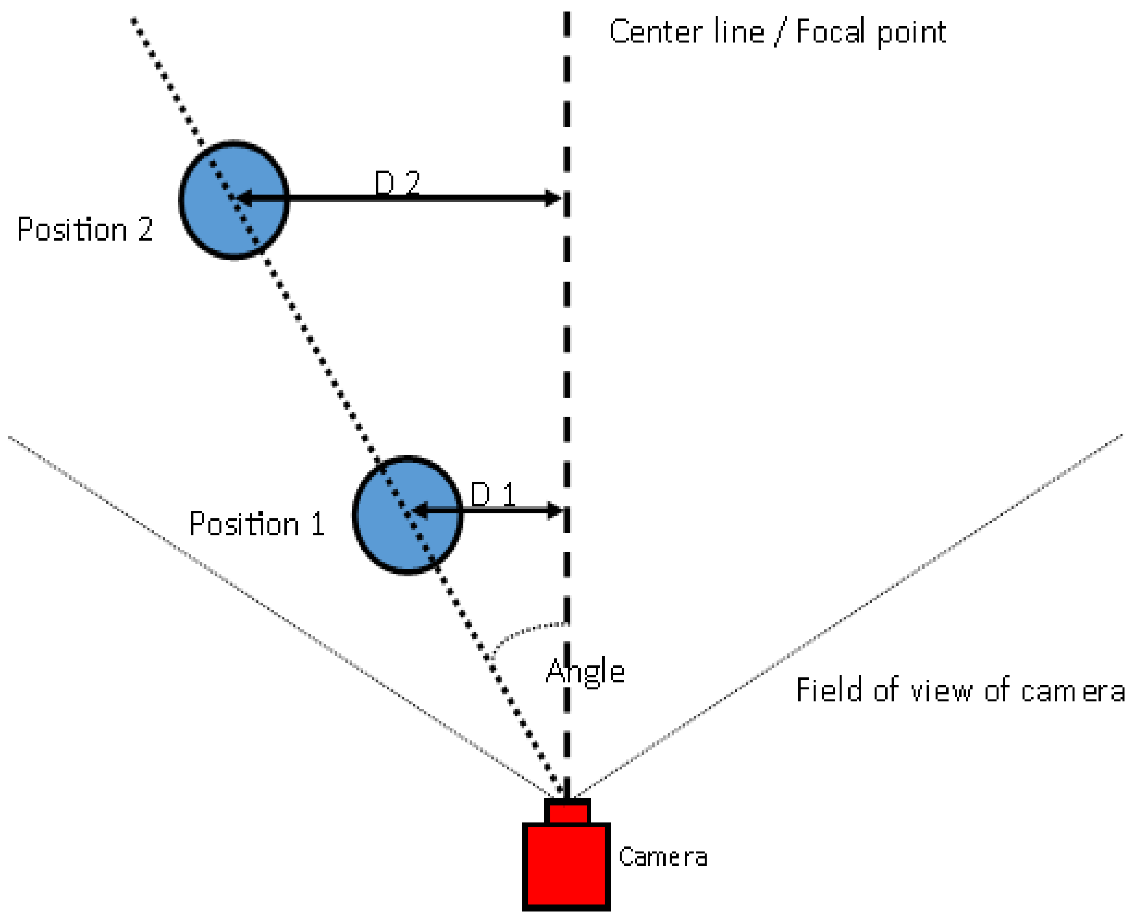


Figure 31: Bird's eye view

With the current design of Ion, the only way to estimate this distance is by measuring the size of the rectangle that is drawn around the face and relate that to the size of an average face. Figure 32 shows the same face in position 1 and 2, based on Figure 31, as perceived by the camera.

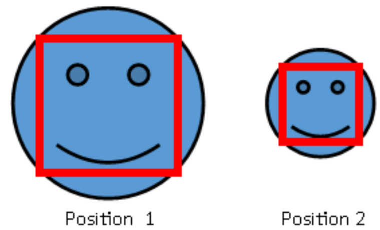


Figure 32: Same face viewed by camera at different positions.

If the size of the viewed face is known, the distance can be somewhat accurately calculated. The lack of accuracy stems from the possible lack of accuracy in the facial detection software. Only a small error in drawing the rectangle around the face can result to a miscalculated distance of the face and therefore a miscalculated target position for the servos. Another source for this type of error could be the difference in size of user's face. A person with a face that's larger than average will always be perceived to be closer to the camera, leading to a constantly overestimated angular adjustment of the servo.

A fix for overcorrection could be a larger focal point for the camera. By reducing the required accuracy of the corrective movement, small errors would result in less continuous, small adjustments in position. The may still be some adjustments if the center of the face is close to the border of the focal point though. To properly avoid jitter and overcorrection, a more dynamic approach to a feedback system may be necessary.

6.1.2.1.4.2 Direction Based Adjustment

Instead of providing a fixed position the servos should move to, a vector can be drawn from the center of the face to the focal point of the camera. That vector can be converted into two vectors (for movement along x, and y axis) to provide a direction for each servo to turn to. This will be done by correcting the position of the servo by a small amount towards the wanted position for every analyzed frame as shown in Figures 33 to 35.

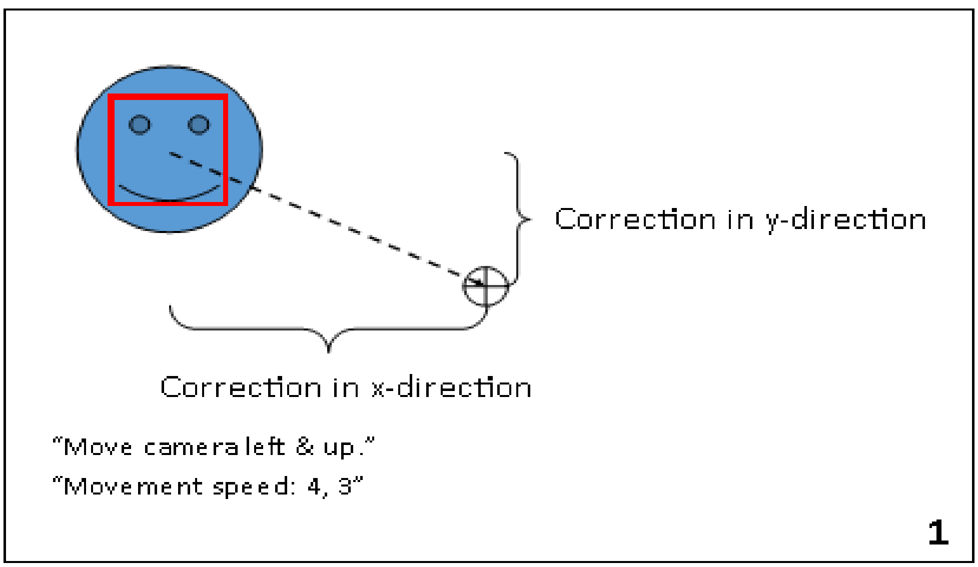


Figure 33: Dynamic feedback system step 1

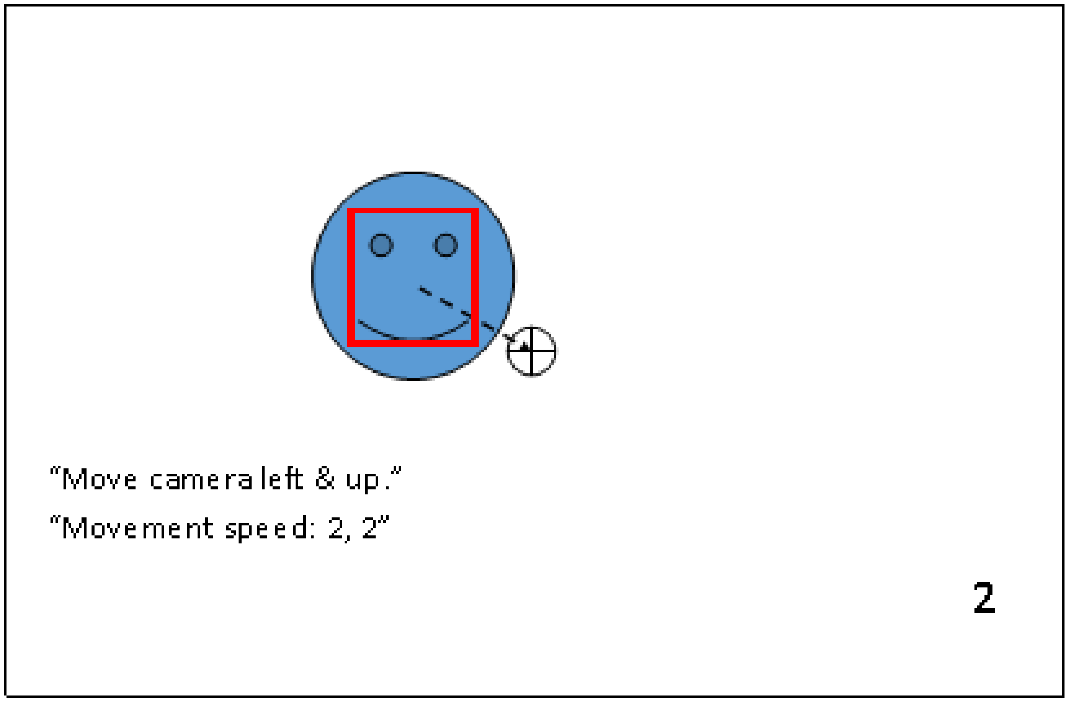


Figure 34: Dynamic feedback system step 2

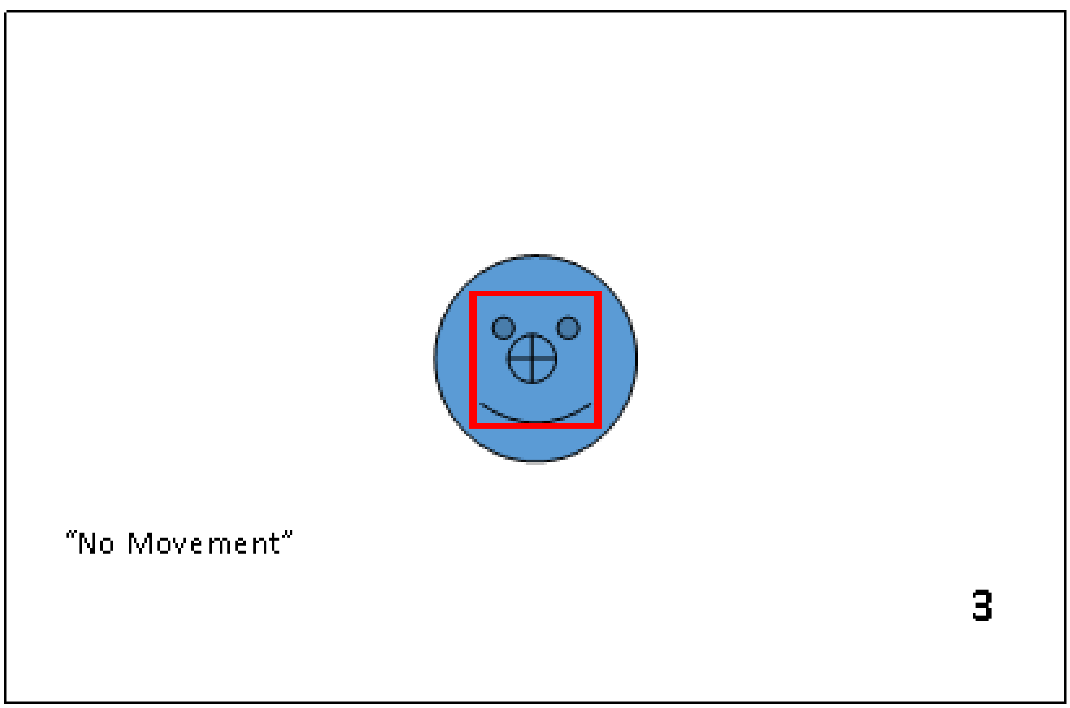


Figure 35: Dynamic feedback system step 3

Since the position will be updated several times per second, the movement will be stopped once the distance to the camera focal point is within a certain range. To avoid overshoot, the movement speed will be adjusted by the magnitude of the vector. The closer the face is to the focal point, the slower the adjustment in the servo position.

The problem with this approach is that the movement will stop as soon as the face is within the closest border of the determined range from the focal point. This will lead to corrections as soon as the face leaves that range. To reduce these types of corrections, as soon as the face is in range, initiation of movement will depend on a leaving a larger area as shown in Figure 36.

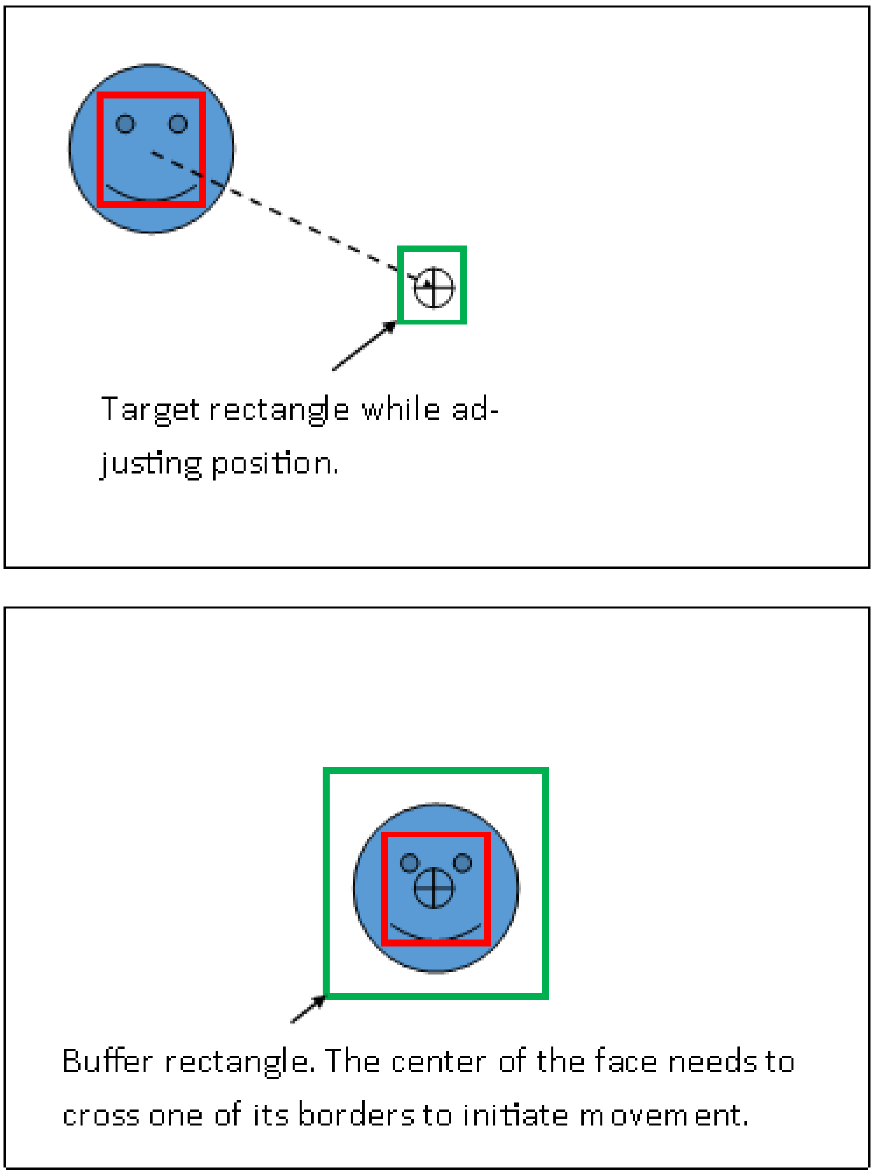


Figure 36: Varying buffer zone based on movement

Another variable to consider when determining the magnitude of the adjustments is the distance from the user to the camera. As discussed in the Position Based Adjustment, the distance from the face to the camera can be estimated by the size of the face. Since a smaller bounding rectangle means that the face is further away, the linear distance measured on the camera frame can lead to an overestimation of the necessary correction to the position. Therefore, the smaller the bounding rectangle of the face, the smaller the corrections should be and vice versa. Different sized faces should not be a problem since the amount of correction will still decrease the closer the face gets to the center of the frame.

In summary, a vector will be drawn from the center of the face to the center of the captured frame. It will then be broken down into two vectors along the x-, and y-axis. These vectors will give the direction of the correction for each servo and the magnitude of these vectors, along with the size of the face's bounding rectangle will determine the amount of the correction. Several corrections per second will result in movement of the camera until the user's face is centered in the frame.

6.1.2.1.4.3 Implementation

The size of the varying buffer zones, as well as the amount of position adjustment based on the face's position can currently not be calculated. Both of these variables depend on the speed and accuracy of the facial detection software, which in turn depends on the power of the CPU and software implementation. Because of this, instead of trying to calculate the appropriate variables before the rest of the system is built, the code for the feedback system will be written in such a manner that it is easy to calibrate these parameters in a finished prototype. The feedback for the MCU will rely entirely on software.

6.1.2.1.4.4 Algorithm Flowchart

Figure 37 shows a high-level flowchart of the algorithm. Note that the function does not repeat itself. The loop of the main program will call this function when needed. This adds the option to pause movement and retain more control over the feedback system.

6.1.2.1.5 Communications

All calculations for the feedback will happen in the CPU, hence the only signal that will be transmitted to the MCU will be the variables that need to change and the amount of that change. Since the MCU and CPU reside on the same PCB with close proximity, an I2C bus will be used. The MCU will not transmit any data to the CPU, so the CPU can be set as master and the MCU as slave. The data sent to the MCU will be saved by the CPU and MCU separately to the respective variables. This will eliminate the need for retrieving data from the MCU.

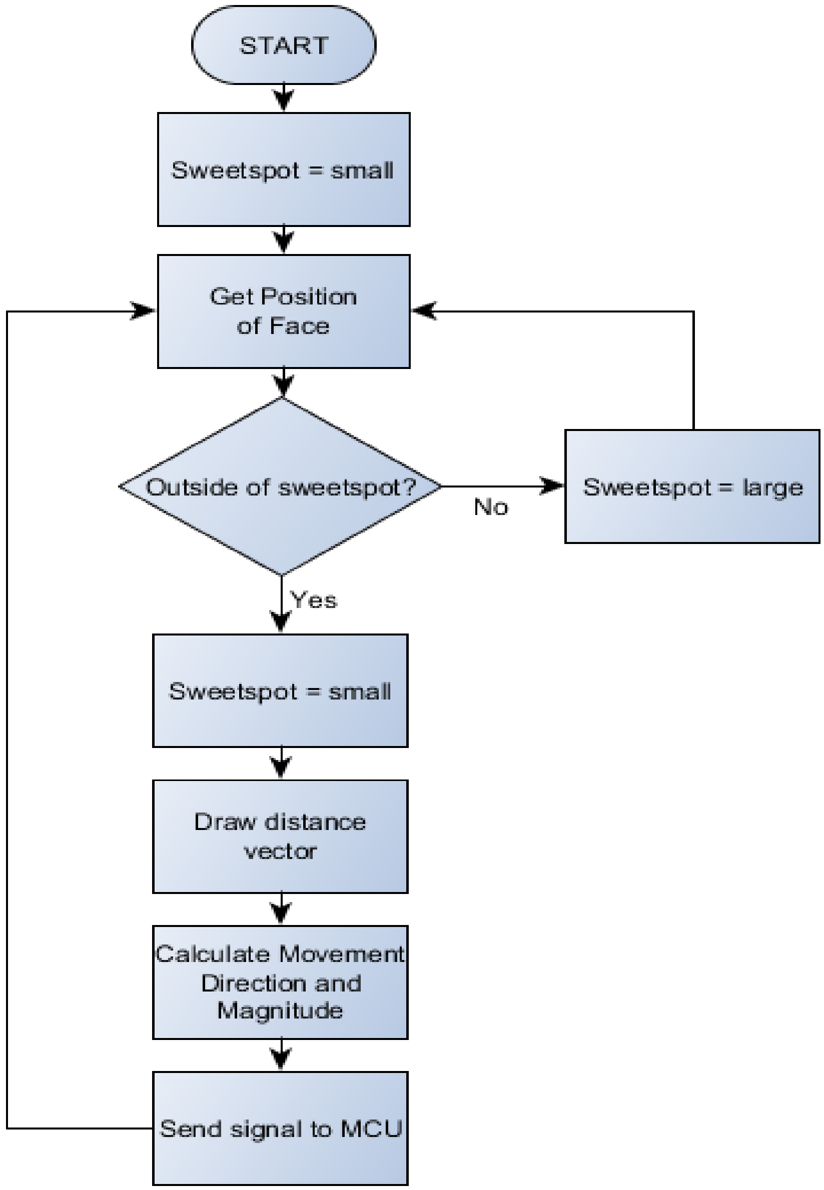


Figure 37: Feedback system algorithm flowchart.

6.1.3 Power System

6.1.3.1 Electrical Power Consumption

Electrical power consumption helps determine the total power consumed by the device. It was important to keep track of it to make sure that the maximum total power consumption of the device being 50W requirement met.

To keep track of electrical power consumption, although not 100% accurate and still an estimate since power consumption would not be constant, each member of the group listed the nominal DC input voltage for each individual circuit along with the nominal current draw. Then a table, illustrated below in Table 8, can be constructed with all the nominal input DC voltages and nominal current draws along with the total of each. After that, using the power equation P=VI, the total power consumption can be calculated by adding up the individual power consumption of each circuit. Note that some of the components' current draw was unknown, so they were approximated. In conclusion, 1A current would be enough to supply the device and 2A would be more than enough. Also, the device meets the requirement of consuming less than 50W.

Component	Nominal Input Voltage (V)	Nominal Current Draw (mA)	Power Consumed (mW)
Audio Amplifier	5	2.8	14
Processor	5	16	80
LCD	5	Approx.: 100	2400
Servo Motors	5	500	2500
Motor Control Unit	5	0.5	2.5
WiFi Chip	3.3	80	264
Camera	5	250	1250
LEDs	5	Approx.: 20	100
microSD Card	3.3	100	330
Total:	Average: 5	1069.3	6,940.5

Table 8: Electrical Power Consumption

6.1.3.2 Power Connections

The power connections were an important part of the design, especially since the power connections show a basic overview of how all the circuits will be connected to each other. The power all begins with the battery supplying a certain voltage and current, and then every circuit will require a certain constant DC input voltage along with a current draw. Since it is expected that all the circuits will be integrated into the PCB, a voltage bus can be created on the PCB along with a common ground bus. There were multiple proposals to design the power connections.

The first proposal was to place a voltage regulator at the input of each circuit to keep the input voltage at a constant DC value if different from the voltage bus value. The only advantage of that power system would be that, it is guaranteed that the current draw for each voltage regulator is accurate, and that the DC voltage being supplied to each circuit is exact. There are many disadvantages to that, if an LDO regulator were to be used, there will be a lot of power wasted, or if any voltage regulator were used, there will be a lot of space being occupied for no reason. The resulting system look something like Figure 38 below, which is very wasteful.

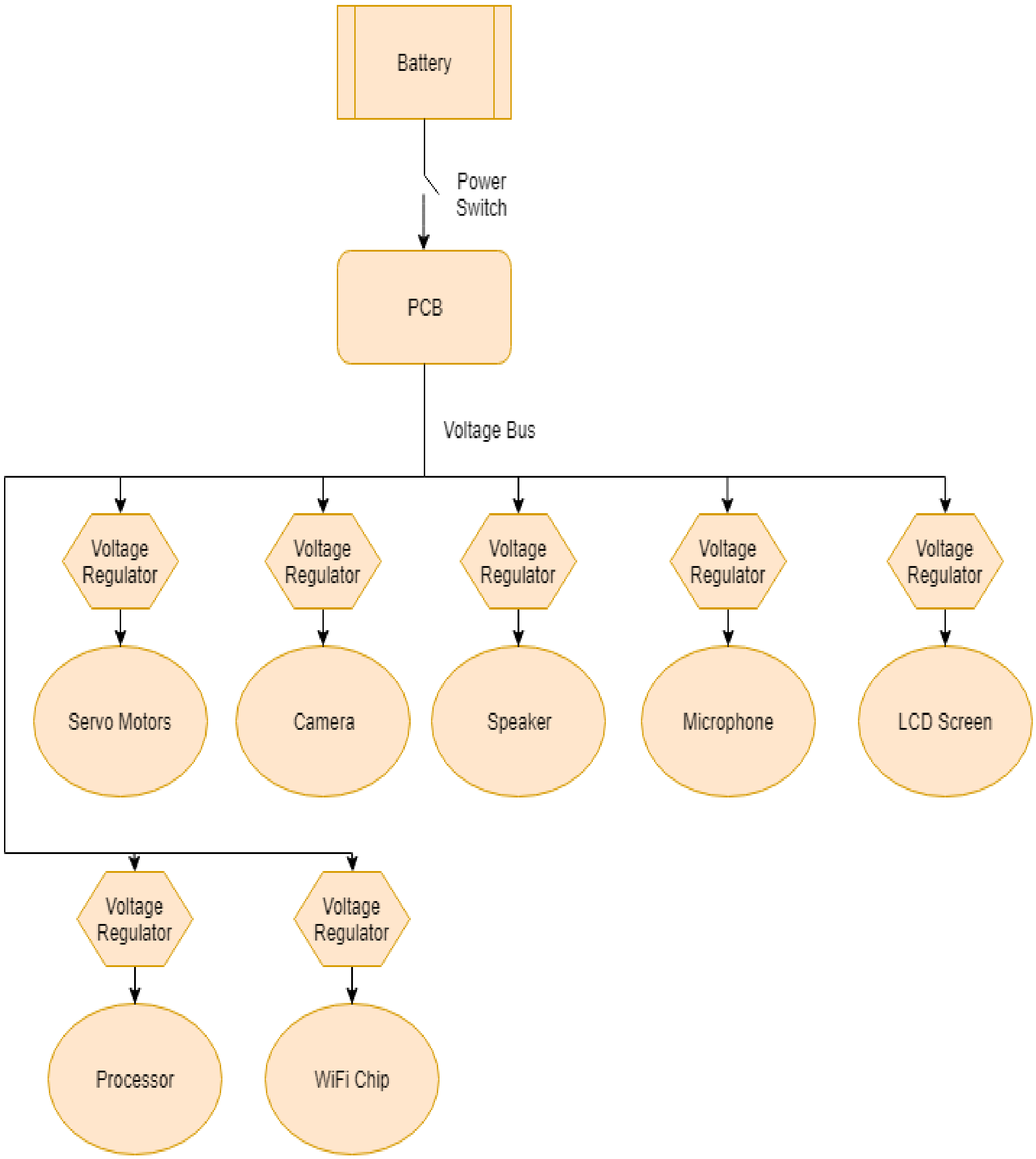


Figure 38: Initial Power Connections Proposal

The second proposal, was to have only two voltage regulators, one that boosts the battery from 3.3V to 5V, then steps down the voltage from 5V to 3.3V for the WiFi chip. This system ends up being simple and easy to implement, already much better than the previous system. But, it turns out the group's processor requires multiple voltage inputs, and then using its GPIOs, it can power some of the components which would lead to a much better and simpler design so long as the current draw is not too high for the processor. The resulting connections are shown below in Figure 39.

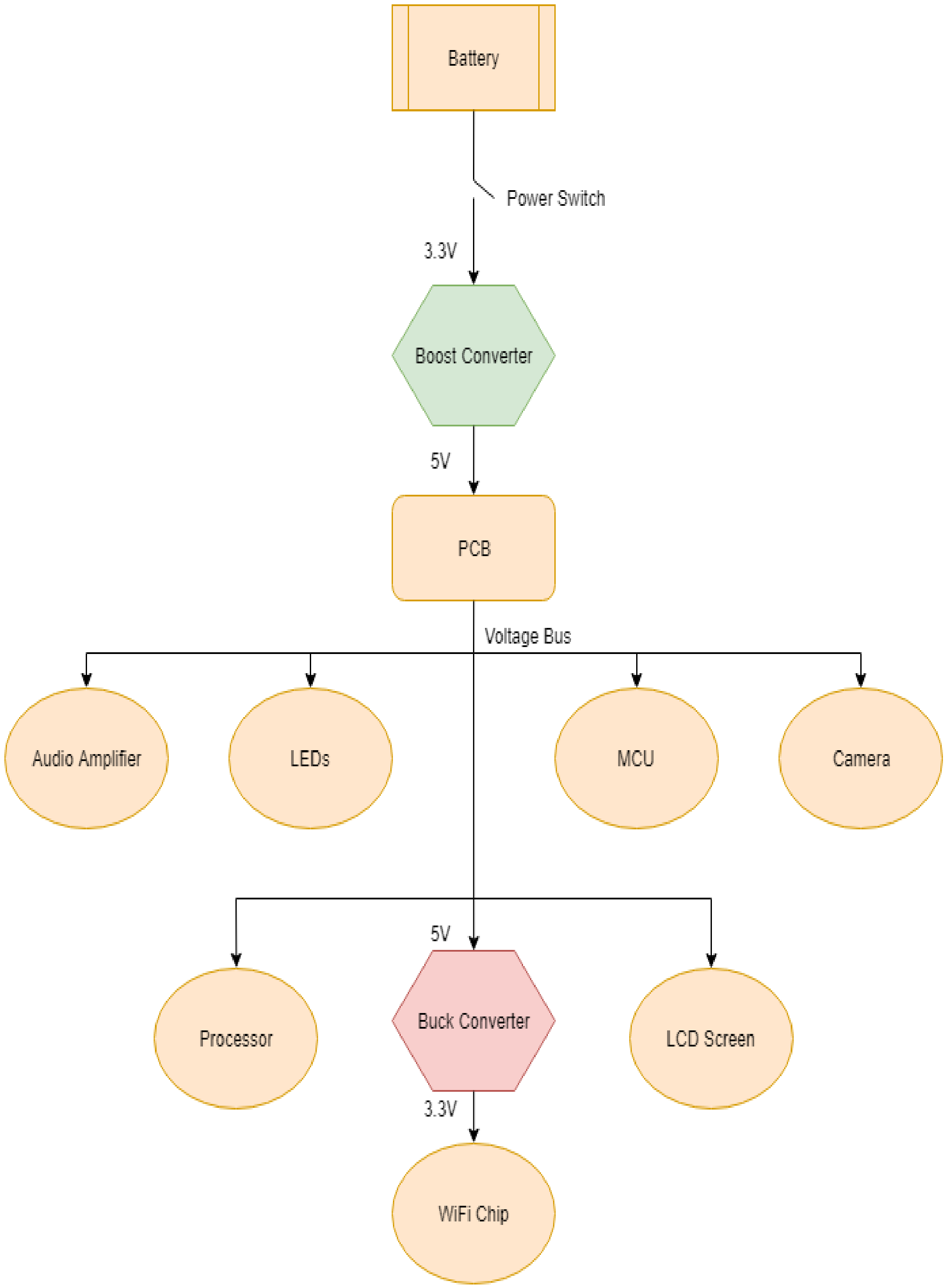


Figure 39: Second Power Connections Proposal

The final proposal, was to create two voltage buses that use DC-to-DC voltage regulators keeping the voltage at a constant 3.3V and 5V since the battery voltage might drop down after multiple uses. Then, two step-down voltage regulators can be used to drop the voltages to 1.8V and 2.5V to power the processor. After that, some of the components can be powered the processor itself using its GPIO pins. The final proposal for power connections is shown below in Figure 40.

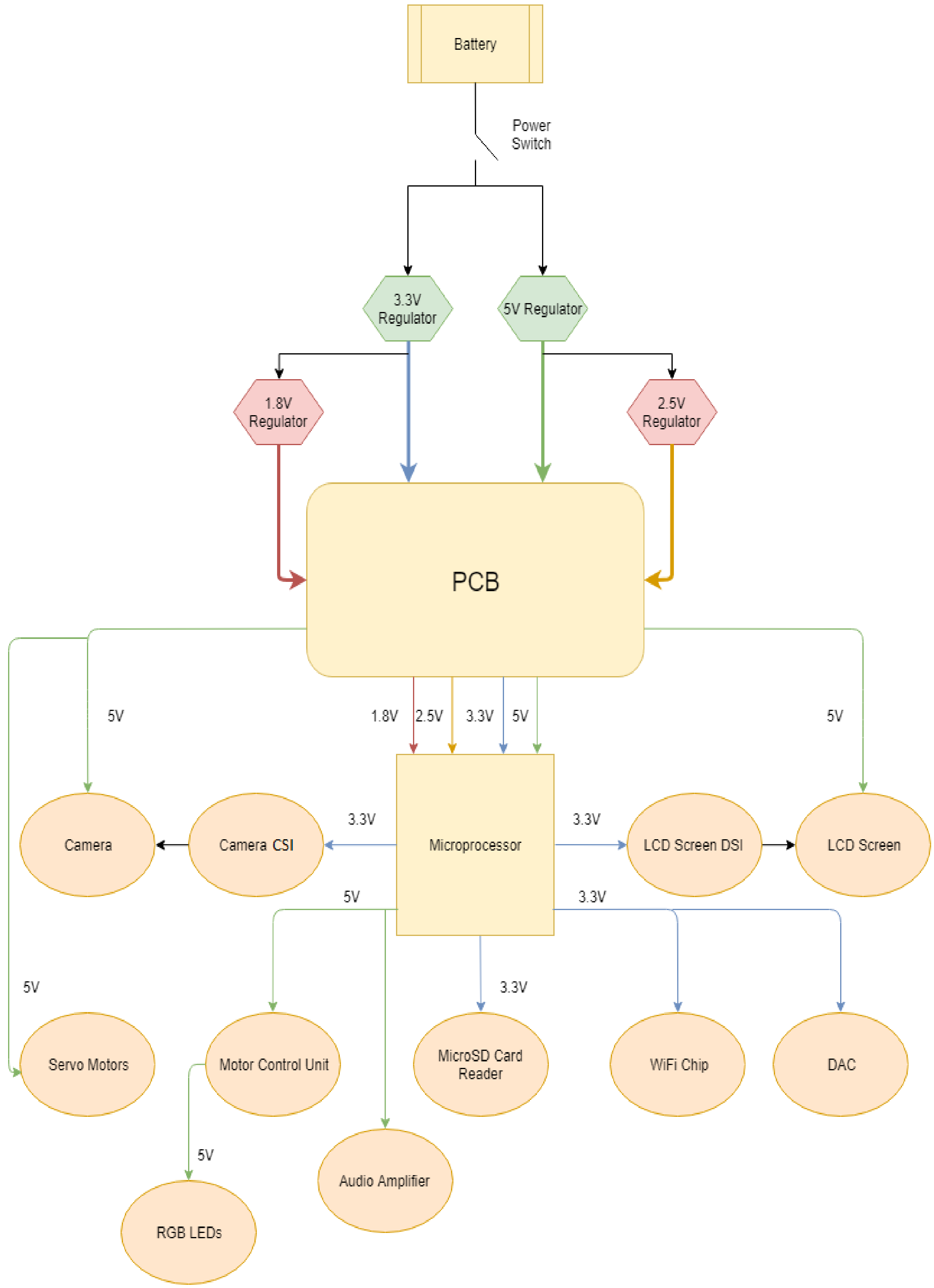


Figure 40: Final Power Connections Proposal

6.1.3.3 Voltage Regulators

A voltage regulator would be necessary when there are multiple circuits in a system with different input voltages, and especially when there is a battery that does not provide a constant voltage over a long time. The goal of the voltage regulator would be to regulate the voltage coming in from the battery through a voltage bus and outputting a specific constant voltage required depending on the circuit or electronic component.

6.1.3.3.1 3.3V-5V DC-to-DC Voltage Regulator

The group decided it was smart to start off with regulating the battery voltage since its voltage will drop after a while. Assuming a rechargeable Lithium-Ion battery is used with a minimum input voltage of 3.3V-5V simulations can be done on WEBENCH® Design Center. Since most of the components used for the device are expected to be powered by around $5V_{DC}$, a boost converter is expected to be used for the battery to regulate the output at 5V and maximum output current of around 3A. Shown below, in Figure 41, is the boost converter TPS61088RHLR schematic to be placed at the battery output along with its important parameters in Table 9 and its bill of materials in Table 10. [10]

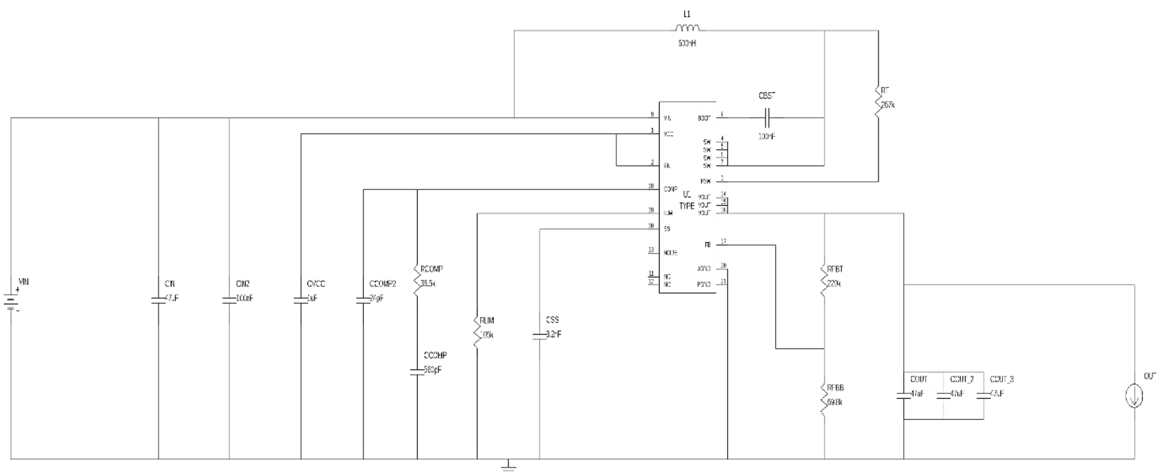


Figure 41: 3.3V to 5V Boost Converter Schematic – TPS61088RHLR – Schematic Credits to WEBENCH® Design Center

Design	BOM Footprint (mm^2)	Efficiency	BOM Count	I_{out} Max (A)	IC Cost	BOM Cost
Fully-Integrated Synchronous Boost converter	151	93%	17	10.6	$1.60	$3.58

Table 9: 3.3V to 5V Boost Converter Important Parameters

Part	Manufacturer	Part Number	Quantity	Price ($)
Rfb1	Vishay-Dale	CRCW0402976RFKED	1	0.01
Rfb2	Vishay-Dale	CRCW04022K94FKED	1	0.01
Cbyp	MuRata	GRM155R60J104KA01D	1	0.01
Ccomp	TDK	CGA4J2C0G1H333J125AA	1	0.09
Ccomp2	TDK	C2012C0G1H182K060AA	1	0.03
Cin	Panasonic	16SVPF1000M	1	0.77
Cout	Panasonic	16SVPG270M	4	0.68
Csense	MuRata	GCM2195C1H103JA16D	1	0.05
Cvcc	Panasonic	ECPU1C684MA5	1	0.22
D1	Vishay-Semiconductor	M3035S-E3/4W	1	0.63
L1	Bourns	SRP1250-1R0M	1	0.69
M1	Texas Instruments	CSD16323Q3	1	0.36
Rcomp	Vishay-Dale	CRCW04022K67FKED	1	0.01
Rfadj	Vishay-Dale	CRCW040276K8FKED	1	0.01
Rivp1	Yageo America	RC0201FR-0744K2L	1	0.01
Rivp2	Vishay-Dale	CRCW040248K7FKED	1	0.01
Rs1	Vishay-Dale	CRCW040297R6FKED	1	0.01
Rsense	CUSTOM	CUSTOM	1	0
U1	Texas Instruments	LM3481MM/NOPB	1	0.80

Table 10: 3.3V to 5V Boost Converter Bill of Materials

6.1.3.3.2 3.3V-3.3V DC-to-DC Voltage Regulator

The 3.3V to 3.3V boost converter is required to create a 3.3V bus within the PCB for multiple uses including powering the microprocessor and other components. The current draw is assumed to be around 3A again. The design shown below in Figure 42 was created using WEBENCH® Design Center. The important parameters and bill of materials are shown in the tables Table 11 and Table 12 respectively. [10]

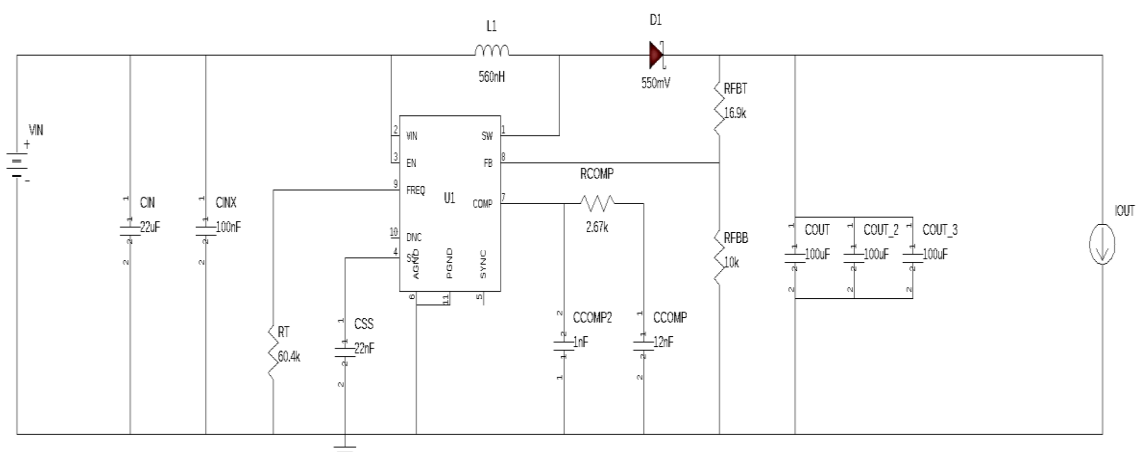


Figure 42: 3.3V to 3.3V Boost Converter Schematic - Schematic Credits to WEBENCH® Design Center

Design	BOM Footprint (mm^2)	Efficiency	BOM Count	I_{out} Max (A)	IC Cost	BOM Cost
Wide Input Range Boost DC/DC converter	208	87%	16	5	$1.30	$2.95

Table 11: 3.3V to 3.3V Boost Converter Important Parameters

Part	Manufacturer	Part Number	Quantity	Price ($)
Coutx	Kemet	C0603C105Z8VACTU	1	0.01
Ccomp	Kemet	C0603C123J3GACTU	1	0.1
Ccomp2	MuRata	GRM1555C1H102JA01J	1	0.01
Cin	MuRata	GRM31CR61A226ME19L	1	0.09
Cinx	Kemet	C0805C104K3RACTU	1	0.01
Cout	MuRata	GRM32ER60J107ME20L	3	0.22
Css	MuRata	GRM155R60J223KA01D	1	0.01
D1	Diodes Inc.	B540C-13-F	1	0.19
L1	Vishay-Dale	IHLP1212BZERR56M11	1	0.53
Rcomp	Vishay-Dale	CRCW04022K67FKED	1	0.01
Rfbb	Yageo America	RC0201FR-0710KL	1	0.01
Rfbt	Vishay-Dale	CRCW040216K9FKED	1	0.01
Rt	Vishay-Dale	CRCW040260K4FKED	1	0.01
U1	Texas Instruments	TPS55330RTER	1	1.30

Table 12: 3.3V to 3.3V Boost Converter Bill of Materials

6.1.3.3.3 3.3V-1.8V DC-to-DC Voltage Regulator

The 3.3V-1.8V voltage regulator will only be used to power the microprocessor which also needs a 1.8V input. The current draw this time does not have to be set to a high value since the 1.8V is not expected to be used for anything else. The following design shown below in Figure 43 was created in WEBENCH® Design Center using a current draw of 1A. The important parameters and bill of materials are both shown below in tables Table 13 and table 14 respectively. [10]

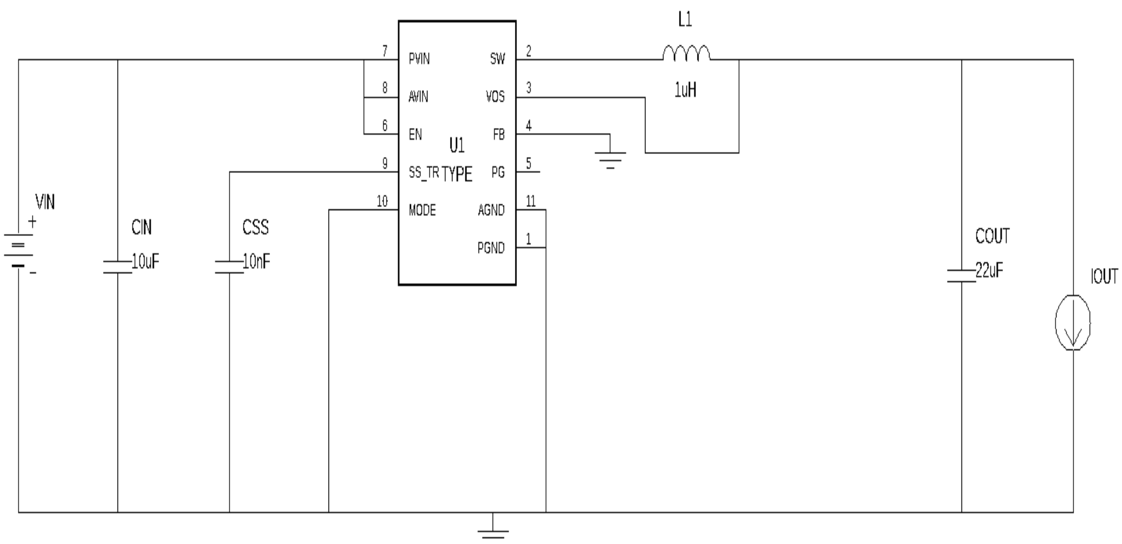


Figure 43: 3.3V to 1.8V Buck Converter Schematic - Schematic Credits to WEBENCH® Design Center

Design	BOM Footprint (mm^2)	Efficiency	BOM Count	I_{out} Max (A)	IC Cost	BOM Cost
2-A High Efficiency Step Down Converter with DCS Control	87	91%	5	2	$0.74	$1.00

Table 13: 3.3V to 1.8V Buck Converter Important Parameters

Part	Manufacturer	Part Number	Quantity	Price
Cin	MuRata	GRM188R60G106ME47D	1	0.02
Cout	MuRata	GRM21BC80G226ME39L	1	0.05
Css	MuRata	GRM033R61A103KA01D	1	0.01
L1	Bourns	SRN6045-1R0Y	1	0.18
U1	Texas Instruments	TPS6209718RWKR	1	0.74

Table 14: 3.3V to 1.8V Buck Converter Bill of Materials

6.1.3.3.4 5V-2.5V DC-to-DC Voltage Regulator

The final voltage regulator will be used to drop down the voltage from 5V to 2.5V DC for the microprocessor input power. The reason behind dropping 5V to 2.5V and 3.3V to 1.8V is to have less of a voltage drop in the regulators. Again, WEBENCH® Design Center was used to create the following design shown in Figure 44 with a 1A output current since 2.5V will only be used by the microprocessor. The important parameters and bill of materials are both shown in tables Table 15 and table 16 respectively. [10]

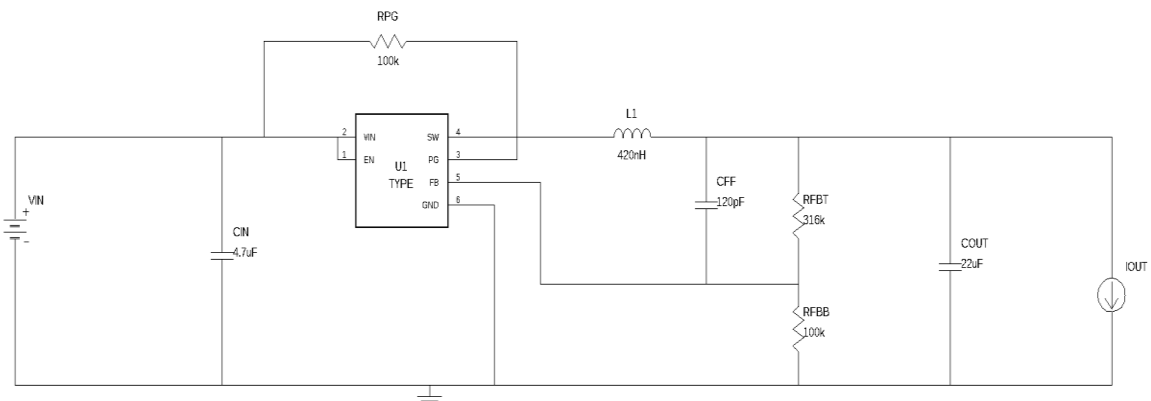


Figure 44: 5V to 2.5V Buck Converter Schematic - Schematic Credits to WEBENCH® Design Center

Design	***BOM Footprint (mm^2)***	***Efficiency***	***BOM Count***	***I_{out} Max (A)***	***IC Cost***	***BOM Cost***
High Efficiency 3-A Step Down Converter	*35*	*92%*	*8*	*3*	*$0.60*	*$0.96*

Table 15: 5V to 2.5V Buck Converter Important Parameters

Part	Manufacturer	Part Number	Quantity	Price
Rfbb	Vishay-Dale	CRCW0402100KFKED	1	0.01
Rfbt	Vishay-Dale	CRCW0402316KFKED	1	0.01
Cff	MuRata	GRM033R71E121KA01D	1	0.01
Cin	MuRata	GRM188R60J475KE19D	1	0.02
Cout	Taiyo Yuden	JMK212BJ226MG-T	1	0.06
L1	Coilcraft	EPL2014-421MLB	1	0.24
Rpg	Vishay-Dale	CRCW0402100KFKED	1	0.01
U1	Texas Instruments	TPS62088YFPR	1	0.6

Table 16: 5V to 2.5V Buck Converter Bill of Materials

6.1.4 Sound System

For the sound system, there are two main components that would be processing all audio operations; the soundcard and the main processor. The soundcard would mainly be consisting of an analog-to-digital converter (ADC) to convert the analog signals coming in from the microphone, a digital-to-analog converter (DAC) to convert the digital signals coming out from the processor to analog to be output by the speaker, and finally, a digital signal processor (DSP) that processes all the signals in digital domain. The group's Motor Control Unit already has an ADC that is not being used for much, so that can be used for the microphone-processor communications. While the group's processor has a built-in DSP, it could end up slowing the main processor. An external DSP can be added instead if that occurs. Finally, the DAC ends up being the only component that should be added externally.

6.1.4.1 Recording

For recording, all the communications would be done in between the microphone and the main processor. The entire process is illustrated in the flowchart shown below in Figure 45. The microphone would transform the audio signal into an analog signal that would be converted into a digital signal using the group's motor control unit ADC. After that, the digital signal is sent to the processor's DSP to be further understood by the processor and stored in the processor's RAM.

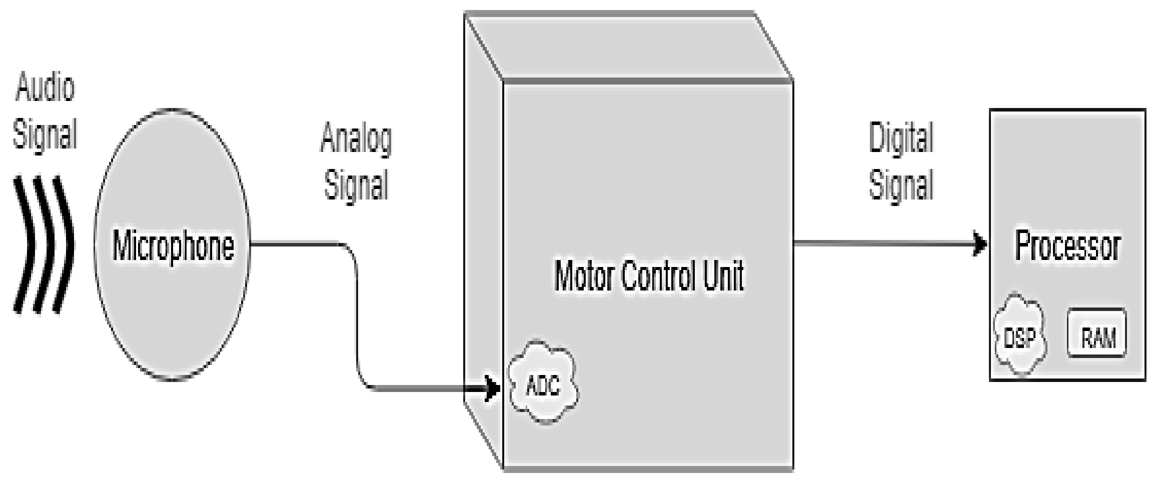


Figure 45: Audio Recording Process

6.1.4.2 Playback

For playback, all the communications are done between the processor, the audio amplifier, and the speaker. The entire process is illustrated in the flowchart shown below in Figure 46. Whether the user wanted to play music through the device, or the device wanted to respond to the user, this is the process it will be using. The processor is going to send out the command to an external DAC to produce an analog signal, then amplify that signal using the group's own mono audio amplifier. Finally, the signal will be good to go to be sent out through the speakers for the user to understand them.

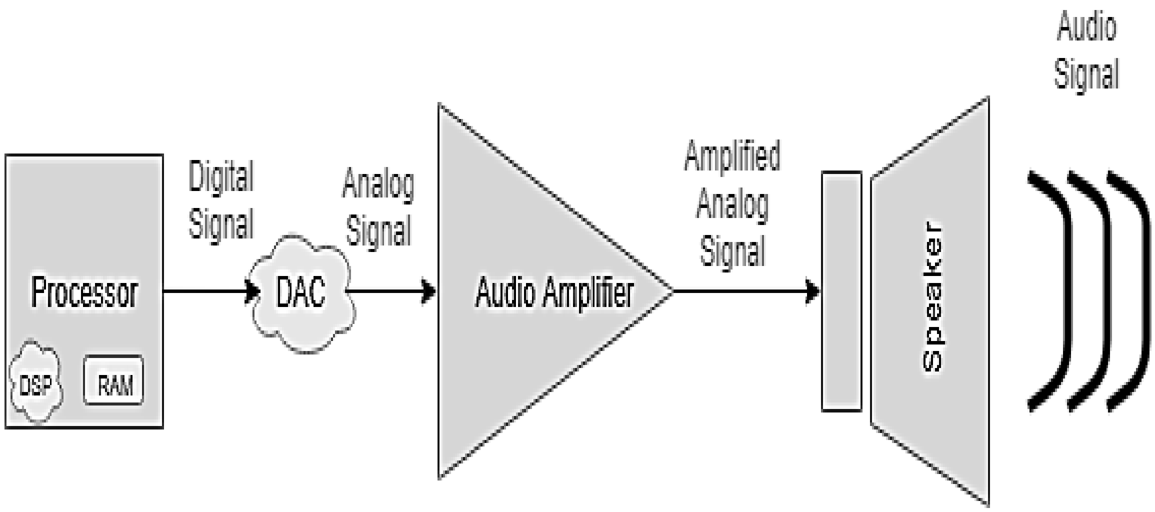


Figure 46: Audio Playback Process

6.2 Software Design

6.2.1 Programming Environment

6.2.1.1 IDE

The IDE of choice for this project will be Atom. Atom is, at base, a text-editor that provides a clean, smart interface for the user to easily configure it to their liking. It is extremely lightweight while having a full, comprehensive package manager so it fits the needs of the software that will need to be developed for Ion. Most of the software will be developed in Python, and Atom supports that wonderfully. As far as collaboration and version control, which will be of huge importance, Atom has built-in Git and GitHub integration to make collaboration more smooth and easy.

6.2.1.2 Revision Control

Revision control will be used to track changes to code, merge sections that have been written by different coders, marking stable versions, facilitating collaboration through cloud storage, and creating backup copies. This will be done with the decentralized revision control system "Git", using Github.com for cloud storage specifically with a Git GUI called GitKraken, which provides a graphical interface along with git command capabilities. Providing a GUI for using Git helps track revisions with more ease.

6.2.2 GUI

The GUI functions as a secondary means of communication between the user and the device, behind voice control. It will be the main point of integration between all that Ion can do including voice recognition, face detection and recognition, user data and profiling, applications such as Spotify, YouTube, and internet searches, and editing user preferences and settings. From boot-up to shut-down the GUI will be handling everything that Ion hears, sees, and says and will provide a way for the user to interact with that. Everything in the GUI can be accessed through voice command by an authorized user, but having the GUI as a backup will allow the user a secondary means of interaction. One last major functionality of the GUI is to display Ion's emotional states as GIFs including smiling, yawning, etc. This provides Ion a fun, interactive way to visually interact with the user.

6.2.2.1 Language and Library Selection

Python is the best language for the functions Ion's GUI will handle, as it is event-driven programming rather than the procedural programming that includes languages like C or Java. Using event-driven programming is great for a product such as a GUI because that's all a GUI is - buttons and menus linked together that are driven by touch or mouse input. In the case of Ion, it is driven by touch and allows the user to navigate the GUI. Python also allows for very smooth integration. With the many technologies being integrated into Ion, mostly through the GUI, it was important to choose a language that would make integration easy. Integrating the voice recognition, face detection and recognition, as well as the multitude of planned features including a face interface to show emotions and playing YouTube videos or Spotify music, Python provides a way to integrate all of those through the GUI with ease.

The library chosen to create the GUI is Kivy, an open-source Python library that allows for development of touch applications with a natural user interface. It includes a library of touch-aware widgets and hardware accelerated OpenGL drawing which will make a great development tool for the GUI. It runs on Raspberry Pi, which will be great for both prototyping and incorporating into the actual product which will have a Raspberry Pi Compute module.

6.2.2.2 Menu Layout

The design of the menu is meant to be clean, simple, and easy to use. It is a secondary interface, the main being voice control, so it will only house the main settings and interfaces, while the main interaction will be through voice on the device. A main functionality of the GUI is to display the human-like emotions of Ion to seem fun and interactive. The main method of doing this is choosing from a library of GIFs to display Ion's reaction and emotion in response to the user's input. A few main facial GIFs will be designed to display Ion's face throughout his interaction with the user - examples include waking up, yawning, etc. and will be displayed at specified times during interaction with the user. This goes hand-in-hand with the user using the GUI and interacting with Ion.

On bootup, the system initializes and automatically boots up the GUI program. This includes Ion's welcome with a GIF. If the user cannot immediately be initialized and logged in through face detection, the login screen will pop up to log in or register. There will also be the option to recover their account or give another shot at Ion detecting their face. The login menu is shown below in Figure 47.

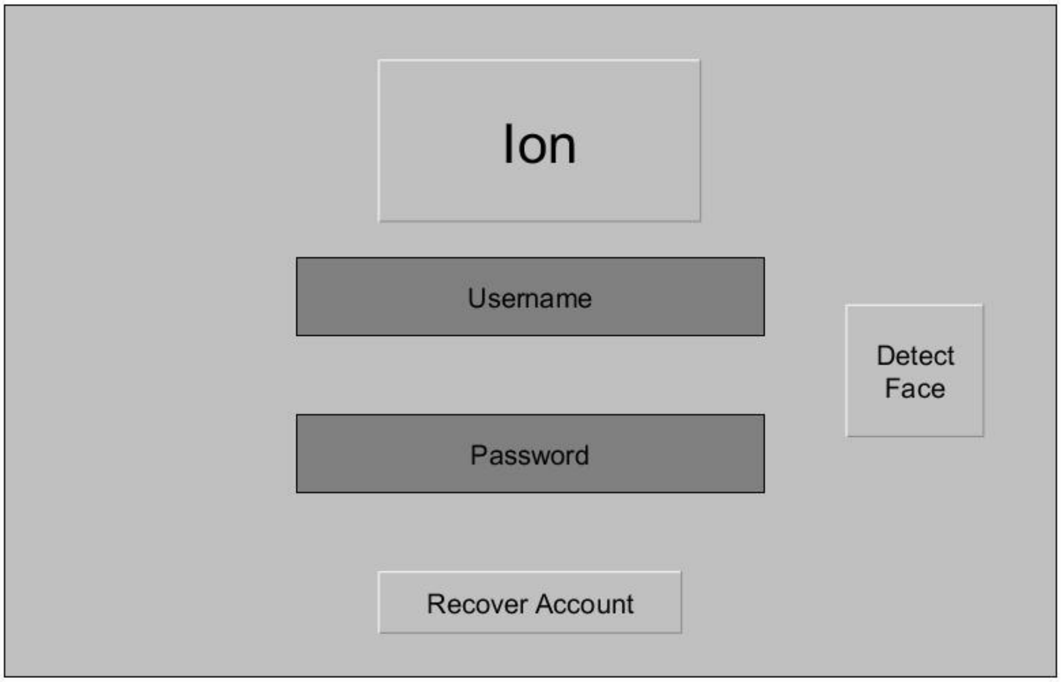


Figure 47: Login Menu

After login and initialization, Ion will automatically go to an authorized rest state which will wait for commands from the user through voice. There is also an option to enter the GUI manually by tapping the screen. The rest state is shown below in Figure 48.

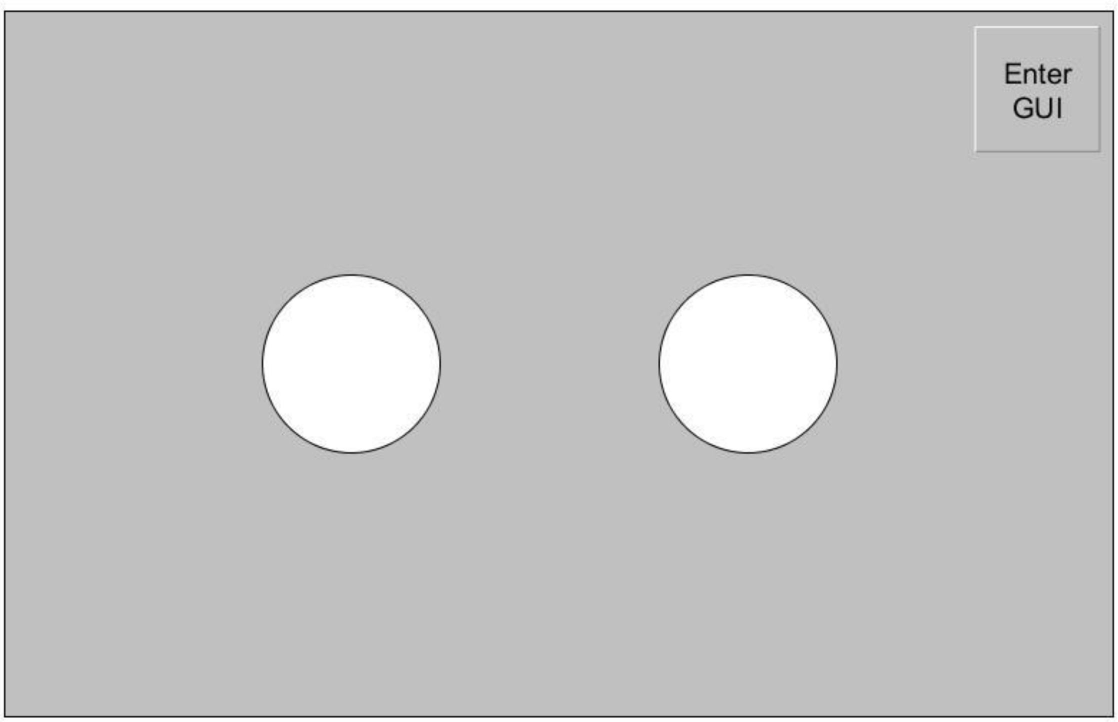


Figure 48: Rest State

If entering the GUI manually, the user will be able to enter different menus including preferences, account settings, and display settings. The preferences menu can be used to edit personal preferences including Ion's personality choice and external account settings like Spotify or YouTube. Account settings give the user access to editing settings such as email, password, phone number, etc. Display settings let the user change display settings including brightness and contrast. All of this can also be accessed and edited through voice commands. The preferences and settings menu is shown below in Figure 49.

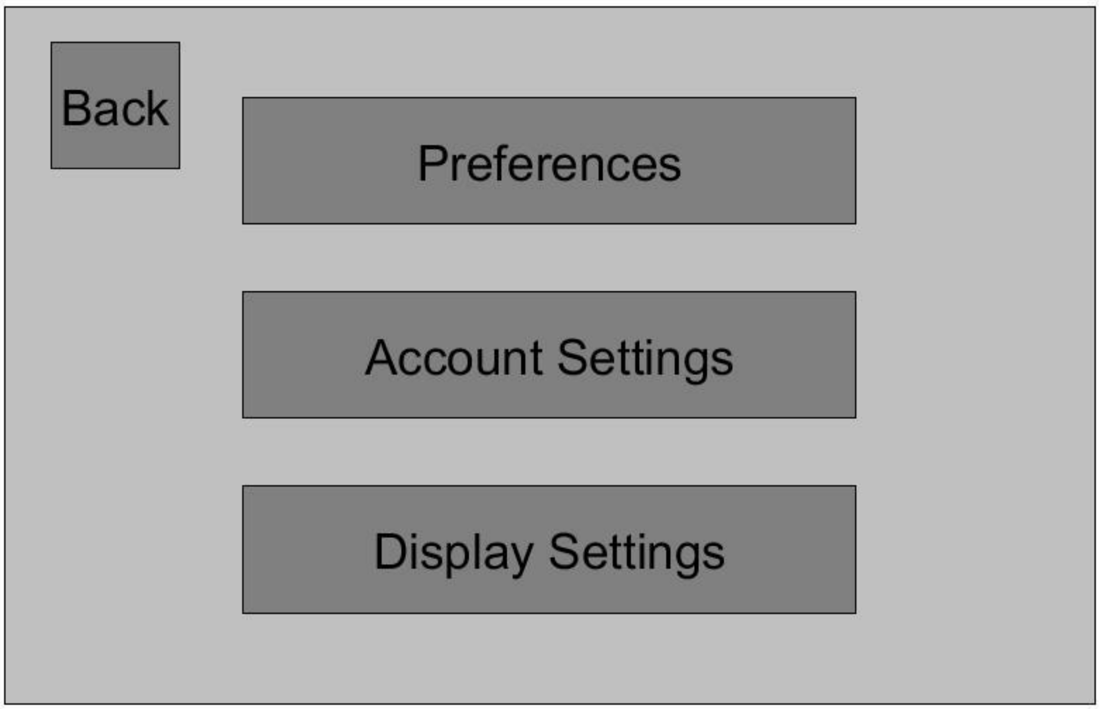


Figure 49: Preferences and Settings Menu

6.2.2.3 Algorithm Flowchart

The Graphical User Interface algorithm can then be better illustrated in a flowchart that is shown below in Figure 50.

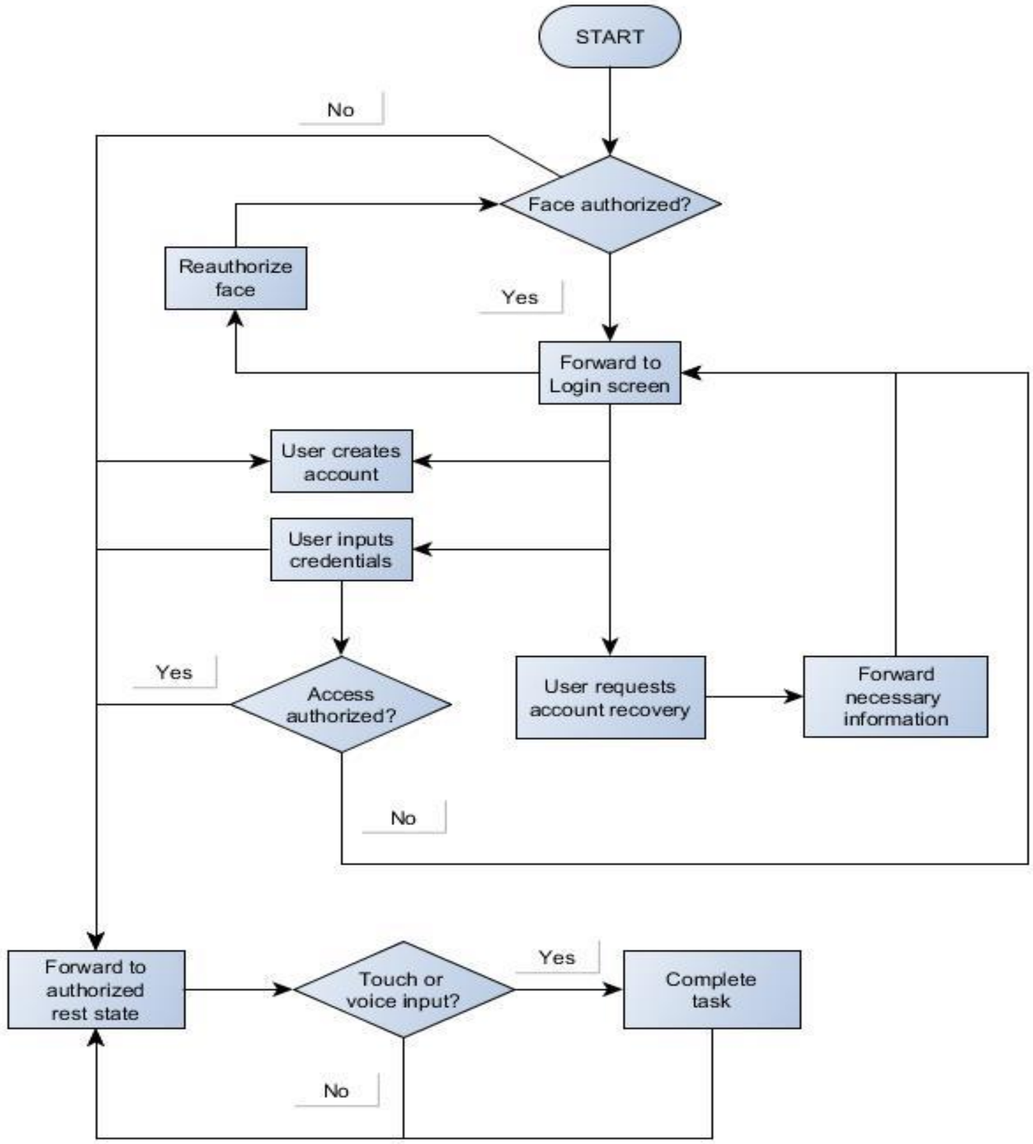


Figure 50: GUI Flowchart

6.2.3 Voice Recognition

6.2.3.1 Framework

The voice recognition program will be implemented using Google Speech API. Bash or Python scripts will be used to create an API request in the form or a JSON file. That JSON file can be processed by Google Speech API and send a JSON file back to Ion to be processed into a command that Ion can fulfill.

6.2.3.2 Key Hardware Constraints

The quality of the microphone may pose a concern if it can't clearly make out speech in different environments and volumes. However, most microphones are usually decent enough to handle voice recognition and speech recognition software has come very far in the past couple years, so much so that a decent microphone shouldn't pose a problem. Processing power may be an issue, as the voice recognition software needs to run at all times as well as process the information very quickly to reduce latency and provide a quick interaction.

6.2.3.3 Algorithm Flowchart

The voice recognition algorithm flowchart can then be illustrated in a flowchart shown below in Figure 51.

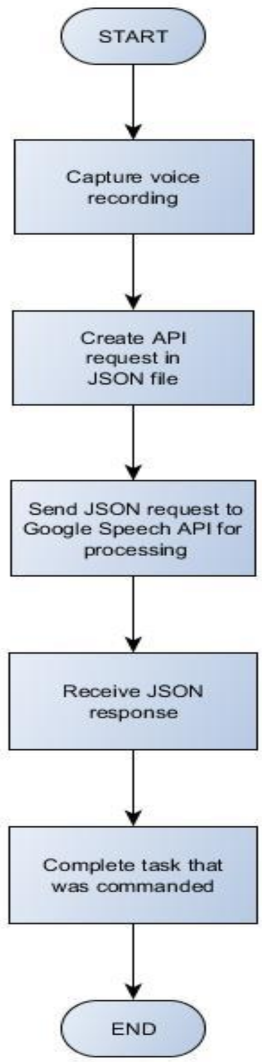


Figure 51: Voice Recognition Algorithm Flowchart

6.2.4 Computer Vision

Computer vision is one of Ion's key components. Its components are necessary to detect faces, provide feedback to the MCU, and recognize the user.

6.2.4.1 Overview

Facial recognition and tracking will be used for several different things:

- Identify the user
- Detect the user's location

To identify the user, a face needs to be detected on a video feed and compared to a database. If a match is found, a prompt will confirm with the user whether the identification was correct or not. Once this has been done, the face tracking feature will take over until the face has been out of sight for an amount of time that can be adjusted by the user. The face tracking feature will determine the position of the face relative to the picture frame and stream its location. On a high level, both the algorithms are combined as follows in Figure 52 below.

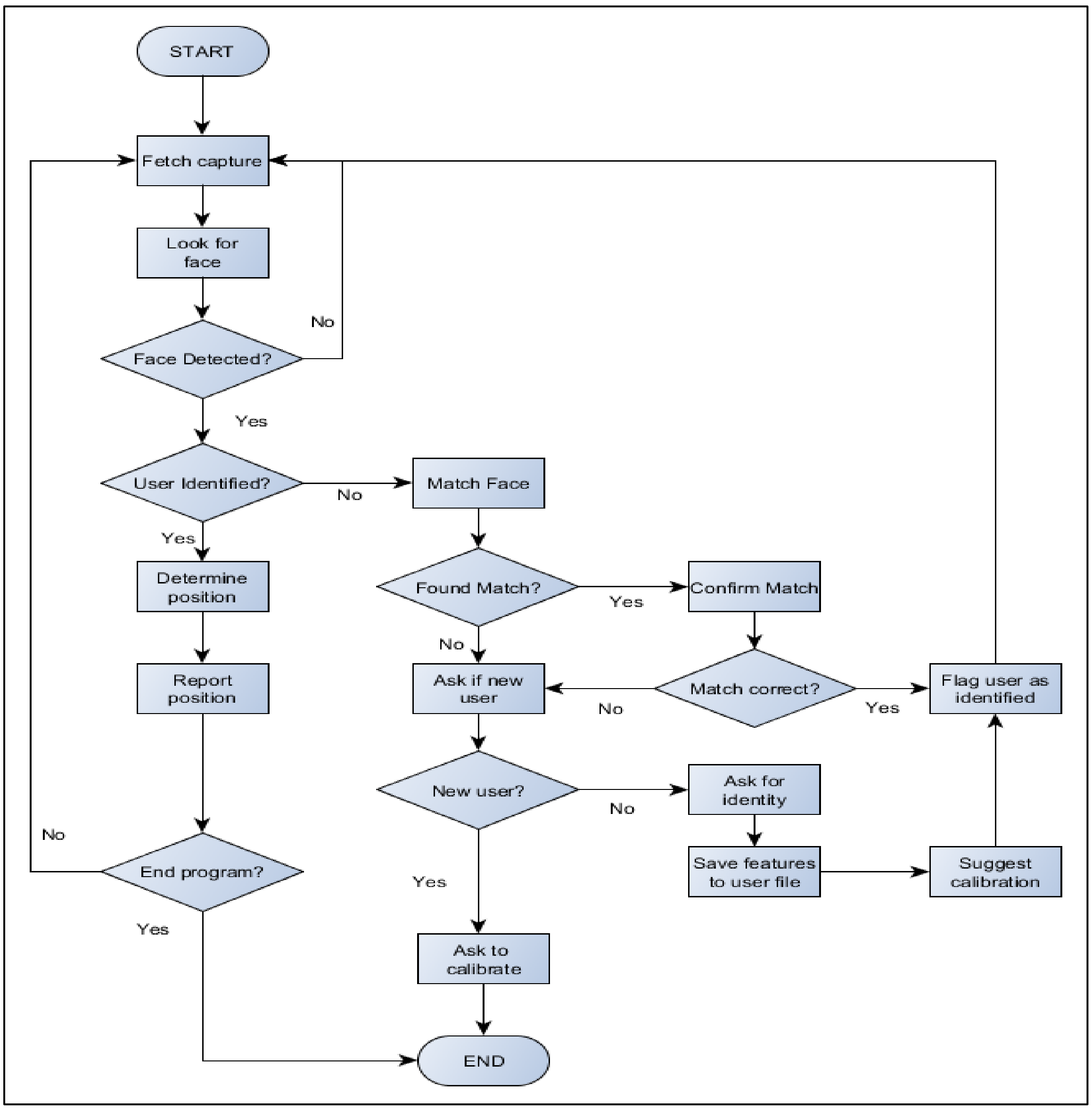


Figure 52: CV flow diagram

6.2.4.2 Facial Detection

The facial detection software's purpose is to detect faces in frames captured by the camera. It is not supposed to identify the user. For user identification, see section 6.2.4.3 - Facial Recognition.

6.2.4.2.1 Framework

The facial recognition program will be written in python and make use of the OpenCV library. Python was chosen because of its readability and portability. It is pre-installed in the Linux operating system and has a broad spectrum of useful libraries that will be used for Ion. Most programming will be done in the Atom editor and prototyped on a pc with the help of a webcam.

6.2.4.2.2 Key Hardware Constraints

The input from the camera may pose some difficulties in low-lighting conditions, but a 640x480 video feed with a framerate of 30Hz is more than enough. The main hardware constraint for facial detection is processing power. Since the facial detection software is a key component of the servo feedback system, lag must be reduced as much as possible, preferably under 100ms. In order to free up processing power for other programs, facial detection will not run continuously. The interval in which facial detection will run will be determined when testing a mockup of the feedback system. As a base assumption, a 250ms interval will be chosen.

6.2.4.2.3 Reference Designs

Two facial detection methods were considered: Haar classifiers and linear binary patterns (LBP) classifier. Both of these methods have key advantages and disadvantages. Haar tends to be more accurate and have a low false positive rate. This would reduce the chance for Ion to mistake an object for a person. However, Haar is slower and has problems in difficult lighting conditions. LBP on the other hand is fast and has less problems with changes in lighting conditions. The drawback is a loss in accuracy.

6.2.4.2.4 Possible Implementation

The two most important factors are speed and accuracy, so it is difficult to select one method over the other. One possibility would be to create code for both methods and switch depending on processor load or lighting conditions. Another possibility would be to test performance of both methods in conjunction with a mockup system and choose the method that provides a better user experience. No matter which facial detection algorithm is chosen at the end, the high level flowchart in Figure 53 below will be the same.

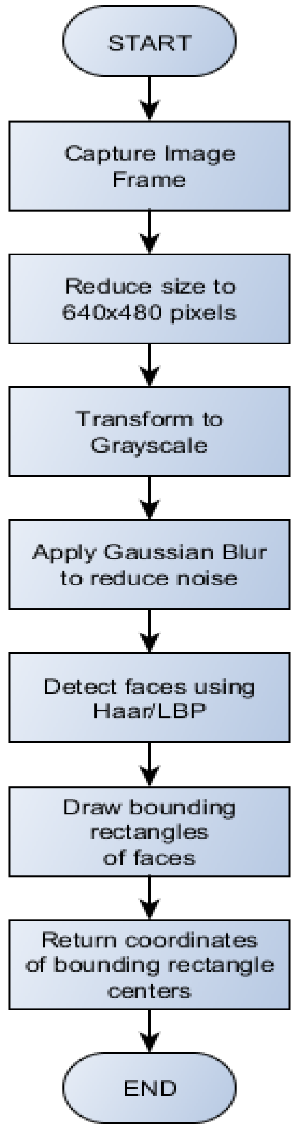


Figure 53: Facial detection algorithm flowchart.

6.2.4.3 Facial Recognition

The facial recognition software will take the output from the facial detection software (bounding rectangle of the detected face and the image in which it was detected) and try to match the detected face to a known user.

6.2.4.3.1 Framework

As with the facial detection program, the facial recognition program will be written in python and make use of the OpenCV library. Python was chosen because of its readability and portability. It is pre-installed in the Linux operating system and has a broad spectrum of useful libraries that will be used for Ion. Most programming will be done in the Atom editor and prototyped on a pc with the help of a webcam.

6.2.4.3.2 Key Hardware Constraints

Facial recognition relies heavily on matrix calculations, so the amount, speed, and availability of multiple CPU cores will determine how fast and accurate this program will be. The minimum required resolution from the camera is 640x480 pixels.

6.2.4.3.3 Design Considerations

Several designs have been taken into consideration and their pros and cons are weighed below.

6.2.4.3.3.1 Eigenfaces

Principal Component Analysis (Eigenfaces) uses a training set of pictures taken in the same lighting conditions. Eigenvectors and eigenvalues will then be computed from a covariance matrix that represents the set of training pictures. These so-called eigenfaces can then be used to compute the difference of a face to these eigenfaces. Comparing these deltas of various pictures will generate a match (within determined range) if the face in the pictures is the same. Because of the reliance in even lighting conditions, this method requires a controlled environment. All compared pictures must be of the same size and normalized [11].

The advantage of using eigenfaces is that it is very fast, does not need a lot of storage space, and is very accurate when the lighting conditions are ideal and unchanged. It also does not need a very high-resolution image which can speed up processing time and reduce storage need even further. The drawbacks are that it handles varying lighting conditions, change in facial expression, varying background, and faces of different size poorly. The recognition depends on lighting rather than facial features.

Because of its drawbacks, the image will be cropped around the face-binding rectangle produced by the facial detection algorithm. This will reduce the effect of the background. The cropped image can then be resized to a predetermined size, which should normalize it (face centered in the image). If that is not enough, it can be considered to apply a radial mask around the face to reduce interference of background even further. To reduce the errors when the user's face is tilted or rotated, several different sets of eigenfaces can be generated by asking the user to take several pictures from varying positions when calibrating the system.

6.2.4.3.3.2 Fisherfaces

Linear Discriminant Analysis, also known as fisherfaces, is an additional step beyond eigenfaces that takes into account different classes (specific features) found in the image and the variance in those features from one image to another. This reduces the eigenfaces' heavy reliance on a controlled environment. [12] The strategy to reduce errors with this method is the same as eigenfaces. It is especially important to reduce image size to reduce processing power and storage requirements.

6.2.4.3.3.3 Histograms

This method involves creating a histogram from the image containing the face and calculating the delta to histograms from images in the database. The closest match will have the lowest delta will be considered a match if the delta is within a determined range. This method will not be implemented as pure facial recognition. It may, however be added as an additional step after a face has been detected, isolated from an image, and a decision needs to be made between two highly likely possible matches.

6.2.4.4 Comparison

Table 17 below shows a comparison of the described methods' pros and cons.

Method	Pro	Con
Eigenfaces	- Less space in the database - Speed (Real time facial recognition) - Can use reduced image sizes	- Sensitive to lighting, scale and translation - Difficulty with expression changes - Differences in background greatly affect accuracy - Depends on illumination, rather than facial features
Fisherfaces	- More accurate than eigenfaces (Less susceptible to lighting, orientation, and size)	- Still susceptible to lighting conditions and varying facial expressions - Requires large storage - Requires more processing power
Histogram	- Easy to implement - Fast - Low computational requirement	- Shapes are not taken into consideration - Inaccurate under different lighting conditions

Table 17 Comparison of facial recognition methods

Based on this comparison, and the fact that the environment's lighting will likely not be ideal, fisherfaces will be used for facial recognition. Once the software is written, prototyping will show how accurate it is and if there needs to be a second verification step via histogram matching. The size of the image that will be processed will be tweaked to balance between accuracy and processing speed.

6.2.4.5 Algorithm Flowchart

Figure 55 below shows the flowchart of the facial recognition algorithm.

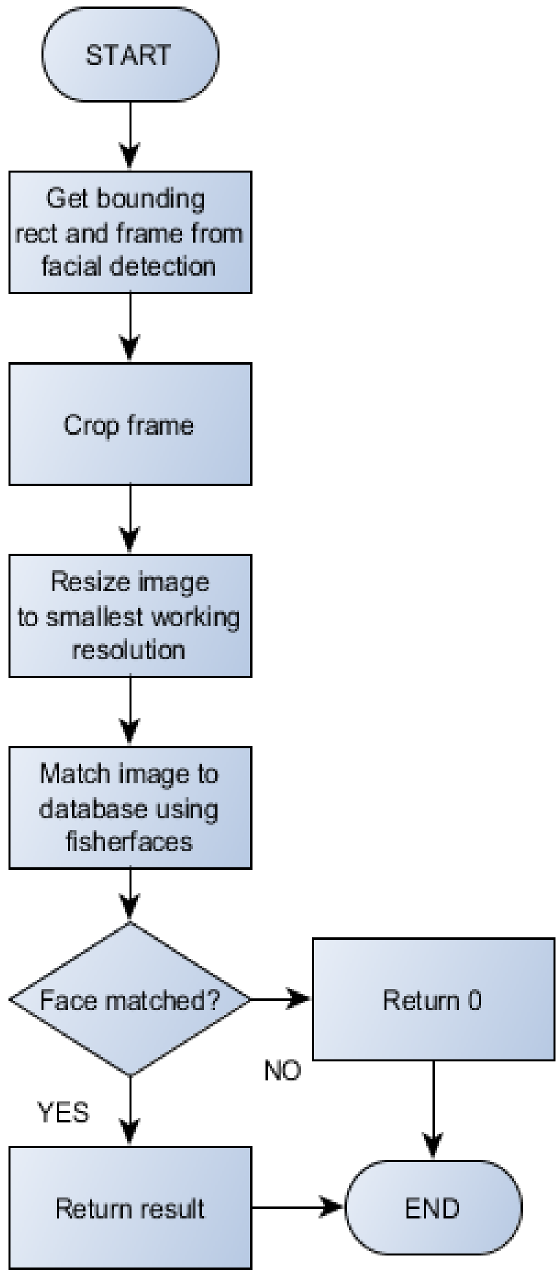


Figure 54: Facial recognition algorithm flowchart

7.0 Project Prototyping and Coding

7.1 PCB

7.1.1 Prototyping Hardware

7.1.1.1 Controller

The Controller (Raspberry Pi Compute Module 3L) will be attached to the PCB via a SODIMM connector. Until the PCB has been created, prototyping will be done with the help of a Waveshare Compute Module IO Board Plus (see Figure 56 below).

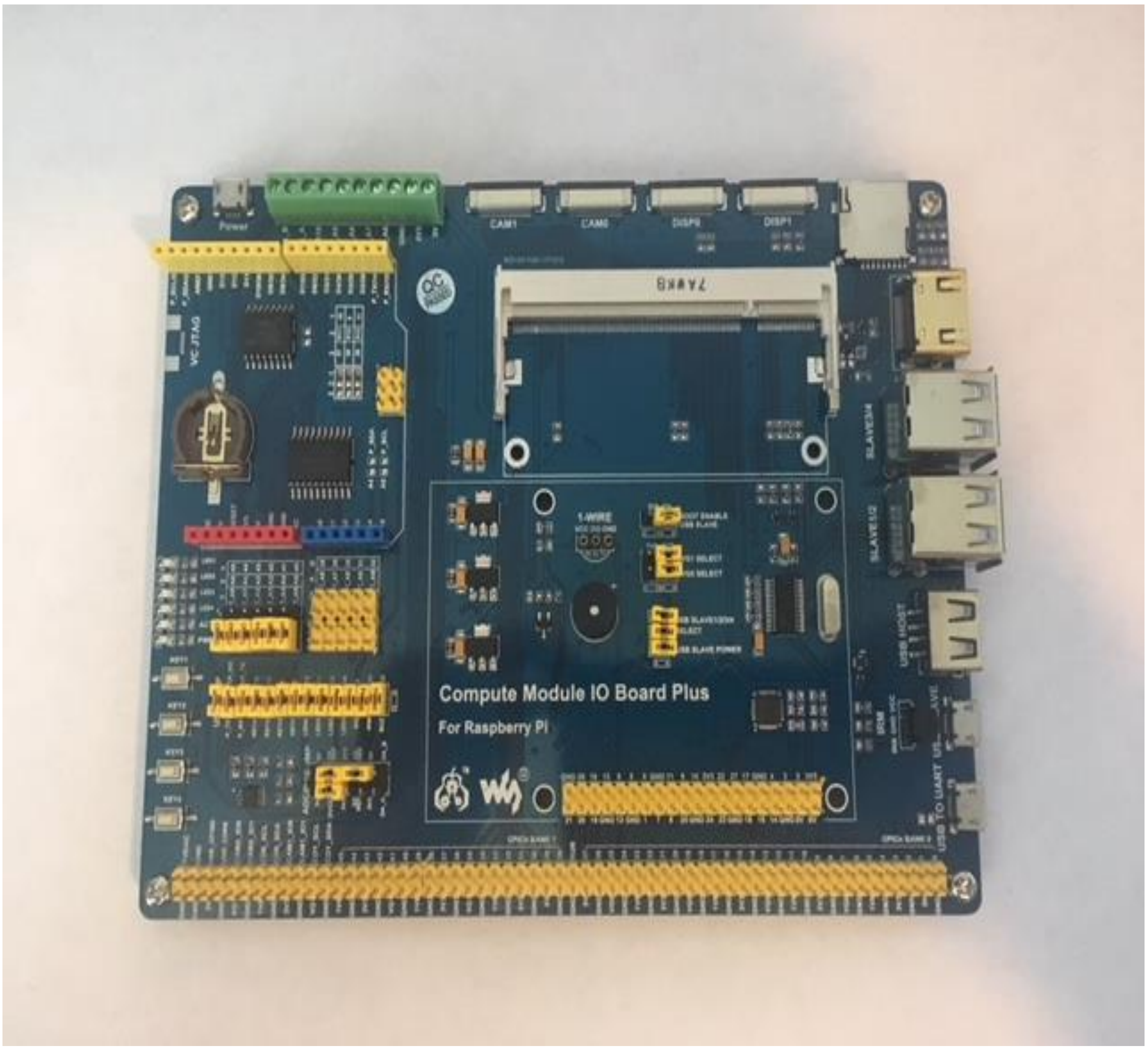


Figure 55: Waveshare Compute Module IO Board Plus

The IO Board has several built-in components that will be necessary for testing: An SD-card slot, ADC conversion, DAC conversion, Arduino headers, CSI interface, DSI interface, Compute Module GPIO header, an RTC chip for I2C, LEDs, Keys, USB connections, and a Buzzer.

The SD card slot will be used to load the OS and other software. ADC and DAC conversion will be used for sound processing. The CSI and DSI connectors will be used to connect the display and camera. An Arduino will be connected via I2C, using the Arduino headers to prototype the MCU. All other components mentioned will be used for software testing, code prototyping and troubleshooting.

Once the prototyping has been completed, the Compute Module and SD card can be transferred to ION's PCB.

7.1.1.2 MCU

The MCU will be prototyped with the help of the Waveshare Compute Module IO Board, shown above in figure 56, an Arduino UNO R3, a small Hextronik HXT900 servo and a battery adapter for AA batteries (see Figure 57 below).

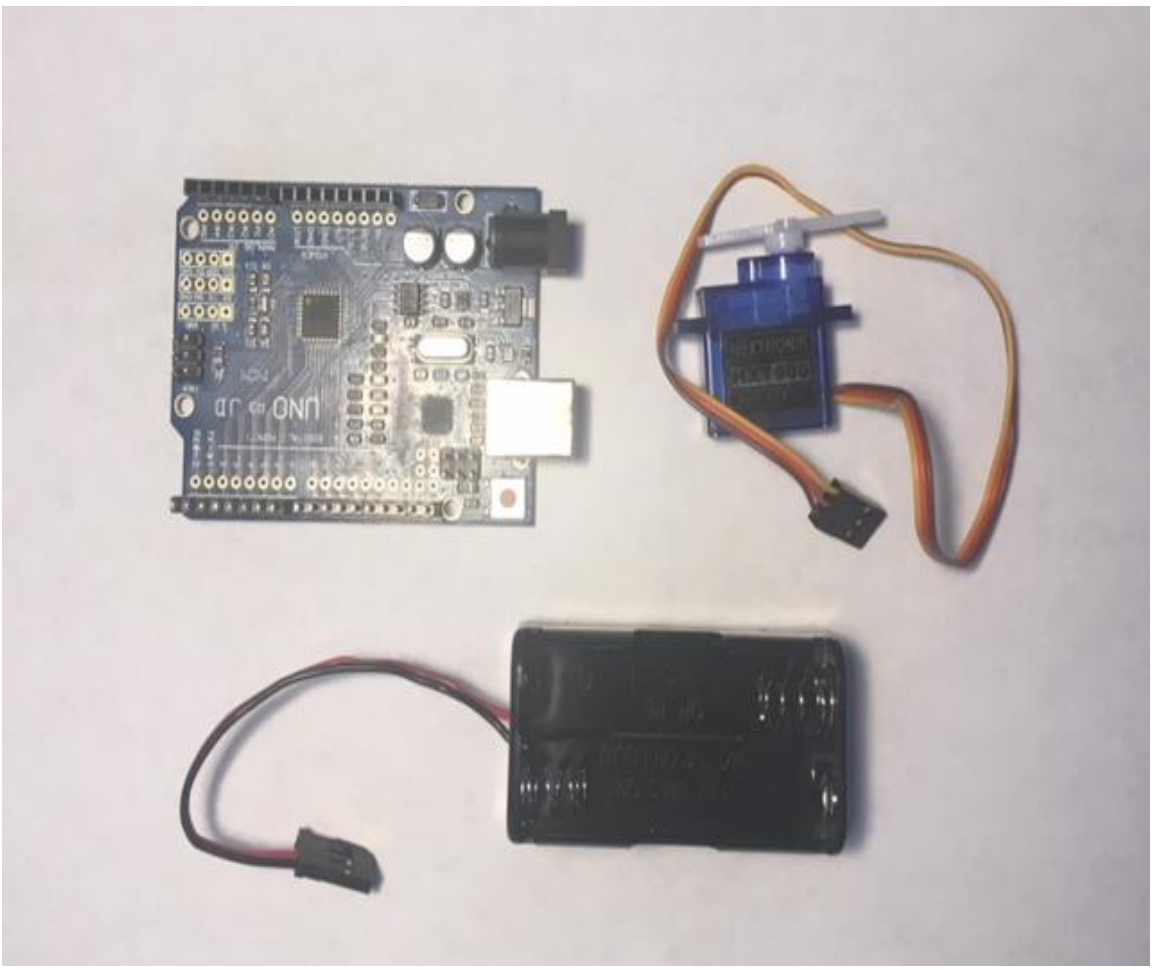


Figure 56: Arduino UNO R3 (top left), Servo (top right) and battery adapter for MCU prototyping

The Arduino Uno will be connected to the Waveshare IO board via I2C and will also receive its power from the IO board. The servo will receive a PWM signal from the Arduino and power from the battery adapter. The battery adapter will contain three AA batteries to provide the servo with 4.5V. A Camera can also be connected to the IO board to test the feedback system but is not necessary for initial MCU functionality testing.

Once the setup works satisfactory, the working code can be loaded onto an ATMega328 chip to be used in the final PCB design.

7.1.2 Vendor and Assembly

The PCB is the core of the project, if it fails the entire device altogether fails. So, it was necessary to pick the right vendor along with whether the group wanted the PCB printed and components mounted on top by the vendor, or whether the group wanted just the PCB delivered and then solder the components by hand. To compare vendors, the key things to look at were the quality of the PCB, the quantity of PCBs compared to their cost, shipping duration, and vendor reputation.

7.1.2.1 PCBWay

PCBWay is a PCB manufacturer from China. Its reputation is pretty good amongst other senior design groups that have already finished printing and dealing with PCBs. Even though they ship the PCBs from China, it only takes 3-4 days to deliver along with a high shipping fee. There are also express options to speed up the delivery if necessary. Compared to other PCB vendors, they provide good quality PCBs that go for around $39 per ten boards with the dimensions of 100mm x 100mm and two layers. With the regular shipping option, the total ends up being around $60 for ten PCBs.

7.1.2.2 4PCB

4PCB is stationed in the United States, which would be a great option for fast and low-cost shipping. They have multiple PCB options, but compared to PCBWay, they seem to be very expensive. Some of their options range from PCBs costing $33 each or $66 each. 4PCB also provides the option to create a custom shape for the PCB. As far as quality, their PCBs are of high quality, but that comes at a high cost.

7.1.2.3 Gold Phoenix Printed Circuit Board Co., Ltd

Gold Phoenix is a well-known PCB manufacturer also stationed in China. They are known for providing cheap PCBs to SparkFun and Microsoft. However, compared to PCBWay, they are not so cheap. Based on reputation, their PCBs are sometimes flawed, so they must be tested carefully. As far as customization, they provide a wide range of options, but the total cost of one PCB ranges from $75-$100 without any customization, which is still too much. Gold Phoenix also provides free shipping to North America.

7.1.2.4 OurPCB

OurPCB is another Chinese PCB manufacturer that provides cheap PCB services. The cost of ten PCBs with two layers and the dimensions of 100cm^2 go for around $36 and take around 4 days to manufacture. The cost is great compared to the other PCB vendors. However, based on reputation, their PCBs sometimes tend to be flawed as well. That might not be too much of a problem given that there could be an order of ten PCBs and only two of them might be flawed, so there will still be plenty of PCBs to work with. Their PCBs are either hand-made or machine-made. As far as shipping goes, it is definitely not free. They use the same shipping methods as PCBWay, so it is expected that shipping costs end up being high.

7.2 Schematics

7.2.1 Controller I/O

To better plan out the schematics for the PCB, a table was first created listing all the inputs and outputs. After knowing all the inputs and outputs, it would be simple to create the schematics. The controller I/O are shown below in Table 18.

Controller: Raspberry Pi Compute Module 3	
Inputs	Outputs
Analog-to-Digital Converter (Microphone)	Digital-to-Analog Converter (Speaker)
LCD Screen Feedback	LCD Screen
SD Card	SD Card
WiFi Chip	WiFi Chip
Camera Feedback	Camera
Power	Power
	LEDs
	Motor Control Unit

Table 18: Controller Inputs/Outputs

7.2.2 Reference Schematics

After finishing the controller I/O, there are some devices such as the WiFi SMT module ESP-12S, the digital-to-analog converter MCP4725, and the microSD card reader that are complicated to design entirely from scratch. So, some reference schematics were used with all credits to Adafruit for providing them. Those schematics were mimicked and modified to fit the group's own PCB schematic. For example, there are some components that are not required for the group's PCB, such as voltage regulators, they could be removed since the controller GPIO itself can regulate the amount of voltage being input into other components. The ESP-12S, MCP4725 breakout board, and the microSD Card reader breakout board schematics are shown below in Figures 58, 59, and 60 respectively.

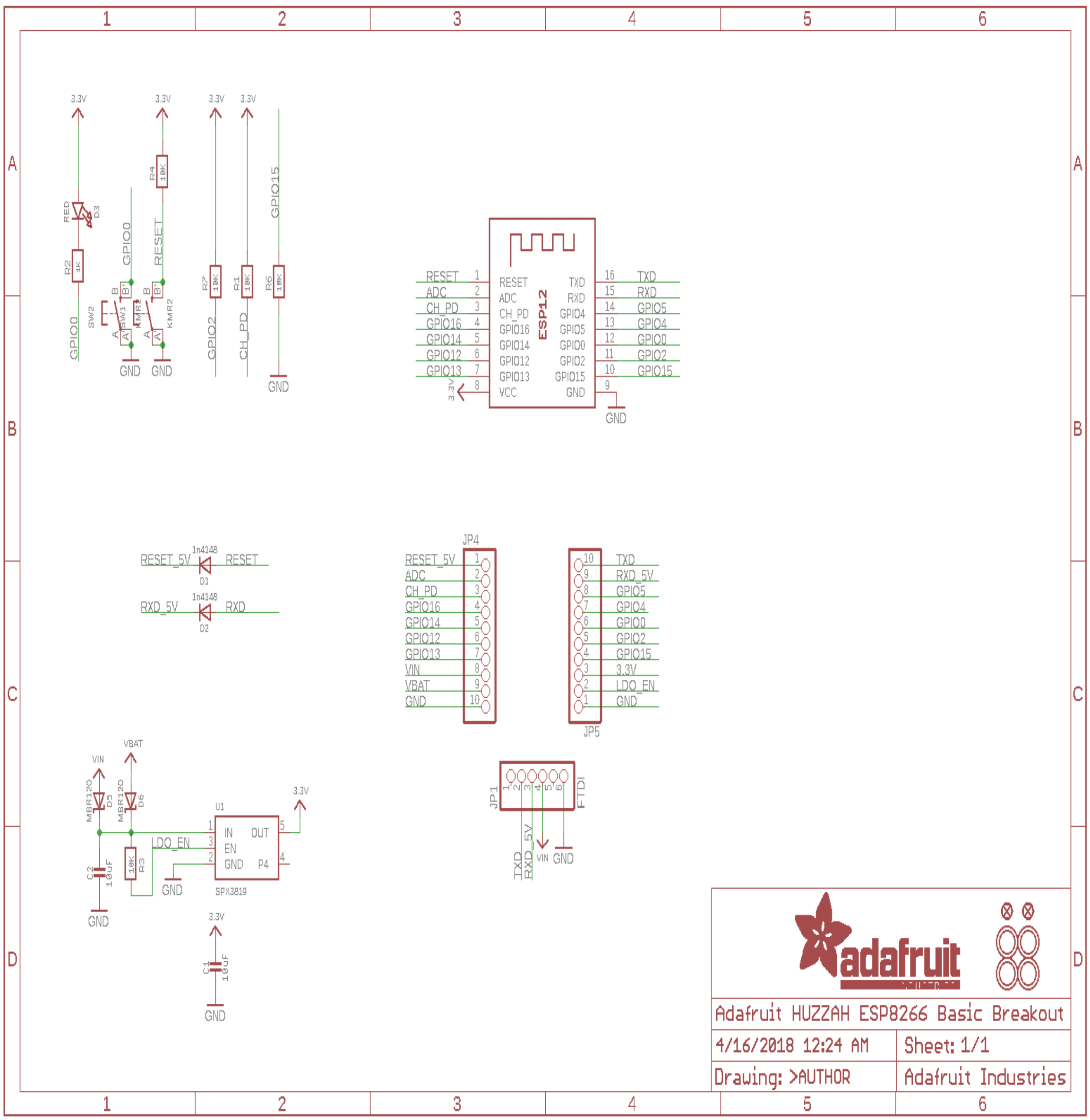


Figure 57: ESP8266 SMT Module Schematic - Schematic Credits to Adafruit

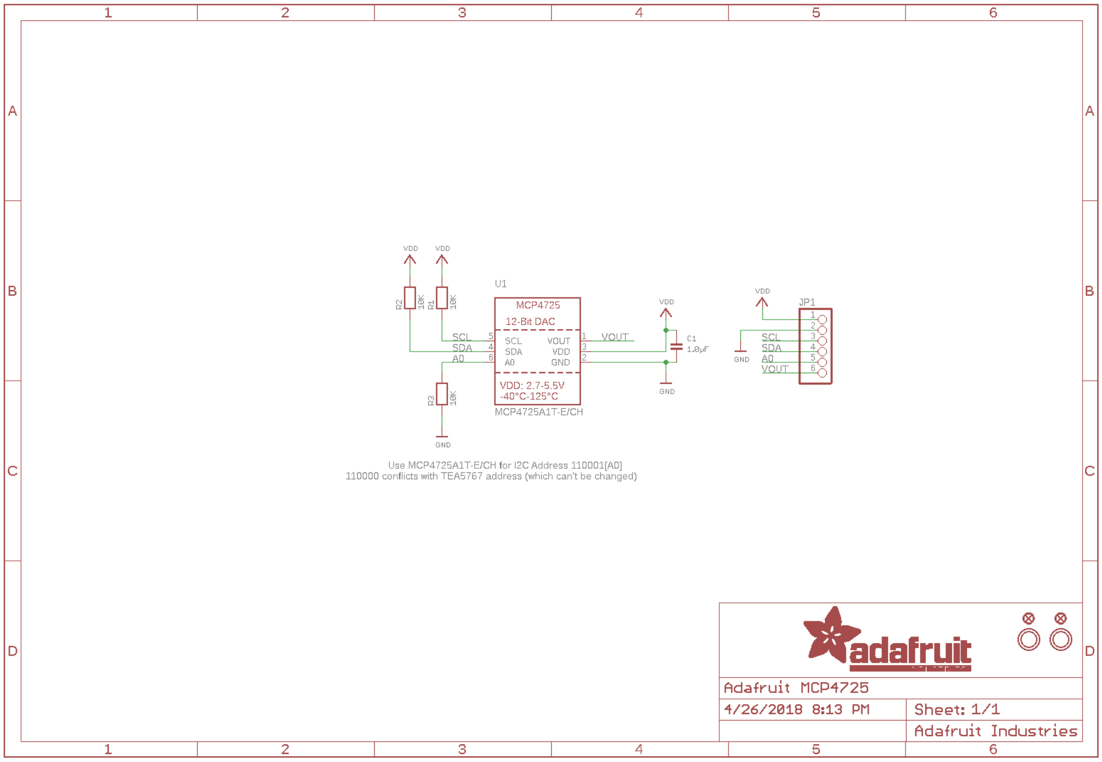


Figure 58: DAC MCP4725 Breakout Board Schematic - Schematic Credits to Adafruit

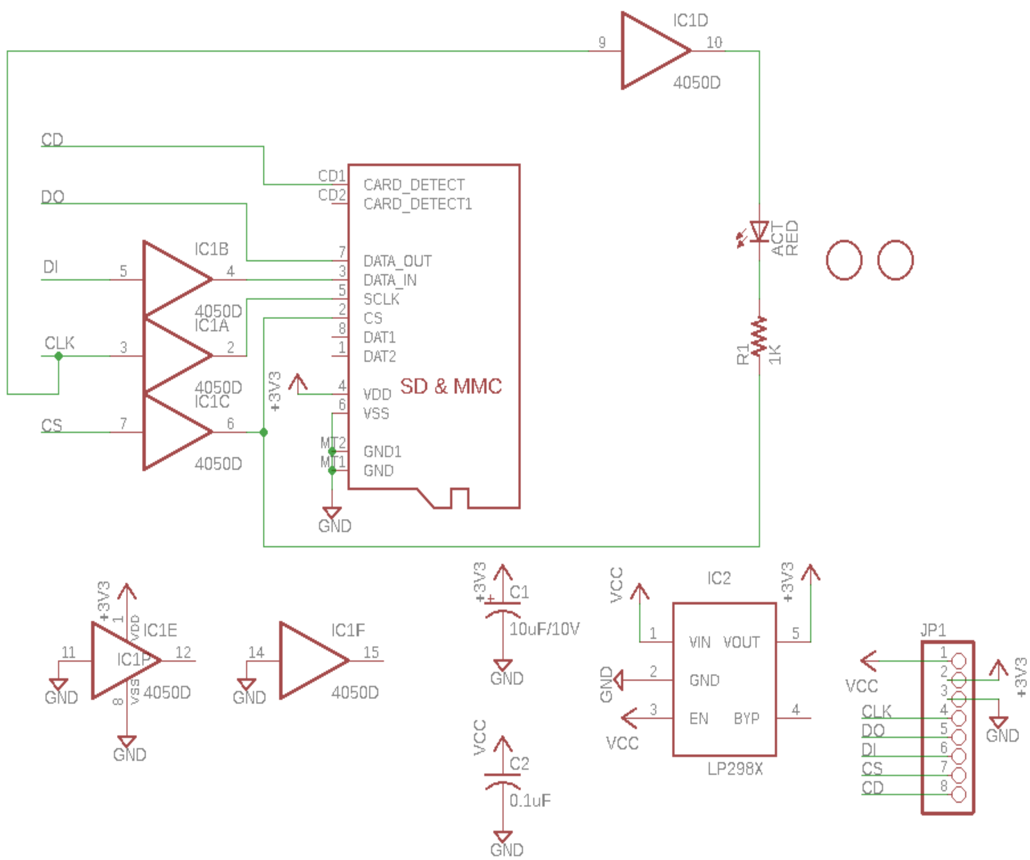


Figure 59: MicroSD Card Reader Breakout Board - Schematic Credits to Adafruit

7.2.3 Overview Schematic

The overview schematic was created using Autodesk® EAGLE by following the controller inputs and outputs and the power connections. The battery will be input into the voltage regulators shown in section 6.1.3.3 of this document, that will then create four voltage sources; 1.8V, 2.5V, 3.3V and 5V. Those will all go into the processor and whatever another component requires 5V or 3.3V could be directly powered. Things to note are that the microprocessor will be powering the WiFi chip using pin 36 (GPIO31 – 3.3V), the camera CSI using pins 76 and 78 (GPIO42 & GPIO43 – 3.3V), the LCD screen DSI using pins 75 and 77 (GPIO22 & GPIO 23 – 3.3V), the micro SD card reader using pin 45 (GPIO12 – 3.3V), and finally the DAC using pin 27 (GPIO8 – 5V). The resulting PCB overview schematic is shown below in Figure 61.

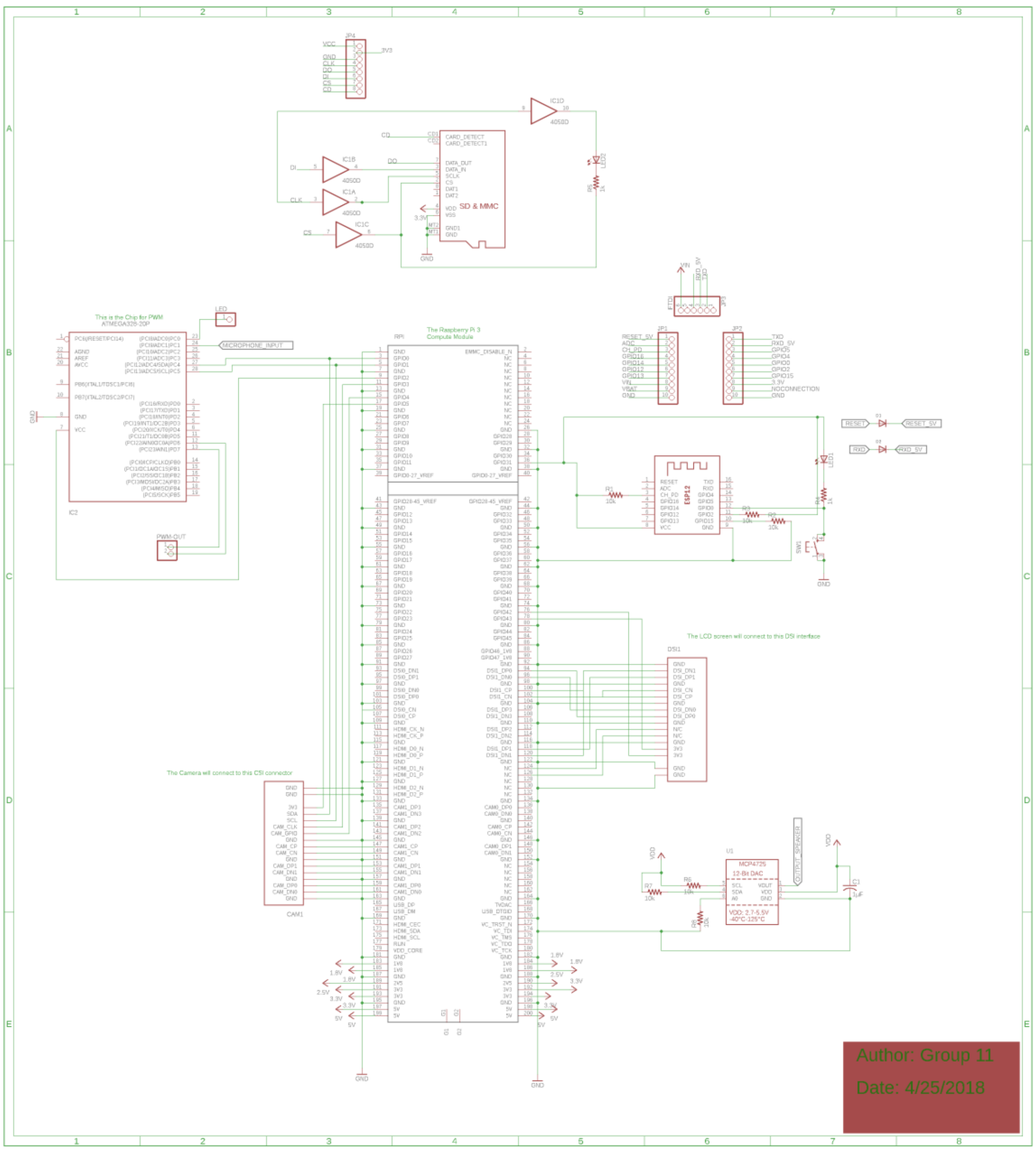


Figure 60: PCB Overview Schematic

7.2.4 Bill of Materials

After completing the overview schematic, it is important to have a bill of materials to keep track of the required components, quantities, and costs. The bill of materials for the overview schematic is shown below in Table 19.

Part	Manufacturer	Part Number	Quantity	Price ($)
10k Resistors	Vishay / BC Components	MCS0402PD1002DE500	6	0.63
1k Resistors	Vishay / BC Components	MCS0402PD1001DE500	2	0.63
Capacitor	AVX	12066C105KAT2A	1	0.30
Chip LEDs	OSRAM Opto Semiconductors Inc.	LG R971-KN-1	2	0.05
Diodes	ON Semiconductor	NSVR0170HT1G	2	0.20
Buffers	Nexperia	HEF4050BT,653	4	0.41
Switch	C&K	KMR221GLFS	1	0.49
1x1 Header	AVX	009296001603806	1	0.38
1x2 Header	Molex	505567-0271	1	0.48
1x6 Header	Molex	505567-0671	1	0.57
1x8 Header	Molex	505567-0871	1	0.61
1x10 Header	Molex	505567-1071	2	1.21
DAC	Microchip Technology	MCP4725A0T-E/CH	1	1.02
MicroSD Socket	4UCON Technology Inc.	15882	1	1.95
WiFi Chip	Espressif Systems	ESP-12S	1	6.95
CPU	Raspberry Pi	CM3	1	53.85
MCU	Microchip Technology / Atmel	ATMEGA328-20P	1	2.50
Total			29	78.70

Table 19: PCB Bill Of Materials

8.0 Prototype Testing

8.1 Hardware Testing

8.1.1 Testing Environment

To test the hardware components, the testing had to be done in a safe environment in case anything went wrong including electrical surges, circuits blowing up or components catching on fire. The appropriate environment the group decided to test the hardware components was the Senior Design lab at the University of Central Florida. The lab had plenty of safety tools, along with a lot of equipment available for use. Equipment included 3-output DC supplies, digital multimeters, oscilloscopes, function generators, computers, resistors, capacitors, and plenty of space to work with.

8.1.2 Speakers

Testing the speaker was key to whether the speaker quality was good enough for the design, whether the number of speakers was enough, and whether there were defects in the speaker. Before testing the speaker, there must be some soldering done, two wires should be soldered to the speaker terminals; one at each terminal. Then a continuity check must be done to test whether the wires were soldered properly, and that the speaker still works. For the speaker to pass the continuity check, the Digital Multimeter should beep once connected to both terminals of the speaker. Equipment used to test the speaker are shown below in Table 20.

Component	Equipment & Tools
Speaker	• Function Generator • Soldering Tools • Digital Multimeter

Table 20: Speaker Testing Equipment & Tools

To test the speakers, first, a very simple circuit could be drawn. Since the speaker being used by the group has a maximum power intake of 0.5W and has an impedance of 8 ohms, it was simple to find the maximum voltage and current that could be supplied to the speaker. The general power equation P=VI was used, then using Ohm's law to substitute the voltage of a resistance into the equation to find the current. The equation ends up being $P=I^2R$, which results in a maximum current of 0.25A and a maximum voltage of 2V across the speaker. The resulting circuit is shown below in Figure 62.

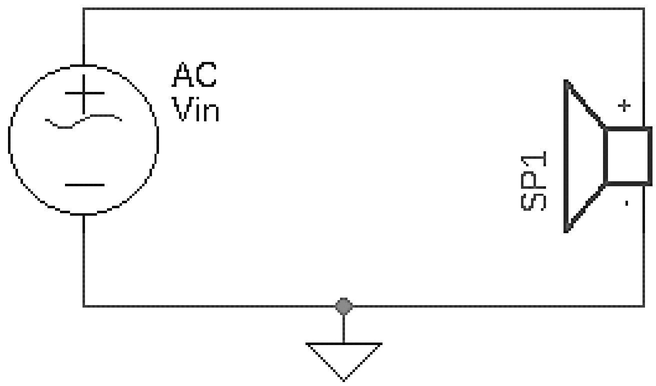


Figure 61: Speaker Testing Circuit

The speaker could be tested in many ways, including building a circuit on breadboard with a sound amplifier for example. But, the fastest and easiest way to test the speaker would be to connect the speaker directly to a function generator and generate random AC signals. The function generator should be set up to produce a sine wave with 4V peak-to-peak, and a 1Hz frequency signal. After that, the group should keep on varying the frequencies to 200Hz, then 500Hz, and finally 1KHz to test whether the speaker produces sound or not, and whether the sound quality is loud and clear enough for the design. The table shown below, Table 21, illustrates the testing plan and expectations. If the expected results are not met, that means it is a failed test.

Waveform	Input Voltage (V_{pp})	Frequency (Hz)	Expected Results
Sine Wave	4	1	Beeps every 1 second
Sine Wave	4	100-500	Continuous noise
Pulse Wave	4	1	A beep every 1 second
Pulse Wave	4	100-500	Loud pulses
Sine Wave	2	100-500	Lower sound compared to $4V_{pp}$

Table 21: Speaker Test Expectations

8.1.3 Microphone

Testing the microphone might require multiple steps. The first step is to test the microphone by itself to check if it works properly. Then, the microphone must be tested for noise. If noise is present in disruptive amounts, then as stated previously, a low-pass filter is required. The last step would be to test the microphone with a low-pass filter if required. Testing equipment and tools to be used for the microphone are shown below in Table 22.

Component	Equipment & Tools
• **Electret Microphone**	• Function Generator • Oscilloscope • Breadboard • Resistors • Capacitors

Table 22: Microphone Testing Equipment & Tools

To check if the microphone works fine, it is given that the Electret Microphone has a power supply input of 5V max, with a maximum load resistance of 2.2kΩ. First, a function generator can be used to supply $10V_{pp}$, connected to a 2.2kΩ resistor, then connected to the positive terminal of the microphone, while the negative terminal is connected to ground. The circuitry is illustrated below in Figure 63. The oscilloscope then should be connected between the positive and negative terminals of the microphone, and it is expected for the group to see waves on the oscilloscope when talking, otherwise the microphone is not working.

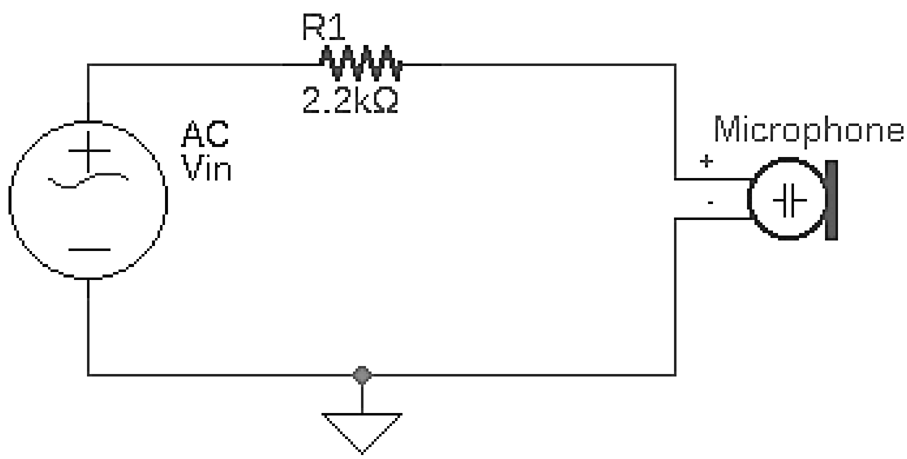


Figure 62: Unfiltered Microphone Testing Circuit

After that, if a lot of noise was present in the signals, a low-pass filter should be added to the circuit. There are multiple options for having a low-pass filter, including a first order RC circuit, fourth order operational amplifier circuit, and many more. For testing, a simple first order RC circuit can be built to filter the noise out. Instead of adding another resistor in series to the previous resistor, both can be combined into one resistor "R0", and then a capacitor is added to the circuit. The circuitry is shown below in Figure 64. The values for R0 and C0 are found using the equation previously derived in section 3.3.3.3 of this document $f_c = \frac{1}{2\pi RC} = 2KHz$, where R=R0 and C=C0. After that, it is expected to view clearer waves on the oscilloscope.

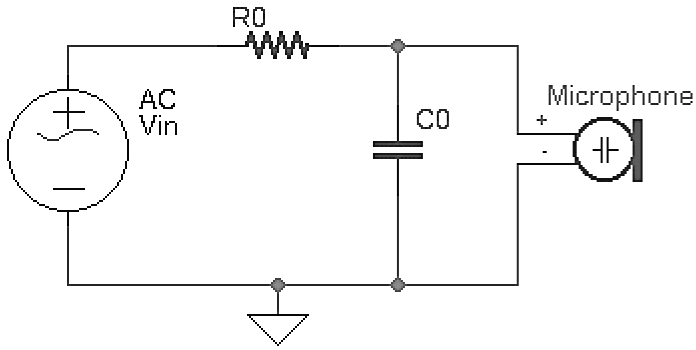


Figure 63: First-Order Filtered Microphone Testing Circuit

8.1.4 Audio Amplifier

Testing the mono audio amplifier breakout requires the use of the speakers once again along with their specifications. The testing equipment and tools to be used for the audio amplifier are shown below in Table 23. First, the mono audio amplifier breakout is powered by a 2.5V to 5.5V DC input, and when that voltage is supplied, a red LED should turn on to indicate that the amplifier is now on. The connections are done by connecting the "+" of the PWR pin to the input DC source, and the "–" of the PWR pin to ground. Next, once the mono audio amplifier LED lights on to confirm that it works, the whole board should be tested using the speaker, and an input AC signal. The gain should be left at 2 V/V without changing the gain resistors at first, then the gain can be changed to test how high up the amplifier can go. The input AC signal can be generated using a function generator to generate a random sine wave with a certain frequency and amplitude. The function generator can be set to generate a sine wave with an amplitude of $2V_{pp}$ and a frequency of 500Hz. To confirm that the amplifier works fine, with a gain of 2 V/V, the results should be the same as connecting the speaker directly to a $4V_{pp}$, 500Hz signal.

Component	Equipment & Tools
Mono Audio Amplifier	• Function Generator • 3-Output DC Supply • Speaker • Breadboard

Table 23: Mono Audio Amplifer Testing Equipment & Tools

For the connections, the "+" lead of the speaker should be connected to the "+" of the OUT pin and the "–" lead of the speaker should be connected to the "–" OUT pin. Finally, the function generator red (positive) lead should be connected to the "+" of the IN pin and the function generator black (ground) lead should be connected to the "–" of the IN pin. The resulting circuit should look like the following as shown in Figure 65 below.

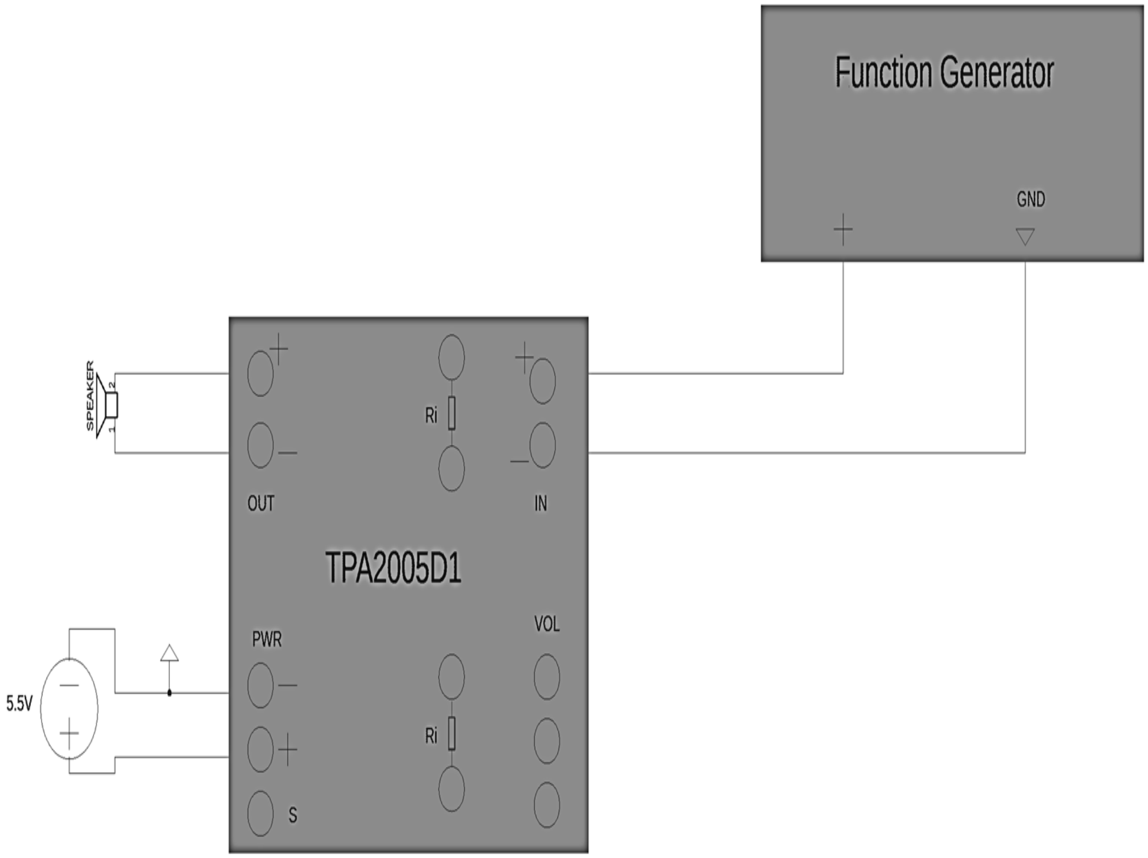


Figure 64: Mono Audio Amplifier Initial Test

After that, the different values for gain can be tested by changing the gain resistors. But, if the gain becomes too high, the speaker might blow up since it can take a maximum of 2V. To fix that, a resistor can be put in series with the speaker in between the "+" leads in order to have a voltage drop across it and achieve 2V at the speaker again. The expected results should be that the further the gain increases, the input signal amplitude should be reduced while the results should stay the same.

Finally, the shutdown pin can be tested by simply connecting it to ground to see whether the amplifier shuts off or not, and after that change the input DC source to 1V and check again whether it stays off or not. Once all the tests are finished, the group's own designed mono audio amplifier is expected to meet all the test expectations and results of the TPA2005D1 audio amplifier.

8.1.5 WiFi Module

Testing the WiFi Module might be a little more complicated than the other hardware components. Since the group would be using the ESP8266 WiFi Module for prototyping, it can be used to observe the multiple inputs and outputs for the WiFi chip and how it works. Once the ESP8266 WiFi module is finished for testing, it can be mimicked and then it is expected that when the group uses the ESP8266 SMT Module the same results should be observed. Testing equipment to be used for the ESP8266 WiFi Module and the ESP8266 SMT Module are shown below in Table 24.

Component	Equipment & Tools
ESP8266 WiFi Module	3-Output DC Supply Microcontroller or PC Wireless Network Soldering Tools
ESP8266 SMT Module – ESP-12S	3-Output DC Supply Microcontroller Wireless Network Breadboard

Table 24: WiFi Modules Testing Equipment & Tools

To test the ESP8266 SMT Module, it is required to use the module schematic provided earlier in this report as a reference, since it illustrates all the inputs and outputs required for it. Once all the connections are made correctly and the module is powered on, the module can then be connected to the group's microcontroller for further testing. Once connected to the microcontroller, the module can then be programmed through a personal computer to work in the same manner as the ESP8266 WiFi module. After that, the SMT module can be tested by checking if it can provide internet connection for the group's microcontroller. Expectations are that the group's microcontroller can connect or disconnect wirelessly to the internet, perform multiple internet functions like accessing a website, and then download a very small file around 500kB or less.

8.1.6 LCD

Testing the LCD has multiple functionalities that must be accounted for - this includes power, using the touchscreen interface, testing the GUI on the LCD, and displaying GIFs and videos on the LCD. To test power, it will have to be connected to a similar power supply and test that it turns on and displays properly. Ion will have a functionality that includes a touchscreen interface to allows the user to interact with the GUI, so that will have to be tested. To test the touchscreen, the necessary connections must be made to power and allow these functionalities. The touchscreen will be calibrated, and multiple touch tests will be conducted to test for sensitivity, accuracy, and functionality. To test the GUI on the LCD, the GUI must be written and loaded onto the device and the LCD connected. The GUI resolution must match that of the LCD so that is displays appropriately. Also related to the functionality of the GUI is the touchscreen, so that must be tested. The last major functionality of the LCD is displaying GIFs and videos that can be played with the different applications that can be integrated into Ion. After integrating the different applications with the GUI and Ion, videos and GIFs should play at the correct size and scaling as well as with minimal lag.

8.1.7 Camera

Testing the camera will ensure that it is in working condition, is connected properly and displays an image of reasonable quality.

8.1.7.1 Needed Equipment and tools

To test the camera, a prototype of Ion is needed with the camera connected as intended in the final design. Additionally, a specialized testing script is needed that will try to capture a frame from the camera and display it on the screen. The script will be written in python specifically for this purpose.

8.1.7.2 Procedure

To test the functionality and image quality of the camera, follow the procedure in Table 25 below.

Step	Desired Result
Boot System	System boots without any error messages
Run camera testing script	An image is displayed that shows the camera's point of view
Visually inspect image	The image appears focused, with natural colors and lighting.
Check for error messages in the console	No error messages are displayed.

Table 25: Camera testing procedure

8.1.8 Servo Motors

Testing the servos will verify that they are in working condition and connected properly to the designated outputs.

8.1.8.1 Needed Equipment and tools

To test the Servos, a prototype of Ion is needed with the servos connected as intended in the final design. Additionally, a specialized testing script is needed that will rotate the specified servo to a desired orientation.

8.1.8.2 Functionality and connection

To test the functionality and calibration of the servos, follow the procedure in Table 26.

Step	Desired Outcome
Boot up system	System starts with no error messages
Run test script	No errors reported, script asks which servo to turn
Enter “1”	Script asks which orientation (0-180)
Enter “0”	Verify servo 1 turns to 0 degree position
Enter “90”	Verify servo 1 turns to 90 degree position
Enter “180”	Verify servo 1 turns to 180 degree position
Enter “X”	Script asks which servo to turn
Enter “2”	Script asks which orientation
Enter “0”	Verify servo 2 turns to 0 degree position
Enter “90”	Verify servo 2 turns to 90 degree position
Enter “180”	Verify servo 2 turns to 180 degree position

Table 26: Servo test procedure

The test is deemed successful when each step has completed with the desired outcome.

8.1.9 PCB Testing

Testing the PCB would be very important since there are a lot of rumors about PCBs not working once they are received from their manufacturers. The equipment and tools required to test the PCB include all the previous hardware equipment and tools along with the hardware components. There are multiple steps for the group’s test plan to test the PCB, first, the multiple PCBs ordered should all be tested and checked for any defects. After that, since the group decided to assemble their own PCB, some of the components of the subsystems can be connected to the PCB to be tested each separately; first, to make sure the PCB is still working fine and second, to make sure the PCB is performing its expected task. After that, once it passes the test of powering one subsystem, multiple subsystems can be connected to it and tested each along the way. If any subsystem ends up failing, it can be tested on its own for troubleshooting, and then if it appears that the failure is from the PCB itself, then a new PCB is required. If not, then the problem should be resolved, and the rest of the subsystems should be connected to the PCB. Finally, once all tests pass, all the components must be soldered onto the PCB and then it should be tested again to make sure that neither the PCB nor the components were damaged due to soldering, otherwise all the PCB testing process should be restarted from the beginning. Once the PCB passes all the tests, it should be good to go and placed in the group’s final design project. The process can then be better illustrated in the flowchart below in Figure 66.

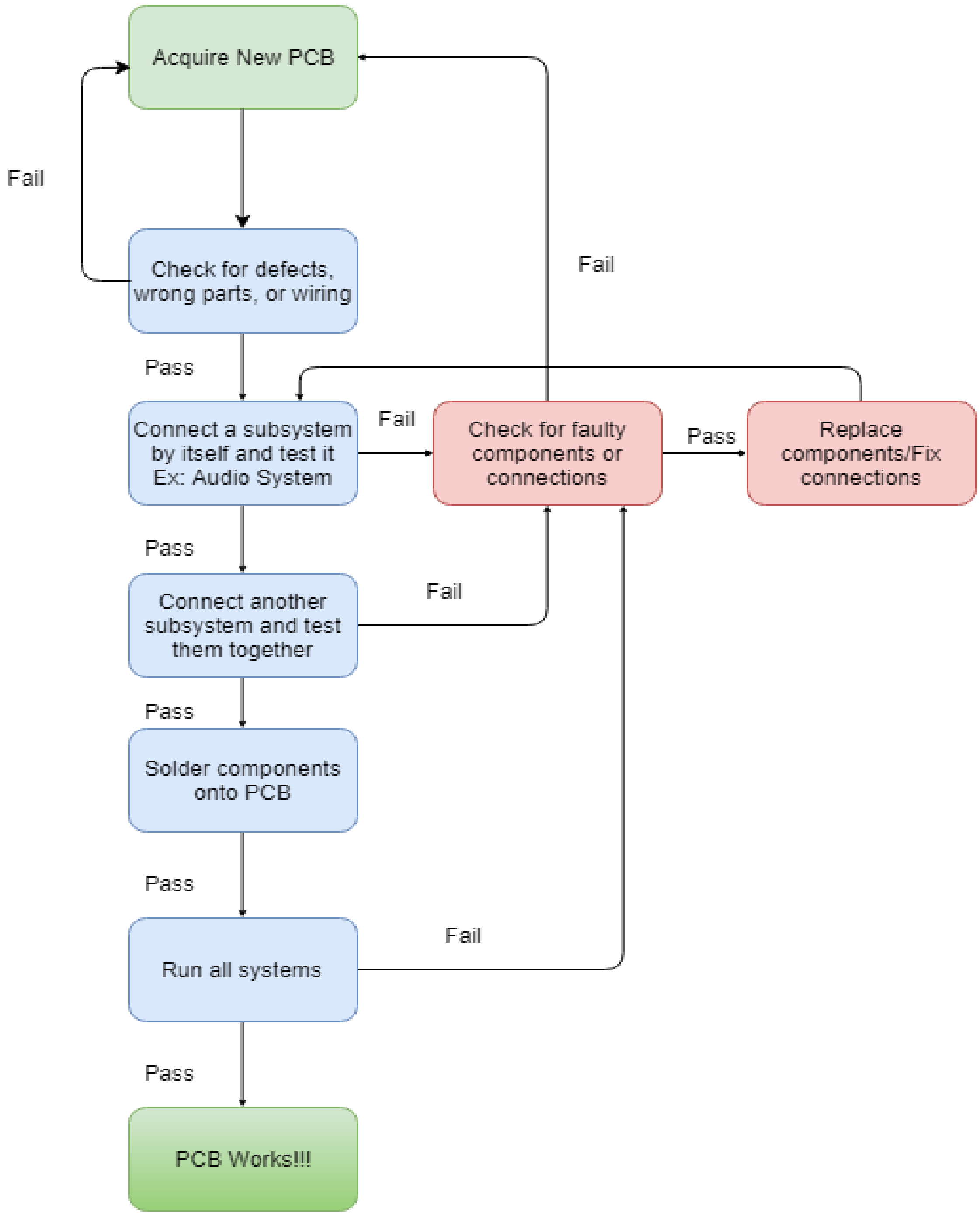


Figure 65: PCB Testing Procedure

8.2 Software Testing

8.2.1 Controller to MCU Interface

Testing the controller to MCU interface will ensure that the I2C I/O points have been connected properly and correct protocol is used to establish a connection. The MCU is passive, so only commands from the CPU to the MCU will be tested.

8.2.1.1 Needed Equipment and tools

To test the Controller to MCU interface (connection via I2C), a prototype of Ion is needed with the MCU connected as intended in the final design. An LED needs to be connected to pin 4 of the MCU and grounded. Additionally, a specialized testing script is needed that will try to establish a connection to the MCU and cause the LED to blink.

8.2.1.2 Procedure

To test the functionality of the Controller to MCU interface, follow the procedure outlined in Table 27.

Step	Desired Outcome
Boot up system	System starts with no error messages
Run test script	No errors reported.
Look at LED	Verify LED blinks at the frequency of 1 Hz.

Table 27: Controller to MCU interface testing procedure

The test is completed successfully, if all steps result in the desired outcome.

8.2.2 GUI

Testing the GUI will rely on many of the other different technologies being already incorporated into it. A true prototype test of the GUI will require it to be fully loaded onto Ion, meaning on the Raspberry Pi Compute module and all other hardware including the microphone, speakers, and LCD correctly connected. The main strategy for testing the GUI will be to test every requirement and feature from start-up to shut-down. At start-up, Ion should automatically boot into the login screen if a face or profile cannot be recognized. At the login screen, all the associated features and options shall be tested including login, account creation, account recovery, and face detection. On boot-up if a face is recognized, then it will log into the profile and load up the welcome screen and rest state to wait for a command. From there, menu navigation must be tested by tapping the screen to bring up the menu and tapping the different buttons to navigate to the respective pages. When the settings and preferences are changed, they should be tested to see if they change the associated values in the system and fully complete the task which they advertise. For example, changing Ion's customizable profile to the female version should change the voice and personality of Ion. Also, for all these settings and preferences, the voice commands that can also control these changes but be tested to see if they appropriately update the GUI. One last big part of testing the GUI is making sure that Ion has a fluid, realistic emotion feedback appropriately represented through GIFs that display on the screen. These can be test by seeing if Ion displays a welcome GIF on boot-up or by otherwise conversing with Ion.

8.2.3 Voice Recognition

Testing voice recognition will require a microphone and the voice recognition software complete. To test it, keywords signifying commands must be spoken into the microphone and it will need to be verified that the Google Speech API is correctly translating and interpreting the voice commands to be utilized. The main keywords that will signify commands and will need to recognize them with high confidence and correctly interpret them 80% of the time, per the software efficiency requirements. The commands will the be processed and Ion will respond or complete the task within two (2) seconds per the software efficiency requirements.

8.2.3.1 Procedure

To test the functionality and accuracy of the voice recognition, follow the procedure in Table 28 below.

Step	Desired Result
Boot System	System boots without any error messages
Say "Open Youtube"	System confirms that it correctly understood the command within 2 seconds
Repeat above step for a total of ten times	System responds with the desired result at least 8 out of 10 times.
Say "Play study playlist"	System confirms that it correctly understood the command within 2 seconds
Repeat above step for a total of ten times	System responds with the desired result at least 8 out of 10 times.
Say "This Banana plays nothing" (does not make sense on purpose to test against false positives)	Systems asks for clarification
Repeat above step for a total of ten times	System responds with the desired result at least 8 out of 10 times.

Table 28: Voice Recognition Test Procedure

8.2.4 Facial Detection

8.2.4.1 Needed Equipment and tools

To test the facial detection software, a prototype of Ion is needed with the camera connected as intended in the final design. Additionally, a specialized testing script is needed that will run in the console environment to provide feedback in text form. The script will be written in python specifically for this purpose.

8.2.4.2 Procedure

To test the functionality and accuracy of the facial detection, follow the procedure in Table 29 below.

Step	Desired Result
Boot System	System boots without any error messages
Run facial detection test script	A live video feed from the camera is shown and the console does not print any error messages.
Turn the camera so that it does not capture any faces. Enter "T".	The live video feed is unchanged and the console prints "0".
Turn the camera so that it captures only one face. Enter "T".	The face in the live video feed is surrounded by a green rectangle and the console prints "1"
Turn the camera so that it captures two faces. Enter "T".	Only one face in the live video feed is surrounded by a green rectangle and the console prints "2"
Turn the camera so that it captures three faces. Enter "T".	Only one face in the live video feed is surrounded by a green rectangle and the console prints "3"
Enter "S" and sweep the camera across the room, preferably with several objects of different size, shape and color in it. Monitor the screen while doing so.	During the sweep, only faces are bound by a green rectangle, not objects.
Check for error messages in the console	No error messages are displayed.

Table 29: Facial detection testing procedure

The test is completed successfully when all steps have been completed and produced the desired results.

8.2.5 Facial Recognition

8.2.5.1 Needed Equipment and tools

To test the facial recognition software, a prototype of Ion is needed with the camera connected as intended in the final design. Two users that have calibrated their profile must be present. Additionally, a specialized testing script is needed that will run in the console environment to provide feedback in text form. The script will be written in python specifically for this purpose.

8.2.5.2 Procedure

To test the functionality and accuracy of the facial detection, follow the procedure in Table 30 below. The test is completed successfully when all steps have been completed and produced the desired results.

Step	Desired Result
Boot System	System boots without any error messages
Run facial recognition test script	A live video feed from the camera is shown and the console does not print any error messages.
Turn the camera so that it does not capture any faces. Enter "T".	The live video feed is unchanged and the console prints "No Face Detected".
Turn the camera so that it captures only the face of a known user. Enter "T".	The user's face in the live video feed is surrounded by a green rectangle and the console prints the user's name.
Turn the camera so that it captures two faces. The face of the previously recognized user and an unknown person Enter "T".	Only the previously recognized user's face in the live video feed is surrounded by a green rectangle and the console prints the user's name.
Turn the camera so that it captures two faces. The face of the previously recognized user and another known user Enter "T".	Only the previously recognized user's face in the live video feed is surrounded by a green rectangle and the console prints the user's name.
Check for error messages in the console	No error messages are displayed.

Table 30: Facial recognition testing procedure

9.0 Administrative Content

This section serves to provide some details on some administrative content related to the project including a schedule of milestones and a layout of spending and finances.

9.1 Project Milestones

The project milestones and tentative schedule are shown in Table 31 below. This table completely outlines all the major milestones through the Spring 2018 and Summer 2018 semesters - from initial idea brainstorms to the final presentation of our project.

Task Number	Task Name	Start Date	Due Date
Senior Design 1			
1	Idea Brainstorms	1/16/18	1/23/18
2	Project Selection & Role Assignments	1/23/18	1/25/18
3	Initial Document - Divide & Conquer	1/23/18	1/28/18
4	Bootcamp	1/28/18	1/28/18
5	Research	1/30/18	1/30/18
7	Divide & Conquer V1	1/23/18	1/28/18
8	Divide & Conquer V2	2/25/18	3/11/18
9	Table of Contents	3/13/18	3/20/18
10	First Half	3/21/18	4/9/18
11	First Half Review w/ Dr. Richie		4/12/18
12	First Draft	3/21/18	4/20/18
13	Report Due		4/27/18
Senior Design 2			
14	Assemble Prototype	TBD	TBD
15	Testing and Redesign	TBD	TBD
16	Finalize Prototype	TBD	TBD
17	Peer Review Report	TBD	TBD
18	Final Documentation	TBD	TBD
19	Final Presentation	TBD	TBD

Table 31: Project Milestones

9.2 Project Budget and Finances

As this project is self-funded by a 3-person group, the group was in budget. The aim was to limit the individual budget to about $200, adding up to $600 in total. All the components that were purchased are listed in Table 32 below, along with the projected cost at the beginning of the project and the actual cost on the date of purchase. As the project wasn't funded by an outside company and there were no plans to sell the product on the market, budget wasn't a huge deal outside of the personal budgets and what each individual group member was willing to spend.

Through research the group figured that the average cost of a similar product, like the Amazon Echo or Google Home, would be around $100-150. Companies like Amazon and Google are absolute powerhouses in the market today, with access to deals with shipping and supply that the group don't have, so naturally their cost will be a lot higher. The project is also only a prototype, so the cost will be a lot higher than a final product whose design would be known and streamlined to be cheaper.

Estimated Component Costs and Budgeting	
Component	**Projected Cost**
Microphones	$3.00
Speakers	$6.00
LCD Touchscreen	$60.00
Raspberry Pi	$30.00
Camera	$15.00
PCB(s)	$50.00
3D-printed body	$50.00
Buttons, switches	$10.00
Resistors, capacitors, etc.	$10.00
LEDs	$10.00
MCU	$20.00
Servo(s)	$30.00
Tools and Equipment	$75.00
WiFi Modules	$32.00
Mono Audio Amplifier	$8.00
DAC breakout board	$5.00
Battery	$20.00
Voltage Regulators	$15.00
Power Switch	$2.00
Battery Casing	$5.00
Battery Charger	$5.00
Processor	$35.00
Delivery Fees	$50.00
Total	$546.00

Table 32: Project Estimated Budget

Appendix A – List of Tables

Appendix B – List of Figures

Appendix C – References

[1] Mono Audio Amp Breakout: https://www.sparkfun.com/products/11044

[2] 0.5W 8-ohm Speaker: https://www.sparkfun.com/products/9151

[3] Electret Microphone: https://www.sparkfun.com/products/8635

[4] ESP8266 Thing Dev Board: https://www.sparkfun.com/products/13711

[5] ESP8266 WiFi Module: https://www.sparkfun.com/products/13678

[6] Round Rocker Switch w/ Blue LED: https://www.sparkfun.com/products/11155

[7] microSD reader: https://learn.adafruit.com/adafruit-micro-sd-breakout-board-card-tutorial/introduction

[8] DAC Breakout: https://www.adafruit.com/product/935

[9] ESP-12S WiFi Chip: https://www.adafruit.com/product/2491

[10] Voltage Regulators: http://www.ti.com/design-tools/webench-power-design/power-designer.html

[11] https://en.wikipedia.org/wiki/Eigenface

[12] https://github.com/bytefish/bytefish.de/blob/master/blog/fisherfaces.md

Appendix D – Permissions

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Mohammad Rizeq
Dear Sparkfun, My group partners and I are currently researching for Senior D...

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thanks for the note, totally OK!

David Jaffie
Mon 4/9, 6:55 PM

Hi,

I am researching for a project for a Computer Engineering degree program and want to ask for your permission to reference your components and use their information and photos in a project report.

Thanks,

David

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5. Peeqo:

Abhishek Singh <abhishek@shek.it>
Fri 4/6, 5:42 PM
David Jaffie

Reply all

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Hey David, thanks for reaching out and I'm happy the project was able to help you in some way. Feel free to reference it in your paper. I took a cursory look at your paper and it looks great but will dig in deeper as soon as I have some time on my hands. Do you have a working prototype built?

David Jaffie
Thu 4/5, 5:27 PM

DeskBot_DivideAndCon...
416 KB

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Hi Abhishek,

I am a senior Computer Engineering student at the University of Central Florida located in Orlando, FL. For our degree program, we take a final course called Senior Design where we design a project that incorporates electric and software components from scratch to working prototype. Through research into personal assistant and robots, we came across Peeqo and were blown away. We love the idea of making a desktop, interactive little assistant who can show emotion and communicate with the user while also being a helpful assistant.

We want to show our appreciation for your project and ask for permission to reference it in our research, paper, and presentation. This includes both the research and information you have presented as well as images and videos of Peeqo.

I have some documentation of our project if you're interested and we'd love some feedback if you have time.

Thanks,

David Jaffie
davidjaffie@knights.ucf.edu