

V.I.S.T.A.

Vent Intelligence System for Temperature Adjustment

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Chapter 1-Executive Summary

Central AC unit systems are widely used throughout most homes and buildings. Due to only one source of air, there is only one temperature that can be set among all occupants. People's bodies run at different temperatures and therefore everyone has different temperature preferences that can have a very wide range. To target this issue and present a solution, VISTA was developed in coordination with the project sponsor, Dr. Q.Z. Sun at the University of Central Florida. The aim of the project is to solve varying room temperature preferences by implementing a vent system to go on top of an existing vent cover that can open and close the vent slats in order to maintain desired temperatures while also considering environmental effects, saving energy and money, and responding to many different room characteristics to provide optimal airflow conditions.

VISTA is primarily composed of the physical system of a register containing moveable louvers and then a separate housing structure containing all of the hardware components that allow VISTA to function and respond to different environmental conditions measured by the different sensors. The physical vent system is attached over an existing vent, with the slats left open, allowing full air flow unless VISTA's louvers are closed. The separate housing structure separately mounts to an outer wall near the vent, not inside the vent duct itself to prevent deterioration of components from humidity and other conditions.

VISTA detects and responds to temperature, occupancy, and humidity through the use of three different sensors, each connected to the overall system to function properly. Based on the detected conditions, the louvers either open or close to adjust accordingly. VISTA additionally includes the implementation of a corresponding web application to display the status of each sensor. The web application must work in sync with the VISTA's internal software, allowing for the web application to act as the user interface.

This report outlines and records the entirety of VISTA's design process, starting with preliminary motivation and background for the project, as well as objective, goals, required standards, and general functionalities of the system. All of the lengthy research for every aspect of VISTA, including both hardware and software components are discussed in great length as well, going in depth through the decision process for every technology and part used and why specific choices were made to be best suited to the needs and applications of VISTA.

The document continues to take a more in depth look at all of the standards and design constraints of the project, particularly concerning both technical limitations of the different technological components as well as more generalized constraints like time and money. Comparing different artificial intelligence technologies is the next large section discussed in this report, mainly comparing results from ChatGPT with other platforms such as GoogleAI, Google, and GoogleScholar. This is an important step to highlight the pros and cons of using AI softwares and discuss the reliability and accuracy by comparing search results. This section is important because it calls out the importance of comparing AI

search results to other search results to check the validity of the results and ensure the information is being pulled from reliable sources.

The report then moves into a highly technical breakdown of the system's internal design and how the different components work and why. This section utilizes Fusion 360 to demonstrate the actual hardware design and all the components and subcomponents that go into the design of VISTA. The following section breaks down the software design, pointing out different aspects of how VISTA responds to room changes using its sensors and the functionalities of the code to be incorporated on the PCB. Thus, the following section provides all PCB details and images of the board to be printed and used for VISTA to function, to which all the components will be soldered onto.

The testing of the system components is then included to ensure that individual products are not faulty before adding them to the larger system, which aids with debugging and improving the project. To wrap up the report, the next section contains the administrative content including, budget, work distribution among team members, and a timeline of the project milestones and completion date requirements. This is followed by a conclusion to wrap up any remaining thoughts and reiterate the importance and functionalities of VISTA, and then appendixes with all of the references used.

Chapter 2-Project Description

2.1 Project Background and Motivation

In an increasingly energy-dependent world, the need to save on power and energy consumption is a driving factor to the production of innovative, smart grid technologies. VISTA aims to increase the efficiency of air conditioning systems in any given space. Operating within a home or commercial building, the system reduces the loss of energy in heating or cooling unnecessary areas. The system will be responsive to the temperature, occupancy, and humidity inputs, allowing occupants to save energy and money.

The heating or cooling of an entire room is no small feat in terms of energy consumption. The heating or cooling of an entire building is an even larger undertaking. The current standard in most homes and businesses is to set a temperature and heat or cool the whole building. Oftentimes, the temperature adjustment or maintenance of a whole building to a consistent temperature is unnecessary and unattainable. A room may be left unoccupied, have better insulation, more natural light, or may be closer or further away from the heating/cooling source. The discrepancy between the temperature needs of a single room and that room's pre-existing thermal conditions creates wasteful energy consumption. The ability to control the flow of air/heat into a specific room simply from a smartphone app is a unique solution that appeals to not only personal preference, but also decreases cost and improves energy profile.

Typical solutions to temperature discrepancies include window AC units, electric fans, and heating units. While these solutions help solve issues of reaching desired temperatures,

there are many drawbacks. Window AC units are energy inefficient, create a great deal of unwanted noise, raise security concerns, and are overall an unpleasant solution that takes up lots of space. Electric fans bring up similar issues in addition to circulating dust particles and other allergens that may be present in a room. Similarly, heating units take up space, create fire hazards, and have to be consistently monitored. All these issues being raised from the most common solutions highlights the need for an alternative temperature control method.

With technological advancements emerging every year, smart homes are becoming increasingly popular. And with that rise in popularity, devices like smart thermostats begin to make an impact in the world. Smart thermostats are an excellent method to save energy in a home. They offer precise temperature control by adjusting settings based on the occupancy of the room and the user's preferences. The ability to change the temperature by simply using a smartphone app empowers people to adjust the thermostat much more frequently- in turn lowering energy costs by eliminating unnecessary amounts of heating and cooling power.

Not everybody can afford a smart thermostat however, let alone an entire smart home. The very advanced technology that is required to power devices like smart thermostats are highly technical and therefore costly. Cheaper options like window AC units, electric fans, and heating units are useful but lack energy conservation and come with a great deal of drawbacks as previously discussed. Therefore, an alternative is necessary that combines both the affordability and usefulness of more typical solutions and the energy conservation of smart home technology. A smart vent system to control amounts of air flow into a given room allows both sides in a unique way that controls the temperature based on the specified space, and even uses infrared sensor technology to measure the occupancy in a room and smart-adjust itself in order to align with the optimal temperatures.

We obtained sponsorship for the project from Dr. Qun Zhou Sun, a professor of power and energy at UCF. She conducts research in many different focuses, one of which being her research on Smart Energy Infrastructure Systems. She has been teaching at the University of Central Florida for almost ten years and continues to inspire students interested in power and energy. The initial proposal Dr. Sun presented ultimately shaped into our project's final idea- a vent intelligence system for temperature adjustment, or VISTA.

2.2 Current Commercial Technologies and Existing Projects

2.2.1 Flair Smart Vent FLAIRVENT

The Flair Smart Vent is an existing commercially available smart ventilation system that claims to reduce energy consumption by up to 30%. It is available in a wide variety of sizes, with nine different sizes available. The most common ventilation size, the 4x10 model, being priced at \$99. This smart vent requires the removal of a pre-existing ventilation unit and replacing it with the Flair Smart Vent. The Flair Smart Vent has the

option to be powered via battery connection or a wired connection for a more permanent installation, the battery connection however allowing the smart vent to be powered on for a couple years. The Flair Smart Vent works by dynamically adjusting the airflow into the room by utilizing its high-performance temperature sensor. This sensor detects the ambient air conditions and allows cool air to flow in through the vents to match the user's desired temperature. The Flair Smart Vent also connects to a mobile app and a device called the Puck. The Puck is powered by two double A batteries and allows use of smart home applications, such as using Amazon Alexa to adjust the temperature or other smart home applications. The Puck includes an embedded screen that can also be used to adjust the temperature in combination with the mobile app. The app allows for the use of geofencing technology, meaning that the temperature conditions of the vent can be adjusted depending on whether the user is home or not. The vent can also connect to other smart home devices, such as an ecobee smart home device, to allow for extra functionalities. The Flair Smart Vent can utilize the ambient light sensor or occupancy sensors of an external device to create changes in the temperature settings. For example, utilizing this smart technology the Flair Smart Vent can respond to a higher number of people entering a room and reducing the temperature.

With all of the above listed technology for the Flair Smart Vent, it positions itself in the market as a higher-end product for people looking to have extra features in a smart vent. Its ability to connect with extra smart devices and the ability to be configured with an API justifies a higher cost compared to other smart vent devices. However, for people looking for a simpler and cheaper alternative, there exists alternatives that provide similar functionality [1] [2] [3].

2.2.2 BLOWIND Quiet Register Booster Fan

The Biowind quiet booster fan is a cheaper alternative to the Flair Smart Vent that can provide similar functionalities, removing some of the higher-end smart functionalities. For one, the Biowind vent is designed to be quiet, claiming to be at an 18 dB volume at its highest capacity. This positions the Biowind booster fan to be placed in rooms such as a bedroom, where a quiet environment would be more desired. Similarly to the Flair Smart Vent, the Biowind vent must be installed in place of a removed vent. The Biowind fan includes an embedded screen on the vent to allow for adjustment of temperature and fan speed controls. It also comes packaged with a simple remote control that can adjust the temperature and fan speed controls. This is useful in case the vent is placed in an inconvenient spot, such as above a door. However in order to see what the set temperature is, one must look at the embedded screen on the vent since there is no available smart app. There is also no available API or ability to connect to a smart device unlike the Flair Smart Vent. The Biowind can also only be powered via a power cord. This means that it can cause an inconvenience for vents placed away from a power outlet. Despite this, the Biowind vent works similarly to the Flair Smart vent by utilizing a high-precision temperature sensor to dynamically adjust airflow into the room, pumping cool air into the room to set a specific temperature. The Biowind vent is also only sold in a limited number of sizes compared to the Flair Smart Vent, with only four available sizes. The standard 4x10 size compatible with most ventilation systems is listed for \$49. This

price point allows for a more straight-forward functionality for reducing energy costs, removing all of the advanced smart home applications seen in the Flair Smart Vent [3][4][6].

2.2.3 Summary

In summary, both ventilation products advertise their ability to reduce the consumed energy expenditure on air ventilation by utilizing temperature sensors to adjust air flow into a room. Both listed products demonstrate differences in their extra functionalities, the Flair Smart Vent allowing for more advanced smart home functionalities and the Biowind smart vent removing these smart functionalities in favor of a lower price point. Due to the success of the Flair Smart Vent device, it is clear that there is demand for a high-end smart vent device that allows for many home conveniences, yet still offers a solid amount of energy saving due to the dynamic airflow technology. This creates a space in the market for a smart vent device that can include extra sensors not seen in other devices, to allow for the same smart technology without having to rely on the use of external home devices. For our smart ventilation system, we will be incorporating more advanced functionalities than what is seen in these smart devices, and still reducing the overall energy expenditure of the home on air conditioning. This increase in technology will justify a higher price point.

2.3 Goals and Objectives

The main objective for VISTA is to create a semi-autonomous system that will decrease loss and overall energy cost of a home. The ventilation device will incorporate thermal sensors and motion sensors to achieve this goal. More of the goals and objectives incorporated in this project are listed below.

Main Goals:

- Build a smart ventilation system that reduces energy consumption of a home/building.
- Create a smart vent system that can be remotely controlled and function autonomously.

Objectives:

- Implement a mechanical device to open and close an air louver autonomously.
- Detect and respond to room temperature and occupancy.
- Detect and respond to room humidity level.
- Enable users to set parameters of device operation via a mobile device.

Stretch goals:

- The device will be able to recharge the battery from a small wind-turbine that converts air coming through the vents into reusable energy.
- The app will be able to connect to additional vents and be controlled simultaneously.

- The device will communicate with a grid frequency sensor to adhere to peak and valley power usage.

2.3.1 Hardware

VISTA aims to reduce home energy consumption, by way of opening and closing air conditioning vents based on a number of input parameters. Each of these parameters: temperature, occupancy, and power grid usage, and user input need to be ascertained, processed, and then acted upon. Every input is sensed and integrated into the rest of VISTA independently. The following section outlines the fundamental hardware requirements for construction of VISTA.

2.3.1.1 Temperature

To appropriately react to changes in thermal conditions, a temperature sensor must be used. Because VISTA is intended to be fastened directly upon the air vent, a sensor detecting the temperature local to the device would not be accurate to the condition of the whole room. As a result, the sensor must be able to read the temperature of a position in the room from a distance, without physical contact. As the device will be battery operated, this sensor should be low-power. Some standards for devices which meet the criteria which can serve as a guideline for selecting contactless infrared temperature sensors, if that is the direction the VISTA project proceeds with.

2.3.1.2 Occupancy

To appropriately react to changes in room occupancy, a wide range of sensor options can be chosen. Most sensors on the market advertised as occupancy sensors are passive infrared motion detectors. As these are often used in security systems, namely security cameras and lights standards exist as guidelines in motion detector designs. These standards will aid in selecting a sensor which will respond to active occupancy while also decreasing the occurrence of false alarms.

2.3.1.3 Humidity

To appropriately react to changes in humidity levels, there are many different sensor options to research and choose from. Many sensors additionally have temperature and humidity measuring capabilities combined into one part. Due to potential issues from high or low humidity levels- such as mold growth from high humidity, or damage to certain materials from low humidity- including a humidity sensor is an important aspect of VISTA's capabilities. Standards will be used to aid in selecting the most appropriate sensor to fit the needs of the project.

2.3.1.4 Power

Operating VISTA inherently will require a power source. Existing products in the marketplace, likely with somewhat similar energy demands, use batteries and claim a life expectancy of approximately 2 years before the battery needs to be replaced. Primarily for ease of installation, while still meeting energy needs, VISTA will also use a battery system. An IEC standard for judging batteries based on performance metrics may be used to ensure the selected battery can maintain a long lifespan. Other standards should

also be used to ensure the selected battery is safe to use in all possible operating conditions VISTA may be in.

2.3.1.5 Processor

Interoperability of the sensors, mobile app, and the lever switching mechanism will be controlled by a processor. The requirements of the processor are to execute the logic controlling the VISTA device. It will need to interact with the mobile app, meaning it should either have an on-chip interface (SOC) or an external module will be needed. In either case a number of communication technologies may be suitable such as IEEE 802.11 (WIFI)[12], or IEEE 802.15.4-2020 (Low Rate Wireless Networks) [13], Zigbee or many more. A major factor in MCU selection will be that of power usage. As VISTA is battery powered, a low power MCU is strongly preferential to a processor with higher power usage, even if performance is also increased.

2.3.1.6 Open/Close Mechanism

The final goal of VISTA is to open or close the louver (set of slats) on an air vent. This requires mechanical motion. If configured right, this can be accomplished by an actuator, servo, solenoid, etc. Most commercial and residential ventilation covers already have an existing lever mechanism to open or close the louver. VISTA will replace the intended human hand to operate this lever. The mechanical device should only need to apply no more than 5 lbs on the end of the lever to operate under ideal conditions. As the speed at which the louver is not of the utmost importance. A slow moving but high torque motor should be used to use as little power as necessary.

2.3.1.7 Mounting

VISTA must be attachable to an existing air vent. It must not involve any work in removing or replacing dry-wall, a ventilation shaft, or any feature of the room. Mounting the device may be achieved in a number of methods. Adhesives (i.e. Command Strips), suction cups, or clipping onto the existing louvers could all support the needs of VISTA. Adhesive standards outline best practices in adhesive manufacturing, which may provide insight in determining which kind of adhesive, if that is the mounting design VISTA will use, would support the necessary weight.

2.3.1.8 Integration (PCB/Housing)

Integration of all the aforementioned components will be connected through a PCB. As no part of VISTA will be subjected to extreme stress or temperature; nor will any component ever need or be capable of drawing unreasonably high power, PCB design and manufacturing can adhere to the generic PCB design standards. There is one particular concern with the physical interaction between VISTA and it's local environment: dust. Because the device is meant to be installed and left for prolonged periods of time, potentially once every 2 years to replace the battery, an ample amount of dust will have the potential of collecting on the PCB or any of the sensors and components. To reasonably avoid debris from interfering with the device's operation an IP-6X [16] case or similarly sealed housing should be used. While some sensors - particularly the temperature and occupancy sensor will have to be placed outside the case, and connected via an IP-6X or similarly rated grommet or gland. Because VISTA must be

mounted to an air vent, it should be as lightweight as possible to reduce the mounting system failing, which will likely result in the device being broken.

2.3.2 Software

VISTA requires the creation of two separate software endeavors. The two software projects involved are the code that will run on the embedded MCU inside VISTA, and the corresponding smart app that will act as the controller for VISTA. Despite the fact that their implementations will be separate, they must work together to ensure a seamless experience. Firstly, the MCU program must be able to control the ventilation system, and be able to read from all connected sensors. Secondly, the MCU software must be able to respond to changes driven by the corresponding smart app. This is important, as the smart app acts as the only way to interface with VISTA since there will not be an embedded screen on VISTA. For the smart app, it must be able to interact with VISTA over a WiFi connection to change the temperature, switch VISTA between Eco mode or the Bare minimum energy mode, and it must be able to receive information from the VISTA device and update the UI accordingly.

2.3.2.1 Microcontroller Code

The chosen MCU for VISTA will be the ESP32-WROOM-DA. This MCU was chosen because of its integration with Arduino Library, which allows for an easy implementation of WiFi enabled software. It is also an ARM microcontroller known for drawing little power, which is essential because VISTA is battery powered. The development environment for this MCU includes a Hardware Abstraction Library written in C. This will allow for easy implementation of common communication protocols, such as UART or I2C, which will be necessary for communicating with all of the available sensors. One of the most important aspects of the MCU program is to read the status of the thermal sensor and respond appropriately to changes in temperature. For example, the MCU will read the status of the thermal sensor and determine whether the temperature is above or below the maximum and minimum temperature values. If the temperature is not in the range, the MCU will send a signal along a designated port to control the vent lever. The vent lever will open or close depending on if the temperature is too high or too low. This is one example of the many responsibilities the MCU program will have in ensuring that VISTA fulfills its requirements. The MCU must also be read from the infrared and grid sensor, and make decisions about their status. Finally, the MCU program must be able to communicate all of its internal variables with the Smart phone app, such as the temperature and its current mode.

2.3.2.2 Smart Phone Application Code

The Smart phone application will be developed as a web-app written in Javascript. This was chosen to allow for cross compatibility for all mobile devices such as Android and iOS. This application is responsible for providing the user interface for all possible interactions with VISTA. It will include the ability to set the user's desired minimum and maximum temperatures for the room, and will relay this information over WiFi back to VISTA. This application will also include the ability to change from Eco mode to Bare Minimum Energy mode and vice versa. Since this application is the only window into the

state of VISTA, it is solely responsible for informing the user about the current temperature of the room, and its selected mode. Therefore, the application must read from the MCU software in order to display the value of the current temperature. The Smart phone application will also include the ability to force open or force close the vents. Finally, depending on the success of this project's stretch goal, the Smart phone application would also include the ability to connect to multiple VISTA devices simultaneously, and display all UI elements for each connected VISTA device.

2.4 Required Specifications

Table 2.4.1: Specifications

VISTA Specifications	
Hardware	
Room occupancy accuracy	Occupancy indication with 90% accuracy
Response time	Less than 5 minutes
Durability	Device lifetime greater than 2 years
Dimensions	Shall not exceed 11" x 3" x 9"
Weight	Shall not exceed 5 pounds
Affordability	Less than \$400
Power supply	
Battery Life	Battery life shall exceed 3 months
Average Power (Wattage)	Shall not exceed 3 mW
Software	
Communication rate	Shall be 2400MHz
Network Range	At least 50 ft.
Energy Usage	
Home energy usage [17]	Reduced home energy usage by a 5%

2.5 Block Diagrams

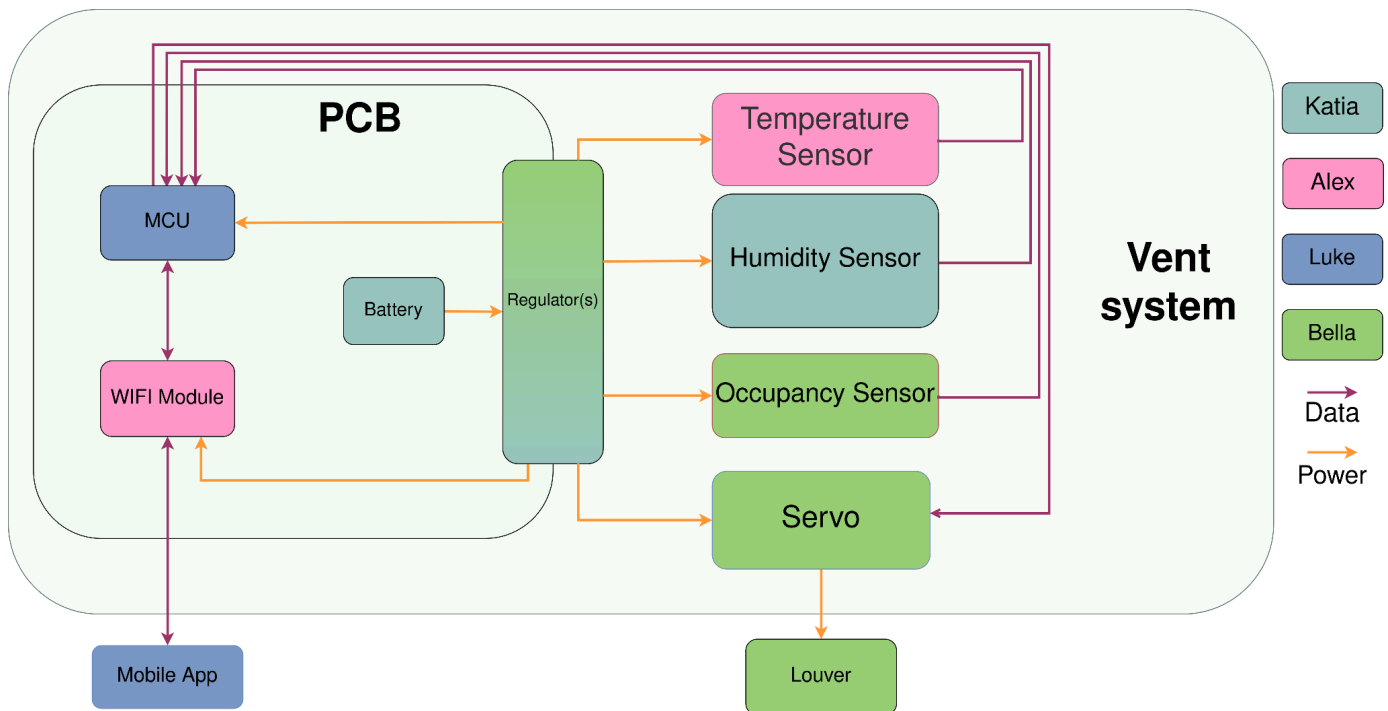


Figure 2.5.1: Hardware Diagram

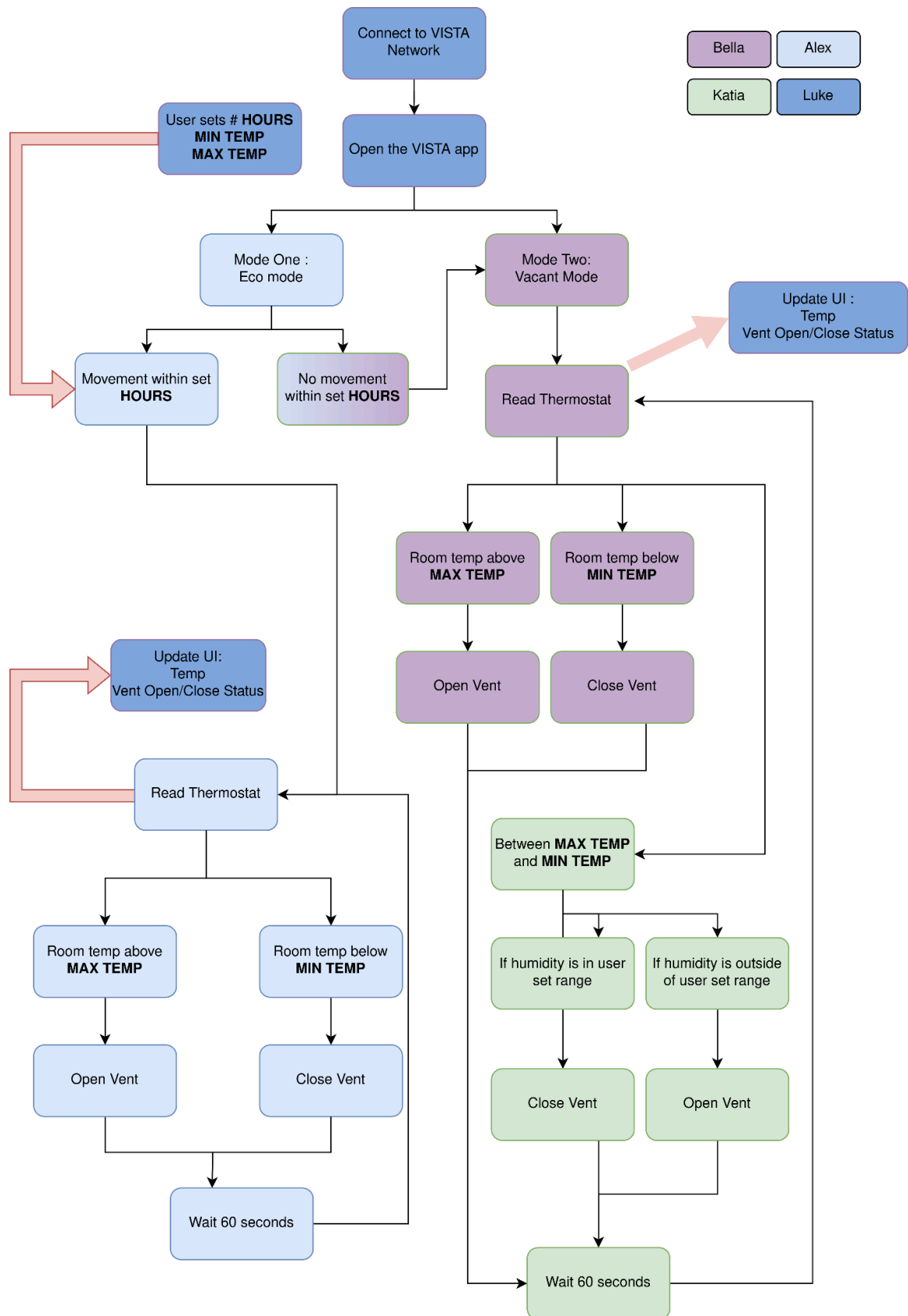


Figure 2.5.2: Software Decision Tree

2.5 House of Quality

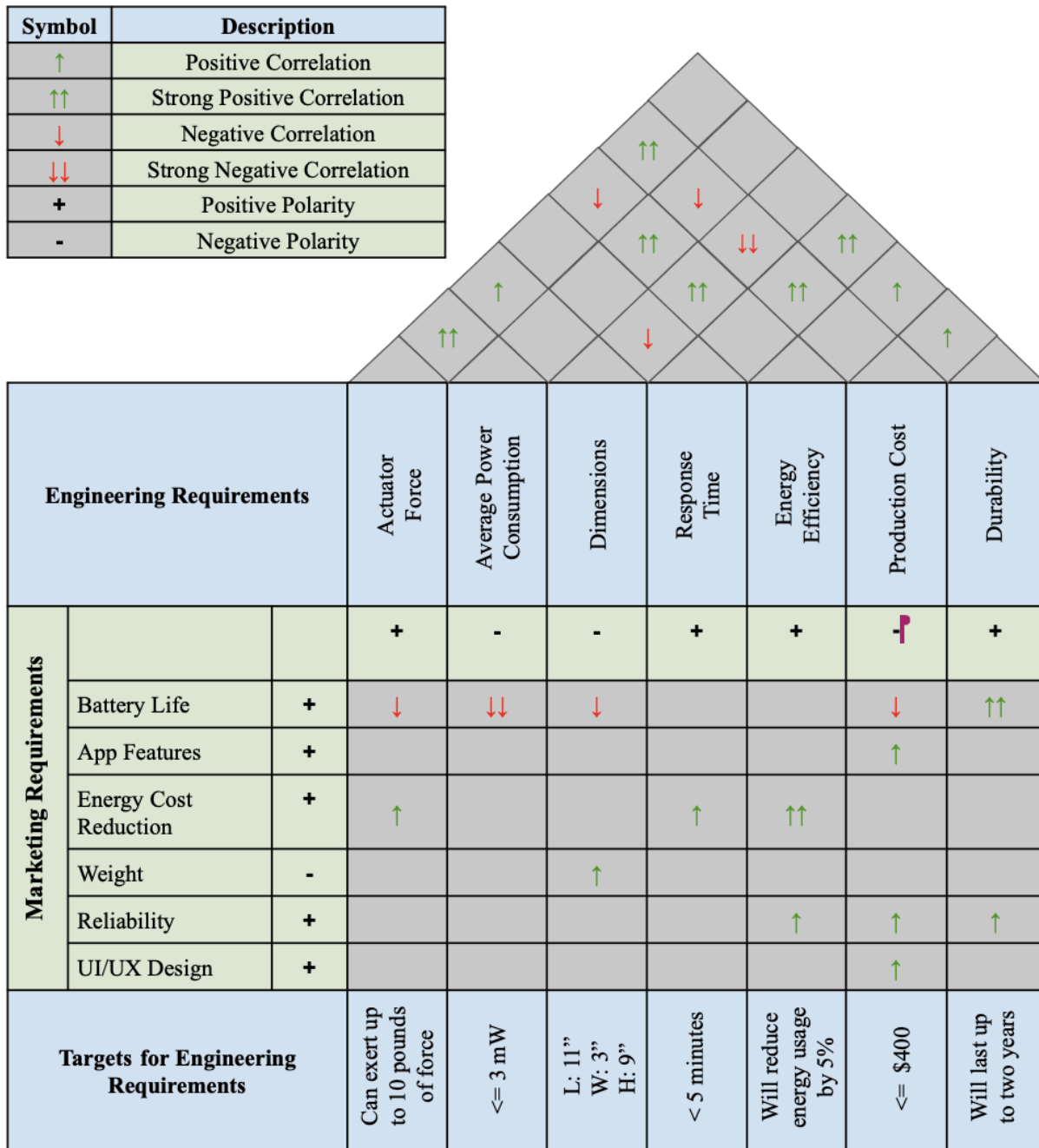


Figure 2.5.1: House of Quality

Chapter 3-Research and Investigation

3.1 Technology Comparison and Selection

3.1.1 Mechanical Control

The main functionality of the V.I.S.T.A. system is the opening/closing of the slats on the vents. Our system will be implemented by adding a new vent system over a pre-existing vent. The new vent system will consist of a system of louvers and registers/slats that are able to open and close to meet the demands of the customer or other factors. There are many technologies that could be used to adjust the vent slats- for instance, a linear actuator, servo, or linear solenoid [19]. Each of these are a device that converts electrical energy into mechanical energy and causes a machine or device to operate. Due to the size and strength needed for this project the mechanical device chosen needs to be small and not have too much linear power. The decision of what device to use will be based on many factors such as force, movement, energy input, and speed. [20]

Linear actuators are used everyday in systems all around us. They can be used in both small and large systems and for a wide variety of machines; for example linear actuators are used in industrial machines, robots, engines, recliners, electric switches, or even table lifts. These devices are typically composed of a DC motor and a gearbox that produces linear motion which extends and retracts a piston rod. The main draw of a linear actuator is its simple operation, if no positional feedback is needed for the system the device will most likely run based on the input voltage. This means when a voltage is applied the rod extends, reverse the voltage and it retracts. Due to the simplicity of the voltage the actuator can be controlled with a PWM signal from the microcontroller. The actuator's simplicity facilitates easier implementation. Another benefit of the linear actuator is the energy efficiency. The VISTA system might only be powered by a couple of batteries, so if a consumer is having to change these batteries every month they may no longer want the product. Because of this, energy efficiency must be kept in mind when deciding which device to use. Electric actuators are energy efficient while still being precise. Actuators only use energy when they are moving, once they are in place they use static loading to maintain their position while other devices may require constant power to hold their position.

While there are many benefits to a linear actuator, there are also disadvantages that must be considered when choosing the proper mechanical device for the system. For instance, electric linear actuators are not suitable in all conditions when surrounded by gasses, chemicals, or high temperatures, the actuators may pose a potential risk. Another issue may be the size of the actuator, the electric motors can be large and therefore unsuitable for the VISTA system. Finally, linear electric actuators may lack precise stopping mechanisms, potentially leading to damage to the existing ventilation system.

The second mechanical device is a servo which is a device that produces rotational motion creating very precise movements. A servo is composed of a small DC motor, a gearbox, and a controller, all housed within a casing with a servo horn extending from the top. If a project requires a specific angle or many different ones a servo is the device to use, they have internal feedback which allows for this precision. Not only can you control the exact angle of servos, they also allow for a specific adjustment speed to be set. This could be useful within our project as the ventilation slats should not be opened or closed

too quickly to avoid breaking the damper. While the precision of the speed and the angle is a nice feature if it is not necessary, or if energy efficiency is more important, a continuous servo could also be implemented. A continuous servo eliminates the feedback mechanism within the device which removes its ability to be set at a certain angle.

The limitations of a servo include, high cost, complex control, and lower efficiency. The precision of the device and feedback elements generally cause a higher investment rate when comparing it to other conventional motors. Servos also require more programming and specialized set up because of how precise they can get. The largest drawback when trying to integrate a servo into the V.I.S.T.A. system may be the lower energy efficiency; because the device needs to run for a long period of time off of small power sources, the mechanics need to be as energy efficient as they can be. Something as tiny as a servo could cause major power loss if it was continually running.

An alternative mechanical device that could be considered is a linear solenoid, which is composed of wire wrapped into an electromagnet coil with a rod (plunger) through the center of the coil. When the coil is powered the plunger is pushed away and when it is unpowered, it is pulled back. One of the primary advantages of the solenoid is its short throw distance, typically ranging a few millimeters or centimeters, which aligns with the project's requirements. However, this limited range may ultimately be insufficient for our needs. Moreover, the simplicity of a solenoid is positive; it operates with just two wires, if voltage is supplied the plunger will extend if not it will deactivate. Despite these advantages, the linear solenoid has drawbacks, such as its cool down period. A solenoid cannot be operated continuously as it will quickly overheat, requiring a cool down period in between uses. This limitation poses a challenge for our project, as rapid changes in vent specifications could require the device to adapt without delay. Given these concerns, the linear solenoid may not be the most suitable choice for the V.I.S.T.A. system.

Table 3.1.1.1: Linear Actuator vs. Servo vs. Linear Solenoid Criteria Comparison

Comparison Criteria	Linear Actuator	Servo	Linear Solenoid
Accuracy		X	
Speed		X	
Energy Efficiency	X		
Simplicity			X
Integration	X		X
Temperature resistance		X	
Size		X	
Rotational capability		X	

After thorough comparisons, the servo proved to be the optimal choice for the V.I.S.T.A. system. The system requires a device that offers precise movement, while also being energy efficient and compact. Among the devices considered, the servo stands out in regard to speed, while still providing precision and accuracy. While its integration with the system may not be as seamless as other technologies, the precision it offers outweighs its complexity. Considering all research conducted on mechanical motion devices, the servo has proven to be the most effective solution, offering an ideal balance of precision, speed, and accuracy that aligns perfectly with the project's technical requirements and goals.

3.1.2 Servo

The VISTA system will be expected to control a lever of the vent system which controls the angle in which the vents are open. This implies that the device used will need to support a specific torque, speed, movement range, and inertia ratio. The Servo best applicable for this project will be measured across these different standards. Torque, which is arguably the most crucial factor, represents the rotational force a servo can produce. Speed is how quickly the servo can rotate to its set position, and movement range is whether you need a servo that can rotate continuously in a full circle or one with a more concise range. Lastly, the inertia ratio is the measure of how difficult it is to change the rotating velocity of an object in motion.

When picking the correct servo for a project the size of the device is the first thing to be considered. Torque and Speed go hand in hand when trying to pick the correct size servo for the project. The relationship between these factors can be observed on a torque curve. There are other common terms that are useful to understand and note when deciding the size of a servo, such as rated torque and rated speed. Rated torque is the maximum torque a motor can produce continuously and rated speed is the top speed that rated torque is available [33].

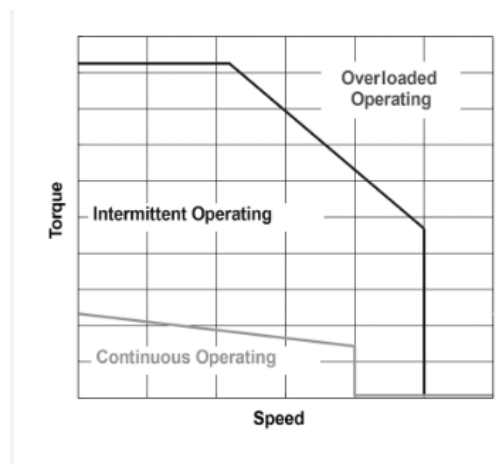


Figure 3.1.2.1: Torque vs. Speed Relationship [75]

The graph above portrays the different operating regions within a servo, these are crucial to understand because if a limit falls within the wrong region of the torque curve, it could be costly for the project. Continuous Torque (RMS torque), is a time-weighted average of torque during a cycle, this needs to fall within the continuous operating region of the curve to be able to maintain a continuous required speed. Peak torque is the most torque that could be required at any one point throughout the cycle. Ideally peak torque would fall in the intermittent operating region as it is not sustainable for long periods of time. If the peak torque falls within the continuous region, it is likely too large for the project. Finally, speed, this factor is just as important as the overall size of the project. If you pick a motor that is too small, it will overheat causing damage; if a motor is too large it will not be cost-effective. Generally when comparing speed and torque, the higher the speed the lower the possible torque. These relationships and factors need to be decided before choosing a Servo size that can accommodate the project.

The other two important factors before choosing a type of servo is the necessary motor range and inertia of the system. The V.I.S.T.A. will be moving in a linear path which implies full rotational movement is not necessary, the servo only needs to be able to move at most 180 degrees. There is a servo that is a mix of linear and rotational which could be useful, but just because the louver only moves linearly doesn't mean a rotational servo is out of the running. The final influence for the type of servo picked is the inertia ratio, which can be further split into motor inertia and load inertia. Motor inertia is part of the servo design and can be found within the manufacturers specification sheet. Load inertia involves all components that are moved by the motor, and is calculated using equations for each individual component. These elements are more important when compared than separate, the load-to-motor inertia is the inertia ratio for a system. Anaheim Automation [76] recommends an inertia ratio of 30:1 or lower, they state the lower the ratio, the better the moto response.

$$Inertia\ Ratio = \frac{J_l}{J_m}$$

J_l = Inertia of load reflected to motor ; J_m = Inertia of motor/rotor [77]

With all the key factors for selecting the appropriate servo now thoroughly discussed, it is time to compare the various types and choose the optimal one for the system. There are five main types of servos that could be applicable: DC and AC servo motors, Positional and Continuous Rotation Servo Motors, and Linear Servo motors [78]. Each type offers unique advantages and disadvantages that must be carefully considered when selecting the best option for the V.I.S.T.A. system.

A DC servo motor is one of the oldest types of servos. The frequency of the electrical input controls them, they are accurate, fast, and responsive to start/stop signals. The AC motor can be controlled by both voltage and frequency. They have high accuracy and precision in movement, speed, and position. Positional Rotational servos are capable of 180 degree rotation, which makes it one of the most common. Physical stops inside the mechanism protect the sensor by preventing excess turning. Continuous rotational motors are similar except they can rotate in any direction indefinitely. The control signal

measures the speed and direction of rotation, both of which can be controlled via the command signal. Lastly, the linear servo motor has an extra set of gears that changes the output of the shaft's movement from circular to back and forth.

The system is compact, as it needs to fit on and near a vent, and energy efficient is a priority. Therefore, the servo must consume minimal power and be easy to integrate. Additionally, since the servos will operate the louvers at relatively low speeds with light inertia, they will not require high torque or speed. These factors will be important when determining the most suitable servo for this application.

Table 3.1.2.2: Servo Technical Specifications

Technical Specifications	SG90 Micro [79]	FS90R Micro [80]	SG92R Micro [81]	DS3218 [82]	ES08MAII [83]
Operating Voltage	4.8 V	4.8 V	4.8 V	4.8 V	4.8 V
Torque	1.8 kg/cm	1.3 kg/cm	2.5 kg/cm	19 kg	1.6 kg/cm
Operating Speed	0.1 s/ 60 degrees	0.5 s/ 60 degrees	.1 s/ 60 degrees	.16 s /60 degrees	.12 s / 60 degrees
Gear Type	Plastic	Plastic	Plastic	Metal	Metal
Rotation	180 degrees	180 degrees	180 degrees	270 degrees	180 degrees
Weight	9 g	9 g	9 g	60 g	12 g
Dimensions (L x W x H)	22.2 x 11.8 x 31 (mm)	23 x 12.5 x 22 (mm)	23 x 12.2 x 27 (mm)	40 x 20 x 40.5 (mm)	23 x 11.5 x 24 (mm)
Price	\$7.50	\$7.50	\$15	\$53 (for 4)	\$7.75

Based on the comparison table above, the FS90R Micro Servo will be the best fit for the Vista system. This servo is lightweight, low-cost, high torque, and low power which is perfect for our application. The SG90 micro servo was a close second, the only outweighing factor being that the MG90S has a lower torque. While this is not a dealbreaker if the FS90R is lighter, cheaper, and consumes less power it is a clear winner for the system.

3.1.3 Controller Type

Deciding on an IC (integrated circuit) is essential in the functionality of opening and closing the vent slats through an actuator. FPGAs and MCUs are two commonly used

integrated circuits for digital design and embedded systems. Both options serve the same basic purpose of allowing a user to determine the desired function to meet specific demands of a product or project. Moreover, both perform the necessary specified functions and are embedded within devices or larger systems. Deciding between the two relies on a variety of factors including programmability, processing capabilities, power, versatility, cost, etc.

FPGAs offer multiple advantages over MCUs, namely processing multiple tasks at once; parallel processing. Most microcontrollers only have one processing/execution unit, where FPGAs allow for more [21]. The parallel architecture of configurable logic blocks and interconnects in FPGAs allows for parallel processing while MCUs are ideal for sequential processing. Having multiple execution cores or units allows a processor to perform parallel processing through which different parts of a larger task can be computed at the same time, which is ideal for higher complexity operations- another advantage of FPGAs [22]. Breaking up the different parts of the larger tasks additionally reduces computing time by spreading the work out among the multiple processors.

Another advantage of FPGAs is the flexibility that allows for quick reconfigurations. This offers more versatility than microcontrollers, which are inherently more difficult to reconfigure for a different task/purpose. FPGAs can be reconfigured at the hardware level where the hardware of MCUs cannot be reprogrammed. Thus, FPGAs offer greater versatility due to the fact that unlike microcontrollers, users can configure and then reconfigure the chip's architecture to meet task demands [23]. MCUs have to read a line of code at a time, which raises concern for the bottlenecking of tasks/operations. Therefore, for situations that involve constantly changing requirements and newly emerging standards, FPGAs are a more suitable choice over MCUs.

Even with all the reasonable support for using FPGAs over MCUs, there are a lot of reasons to consider using an MCU instead. The reconfigurability and parallel processing capabilities of FPGAs offer a great deal of advantages for high complexity processing needs, which is useful for large-scale projects. However, for a project or task that requires lower complexity processing capabilities, MCUs offer many advantages over FPGAs. To start, MCUs are significantly easier to program due to their inherent simplicity. The complex processing offered by FPGAs requires more than just a basic understanding of a coding language to program. Additionally, they require keeping track of large amounts of variables and understanding a hardware description language. MCUs on the other hand are highly suitable for lower complexity applications, as they require only a basic understanding of a coding language to be programmed. Programming a microcontroller only requires using an integrated development environment (IDE) to use any high level language to perform the necessary functions/tasks, where programming an FPGA involves hardware architecture design, writing register-transfer logic, verification, synthesis, integration of pins, clocks, signals, etc., implementation, and debugging/testing [24].

Another advantage of MCUs over FPGAs is the power consumption. MCUs are optimized for less power consumption than FPGAs, which makes them suitable for battery power

operations and applications. Energy efficiency of microcontrollers over FPGAs is a significant advantage in applications where power consumption is a concern. Additionally, the compact design offered by a microcontroller holds value in instances where size and weight is a concern/important factor. MCUs have all the necessary components integrated onto a singular, small chip, where the greater complexity of an FPGA, which can run multiple chips in parallel, requires more space.

Due to the lower complexity and smaller size of an MCU compared to an FPGA, microcontrollers are much more cost effective. MCUs are quicker and easier to mass produce with the lower quantities of components that they require to run computations. Additional components or peripherals are unnecessary when using MCUs and therefore can assist in a large cost reduction in an overall application/project. And even with significantly less components than FPGAs, although FPGAs offer a high level of versatility, microcontrollers are flexible in that though they cannot be reprogrammed on the hardware level, they are easily reconfigured on a software level to allow for updates, optimization, or entire reprogramming.

Table 3.1.3.1: MCU vs. FPGA Criteria Comparison

Comparison Criteria	MCU	FPGA
Energy efficiency	X	
Ease of use	X	
Processing capability		X
Affordability	X	
Versatility/Reconfigurability		X
Computation time		X
Simplicity	X	
Integration	X	
Size/Weight	X	

Through considering the many advantages and disadvantages of both MCUs and FPGAs, the scope of the project is met more efficiently through using a microcontroller. The usability, cost efficiency, and power consumption of MCUs fit all the application requirements of VISTA, where the complex additions that FPGAs offer go beyond the necessary scope of the project, which in turn presents disadvantages in areas like cost and energy efficiency while also not being used to its full potential.

3.1.4 MCU

Due to a multitude of specifications regarding MCUs and FPGAs, using an MCU was determined as it better fits the scope of VISTA. There are many different options for MCUs with all different specifications and qualities. Some popular MCU choices include the Arduino Uno, STM32L475, ESP32, and nRF5340.

The Arduino Uno is a microcontroller that offers a beginner-friendly IDE (integrated development environment) that is easy to use and program in. It is relatively inexpensive in terms of cost compared to other MCU boards, and has a great deal of versatility [84]. Not only does it have many resources on how to code due to its popularity, but it also allows for rapid prototyping and iteration. There are some drawbacks however, as the Arduino Uno has limited processing power and may struggle to handle more complex algorithms. Therefore, it may not be suitable for tasks or applications that require greater intensity and complexity. Other, more advanced MCUs may have faster processing speeds and greater memory capabilities and capacities.

The STM32L475 is another option in terms of MCUs that is part of the STM32L4 series of ultra-low-power and performance MCUs. It offers 256 KB to 1 MB of flash drive and 64-100-pin packages [84][85]. The STM32L475 also has a memory range that can easily be extended using SDIO, Quad-SPI, and FSMC interfaces. Additionally, it improves the existing low power performance with the Arm® Cortex®-M4 core with DSP and floating-point unit (FPU) at 80 MHz. Overall, the STM32 series has excellent power efficiency, lots of flexibility with application range, and performs very well with code execution and transfer/processing of data. In contrast with the Arduino Uno, the STM32L475 has a wide range of capabilities (performance, memory, peripherals) that allows it to be a very suitable choice for more complex applications. A major advantage of this option, additionally, is that it is available for free to be used in VISTA (already owned by the team).

The ESP32 is an MCU that, like the STM32L475, consumes low power making it very efficient. It has not only a high level of integration with many built-in components, but also has two 240MHz cores- each with a Tensilica Xtensa 32-bit LX6 microprocessor [86]. And similar to the STM32L475 once again, it has an ultra low power mode that can be used for simpler tasks. Additionally, the wifi and bluetooth capabilities are built-in. All in all, the ESP32 is very inexpensive and versatile, and can be used for a wide variety of applications due to its powerful capabilities. However, the extent of the uses does go beyond the necessary applications of VISTA- and since the technology is newer, there are more kinks and bugs that one may come across and less support to fix them.

The nRF5340 microcontroller is a wireless SoC (system on chip) that combines a high-performance application processor with a fully programmable, ultra-low-power network processor. It can withstand temperatures up to 105 degrees Celsius and includes features like USB, high speed SPI, and Bluetooth [87]. A key factor of this option is the security, supported by an Arm CryptoCell-312, a solution for low power designs. It enhances security features of the SoC by protecting the confidentiality and authenticity of

the code and data that is meant to be protected. The main goal of the nRF5340 is to combine the features mentioned previously with better performance and memory while minimizing current consumption, in order to offer a competitive product for many users. Like the ESP32, there are a lot of powerful, built-in features that may go beyond the scope of requirements for VISTA, but that does not necessarily take this option out of the running.

Table 3.1.4.1: Technical Specifications Comparison for MCU Options

Technical Specifications	Arduino Uno	ESP32-S-WROOM	STM32L475VG T6	nRF5340
Chip	ATmega328P	ATmega328P	ARM Cortex-M4	Arm Cortex-M33
Memory Size	32 KB	32 KB	1 MB	
RAM size	2 KB	2 KB	128 KB x 8	512 KB
Flash memory	32 KB	32 KB	32 KB	1 MB
Clock speed	16 MHz	16 MHz	16 MHz	64 MHz
Power Consumption	Low	100-200 mA	Ultra-low	3.2 mA
Bluetooth	No	Yes	No	Yes
Supply voltage range	6 - 20 V	3.3 - 3.6 V	1.71 - 3.6 V	1.7 - 5.5 V
Operating temperature	-40 - 85°C	-40 - 125 °C	-40 - 125 °C	-40 - 105 °C
Cost	\$1.61	\$3.05	\$9.67	\$7.27

From comparing and contrasting the multiple MCU options, it can be concluded that the most suitable option for VISTA is the ESP32. This is primarily due to the advanced capabilities that allow for more complex applications and the readily available and easily integratable capabilities. Additionally, the ultra low power allows for efficiency with power and energy which is beneficial in long-term scenarios.

3.1.5 Temperature Sensor

The primary function of the entire design is to reduce energy consumption while maintaining a set temperature. Detecting that temperature can be achieved in an endless number of ways. The effects of heat (temperature) and its interaction with the environment comprise countless fields in science and engineering. As the VISTA is not intended to be in any extreme use cases, extra caution to accommodate these unlikely bounds are not a factor in deciding on a technology or methodology a temperature sensor uses. To clarify, extremes such as temperature, pressure, water, vibrations, motion, etc; are all not a factor in technology selection.

The most important factors in deciding on a temperature sensing technology are a result of the intended design of the rest of the VISTA system. Since one of the primary selling points of the VISTA is the potential to reduce costs, the frequency of battery replacements must be kept to a minimum. This means minimizing power consumption must be a chief priority when selecting a sensor technology.

A secondary consideration that must be accounted for is to ensure the temperature being sensed is the correct temperature in the first place. Due to the inherent nature of the design; the sensor module will be located directly on, or near the air vent. This locale is unlikely to provide an accurate temperature reading of the dissipated temperature across the overall room. This inherent issue has two practical workarounds.

The sensor module could be detached from the rest of the system and communicate back to the main device. This would involve the construction of a secondary PCB and enclosure. If the sensor module communicates via a wired connection to the main unit, the user of the device would be responsible for mounting and placing the sensor module. Utilizing a wireless connection would mean simpler installation, however it would introduce the added complexity of a wireless communication module, an extra battery and present many more potential sources of errors.

Many types of sensors can fulfill the sensing needs. Thermistors are amongst the most simple and widespread temperature sensors [25]. All thermistors operate on the principle that the resistance of a given material changes according to the material's temperature. Thermistors all use a material with a known resistance profile across a spectrum of temperatures. Packaged thermistors output a temperature in Celsius, Kelvin, or Fahrenheit but internally make an approximation of the relationship between temperature and resistance. In the case of the VISTA, most off the shelf thermistors are more than accurate enough for the use case.

Commercially available thermistors come in a few main varieties. There are two common types of component packaging: epoxy and glass-encapsulated [26]. Epoxy thermistors seal the thermistor material in epoxy while the glass-encapsulated thermistors seal the thermistor material inside a layer of glass. Epoxy packaging aids in resilience to moisture effects. Similarly, glass encapsulation adds a small layer of insulation around the resistive material [27]. This reduces sudden temperature fluctuations, often due to moisture, wind,

etc, and as the insulation is more material which needs to heat/cool before any energy is added to the thermistor, it results in a smoother, more consistent reading. These packages are not mutually exclusive. Some thermistors can be packaged inside both glass and epoxy to better ensure reading stability [28].

The other attribute of off the shelf thermistors are the based on the types of contacts. Depending on the application, it may be necessary to obtain a temperature reading of the local air, a specific material, or as is the case of the VISTA- the temperature of air located a significant distance away from the circuit assembly. Manufacturers sell devices for many of these common use cases. The most common type of thermistors known are called disc and chip thermistors, for thru hole and SMT respectively . This is due to the way they are manufactured, where a material is cut or deposited into a disc or small cylinder, with two opposing sides in contact with a conductive pad. The device is then sealed in one of the aforementioned packaging techniques. Often found in kitchen thermometers (amongst numerous other applications) *probe thermistors* are able to sense the temperature of a material by making physical contact between the material and the probe. These can vary in size from a few millimeters to a few meters.

Probe thermistors are the first suitable candidate for the VISTA use case. Probes are readily available and can be quite accurate in readings. The accuracy of probe thermistors can be measured by comparing the specified resistance/voltage variation and the corresponding temperature changes. The larger the resistance/voltage value changes per unit change in temperature indicates a more accurate reading.

Utilizing a probe thermistor does have some drawbacks. The biggest concern is again, that of mounting. Probe resistors are sold with the probe attached either directly to the SMT/Thru Hole component or connected via cable [29]. PCB mounted probes are typically only a few inches to a foot in length. Any longer in length would likely lead to failure as the longer the probe extends, it exerts more torquing force at the device and PCB. With these considerations in mind, the only valid thermistor type remaining is a cable connected probe.

Cable connected probes work around the main shortcoming of a component mounted probe. Using a cable of varying length, the probe can be mounted separately and can still be read without utilizing any communication protocols or processing overhead. As previously mentioned, this does come with the drawback of requiring the system user to separately mount the probe device and the associated cable; however, with a suitable enclosure design, this snag may be avoided. The enclosure could be designed with a mounting point for the probe, located away from the and be pre assembled, foregoing the need of the user to mount a second device.

A suitable alternative to a thermistor sensor may be an infrared based contactless sensor. Contactless temperature would be ideal in the VISTA as the sensor could be mounted on the PCB with the rest of the device and remotely read the temperature from a distance. Commonly found in handheld fever thermometers, the sensor measures temperature by detecting the resistance/voltage change of a specific material whose electrical properties

change as a result of infrared radiation.

The infrared sensor's biggest potential drawback is effective range. Most off the shelf infrared sensors are only effective up to five feet. This is due to the inherent exponentially increasing size of the sensed area growing as the distance to the sensor increases [30]. This effect can be seen with a flashlight's beam pointed at distant surfaces. However, this drawback may not be significant as the sensor will read closer to an average of the covered area. This means the reading will have negligible effects to localized heating or cooling sources such as a window or hot plate being in the view of the sensor.

Infrared sensors are commonly sold in two varieties-analog and digital readings. Analog components output a continuous reading, typically based on the resistance/voltage measured across the infrared radiation susceptible material. Digital devices however, are limited in accuracy (eg 10bit, 12 bit etc) and communicate over a part-specific protocol (SPI, I2C etc). Either type of device is suitable for the VISTA, as the accuracy lost from an analog to digital translation is negligible. However, for ease of use, a digital output device is slightly preferred.

Semiconductor temperature sensors are another type of temperature sensor which operate under a similar principle to thermistors. As the temperature of the semiconductor material changes, the electrical characteristics react as well [126]. This results in similar drawbacks to thermistors where they are limited to measuring local temperature.

Additionally, semiconductor based temperature sensors are typically able to provide a level of accuracy suitable for most applications. However, due to the inherent nature of the semiconductor material, and the common packaging materials, two seemingly identical sensors will often provide different readings[127]. Semiconductor temperature sensors also cost substantially more despite having similar specifications that are relevant in application to the VISTA design.

Table 3.1.5.1: Thermistor vs. Infrared Criteria Comparison

Comparison Criteria	Thermistor	Infrared	Semiconductor
Accuracy	X	X	
Contactless Sensing		X	
Ruggedness	X		X
Digital Output (depends on specific part)	X	X	X
Additional Installation	X		

Additional Structural Design Considerations	X		
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As a result of the advantages of an infrared sensor in comparison to any thermistor or semiconductor based sensor, the infrared sensor is undoubtedly preferred. The added complexity, components, cost and effort needed to design the VISTA to use a thermistor based sensor, all for no measurable benefit over an infrared sensor is unnecessary. An infrared sensor will function as close to a “plug-and-play” sensor as possible for a sensor to remotely sense temperature. The device could not be simpler, it just needs to be mounted on the PCB and have the power and data lines connected appropriately.

3.1.6 Contactless Infrared Temperature Sensor

Infrared temperature sensors are definitively the foremost option for the VISTA. However, as previously mentioned, there are many different varieties and types of infrared sensors. Every temperature sensing device drives either a digital or analog signal. For simplicity's sake, a digital output is significantly easier to interact with. Nearly every digital sensor can be interfaced with at least one of the common interface types: I2C, UART, or SPI. Using a standard interface type will maintain design consistency and cohesion.

An additional consideration comes with device package types. Infrared (IR) sensors are sold in two common packages— tube/can, and panel. Both package types are generally capable of achieving the same specs, although tube/can packaged devices support larger lenses. For manufacturers, decreasing the field of view, which inherently requires a larger lens, can be easily accommodated in a tube or can package by just extending the length of the can. Flat panel packages with comparable lenses do exist, however they are less common, harder to find and more costly. It is worth noting that Tube/Can devices are almost exclusively through-hole while panel devices are almost exclusively SMT.

Having a smaller field of view (FOV) means the device is able to sense a smaller area from a distance, relative to a smaller FOV device. This is ideal for the VISTA, as objects closer to the ventilation system are likely to obscure the temperature to be slightly colder than the true ambient temperature. Additionally, the design of the sensor should be hardened against local temperature variations or noise introduced as a result of the device operation. In real world situations, electricity generates heat, especially batteries, (which will be present on the VISTA PCB) therefore resilience to these irregularities is a must.

Melexis Technologies MLX90640 and MLX90641 Series

A quick search on DigiKey first yields the Melexis MLX90640 and MLX90641 series sensors. These sensors use a planar array of sensors (32x24 and 16x12 respectively) where each individual sensor independently generates a temperature reading [89]. This feature does add accuracy and the ability to identify specific regional temperatures. This means a specific region, such as a window, could be disregarded in the ambient

temperature readings. Reading and analyzing the full sensor data adds a magnitude of complexity to achieve a simple task of reading the ambient temperature of a room. For this reason, these sensors, or any IR array based sensor is not a suitable fit for the VISTA.

Melexis Technologies MLX9061 Series

The thoroughness of the documentation associated with the previously analyzed MLX90640 warranted a search for an alternative device from the same manufacturer, in hopes an equitable quality of documentation was present. This search yielded the MLX9061 series of IR sensors. Utilizing just a single IR sensor, this device meets every technical criteria the sensor must meet. The device is low power, using less than 2.5 mA in the 3V model [151]. Additionally, the device is sold with different lens sizes, from 35°, down to as small as 5°. This could perhaps be the perfect device for the VISTA.

The only downsides with the MLX9061 series is the cost and availability. Currently, the only models available on most major distributors is the 3V 35° model. This focal length may be suitable, however the other major drawback is the price of a single unit is over \$25.02 at time of writing. This is quite expensive as throughout the prototyping process purchasing more than one may be necessary. A better option would match, nearly match or exceed the technical specifications of the MLX9061 while being available and more affordable.

TE Connectivity G-TPMO-102

TE Connectivity manufacturers perhaps the most suitable sensor for application in the VISTA. The G-TPMO series is comparable to the MLX9061 series of sensors, but readily available at a significantly cheaper price. This price difference is because the G-TPMO-102 does not have an additional lens to decrease the field of view. The standard FOV is 88°, which is likely to be narrow enough to provide an accurate reading of true ambient temperature. The documentation on the G-TPMO-102 is also extensive.

The G-TPMO-102 performs the ADC conversion internally and goes into detail on this process in the data sheet. Certain parameters are configurable and the necessary formulas for determining those values are explained in detail.

Table 3.1.6.1: Infrared Sensors Criteria Comparison

Comparison Criteria	Melexis Technologies MLX90640/90641 Series	MLX9061 Series	TE Connectivity G-TPMO-102
Accuracy	X	X	X
Interface		X	
FOV	X		X

Cost	X	X	X
Power		X	

For the cost, simplicity, and quality of documentation, the MLX9061 will be used. The MLX9061 features an extensive list of functions. The sensor is able to interface to another device via PWM or SMBus. Interfacing via SMBus allows the internal registers used in the sensor operation to be customized. These registers control the PWM functionality, sensitivity, calibrated range, SMBus address, and time between reads. The sensor can then also be commanded into a low power mode, which would be ideal for the VISTA. Another major benefit to the MLX9061 is the sensor already contains signal filtering features internal to the package. The output reading is resultantly consistent and accurate.

3.1.7 Occupancy Sensor

When deciding the most suitable occupancy sensor for the system, it is important to evaluate various options based on their accuracy, energy usage, and integration capabilities. The system could use various sensors such as passive infrared, bluetooth low energy beacons, or thermocouples. These sensors will be compared based on these criteria to determine which best meets the needs of the V.I.S.T.A. sensor. The sensor will be used to determine if someone has not occupied the room for more than a certain amount of time, that of which can be set by the user. This functionality can be used to conserve energy within the home while also keeping the room within a given range of temperatures [31].

One sensor that could be used is the bluetooth low energy (BLE) beacons [32], a device that uses bluetooth low energy to measure and send occupancy data to a smartphone or other device. The ability to immediately communicate with smartphones could be useful within the V.I.S.T.A system due to its already established user interface. BLE occupancy sensors use technology to determine how many occupants are in a building. The main benefits of the BLE sensor is its energy efficiency, low cost, and accuracy. Energy efficiency is a critical aspect of our project, as the system is designed to operate for over three months, potentially on just a few batteries. This necessitates careful attention to minimizing energy consumption throughout the design process. The bluetooth low energy is more energy efficient than most due to its sleep mode, which causes the device to only use power when waking up to exchange data when necessary. The BLE device was also designed to operate at a much lower power level than standard bluetooth, contributing to its energy efficiency. This device is also better suited for indoor locations, they have a short range but are therefore more accurate. Due to the scope of the vent, the range would not have to be very long for a sensor. Lastly, the low cost of these sensors is a consideration. In designing a system where small expenses can quickly accumulate, finding opportunities to save is essential.

While there are many advantages to BLE sensors there are disadvantages that need to be taken into account when deciding the best sensor for the project [33]. Some of these include, Lower data rates and environmental impacts. The device is designed for low power systems and therefore has a reduced data rate, this means that it cannot transfer data as quickly as other wifi or cellular. The other main disadvantage of this type of occupancy sensor is the environmental impacts, and not as if they are bad for the environment but rather what environment they are in could cause issues. The performance of the sensor can become degraded by obstacles such as walls or bodies. These limitations—slower data transfer and potential interference from physical obstacles—must be carefully weighed against the advantages when determining the most appropriate sensor for the V.I.S.T.A. system. Ultimately, while BLE sensors offer energy efficiency and low cost, their reduced performance in certain environments could hinder their reliability within our project.

Passive infrared sensors are another device that could be used to detect the occupancy within a room. These sensors used infrared radiation to detect motion and occupancy within a space, when a person enters the room the sensor can detect the increase in temperature from the person's body heat. Passive infrared sensors have a wide range of detection, are energy efficient, and can integrate into a microcontroller system. These sensors have a field view of 360° [34] and are usually designed to be near the ceiling which is where ours would reside if picked. These sensors can also detect infrared energy over 100 feet away, this is significantly more than our project needs, but this is helpful if the project were to transition into a larger space. Passive infrared sensors also have relatively low power consumption, only about .8 watts to 1 Watts. They can also operate within sleep mode, standby mode, and mask mode [35]; each of these can help limit power consumption of the system. Sleep mode will put the sensor within a low-current state when it does not detect movement; this mode could be useful within the scope of the V.I.S.T.A. system. Lastly, passive infrared sensors are easy to install, they are small and lightweight which is ideal for our system. While these sensors possess a lot of good qualities they also possess some negative ones that could hurt the functionality of our system.

Passive infrared sensors come with several limitations, including limited sensitivity, a line-of-sight requirement, and inaccuracies [36]. One major drawback is their difficulty to detect very slow-moving objects, which could impact performance in certain scenarios. They also have trouble operating in temperatures above 95° F, as warmer conditions diminish their sensitivity and affect detection accuracy. Given that the system is intended to operate in Florida, where temperatures can exceed this threshold, this could present challenges. However, since the indoor environment will typically be maintained below 95 degrees, this may not entirely disqualify the sensor. Another concern is the sensor's need for direct line-of-sight; while it performs well in simple open spaces, it may encounter issues in rooms with irregular layouts, particularly in corner areas. Compared to other sensor types, PIR sensors also tend to be less accurate due to external factors such as temperature changes, bugs, or wind. Fortunately many of these factors can be controlled within an indoor setting. The advantages and limitations must both be carefully considered within the context of the project's specific requirements and environment.

The last sensor in consideration for the V.I.S.T.A. system is a thermocouple sensor. This type of sensor uses the temperature of the space to determine if it is occupied. This sensor is similar to the passive infrared sensor in the respect of using temperature to determine occupancy; but while these sensors are similar in that way, each still possesses its own advantages and disadvantages. Some advantages of using a thermocouple occupancy sensor include, fast response times, low cost, and wide range of environmental settings. The thermocouple sensor has a quick response time that makes communication between the sensor and the user face more accurate and reliable. The sensor is also small which reduces the overall cost of the project. Due to the simplicity of the design, this sensor is easy to integrate which could benefit the overall ease of the project. These sensors also have a wide variety of temperatures under which they can operate, they are known to be more versatile in this manner than most sensors. Thermocouple sensors can operate accurately anywhere from cryogenic temperatures to extremely high ones. This is a feature that is often uncommon when comparing sensors which sense heat for occupancy.

While the thermocouple sensor can operate in a wide range of temperatures, respond quickly and not break the bank; it still has some aspects which may not be as useful for our project. Thermocouple sensors are less stable and have a non-linear output. These sensors while being able to operate in extreme temperatures will over time drift, this can cause issues within the vista system, especially if the occupancy mode is being used often. The other issue with the thermocouple sensor is the non-linear output, this is a less common feature amongst sensors and therefore may cause issues when trying to integrate it into our system. As the sensor itself offers many of the same features as the other occupancy devices, the non-linear output feature might make integration more trouble than the device is worth.

Table 3.1.7.1: Thermistor vs. Infrared Criteria Comparison

Comparison Criteria	BLE sensor	Passive Infrared	Thermocouple
Energy efficiency	X		
Different Modes		X	
Size	X		
Accuracy		X	X
Distance		X	
Environmentally compatible		X	
Fast Response			X

Integration Simplicity		X	X
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While all sensors possess their own unique features that could benefit the project, the best sensor for our scope is the passive infrared sensor. This sensor is small, energy efficient and accurate. The ventilation system will only be interacting with a short room so the large range of the sensor is not extra useful for the scope of this application, but can be used to aid expansion. This sensor also offers different modes that it can operate in, this will help reduce overall consumption. Overall this sensor is small, easy to integrate, and can ready occupancy from very far away. Making the passive infrared sensor the best for the V.I.S.T.A. system.

3.1.8 Passive Infrared Occupancy Sensor

One mode of the VISTA system will give users the ability to lower their air conditioning usage while they are away. This will be called “Travel Mode”, it will read the occupancy in a room and adjust the temperature accordingly. If there have been people in the room within a set amount of time, then the temperature will remain where the user originally set it. If there have not been people in the room, then the temperature will adjust accordingly. For this mode to be feasible, the VISTA system must have some sort of occupancy sensor. After lots of research a passive infrared sensor was found to be the best type of occupancy sensor. Next specific infrared sensors will be compared and the best one for the system will be used in application. The best sensor will be chosen based on features such as coverage range, power consumption, accuracy, working temperature, and integration.

Coverage range is one of the criteria for choosing a specific passive infrared sensor. The coverage range is affected by the type of lens the sensor is using, the lenses are individually segmented to see different sections of the room; and each segment is turned to cover an individual space within the room.

The next comparative is power consumption, our system is designed to be energy efficient for a long battery lifetime. Whichever PIR sensor is chosen needs to also be energy efficient which generally means low power consumption. While we do not want the power consumption to be astronomical, the passive infrared already is a cut on power usage, so if a sensor uses a little bit more power but is better in every other way, then it is still a possible component.

Passive infrared sensors are about 92% effective [92], but accuracy can vary depending on use cases and their environment. A PIR sensor can estimate occupancy count with 91% accuracy [93], this is a relatively low error but if a sensor is put in an oddly shaped room it will be less efficient as they can only read infrared of objects directly in their line of sight. This issue could be solved with the possibility of implementing a ceiling mounted sensor or placing the sensor at a specific angle where it can see most of the room.

If a sensor does not have a wide range of working temperatures it is not suitable for our project. Living in Florida a room with direct sun can get in the high 90's, maybe even reach 100 degrees if there is minimal air conditioning. This could be common for our prototype so the sensor needs to have a wide range of working temperatures. There are two different types of PIR sensors when relating them to active temperature, sensors with temperature compensation and without [94]. Passive Infrared sensors with temperature compensation can adjust their sensitivity to compensate for temperature differences within a space. Under ideal conditions, the average human has a body temperature of 36.6° C which differs from the ambient room temperature; this allows sensors to recognize the difference between the human and the room. In situations where the ambient room temperature may be closer to the average body temperature, the extra compensation can help a device note a body walking into the room. The other type of passive infrared sensors are those without temperature compensation, these can be affected by changes in temperature, which can lead to false alarms or missed detections [95].

The final comparison criteria for the passive infrared sensors is the integration type. There are many different types of mounting/integrations for large scale occupancy sensors such as lights. But due to the size of the VISTA system, the occupancy sensor will be small enough to fit on a PCB. There are two main options for integration, SMD and through hole [96]. SMDs are mounted on the surface of the board, while through hole components have pins that are inserted into the holes in the PCB board. The difference in integration isn't the biggest issue, but more what each integration type implies. Through hole components are generally larger, more reliable, and easier to repair. SMDs are smaller, assembled into the PCB, and are high-speed. Each of these comparisons must be taken into account when comparing different types of passive infrared sensors.

Table 3.1.8.1: Occupancy Sensor Technical Specifications

Technical Specifications	AM312 mini [97]	HC-SR505 mini [98]	AMG88m [99]	Adafruit Part 189 [100]
I2C Support	No	No	No	No
Digital Signal	Yes	Yes	Yes	Yes
PCB Dimensions	12 x 24 mm	10 x 23 mm	33 x 24 mm	25 x 33 mm
Power Consumption	< .1 mA	<50 uA	<2 uA	15 mA
Field of View	100 degrees	<100 degrees	100 degrees	120 degrees
Detection Range	3-5 meters	3 meters	12 meters	6 meters
Ambient	-20 to 85 C	-20 to 85 C	-20 to 80 C	-20 to 85 C

Temperature Range				
Object Temperature Range	-20 to 70 C	-20 to 70 C	0 to 80 C	-20 to 70 C
Integration	Through Hole	Through Hole	SMD	Through Hole
Price	\$8.69	\$9.50	\$34.87	\$9.95

Each passive infrared sensor has its distinctive qualities that influence its compatibility with the VISTA system. Given the project's requirements for a passive infrared sensor that is compact, energy efficient, and offers a detection range big enough for a bedroom, the Adafruit Passive Infrared Sensor is the most suitable option.

Adafruit's PIR sensor's design allows for easy integration using the through holes, which is essential for our system's more unique placement. Though its power consumption is higher than the other options, it is low in comparison to most infrared sensors. This low power consumption also aligns with the VISTA's energy efficiency. Lastly, the detection range when compared to the size of the device is incomparable to any other sensor's specs.

Considering all of these factors, the Adafruit Passive Infrared Sensor not only meets but exceeds the project's requirements, making it the ideal choice for the best functionality the VISTA system can offer.

3.1.9 Humidity Sensor

When planning the scope of VISTA's capabilities, it was determined that an important factor to consider was humidity. Particularly considering the high humidity levels present in many locations, including Florida, using a humidity sensor in the system was decided to be an important addition to the overall functionality of the project. With that in mind, there are many different technologies to consider when determining what kind of humidity sensor to use. Some popular choices include capacitive, resistive, and psychrometric, each with many advantages and disadvantages as discussed below.

Capacitive sensors are a type of a humidity sensor that consists of a thin strip of metal oxide between two electrodes [128]. They are mainly known for their high accuracy, particularly when compared to other humidity sensors. Another advantage of choosing a capacitive humidity sensor is the stability of the sensor to produce such highly accurate and repeatable results. They can additionally detect relative humidity levels within a very wide range. This wide range includes levels of humidity from 0% to 100%, due to the output voltage being nearly linear. Capacitive sensors can withstand wide variations of temperature fluctuations as well as any chemical interference or exposure, all while

providing quick and stable results with their fast response time. Additionally, the sensors require little maintenance throughout their use [129].

There are plenty of disadvantages of capacitive humidity sensors to take into consideration as well. Primarily, the cost may be high when compared to other options, although this is not always the case. Capacitive sensors also have complex circuits, and there are limitations on distance between the signaling circuit and the sensor in order to operate efficiently. It is important to note that regarding the wide range of relative humidity measurements that, under 5% relative humidity, there is a loss of relative accuracy. Additionally, in regard to the excellent stability of these sensors, the stability is not a long-term characteristic and becomes limited. Furthermore, capacitive humidity sensors are sensitive to condensation and dewing, as well as strong chemicals, making them unsuitable for extreme operating conditions [130]. Depending on different scenarios and applications, capacitive humidity sensors could be a suitable option or not.

Resistive humidity sensors are another type of humidity sensor that consist of metal electrodes deposited on a substrate surface through photoresist techniques and then covered by a salt layer [131]. A key advantage is their low cost compared to other options. They are additionally environmentally friendly, as they have a low footprint. Unlike capacitive sensors, resistive ones have no calibration standard and therefore can be used interchangeably and are easily replaced. Also unlike capacitive sensors, they do not have a limited distance allowance between the signaling circuit and the sensor, making them suitable for remote applications. Resistive humidity sensors can have large signal circuits, meaning a high surface-to-volume ratio. This allows for relative humidity reading up to 90% at room temperature [129]. Some other advantageous factors include long-term stability, small size, and quick reaction time.

Disadvantages of resistive humidity sensors include sensitivity to contaminants. Many sensors use ceramic substances as added protection to combat this issue. The output readings of the sensor can shift if used with water soluble products. Additionally, similar to conductive sensors, they are not optimal for measuring humidity levels below 5% [129]. Output readings can also be shifted and impacted inaccurately due to factors like condensation or chemical vapor, as resistive humidity sensors are sensitive to such factors. The sensors have significant dependencies on temperature as well, particularly when placed in environments with large temperature fluctuations.

Psychrometric humidity sensors, or wet-bulb sensors, consist of two temperature sensors, one covered with a wet sock, that draw in air and then compare the difference to determine the amount of water vapor present. Compared to other humidity sensor options, they are cost efficient and unaffected by condensation [132]. They are a very strong option when choosing due to their high accuracy and reliability compared to others. Additionally, the sensors can operate without any issues between the full range of 0% to 100% relative humidity. They also have good longevity, as there is no wear and tear unless the wick is contaminated [130]. In terms of durability, psychrometric humidity sensors are highly resistant to environmental factors and therefore are very durable.

Something unique about these sensors is the lack of requiring any external power source, including any battery power.

While psychrometric humidity sensors appear to be an excellent choice due to the durability, accuracy, and cost effectiveness, there are certainly drawbacks that come with their use as well. They cannot provide reliable readings below 0 degrees Celsius or with too low humidity, although for the scope of VISTA this would not be an issue. A key disadvantage of the psychrometric sensor is the required maintenance to keep the wick in good condition and to keep the water reserve filled, without which the sensor would be inoperable. To operate the sensor well, skill and consistency is required, which is a large disadvantage for the purpose of making VISTA user friendly. Furthermore, psychrometric humidity sensors are inaccurate in small spaces and the many variables account for a high uncertainty [132].

Table 3.1.9.1: Humidity Sensor Technical Specifications

Comparison Criteria	Capacitive	Resistive	Psychrometric
Stability/Accuracy	X		
Wide Humidity Range	X	X	X
Temperature Resistance	X		
Chemical Resistance	X		
Quick Response Time	X	X	
Environmentally Friendly		X	
Interchangeable		X	
Remote Use		X	
Small Size	X	X	
Condensation Resistance			X
Recovery Time	X		

After comparing three different types of humidity sensors, it is clear that the optimal choice for VISTA is the capacitive humidity sensor. This is due to many different factors as compared above. And while resistive came in a close second due to having similar qualities, when you compare more in depth capacitive has higher accuracy and stability as well as faster response time and recovery time. Therefore, capacitive is the optimal choice for the needs of the project.

3.1.10 Capacitive Humidity Sensor

Based on the many different characteristics of the different humidity sensor technologies, it was determined that a capacitive humidity sensor is the ideal choice for VISTA. With this decided, there are a wide variety of different capacitive humidity sensors to investigate and choose from. Some viable options that provide useful functionalities such as low power include the Honeywell HIH-4000 Series: HIH8120-021-001, the Sensirion SHT30 (or SHT3x Series): SHT30-DIS-P2.5KS, or the TE Connectivity HDC1080 (or HDC2080): HDC2080DMBR.

The Honeywell HIH-4000 Series: HIH8120-021-001 is an advantageous option that has an accuracy of ± 2 relative humidity. Some other advantages include the long term stability and accuracy of the sensor, which is extremely beneficial for applications like VISTA where a goal is to have low maintenance for a customer. Another benefit is the sensor's relatively low cost, making the product affordable overall. The Honeywell HumidCon is available in ultra small package sizes and options as well, aiding in the smaller size and lighter weight of the overall design of VISTA. The sensor is also very energy efficient, which is an important aspect of any product, particularly when looking to save money on AC bills. This sensor also has a temperature sensor, though this feature can be ignored due to another temperature sensor with better parameters being chosen. The sensor provides true temperature-compensated digital I2C or SPI output [133].

The Sensirion SHT30 (or SHT3x Series): SHT30-DIS-P2.5KS is another beneficial option in terms of humidity sensors. This product offers a wide range of supply voltage, more so than other options. Additionally, it offers an accuracy of ± 1.5 relative humidity. This sensor has fast startup time, fast measurement time, and is available in a tiny 8-pin package. Other advantages include I2C interface with communication speeds up to 1MHz and two user selectable addresses. Sensirion technology has high reliability and long term stability, as well as high processing capability. This is in addition to having a high signal-to-noise ratio. Similar to other options, this sensor also has a temperature sensor combined onto the same product, offering fully calibrated, linearized, and temperature compensated digital output [134].

The TE Connectivity HDC1080 (or HDC2080): HDC2080DMBR is an additional humidity sensor option with similar advantages. The accuracy is ± 2 relative humidity, and the sensor comes with sleep modes and auto measurement modes. It provides high accuracy measurements with low power consumption, ideal for battery powered operations. The sensor is available in a small package, like all other options. The supply voltage range is relatively wide and the sensor includes I2C interface compatibility. Ideal applications for this kind of sensor include smart thermostats, which is ideal for the purpose of VISTA. Like the other options, this sensor also had a built in temperature sensor [135].

Table 3.1.10.1: Capacitive Humidity Sensors Comparison

Comparison	HIH8120-021-001	SHT30-DIS-P2.5KS	HDC2080DMBR
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Criteria			
Supply Voltage Range	2.3-5.5 V	2.15-5.5 V	1.62-3.6 V
I2C Compatibility	Yes	Yes	Yes
Accuracy	±2 RH	±1.5 RH	±2 RH
Stability	High	High	High
Mounting	Through Hole	Surface	Surface
Response Time	6 sec	8 sec	8 sec
Package/Case	4-SIP Module	8-VFDFN Exposed Pad	6-WDFN Exposed Pad
Resolution	14 bit	16 bit	14 bit
Operating Temperatures	-40°C ~ 125°C	-40°C ~ 125°C	-40°C ~ 85°C
Price	\$16.87	\$4.44	\$2.90

Despite the much larger price, the HIH8120-021-001 humidity sensor is the best option primarily due to the through hole mounting, which is ideal for soldering the actual piece onto the board while also providing room for error and updates in case the sensor needs to be changed or switched out. Additionally, while all sensors provide high accuracy and stability, the Honeywell humidity sensor has the fastest response time and a wide operating temperature range and a decently wide supply voltage range.

3.1.11 Vent System Material

A primary component of a smart vent system is the register that uses louvers, or vent slats, which open and close to limit or increase air flow throughout a designated space. Vent covers not only protect the HVAC system from debris, but they increase the efficiency of a heating/cooling system through the control of air flow throughout different rooms. VISTA aims to streamline the proficiency of heating/cooling different rooms based on personal preference for utmost comfort and economical advantage. Determining the functionality and material of such vent covers is a crucial step in the design process of VISTA. There are a few different methods of which to allow the vent slats to open and close as discussed below.

Different methods to open and close the vent louvers include an actuator that physically pushes the existing vent lever up and down to open/close the existing, or a vent that goes over existing (on wall), original is either removed or kept open. Determining this sort of

design will allow for a better scope of the project's needs and functionality. Keeping the original vent cover seems like an easier choice due to not needing to build a new vent cover with louvers that open and close, and instead just using the actuator to push the existing lever on the vent cover. However, a great deal of force would need to be generated in order to move the lever autonomously- and two actuators would be needed on either side for up and down movements. Additionally, it would be more difficult to ensure that the design is universal to any vent sizes and design due to the position of the lever or the possibility of there not even being one. Some vent slats have to each be moved separately with one's hands in order to open or close. Therefore, a solution to these issues is the second design option: a new vent cover that either goes over the existing vent (is mounted to the wall on top of the old vent cover) which is kept open, or the old cover can be removed and the new cover is mounted the same way. This way the design is universal to all pre-existing vent cover designs and the customer can choose whether they want to remove the old vent or not. Additionally, the functionality of the slats opening and closing would be built into the new design and eliminate the need for enough force to push the existing lever if there is one. Thus, the second design option is more suitable for the widespread applications of VISTA. Now that it is determined that the best course of action is to create a new register/louver system as opposed to using pre-existing vent cover systems, the next step is to determine the most suitable material to be used for such registers and louvers. Possible materials that could be used include metal, plastic, or wood.

Using metal as the louver/register material comes with many advantages and disadvantages. Metal is an extremely popular choice for most homes and buildings due to its durability. They have become somewhat of a staple when it comes to construction of buildings. Another advantage of metal registers include resistivity to factors such as water damage [37]. Metal is resistant to humidity and other sources of water, primarily in bathrooms. Additionally, when taking into consideration floor vents, metal is the strongest available option when the vent may have a lot of foot traffic or furniture moved around on top of. A common issue that presents itself in homes and other buildings, particularly in air vents, is mold. Metal registers are completely mold resistant, another advantage. Similarly, metal is fire resistant and cannot catch on fire if there is any nearby, which could prove useful in some scenarios. While metal may seem like the ideal choice, there are just as many reasons to reconsider due to the disadvantages. First and foremost, metal is costly, particularly when compared to other options. Depending on the application, metal also may be unsuitable because it is heavy and noisy. Lightweight materials, especially when attached to a wall, are typically an advantage. And due to many properties of metal such as density, sonority, distortion, and stiffness, it can make a lot of noise through vibration or ringing. Moreover, metal vent covers are susceptible to condensation and tend to stick out more than other materials might- particularly when considering floor vents on wooden flooring. Therefore, using metal for registers and louvers on a vent cover leaves much room for consideration and comparison.

Using plastic for the registers and louvers of a vent cover is another option that brings along just as many pros and cons. A key component of plastic is that it is not only cost efficient but also lightweight. Plastic is a lot cheaper to manufacture than wood, and

weighs less too (depending on the type of woods and metals used). While typical plastic is less durable than metal, modern plastics like polypropylene can be made with specific additives that offer protection for UV rays- extremely beneficial when manufacturing vent cover for outside use [38]. Such modern plastics are much more durable than their predecessors and can resist practically any environmental wear and tear like extreme weather or airborne objects. Additionally, while metal is unsuitable for extreme hot and cold weather conditions due to expansion and contraction of the material, newer plastics are a lot more durable. And while metal is “water-resistant”, prolonged water exposure can create rust whereas plastic can be completely immersed in water for extended periods of time and have no effects. Another advantage of plastic is the malleability of the material compared to other options. Though vent duct openings typically have the average rectangular shape, the shape of the louvers- very angular, with spaces in between- are much easier to create using plastic over metal. Also, plastic has smoother, rounded edges, where metal can be more jagged and therefore more difficult/dangerous to install. However, plastic does have some downsides, including that they can still be less durable than metal, particularly in indoor applications. They would not be a suitable choice for floor vents where there can be high amounts of foot traffic and weight over the vent covers. Plastic may require more maintenance and inspection, depending on the type of plastic used and the application. Plastic is also more prone to discoloration than metal, as well as could be less efficient if the plastic used does not allow a good seal between louvers to when limiting airflow.

An uncommon but still viable option for louvers and registers is wood. When choosing the right type of wood material, it can actually be a very cost efficient option. Wood registers are also very easy to install and can be lightweight. And compared with metal and plastic, wood is just as durable. The main advantage of using wood vent covers is the aesthetic components. Wood is easily customized through paint, stain, texture, etc. to match the style throughout any home or building. For many applications that consider just the basic needs and functionalities of a vent cover, using wood may prove to be the best choice when particularly concerned with style and cohesiveness. Compared to wood and plastic, the advantages of wood are on par. In a more in depth evaluation, however, there are many more specific qualities that wood and metal can provide that wood simply cannot. Wood is unsuitable for high humidity or outdoor use, as well as for floor vents. Wood is much more prone to mold than any other material options, and wood cannot be wet for long at all without causing damage. Therefore, wood registers would require more ventilation than other just as suitable options. Also, if the right woods aren’t used, it can actually be more expensive than its alternatives. Thus, there are just as many advantages as there are disadvantages.

Table 3.1.11.1: Material Comparison for Registers/Louvers

Comparison Criteria	Metal	Plastic	Wood
Durability	X	X	X
Mold-resistant	X	X	

Water-resistant		X	
Lightweight		X	X
Floor vents	X		
Manufacturability		X	
Affordability		X	X
Ease of installation		X	X
Minimal noise		X	X

Through careful consideration and comparison of the different material options to be used for the registers and louvers of VISTA, the most suitable material is plastic. This choice was made based on a wide variety of factors such as cost, resistance to environmental factors like mold and humidity/condensation, durability, etc. as well as taking into consideration the engineering and marketing requirements as presented in the house of quality. This is an important step to determine in parallel with determining the design of the register/louver mechanism and functionality as previously discussed.

3.1.12 Plastic Filament

The most suitable material determined for the design of the registers and louver was plastic, based on a variety of factors depending on the requirements and applications of VISTA. The best method of producing the resulting design would be by 3D printing using plastic filament. Some popular plastic options for 3D printing filament include PLA, ABS, PETG, and PP. Each option brings up different advantages and disadvantages that come from a wide variety of factors as discussed below.

Polylactic acid (PLA) is the most commonly used 3D print material. It is a biodegradable plastic that is extracted from natural sources/materials such as corn starch and sugar cane. Thus, a major advantage is that it is an environmentally friendly option [101]. PLA is safe/non-toxic and does not release any harmful fumes, which is another important benefit. PLA is also available in hard and soft form, which greatly extends the range of its use. Additionally, hard PLA is extremely durable, extending the lifetime of any product or application[102]. It is also very easy to print with/use and works well with most adhesives and paints. While other options have issues with energy usage and warping, PLA offers low energy usage and resistance to high temperatures. However, PLA is very brittle and difficult to manipulate. This can be an issue for trying to make suitable physical products like ones with moving parts, such as the louvers of the vent[103]. It also has a low melting point, making it an unsuitable option for high temperature applications, though this is not a concern for VISTA. PLA is also not recyclable, as its properties differ from other plastics and therefore it can not be mixed in with them. It also does not decompose quickly without a controlled environment. In terms of cost, PLA is relatively expensive in

comparison with other materials, providing an economical disadvantage. Additionally, PLA is permeable to moisture, which can cause issues in humid environments.

Acrylonitrile butadiene styrene (ABS) is another commonly used 3D print material that is petroleum-based. ABS is a very good option primarily due to its durability. The material has good mechanical properties like stiffness and great strength, making it highly resistant to breaking or bending from stress[104]. It is also a very versatile material, able to be used for a wide variety of applications due to the ease of molding or shaping to desired forms while 3D printing due to a low melting point. Furthermore, ABS has good insulation properties and low conductivity, making it ideal for electrical/electronic components. It also has high chemical resistance, exhibiting no change in properties and appearance from the introduction of chemical solvents. Plus, ABS is easy to install due to its lightweightedness and won't rot, mold, or corrode. There are some downsides to using ABS too, however. The price, similar to PLA, is rather high- making products relatively expensive to produce. Also similarly to PLA, the low melting point is unsuitable for high temperature applications, though that ranges outside the scope of VISTA's requirements/uses. Furthermore, the burning from ABS exposed to too high temperature can then potentially release toxic fumes. ABS is unsuitable for outdoor applications, as it is not resistant to weather conditions like high heat and UV radiation. And for applications with low tolerance to changes, ABS may not be a good option due to its high coefficient of thermal expansion, particularly compared to other plastics.

Polyethylene terephthalate glycol (PETG) is an additional option for 3D printing with plastic material, a thermoplastic material that is very durable and flexible[105][106]. The strength and impact resistance allows it to handle lots of pressure without cracking. And the flexibility of the material prevents stress cracks and allows further bending without failure as opposed to other material options. It is also environmentally advantageous, due to the ability to recycle it and the lack of releasing fumes while printing. Similar to ABS, PETG is resistant to chemicals and moisture, which can be highly beneficial depending on the application. Additionally, PETG has a higher melting point than its competition, making it ideal for high temperature scenarios. Due to its low shrinkage rate, PETG is safe from warping and has better accuracy while printing. Like other materials, PETG is rather costly but even more so than others discussed. It also requires higher temperatures to print which can wear down the machine. Low resistance of PETG can cause blockages during slow printing while its higher viscosity causes stringing when not printed slowly, which causes some conflict in finding the right printing speed. The durability of PETG causes it to be more difficult to sand/smoothen, and it is prone to scratches more than other plastics. It is overall unsuitable for post-processing techniques.

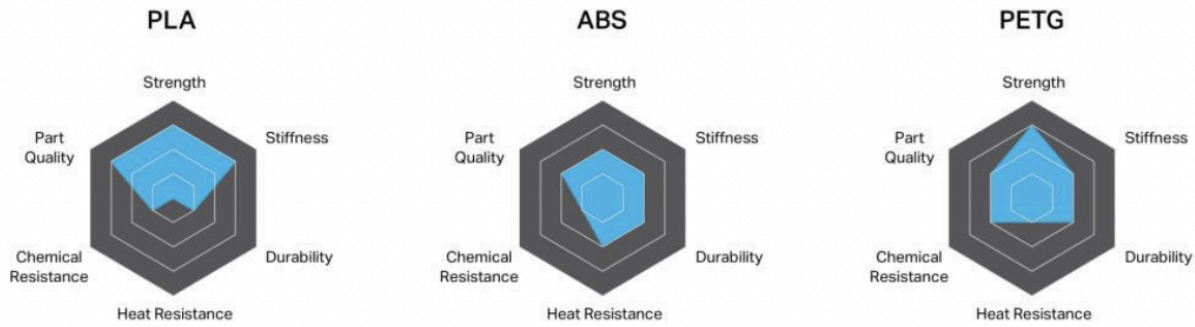


Figure 3.1.12.1: PLA vs. ABS vs. PETG Comparison Diagrams [107]

Polypropylene (PP) is an alternative 3D print material made from lightweight, semi-flexible plastic. It is resistant to chemicals and moisture, similar to other available plastics. PP is also a more cost effective option than all others discussed. Additionally, the material is malleable and can easily be formed to desired shapes [107]. Another advantage is the environmental friendliness, as PP can be recycled and creates little waste. The low melt viscosity of PP also gives it a smooth, flowing consistency when printing. There are plenty of drawbacks to PP too, though. It is greatly affected by UV degradation, and can become brittle and broken due to the sun. It also is very flammable with a low melting point and has low surface energy, making it difficult to paint due to poor bonding. Additionally, PP is not exactly safe, as skin contact from a powder form can cause irritation (though generally considered non-toxic).

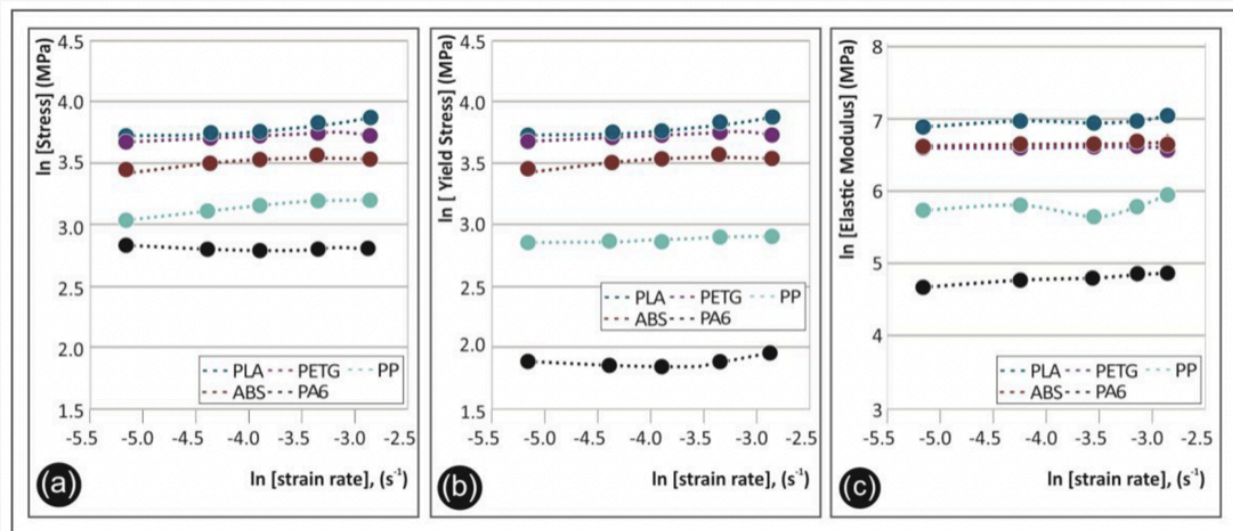


Figure 3.1.12.2: $\ln(x)$ to $\ln(\text{strain rate})$, (s^{-1}) for all five polymers tested, where $x =$ (a) maximum tensile stress (MPa), (b) yield stress (MPa), and (c) tensile modulus of elasticity (MPa). [108]

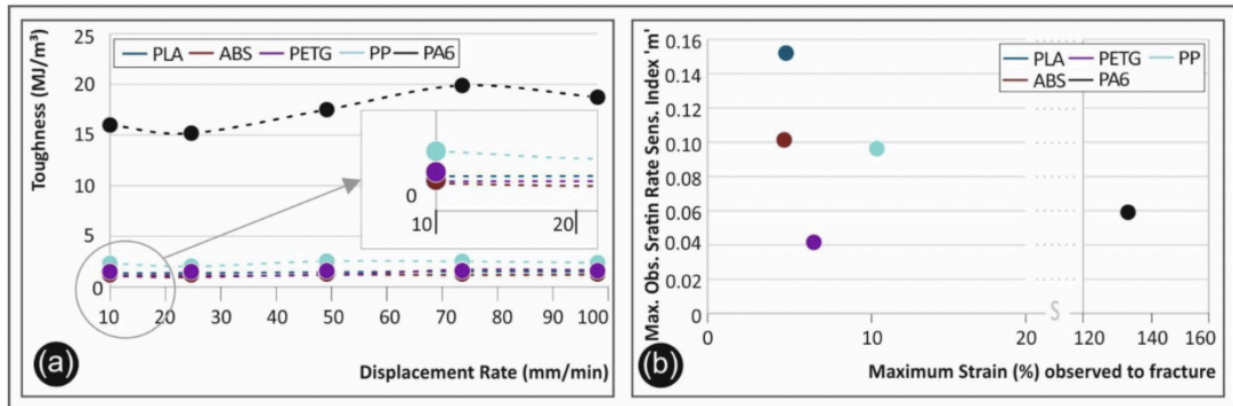


Figure 3.1.12.3: (a) Toughness (MJ/m³) to the displacement rate (mm/min) for all five tested polymers, and (b) maximum strain rate sensitivity index “m” calculated to the corresponding strain (%) of the specimen for all five polymers tested. [108]

$$m = \frac{\Delta \ln(\sigma)}{\Delta \ln(\dot{\epsilon})}$$

Figure 3.1.12.4: Strain Rate [108]

The figures above show stress, strain, elasticity, toughness, and maximum strain comparisons between the four options discussed and another (PA6) which is not under consideration for the purpose of VISTA. As evident by the plots, PETG showed the most promising behavior for 3D printing via FFF AM processing [108]. It exhibited the lowest dependence on/sensitivity to the strain rate “m” according to Figure 3.2.5.4b, which is evidence of better mechanical properties. Strain rate index, “m”, is a property of materials that measures how the dynamic stiffness correlates to variations in strain rate. It indicates how resistive material is to deformation and relates to the ability of a material to withstand static mechanical loads of different strain rates.

Table 3.1.12.5: Plastic 3D Print Filaments Comparison [109]

Comparison Criteria	PLA	ABS	PETG	Polypropylene
Durability		X	X	X
Thermal Resistance			X	
Environmentally friendly	X		X	X
Chemical resistance		X	X	X
Moisture		X	X	X

resistance				
UV resistance			X	
Post-processing	X	X		
Flexibility			X	X
Affordability				X

With many different characteristics in mind, the comparison of all four plastic options to be used for 3D printing leads to one material that proves the most suitable and advantageous choice: PETG. Choosing the type of printing filament is a majorly important step in the design and production process, as VISTA needs a material that meets all the requirements and can withstand typical environments of the system.

3.1.13 Power Source

In order to allow the actuator to perform its necessary functionalities, choosing a proper power source is a crucial step in the operations of the actuator and other project components. Lithium-ion batteries, lead acid batteries, alkaline batteries, nickel-metal-hydride batteries, and connecting directly into the power supply of a home/building are all sources of power that could be used for an application like VISTA, each with their own pros and cons. All options perform the basic functionality of delivering and sometimes absorbing electrical energy in power electronic circuits. Power sources are necessary to deliver a constant output of voltage to supply to a system or device.

Lithium-ion batteries are a rechargeable power source that serves a wide range of purposes. In comparison to other power sources, a particular advantage of using lithium-ion is that lithium is the lightest available metal, so it is a very suitable choice in cases where weight is a concern [46]. In addition, lithium has the greatest electrochemical potential compared to other metals- meaning it has very high energy density in a battery and can store a great deal of energy with a small footprint, particularly when coming from renewable sources. High energy density also designates a longer battery life in relation to its size, which greatly expands the applications and possible uses of the battery[47]. Lithium-ion batteries are also very quick to recharge, which is a significant advantage for most to all applications, as wait time to be able to use a device again is cut down by a great deal. Another benefit of lithium-ion is their low self-discharge rate. This means that when the battery is not being used, the charge contained is retained as opposed to being lost over time like many other battery options. This largely improves their overall reliability as a power source. In terms of versatility, lithium-ion is an excellent option as they come in a variety of shapes and sizes to fit the needs of any project and are very low maintenance.

Despite all the advantages to using lithium-ion batteries, there is a lot of potential for concern. The batteries have a high sensitivity to temperature, making them unsuitable for many outdoor applications where the temperature is too high. Conjunctly, if the energy density is too high, the operating temperature could possibly exceed the maximum allowance determined by the manufacturer and in worst case scenarios result in fire or explosions (thermal runaway). Therefore, depending on the intended application/use of the lithium-ion, another type of battery could prove as a suitable alternative.

Environmental impact is another area of worry, as the disposal of lithium-ion is very difficult due to the extraction process of the lithium and other rare materials. Which brings up possibly the major concern of lithium-ion batteries- the cost. Due to a multitude of factors such as advanced technology incorporated in the battery or production process, expensive materials, the design of the battery cell, etc., lithium-ion is a very expensive battery to manufacture.

Lead acid batteries are another rechargeable power source option that presents a wide range of advantages and disadvantages. A key appeal to using lead acid batteries is the high availability and low cost, due to an inexpensive and relatively simple process to manufacture and a low cost per watt-hour of usage [48]. These batteries are also very easy to install, use, and then recycle. This is highly beneficial for a wide range of uses, and provides some positive environmental impacts as the entirety of the battery is reusable/recyclable without any loss of performance. Similar to lithium-ion, lead acid is conveniently quick to recharge. This is always a beneficial quality in order to prevent long wait times to use certain products or other applications. Another similarity to lithium-ion is a low self-discharge rate, the lowest of all rechargeable power source options in fact. Lead acid batteries retain their stored energy at an impressive rate by having very few self-running electrochemical processes, meaning much of the originally stored quantity can be used after storage. Another positive of using such batteries is the high power output capability. Lead acid batteries have a high specific power, meaning they are capable of producing and outputting high discharge currents.

While lead acid batteries are a widely used option for power source in all kinds of different applications due to their many advantages, there are just as many disadvantages that may lead one to consider other options. Lead acid batteries are very bulky and heavy compared to other battery options. This is a direct result of the high content of lead, which is an extremely dense therefore heavy metal, as well as the sulfuric acid electrolyte essential for energy storage and delivery. Unlike lithium-ion batteries, lead acids have low energy density and thus are inefficient in terms of energy use, causing a lack of versatility. Lead acid batteries furthermore have a short lifespan due to depletion of active material. If kept in the discharge state for too long, the lead sulfate crystallizes causing the battery to discharge completely and release sulfur. Another downside to lead acid batteries is the corrosive acid which is unavoidable, as the chemical reactions performed to charge and discharge the battery can release gasses that corrode the battery. And although the battery being fully recyclable is good for the environment, the negative environmental impacts outweigh the positive. Lead acid batteries are not eco friendly by most standards, as they cause pollution by emitting fumes- particularly hydrogen and oxygen gas- during charging, which is both harmful and highly flammable (combustible, similar to lithium-ion

batteries). Moreover, lead is a very toxic element that can prove extremely harmful to humans and wildlife if exposure occurs. So even with the attractive qualities of affordable and dependable, lead acid batteries leave a lot of room for consideration as a power source option.

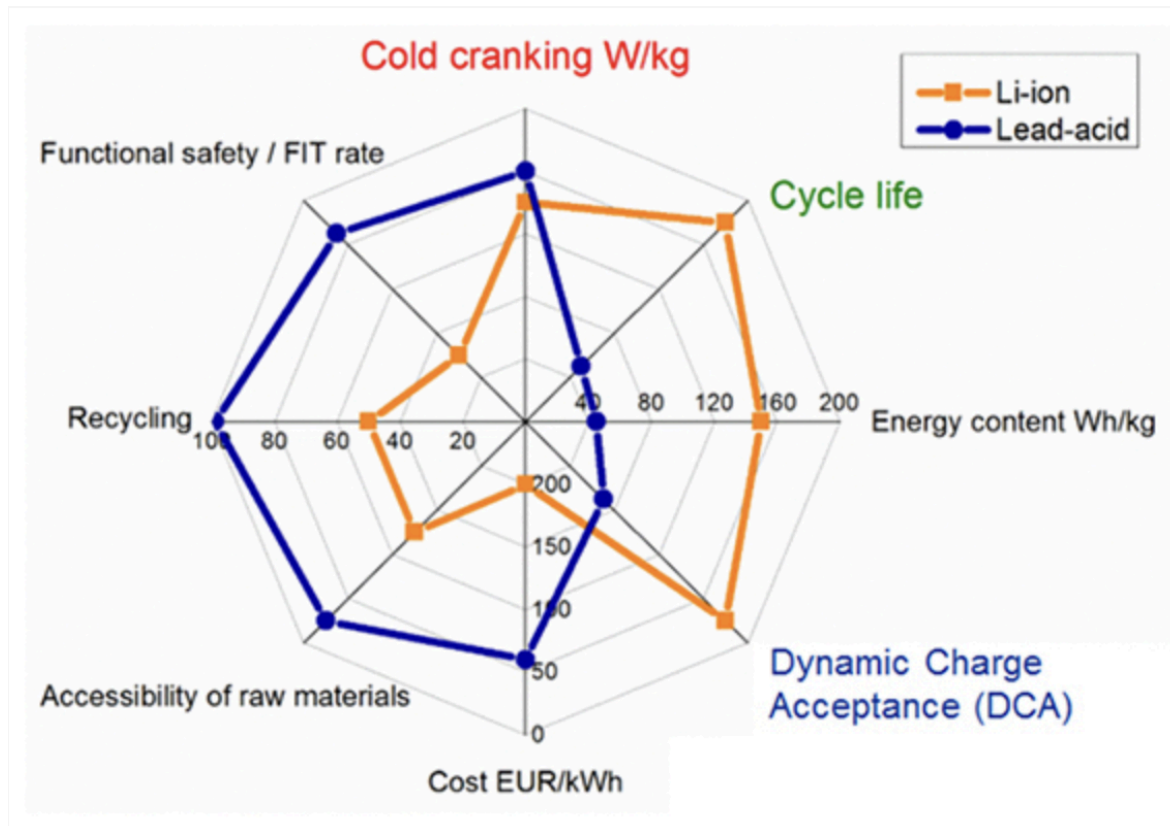


Figure 3.1.13.1: Comparison of Lead Acid and Li-ion as Starter Battery [79]

Alkaline batteries are another rechargeable battery option that can serve as a power source for many different uses. They bring many advantageous qualities, such as low cost, which tends to be a key characteristic for determining final options. Similar to previously discussed battery option lithium-ion, alkaline batteries have a high energy density, meaning they last longer than other batteries. Additionally, alkaline batteries can be exposed with restrictions like many other batteries require, as they will not create fires during transportation or at landfills and recyclers. Rechargeable alkaline options specifically can be reused/recharged hundreds of times without losing efficiency or needing to be replaced, which is highly beneficial for eliminating the need for maintenance on a battery-operated system. Compared to other batteries, alkaline also has a greater resistance to low temperatures which can be useful depending on the needs of a situation/device. And unlike its counterparts, alkaline batteries store very well without any erosion of loss of performance and function, and they are overall very safe (and nontoxic) in comparison to other options.

Like all other power source options, alkaline has just as many cons as it does pros. Compared to lithium-ion batteries, alkaline is bulky- though not to the extent of lead acid.

Like most options, there is a possibility of explosion and corrosion. Short-circuiting and over discharging during charging can result in an abnormal rise of internal pressure and hence cause corrosive liquid to leak out. And, in extreme cases, the battery has the potential to explode. Additionally, alkaline batteries have high internal resistance, which reduces overall output of voltage and power.

Nickel-metal-hydride batteries, or NiMH, is a replacement of the commonly used nickel-cadmium (NiCd) battery due to the environmental concerns of their use, both being options for a power source [49]. NiMH is similar to alkaline batteries, and, in some cases, they may be used interchangeably. However, when compared, NiMH rechargeable batteries provide a steadier discharge than alkaline batteries. Similar to alkaline batteries, NiMH are cheap and completely safe as they do not release any toxic gasses and can be thrown away (considered non-hazardous waste). Additionally, they are both reliable options for battery-operated power and are easy to store, easy to transport, recyclable, and thus environmentally friendly. Compared to lead acid batteries, NiMH batteries have higher power output, higher energy density, and a longer lifespan.

Despite the many advantages, some major concerns of NiMH include that they can be very expensive depending on the application. In addition to this, the self-discharge rates are low meaning low lifespan and poor stored energy retention, particularly when compared with other battery options. NiMH batteries are unsuitable for high temperatures much like lithium-ion, as they produce a large amount of heat in such conditions. They also cannot tolerate as many recharging cycles, so the lifespan is once again lower than its alternatives. Although the NiCd batteries are replaced by NiMH due to environmental concerns, many aspects are not up to par with the older model such as charge time and others mentioned already.

Connecting or wiring directly to a home or building's power supply is another potentially suitable option for a power source that is different from a battery primarily because it does not need to be recharged and replaced (neglecting wear and tear of a house/building or other unusual factors). A key difference between using batteries for power versus a wall connection is that the supplied power will be DC versus AC [50]. AC power is less expensive and easier to generate than DC power, and has less power loss during transmission. Other advantages include greater durability, better power efficiency when sharing loads among different phases, and voltage can be increased/decreased with transformers.

Utilizing a wall connection as a power source is not always the best option, however. Either you would have to physically cut into a wall to connect the system directly to the power lines, or use an outlet connection. Cutting through a wall is extremely inefficient as it causes damage that will later need to be repaired, spikes the installation time, and is a difficult process overall, among other reasons. Using an outlet seems efficient until you consider that there would need to be an outlet nearby every single vent in order for VISTA to function, and then the wires connecting to the outlet would be visible and obstructive. Besides just the installation and overall appearance, when concerning the type of power DC is a more suitable choice- which comes from batteries as opposed to a

house/building's power system. DC power is more energy efficient and is made up of entirely active power, meaning that the capacitance of wires causes almost no loss of power over long distances. Additionally, AC power has higher risk from peak voltage, is easily distorted, and installation requires more precautions due to the possibility of getting shocked during the process.

Table 3.1.13.2: Comparison of Power Source Options

Comparison Criteria	Lithium-ion	Lead acid	Alkaline	NiMH	Wall Connection
Affordability		X	X		
Efficiency	X	X	X	X	
Disposability			X	X	X
Long life cycle	X		X		X
Environmentally friendly			X	X	X
Temperature resistant			X		X
Lightweight	X		X	X	X
High energy density	X		X	X	
Self-discharge rate	X	X	X		
Rechargeability	X	X	X	X	X

With many different power source options in mind, the many pros and cons of each must be carefully considered to determine what best meets the scope of the VISTA system. Due to the most important factors- taking into consideration the marketing and engineering requirements- such as cost, ease of use, longevity, size and weight, and environmental factors, alkaline batteries are the most suitable option.

3.1.14 Alkaline Batteries

The most suitable source of power for VISTA was determined to be alkaline batteries. There are many different types of alkaline batteries available that could be used, all with different benefits and drawbacks. Some popular and potentially ideal choices for alkaline

batteries include AA, C, D, and 9V. All of these options share the same basic advantages of alkaline batteries, which includes long shelf-life, high energy density, safe, able to operate in extreme temperatures, affordable, eco-friendly, etc. While there are few differences between the different alkaline batteries, there are some important factors to consider and how it may affect an application.

AA batteries are by far the most widely used batteries. They are most suitable for smaller applications that involve small electronic devices. You would most often see AA batteries in things like TV remotes, toys, small flashlights, etc. AA is a standard, small battery option that gives 1.5V of power output and lasts a decent amount of time in small devices. They are ideal in devices that are not constantly on or require a very low power output to remain running.

C and D batteries are very similar in that they are both around the same size, larger than AA batteries. They both still only produce up to 1.5V, but the increased size allows for greater capacity of stored energy. This in turn allows the batteries to last longer periods of time overall if used for the same device as AA batteries, instead just taking up more space in the design. The main difference between C and D batteries is simply that D batteries are slightly larger and hence store a bit more energy and last a bit longer when in the same application. C batteries are commonly used in toys, larger flashlights, radios, automatic toilet flushing sensors in public bathrooms, etc. They are perfect for more heavy duty applications where devices require frequent use. D batteries on the other hand are typically used in devices like sensor faucets, soap dispensers, stereos, etc. With the increased energy capacity from C batteries, D batteries are suitable for devices that require extended periods of power time. They provide hours of constant use and power many heavy-duty, commercial applications.

9V batteries are unlike other options because instead of a singular 1.5V cell, it contains 6 stacked cells making up a total of 9V. This specialized higher voltage allows for a unique scale of applications like electronic circuits, smoke detectors, infrared thermometers, etc. And despite the high voltage, 9V batteries can sometimes be even smaller than AA batteries. They are very durable, able to withstand extreme temperatures on both ends of the scale, and have very good performance. These batteries are an ideal choice for unique electronic applications.

Table 3.1.14.1: Alkaline Batteries Comparison

Comparison Criteria	AA	C	D	9V
Lifespan		X	X	X
Affordability	X	X	X	X
Energy Capacity		X	X	

Small size	X			X
High voltage				X
Temperature resistant		X	X	X
Durability		X	X	X

After considering the four different types/sizes of alkaline batteries as discussed and shown in the table above, it can be determined that the most optimal choice for battery would be the 9V. This is mainly due to the high voltage capability, which is ideal for applications that require unique and specific electronics.

3.1.15 Regulator

A regulator is a device that maintains a constant voltage level in a power supply circuit [155]. In the context of the VISTA system a regulator will be used to control the voltage output of the power component. The system is going to use a nine volt battery, but most of the components operate on a 2-3.3 volt range so a regulator is necessary to control the power exchange between the components. Each component that requires a different operating voltage will need a different regulator, for instance a 3.3 regulator cannot also be used on a component that requires 2 volts of power. There are three different types of regulators that can be used for this project, linear, switching, and zener regulators. Each regulator has its own ideal use case. A better understanding of each is needed to determine which is ideal for the VISTA system.

The first type of regulator is a linear regulator; it maintains a constant output voltage by adjusting its resistance in response to changes in input voltage or output current. A linear regulator is generally chosen due to its simple design, low noise, and low price [156]. There are even two different types of linear regulators that can be chosen, series and shunt regulators. These are important to consider because they bring more variability to linear regulator selection. Linear regulators are one of the simpler designs because they only connect capacitors to both the input and output. The simple design is a strong component in the low noise and low price of the product as well. The advantages of the linear regulator make it a strong component for the VISTA system due to its need for multiple regulators, but the disadvantages may change the dependability of the regulators.

The disadvantages of linear regulators are large loss, heat generation, and limited voltage flexibility. The loss of the regulator is increased because there is a large difference between the input voltage and output voltage. This in turn decreases efficiency of the regulators. This issue is prevalent in implementation within the VISTA system. The power source is 9V and the output voltage would be around 3V which would most likely be a large enough jump to cause issues within the system. Another disadvantage is the limited functionality of this regulator, it can only perform step-down operations. This is not an

immediate issue within the system but could limit future uses of the project. The final main disadvantage of this type of regulator is the heat generated by them. The large amounts of heat generation occur again when the voltage drop between the input and output voltage is too large. Excess amounts of heat could disrupt the temperature readings of the system, likely making the linear regulator inapplicable to the project.

The second type of regulator is the switching regulator, it is a circuit that converts an input voltage to a desired output voltage using a power switch, inductor, and diode. Some advantages of this device include, high efficiency, low heat generation, and size. A switching regulator is one of the most efficient types of regulators, this is because the series element is either fully conducting or switched off, so it loses almost no power [157]. This high efficiency is a desirable quality for the VISTA system. Another advantage is its low heat generation, all regulators are going to produce some heat generation from energy flow but the lower the heat generation, the better for the system. And finally, this type of regulator is smaller and lighter than other types of regulators (specifically linear regulators); this is due to the lack of line-frequency transformers that are required within linear regulators. A small and light regulator is optimal for the VISTA system due to its project requirements and placement feasibility.

Even though the switching regulator has a lot of advantages that would work very well with the system, its disadvantages also need to be considered. Switching regulators are more complex, can generate electromagnetic interference, and ripple voltage. Due to their design switching regulators are more complex than linear regulators, but this can also create more flexibility within a system [158]. The complexity could prove to be more of an advantage than not. Another concern is electromagnetic interference (EMI). EMI is unwanted noise/ interference in a circuit caused by an outside source, in the VISTA it would be the regulator. EMI can negatively impact performance of a device which should be taken into account when choosing a regulator [159]. The final disadvantage is the creation of ripple voltages, this is another creator of noise within the circuit.

The last type of regulator that could be used for the VISTA system is the zener regulator. A zener regulator is a voltage regulator that uses a Zener diode to maintain a constant voltage across a load [160]. The advantages of a zener diode are its cost-effectiveness, simplicity, and wide range of operating voltages. A Zener regulator like a linear regulator only requires a couple of components which makes them inexpensive, especially when compared to switching regulators. This could be preferable within the VISTA system if other components costs are becoming too high for the budget of the project. Another advantage of the Zener regulator is its wide range of operating voltages, it can operate on a wide range of input voltages and load currents. This is extremely beneficial to the system considering the voltage range for this system is pretty broad.

The downsides of the Zener regulator include, poor efficiency, output voltage changes, and non-adjustable output voltages. The design of the diode is simple, but inefficient; when heavy loads are applied large power loss will occur because of the series resistor and zener resistance. This is a characteristic that must be weighed against the benefits to deem if it is too costly. Another issue with this regulator is the change in output voltage,

because the diode has resistance, whatever the input voltage is, it will not only regulate it but also throw it off by a certain resistance. This issue could be accounted for in calculations, making it not too important when choosing a regulator. The final, and arguable largest disadvantage of this diode is the constant output voltage. Due to its design the output voltage of the regulator cannot be changed. The un-flexibility makes it an unlikely candidate for the VISTA system. With all of the different voltages the system will need to accommodate, a flexible regulator will be necessary.

Table 3.1.15.2: Regulator Comparison

Comparison Criteria	Linear Regulator	Switching Regulator	Zener Regulator
Simplicity	X		X
Size	X	X	X
Efficiency		X	
Wide Voltage Range		X	
Low Power Loss		X	
Cost	\$	\$\$	\$

3.1.16 Switching Regulator

The switching regulator chosen for integration into the VISTA must be able to correctly power each component from a given power source. In the case of the VISTA, the power source is a 9 volt battery. The selected components all have different power input ranges and fluctuation tolerances. The selected servo requires an input of 4.8 V to 6 V. DC All other components are recommended to operate at a voltage level of 3.3 volts DC.

These different voltage levels can be output by either separate, independent regulators, or by configuring a multi-output regulator which is capable of outputting both levels. Different buck regulators (step down) also differ in their output fluctuation tolerances. Although the output is DC, real world applications produce small fluctuations in the output. Many designs reduce the undesirable noise by adding ripple filters internally to the component.

To reduce potential sources of error, multiple regulators with small output tolerances are preferable. Throughout the prototyping and development process, it is possible, and reasonably probable, that different portions of the design may be overpowered, damaged or otherwise contaminated. Many of the other components: the MCU, sensors etc, all have relatively low max voltage tolerances. Accidentally exceeding these parameters are

almost certain to damage the devices. To combat these likely issues, separate regulators will be used, and placed on separate PCBs to isolate any potential damage from spreading. This allows individual testing of power input before connecting and potentially damaging the design.

Texas Instruments TPS562201DDCR

The TI-TPS562201DDCR meets all criteria needed for the VISTA design. It is able to output anywhere from 2.5 V to 8V from a 9V input and fluctuate by only .02% [136]. The cost for the device is very reasonable and most importantly, it is extremely low power. Its quintessential current is just 20 μ A, which will cause very little parasitic draw.

Diodes Incorporated AP64060

Diodes Incorporated AP64060 offers similar specifications to the TI TPS562201DDCR [137]. The AP64060 supports a wider range of both input and output values. Additionally, its ripple is limited to 0.1%. Although this is more than the TPS562201DDCR, it's well within the input tolerances to all other components.

Richtek USA RT8258GJ6

The RT8250GSP from Richtek USA again offers similar specifications to the aforementioned devices [138]. It supports input from 4.5 V to 23V and is able to output anywhere from 0.925 V to 20 V. It has less than 0.1% ripple in output and costs similar to both of the previously mentioned devices.

Table 3.1.17.2: Substrate Finish Comparison

Comparison Criteria	TI TPS562201DDC R	Diodes Inc AP64060	Richtek RT8258GJ6
Input Range (V)	4.5 - 17	4.5 - 40	4.5 - 23
Output Range (V)	0.76 - 7	0.8 - 12	0.925 - 20 V
Ripple Tolerance (%)	.02%	<0.1% at 12V	< 0.1%
Cost	\$0.35	\$0.93	\$1.60
Quintessential Current	~100 μ A	90 μ A	70 μ A
Max Output Current	2 A	600mA	3 A

The VISTA will best utilize the Richtek RT8258GJ6 because it is able to support a higher output load current, while still meeting all other parameters. As the MCU and other

components do have a combined max current draw approaching 2A, adding an extra cushion will decrease the likelihood of failure.

3.1.17 Printed Circuit Board

All components must be integrated together onto a printed circuit board (PCB). PCB manufacturing is an entire industry in of itself and has many different design parameters, features, and processes. The main considerations in PCB selection is the number of layers. Design density, complexity and designer preference all dictate the number of layers necessary in the PCB.

Each additional layer linearly increased the surface area available for nets to run. The VISTA system is not overly complex and does not require extreme component density in the design. As a result, only a simple two layer PCB is necessary. This allows components to easily be connected and potentially dedicate an entire layer as a ground plane.

Another consideration in PCB construction is the material of the substrate. Many different materials exist, each with different pros and cons. As the frequency of signals transmitting through increases, electrical and thermal dissipation become extremely important factors to the success of the design [51]. The VISTA will be operating well below any gigahertz frequencies on the board (although higher frequencies will be used internal to the communication module) meaning these specific factors do not have to be taken into consideration [52].

FR-4 are commonly manufactured for designs with certain considerations in mind. Specifically, FR-4 PCBs are manufactured to a specific temperature rating. There are two main factors to consider: the glass transition temperature (T_g) and the thermal decomposition temperature (T_d). T_g is the temperature in which the substrate material transitions from a solid glass-like material to a workable rubbery material. T_d is less important in the case of the VISTA, as it is typically significantly higher than the T_g point, and most soldering processes. However, it should be noted that if the temperature were to exceed the T_d point, it would result in physical deconstruction of the substrate material. This would unnecessarily introduce additional sources of potential errors in the design.

As the VISTA is likely to require some components to be soldered on, this process could involve heating the substrate material past its T_d or T_g point, resulting in severe damage to the board. In the case of exceeding the T_g point, the board may slightly deform and components may be able to ever so slightly change position on the board. This could mean two nets are unexpectedly touching or a component becomes disconnected from the net. Commonly used T_g ratings are [$130^{\circ}\text{C} - 140^{\circ}\text{C}$] , [$140^{\circ}\text{C} - 150^{\circ}\text{C}$] , and [$150^{\circ}\text{C} - 160^{\circ}\text{C}$]. It may be apparent that solder temperatures are typically much higher than the common T_g values. Many solder materials have a melting point between 200°C and 300°C [53]. This discrepancy (soldering temperatures being significantly higher than T_g) is indeed safe, as to begin heating the substrate layer, the above solder mask and conductive layers must first be heated before significant heat will transfer to the substrate

[54]. As the VISTA PCB will likely require hand soldered components, common industry practice is to use FR-4 PCBs with Tg ratings above 140°, or higher to be on the safe side. While other alternatives may meet and exceed the specs of an FR-4 board, the cost significantly increases. For this reason, FR-4 with a Tg rating of 150-160°C is the most ideal candidate for the VISTA design.

Board thickness is an additional parameter in PCB design which must be taken into consideration. The substrate layers thickness can be controlled in the manufacturing process for special use cases. High power PCBs will often use a thicker PCB to isolate layers and reduce fault risks. As the VISTA will not utilize any high power systems, this practice would be unnecessary. The common industry practice of 1.6mm thickness provides more than enough stability and rigidity for the design.

Trace spacing is also designer controlled in most PCB manufacturing processes. As components are moved closer together, the effects of leakage and electromagnetic interference pose a challenge [55]. An ideal design chooses the happy medium between saving space (by decreasing spacing) and avoiding the aforementioned obstacles (by increasing spacing). As the communication module will be on an isolated module, the VISTA's custom PCB will not operate above gigahertz frequencies.

Industry practices and standards for low voltage systems call for a track spacing of 0.05 mm - 0.13 mm, or 1.9 mil - 5.11 mil at a minimum. The cheapest option from many PCB manufacturing services happens to be 6 mil, which exceeds these minimum requirements. Using a 6 mil track spacing would therefore not only be the most cost effective, but provide a safety margin, nearly guaranteeing the effects of interference and leakage will not be present in the design. For these reasons, a track spacing of 6 mil is the most suitable candidate in the VISTA design.

The next parameter to consider is the PCB surface finish material. Each conductive layer in the PCB, typically made of copper, is often finished with a special material to affect the electrical properties of the layer. Hot Air Level Soldering, or HASL for short, has historically been the industry standard for basic surface finishing. By applying a layer of solder material on top of the copper, it protects against corrosion and environmental effects [56]. HASL sealed boards utilize a number of different materials to achieve this effect, all typically a tin alloy. Lead based HASL is often the cheapest and historically most common option, however it comes with a few drawbacks. The biggest issue with lead based HASL is the lead itself being a health and environmental concern. Lead is a known carcinogen and can potentially leak into the environment from the PCB. Apart from regulatory concerns, consumers themselves are likely to be put off from the prospect of lead being in a device mounted directly on top of the air ventilation system, which circulates air the consumer breathes [57]. Additionally, for any type of HASL based finish, the final result can often have slight level variations. In other words, the surface may not be ideally flat, which can lead to issues in assembly and soldering [58].

The benefits of utilizing a lead surface finish is again inherent to the nature of lead. Lead

is easily solderable and components can be mounted with standard soldering equipment. Lead is known to provide a consistent and durable contact when soldering correctly [59]. Alternatives to lead based surface finishes are significantly more expensive. HASL PCBs can be manufactured with tin alloyed with nickel, silver, copper and other precious metals. These alternative materials do overcome the environmental and health issues presented in lead based finishes however they are still victim to level inconsistencies. Nickel, Silver and even Copper are also significantly more costly than lead, which of course results in more expensive PCB manufacturing costs[60].

Alternatives to HASL finishes can often be even more expensive than lead-free HASL. Immersion finishes differ from HASL in that the copper layer is immersed into a liquid metal. These metals are often silver or tin. Because of the added complexity required to liquify a metal and accurately fuse with the copper layer, the process is vastly more expensive. Additionally, the pure metals are often susceptible to different kinds of issues. Silver can tarnish, and while tin is more affordable than silver or gold, it is subject to the possibility of forming whiskers [61]. Tin whiskers are rogue strands of tin pushed out of their intended boundary during the manufacturing process. In some cases this could result in undesired connections between two nodes.

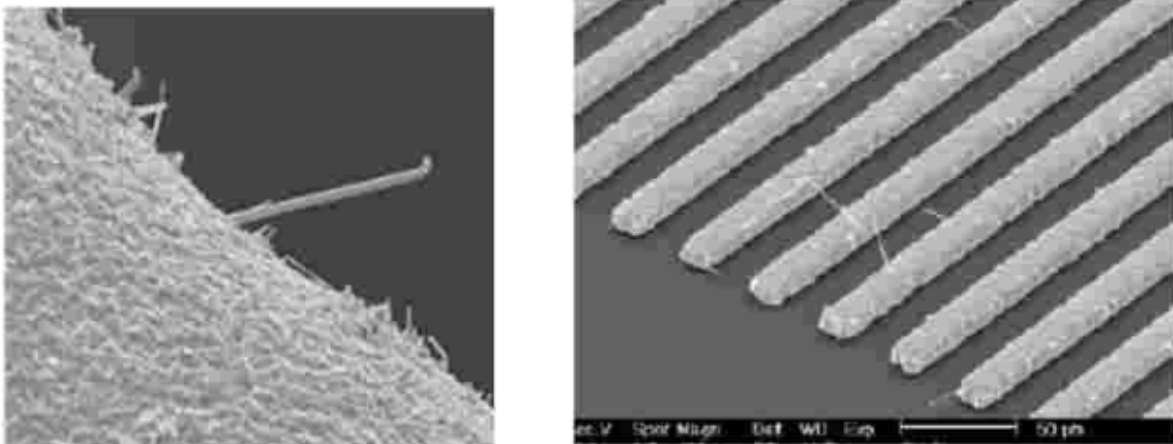


Figure 3.1.12 Tin Whiskers [61]

Organic Solderability Preservative (OSP) is a relatively new surface finishing technique. OSP uses an organic material which is able to bond to copper under specific conditions. The final result is significantly more uniform (flat) than the previously mentioned processes. This could lead to issues in the assembly process although advances in tooling have reduced this risk. The other caveat is that the layer can degrade from handling, That is the oils secreted from a human hand can chemically break down the finish. In the event the finish is destroyed, the potential for the copper to degrade is increased, potentially resulting in failure.

By far the most common industry practice in the modern era is Electroless Nickel / Immersion Gold (ENIG) plating. ENIG plating avoids many of the downsides of all the previously mentioned plating processes. The process avoids the use of lead, and the final top (exposed) later is high quality gold, meaning the board will be strong, solderable and

extremely flat. ENIG finishes are essentially made of two distinct layers. The bottom layer, which is bonded to the copper, is made entirely of nickel. Nickel is an excellent bonding agent to solder. Many different types of solder (lead, lead-free etc) can reliably and securely be soldered on nickel and nickel alloys [62]. Nickel is also significantly harder than many of the other materials used in surface finishing. Tin, gold and silver, the three common non-nickel materials, are significantly softer than nickel [63]. The ENIG process results in a relatively thick layer of nickel, and due to its hardness, creates a strong structural support to the board.

The layer of nickel is then encapsulated with a layer of gold. Gold not only is durable to environmental and common use conditions such as temperature, hand oils, etc, making it a perfect protective layer to nickel [64]. To add this thin layer of gold, gold particles are ionized in an effort to use an extremely thin layer of gold. The need for the gold layer to be thin is also one of the biggest downsides to ENIG. Gold is expensive, and the gold used in the immersion process must be high quality and avoid contaminants during the entire plating procedure. The necessary material and manufacturing costs can massively increase the cost of production.

Table 3.1.17.2: Substrate Finish Comparison

Comparison Criteria	HASL Lead	HASL Lead-Free	Immersion Silver/Tin	OSP	ENIG
Solderability	X	X	X		X
Environmental Durability	X	X	X		X
Handling Durability (skin oils)	X		X		X
Manufacturing Consistency	X	X		X	X
Flatness		X	X		X
Cost	\$	\$\$	\$\$\$	\$\$	\$\$\$\$

The full specifications of the ideal PCB for the VISTA consists of a double sided two layer FR-4 substrate with a Tg rating of 150-160°C, finished with Lead free HASL and utilizing industry standard parameters on thickness, track spacing etc. This ideal PCB allows for ample room for component placement and routing. Soldering is not likely to introduce damage, and the overall cost will remain reasonable. Choosing these parameters, while perhaps overkill, does reasonably promise for the PCB to not become a potential source of any error.

3.1.18 PCB Configuration

The most ideal PCB technology must utilize a double sided two layer board with FR-4 substrate having a Tg rating of 150-160°C and a surface finish made lead free HASL. A near endless number of PCB vendors are able to fulfill these parameters. Choosing between the different vendors comes down to cost, production time, quality and ease of use.

Additionally, it is extremely desirable for the vendor to additionally offer full assembly services as well. While the SMT components could be manually soldered with a stencil and oven, to decrease the likelihood for this being a source of error, vendor assembly is preferred. To benchmark between the different vendors, the same parameters were used to estimate/quote a price:

Note: Some values not previously mentioned may or may not be accurate of the final design. For example, board size and hole size may be subject to change.

Size	100 mm x 100 mm
Quantity	5
Layers	2
Substrate Material	FR-4
Tg	150-160 Celsius
Surface Finishing	Lead-Free HASL
Thickness	1.6 mm
Spacing	6/6 mil
Hole size	0.3 mm
Include Assembly	No
# of SMT Components	20

Table 3.1.18.1: PCB Specifications

PCBWay

PCBWay is one of the most common vendors for retail PCB solutions. They advertise extremely low pricing and fast shipping. Their online reputation is that they are of reasonably high quality, especially for smaller (complexity) projects. They also offer PCB Assembly (PCBA). Their assembly service is somewhat limited as any components they

do not have stocked must be supplied by the customer. This can be quite a hassle with ordering and the amount of time it takes for delivery.

JLCPCB

JLC PCB is the other major player in retail PCB manufacturing. Offering similar services to the previously mentioned PCBWay. JLC PCB does offer a major advantage as their component availability is relatively massive. This makes the assembly process much easier as they likely have more components already stocked and ready to assemble.

Elecrow PCB

Elecrow offers PCB manufacturing and assembly services at a slightly cheaper cost. This does however come with significantly longer lead times. Elecrow's advertised assembly services do claim to have a wide selection of components on hand, however in the fine print they do mention that resolving any issues in assembly such as component selection may take up to 24 hours between replies. Online reviews do often complain of customer support being poor.

Seed Studio Bazaar

Seed Studio Bazaar is an internet based company which not only manufactures and assembles custom PCBs but also sells completed pre-designed PCBAs. The biggest advantage is Seed Studio offers near 24/7 support in addition to a community supported forum to offer insight into any technical or nontechnical problems. The biggest drawback of Seed Studio is that they do not offer any FR-4 Substrate with a Tg rating of 150-160°C. As previously mentioned it is not absolutely necessary to use this rating (the 140-150°C rating is likely fine) but having a slightly higher rating gives a comfortable cushion in heat tolerance. Unless the other options are extraordinarily impractical to use, Seed Studio is likely not a viable candidate because of its lack of ideal material.

Table 3.1.18.2: PCBA Vendor Comparison

Comparison Criteria	PCBWay	JLC-PCB	Elecrow	Seed Studio
PCB(s) Price	\$5.00	\$3.30	\$6.90	\$12.90
PCB Assembly Cost	\$129.32	\$0.00	\$42.00	\$25.83
Cheapest Shipping Cost	\$23.21	\$18.06	\$10.35	\$26.66
Discounts/Promotions	-\$100.32 Assembly -\$23.21 Shipping	Free Assembly on First Order	None	-\$13.33 On Shipping
Final Quote	\$34.00	\$21.36	\$59.25	\$52.06

Estimated Delivery Time	2-4 Business Days	2-4 Business Days	2-5 Business Days	3-5 Business Days
Customer Support	Fair	Fair	Poor	Good
Reputation	Good	Good	Poor	Fair
Manufacturing Quality	Good	Good	Good	Good

The clear choice of PCB vendors is JLC PCB. Not only are they the least expensive, they also have the widest selection of parts on hand, fast delivery and an overall good reputation. While Elecrow and Seeed Studio have specific shortcomings, PCB Way and JLC PCB are at the very least meeting all minimum requirements of a retail PCBA manufacturer. Although the cost is likely to significantly change compared to the benchmark, it is clear JLC will either be the cheapest option, or very close to it.

3.1.19 Mounting

The VISTA's design calls for installation on or near an indoor air vent. This can be accomplished in a number of different ways. The PCB can be enclosed into a case designed to be mounted via screws, adhesive, or even hooked onto the vent itself. Since mounting items like paintings, picture frames, and televisions on interior walls is so common, a wide variety of commercial solutions are available.

Screws are a tried and true method of attachment. By threading into an existing support structure: 2x4's internal to a wall, or concrete block, the mounted item is securely attached to the wall. The design of a screw significantly differs based on the intended use application. Screws intended to drill into wood are designed to reduce withdrawal (screw loosening) from moisture variation causing expansion/contraction, and density variation as a result of woodgrain inconsistencies [65].

One of the primary design considerations for wood screws is the length of the shank. As the withdrawal force of the fastener is linearly increased with length, the best practice would theoretically be to use the possible length of screw to ensure stability. The secureness of the screw is also greatly affected by the size of the lead hole. If the lead driver is too large, the screw is not able to fully bite into the wood, resulting in a weaker withdrawal strength. If the lead hole is too small, the screw will reduce the structural integrity of the wood as the screw will twist and rip wood fibers as it is driven in.

A special type of wood screw, called lag screws, are designed very similarly to standard wood screws [66]. They differ in size— both length and diameter, along with the type of fastening head. Instead of a standard phillips/flathead, lag screws are typically fitted with a hex fastener to allow a greater amount of torque be applied. While standard wood

screws are meant to attach lighter materials to wood, lag screws are intended for heavier loads. They still come with the same drawbacks as well.

Because wood screws are typically used in lighter loads, wood screws are not significantly affected by the direction they are driven relative to the grain. For higher-load lag screws, the effect is more significant as the potential withdrawal strength discrepancy between installation locations varies linearly [67]. When driven perpendicular to the woodgrain, screws are able to achieve their maximum theoretical withdrawal strength. Compared to being driven parallel to the core, the strength may be diminished by as much as 25%. The exact loss can be calculated by the equation in figure 3.1.11.1. With P being the maximum theoretical withdrawal strength if driven parallel to the grain, Q perpendicular, θ the relative angle being driven and N the theoretical maximum strength driven at angle θ into the grain.

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta}$$

Figure 3.1.19.1 Exact Loss Equation [67]

As not all interior walls are constructed of wood supports, a common alternative is plaster/concrete/brick block based walls. These walls would require the use of screws capable of drilling into the rock based material. Concrete screws are significantly harder than common wood screws as they must be capable of overcoming the significantly tougher material [68]. The screws are often reinforced with hardened carbide tips to cut through concrete.

Concrete screws are often rated for higher loads, in part because a concrete wall is capable of supporting more lateral weight than an equivalent wood wall. In the United States, the vast majority of residential and commercial buildings use a wood structure for interior walls. Outside the United States, particularly in Europe and Latin America, block construction is the primary construction framework [69]. This means designing the VISTA around just one of the mounting technologies, wood or concrete screws may regionally isolate the potential market.

Another major downside to using both wood and concrete screws is the necessary steps in installation. Both require pilot holes, meaning the user must first drill an appropriately sized hole into the intended mounting location before the screw itself can even be installed. Sourcing the materials for installation: a power drill and correctly sized drill bit is likely to be a major put off to potential users.

Thankfully a common feature of most interior air vents, is a vent cover. Attached over the face of the air vent, these covers often have at least two machine screws on either side of the cover, which attach into the face of the actual vent. Repurposing these existing screw holes would allow the VISTA to still have structural support without requiring the need for a user to drill into a wall. A common hand turn screwdriver would be the only necessary

equipment to install the device. Mounting the VISTA onto the existing vent cover would necessitate the use of longer screws. The length of the screws can be determined by adding the thickness of the VISTA mounting point in addition to the length of the original screws.

An common alternative to screws, particularly for interior wall purposes is the use of special adhesive strips. Adhesive strips can vary in design, but generally follow a few main principles. The main contributing factor to the effectiveness of adhesive strips are their double sided property [70]. Each side of the strip is enveloped in a glue, formulated to adhere to a specific type of material. For interior walls, one side of the strip is formulated to adhere to oil based paint layered over sheetrock. The other side is either a universal adhesive, or as is the case of the VISTA where the mounting object is of a known material, can have an application specific glue.

Depending on the material, the strength of the bond varies. The strongest commonly available adhesives are only able to bond with certain plastics [71]. This is because some glues are formulated to react and chemically bond between the two materials. For these ultra strong adhesives, the bonds can be so strong, it damages the substrate of the material. Damage to walls, even if just cosmetic, is not suitable for the VISTA design, especially if other technologies are able to achieve the necessary support without causing any destruction.

The performance of an adhesive is determined by five primary factors: the strength of the adhesive material itself, the environmental conditions, the substrate material, the pressure used to apply the adhesive and finally the time the adhesive is given to cure [70]. The strength of the adhesive material is in turn determined by another multitude of factors. The hardness of the material contributes to the amount of force required to cause the adhesion to fail [72]. This is because a hard material has more cohesion, or in other words, forces applied to the surface of a hard material, the internal forces are stronger than a soft equivalent [71]. A hard adhesive however has a significant drawback, as the harder a material is, the ability for it to adhere to any rough, porous or otherwise non-uniform surface decreases. In the case of interior walls, where paint irregularities and wall texture are common, a hard adhesive is unlikely to support the VISTA.

The substrate material further affects the performance based on the substrate's surface energy. Surface energy is the net electromagnetic molecular forces of a material, present at the material's surface [73]. The amount of surface energy a material has affects how any other object interacts at its surface. A common example used to demonstrate the surface energy of a material uses just purified water. In figure 3.1.11.2 below, the water is observed to form large beads in the non-stick pan as it has a very low surface energy. This means there is less energy pushing the water particles away from the surface. This is in comparison to the steel pan which has a high surface energy.



Figure 3.1.19.2: Good vs. Poor Wet Out [73]

The stronger the surface energy of a substrate material, the harder it is for the adhesive to bond to the material. The energy causes the adhesive to be physically pushed away from the substrate, albeit on a very small, molecular scale [73]. The surface energy of an interior wall is generally categorized as low to medium. This leaves a wider choice of potential adhesives for the VISTA.

In summary, the potentially most effective adhesives for the VISTA is likely to be a soft adhesive, formulated to work with low-medium surface energy substrates. Soft adhesives are commonly available from three material types. Rubber adhesives, both natural and synthetic rubber, are the most common for indoor household applications. They perform well on both low surface energy (LSE) and high surface energy (HSE) materials [70]. Depending on the specific product formulation, rubber adhesives can be engineered to support extreme loads.

Acrylic adhesives, while also commonly used as a general purpose interior adhesive, suffer from a relatively weaker bond to LSE materials. This is particularly true for solvent acrylics, and resultantly are generally only used for small, non-critical applications [71]. Emulsions acrylic adhesives, while still ultimately weaker than a rubber counterpart, are potentially capable of supporting high enough loads to be a suitable candidate for the VISTA.

Silicone adhesives are the least suitable candidate for the VISTA. While silicone adhesives provide an incredibly strong bond strength, the initial strength (before fully cured) is relatively, incredibly weak. The curing time for most silicone adhesives would not be able to support a load similar to the VISTA until well over 24 hours after initial application. This makes the use of silicone adhesives completely impractical.

The primary differences between the identified candidate adhesives— rubber and emulsion acrylic are cost, bond strength, and durability. Rubber adhesives are significantly more expensive. Common off the shelf rubber adhesives can often cost four to ten times the cost of an acrylic adhesive of the same surface area. However, rubber adhesives are ultimately preferred over acrylic. Some application specific formulations can be stronger than an acrylic adhesive by orders of magnitude. For this reason, the

most suitable adhesive for the VISTA is a rubber based adhesive, particularly a rubber adhesive formulated for an interior wall or similar environment.

Table 3.1.19.3: Mounting Comparison

Comparison Criteria	Wood/Concrete Screws	Machine Screws (Pre-existing holes)	Rubber Adhesive	Acrylic Adhesive	Silicone Adhesive
Cost	\$	\$	\$\$	\$	\$
Strength	+++	+++	++	+	-
Ease of Installation	-	+	++	++	-
Durability	+++	+++	++	+	-

Choosing *between* screws or adhesives may not be necessary. Combining the two technologies may be the most effective, reliable and add necessary redundancy. Interior air vents are often located more than six feet off the ground. If the VISTA were to fall from this height, the likelihood of functional failure is extremely high. The VISTA enclosure should be designed with mounting points to attach to the pre-existing screw holes, as well as a surface to mount with a rubber adhesive.

3.1.20 Machine Screws and Rubber Adhesive

The VISTA should be duly mounted for extra reliability. This will be accomplished by utilizing both extended machine screws and rubber adhesive tape. As for the machine screws, because the pull-off strength is already so substantial, design differences in thread type, thread depth, pitch, head type etc do not add any necessary support strength. Machine screws are often rated to support upwards of 50+ pounds. The total weight of the vista is likely to be less than 10% that rating.

As such the only real criteria in choosing an individual machine screw is length and material. The standard screw diameter for most commercially available vents is #6 (0.138 inches or 3.51mm). This thread size is readily available and has a consistent design across brands. As already established, the length of the screw should be the length of the original screw, plus an additional thickness of the mounting hole attachment. At time of writing, the mounting hole attachment thickness is not known. To account for this discrepancy, washers can also be used as needed to attach to the mounting screw.

As for the head type, to make installation as easy as possible for users, a standard Phillips head screw is needed. Phillips head screws come in button, cap, pan, oval and many more head types. For the purposes of the VISTA, a common button cap screw is

best suited. It provides a large surface area to build tension on and is generally the easiest to tighten “by hand.” The cheapest available option that meets all these criteria is the Hillman 6-mm 1 x 45-mm Phillips-Drive Machine Screw which is sold at most big box hardware stores[120].

As for the rubber adhesive tape to add extra stability to the design, we know a couple of parameters needed in choosing the specific part. First, the adhesive must be able to bond to both PETG (the VISTA) and steel (existing air vent) or drywall. A plethora of options are available to choose from . Double-sided duct tape and mounting tape are the primary types of double sided rubber adhesive tapes used for relatively high loads (anything more than a few grams) on a wide variety of surfaces.

Command™ Brand Strips

Command™ strips have become a common household name for hanging interior articles on the exact surfaces the VISTA will be installed on. They have the additional benefit of having the ability to be removed easily, and without damage. The strips feature a small pull tab at the bottom which, when pulled, rips the adhesive from the glue. This is only possible due to the softness of the adhesive. The inherent drawback of this, is that the strength of the adhesive is relatively weak.

Gorilla Max Strength Mounting Tape

Gorilla Max Strength Mounting Tape is much larger and advertised to support much higher loads (45 lbs) than the previously mentioned strips. This makes it a far more attractive candidate for use in the VISTA. The tape however has a distinct warning about bonding to polyethylene plastics. This is likely due to the adhesive permanently bonding to polyethylene likely causing deterioration in the plastic device.

Gorilla Double Sided Tape

Double sided (duct) tape may fulfill all the needs of the VISTA. It can support relatively high loads, specifically is advertised to work on interior walls and polyethylene. The only potential downside to this is that compared to the tape explicitly advertised as mounting tape, the double sided tape does not advertise it’s tested lifespan. This is likely because the strength of the adhesive slowly deteriorates and eventually fails

Comparison Criteria	Command™ Strips	Gorilla Max Strength Mounting Tape	Gorilla Double Sided Tape
Strength	<5 lbs	45 lbs	“Heavy Duty”
Lifespan	Indefinite	Permanent	Unknown
Polyethylene compatibility	✓	X	✓

Removal	✓	X	✓
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Table 3.1.20.1: Mounting Comparison

Considering the majority of the weight will be supported by the machine screws, which is extremely unlikely to fail, the strength of the adhesive is not of the utmost importance. The Command strips are certainly the most feasible in terms of adding stability and a reasonable amount of redundancy to the design. For this reason, they are the best option to use.

3.2 Communication Protocol

3.2.1 Wireless Communication

For the V.I.S.T.A system to effectively communicate with the user's app, it is important to establish a reliable method of communication. Different types of communication offer distinct functionalities that could help the system in various ways depending on the specific requirements. Bluetooth, Wi-Fi, and Zigbee are the primary communication methods being considered for this project. Each communication method presents unique benefits and trade-offs, and selecting the ideal one will depend on factors such as environment, level of data, and power constraints. Careful research and consideration of these aspects will be crucial in ensuring the V.I.S.T.A. system operates seamlessly, delivering optimal user experience.

Bluetooth technology allows devices to communicate without cables or wires. It uses radio waves to transmit data and has a relatively short range [39]. It is a very popular type of communication as it is already installed on all potential user's devices. This will make implementation of bluetooth relatively simple and familiar to new users. This type of communication is short-range, less expensive, and energy efficient. Bluetooth typically has a range of up to 30 feet, though it can sometimes be extended up to 164 feet. This is ideal for our system, which is designed for use in an average sized room. The range may become a limitation in the future if the system were to transition to larger spaces or if interconnection between vents is necessary. However, since these factors are not a part of the immediate prototype of the system, they will not be a major factor in choosing the best communication method. Bluetooth is also less expensive, due to the established standards and software in devices. An important factor of this type of communication is its energy efficiency, it uses way less power when compared to Wi-fi or Zigbee communication. It can also be used on devices with very low battery life, making it more versatile with users.

While there are many advantages, some disadvantages of bluetooth include low bandwidth, loss of connection, and limited devices [40]. Low bandwidth could result in a reduction of data transfers, this could result in slow connectivity between the system and the user's interface. The good news is that the V.I.S.T.A. system should not need to communicate loads of data, it only needs to communicate temperature and occupancy of a room. Another limitation is loss of connection, Bluetooth is known to lose connection

due to many random and sometimes environmental factors. This could cause issues within customer experience, but should not affect the usefulness of the system. Lastly, this type of communication only allows communication between a limited number of devices, as mentioned earlier a stretch goal of the project is to have intercommunication between vents. The limitation of devices could cause issues with the further development of the system.

The second type of communication technology that could be used is Wi-Fi, it uses radio waves to send signals but also connects to a router and then to the device to transmit data. It is cost effective, efficient, and flexible. Wireless networks are cheap to install and generally have an established standard that the V.I.S.T.A. could integrate into. It is also way cheaper than having to attach a form of communication to the pre-existing cables within the home. Wi-fi is also efficient, it can send lots of data quickly, it can support an amount of data much larger than what would be necessary for the scope of our project. Finally, Wi-fi offers flexibility, with a range of up to 300 feet, which could help solve the issues in future use cases for the project. Additionally, if the range proves insufficient, Wi-fi can be extended with Wi-fi boosters, enabling communication over even greater distances. This versatility makes Wi-fi a strong candidate for the V.I.S.T.A. system.

The drawbacks of Wi-fi include higher power consumption and latency [41]. When compared to Zigbee and Bluetooth communication, Wi-fi typically requires more energy, which could be an issue for low-power systems. Since our project is designed to be energy efficient, potentially even fully battery operated, this higher power could pose a challenge. However, with the variety of W-fi standards available, there may be an option that suits the system's needs. Another concern is latency. While bluetooth also experiences delays, Wi-fi is typically more prone to latency due to network congestion or interference. Latency can be problematic for real-time applications, the V.I.S.T.A. does not require real-time responsiveness, making it less of a critical issue. Overall while power consumption and latency are a concern when deciding the communication technology, they may not be as detrimental as some of the other trade offs of Bluetooth and Zigbee communication.

The final form of communication that could be used for the system is Zigbee [42]. This is a wireless technology designed for use in low-cost, low-power data networks. The advantages of Zigbee include scalability, encryption, and power consumption. Zigbee is currently an open standard, which helps in the creation of custom solutions. Since it is not as established as Wi-fi or Bluetooth manufacturers can still find new and innovative ways to use this communication network. Zigbee's network can support up to 65,000 devices, this is due to the mesh networking they use. Although this is not the current scale that is needed for the project, when considering future installation this is an advantage that the other devices do not possess. This technology is also secure, it uses an encryption algorithm with a 128-bit password which can guarantee transmission confidentiality [43]. This was a lack in the other two devices, as Wi-fi and Bluetooth are not known for having the best security. Another advantage of Zigbee is its energy consumption, it uses a low power consumption design making it practical for our system. Their low consumption can make the battery of the system last 6 months to two years. This would work well with our

system as it needs low power consuming components.

Despite Zigbee's many advantages, it also has notable disadvantages too, such as complexity and potential interference. As an open standard, Zigbee can be difficult to integrate and configure which may not align with the need for simplicity within this system. The complexity makes it a less appealing option for the primary communication method. Additionally, while Zigbee uses a frequency capable of delivering fast data, it could interfere with devices using Wi-fi, potentially causing frustration for users [44]. This interference could negatively impact user's experience with V.I.S.T.A. and reduce the overall appeal.

Table 3.2.1.1: Wifi vs. Bluetooth vs. Zigbee Criteria Comparison

Comparison Criteria	Wifi	Bluetooth	Zigbee
Data transfer size	X		
Flexibility	X		
Communication Range	X		
Security			X
Malleability			X
Energy efficiency		X	

Each communication technology offers its own advantages for the V.I.S.T.A. system, Wi-fi is the most suitable communication method. Its ability to transmit large amounts of data quickly, along with its flexibility and wide range, make it an ideal fit for the current and possibly future systems. Even though Wi-fi has higher power consumption when compared to Bluetooth and Zigbee, the variety of standards available will help this issue. While latency and interference are also concerns, the V.I.S.T.A. system does not require real-time responsiveness, making these issues less prevalent. Overall, Wi-fi's scalability, efficiency, and adaptability outweigh the disadvantages, making it the best option to ensure reliable communication and user satisfaction.

3.2.2 Wifi

The wifi module choice for the project will determine how quickly the data from the sensors/MCU is going to reach the user interface. For simplicity sake the module picked should be in compliance with popular standards. This will make integration of the module with the board more straightforward. The module picked also needs to have an ideal transmission rate, coverage, power consumption, and size [110]. All of these requirements should be compared and reveal the best wifi module for the VISTA system.

The transmission rate of a wifi module is responsible for the speed at which the wireless devices transmit data, typically measured in megabits per second. This rate is an important factor in ensuring efficient and timely communication in wireless systems, especially if a system demands real-time exchange. The VISTA system would ideally be as close to real time as possible. The transmission rate of a module is influenced by several factors, some being the generation of the module and the selected protocol [111]. Each generation of wifi has new advancements in data transmission, with new standards offering higher transmission rates. For example, previous generations of modules could support rates such as 600 Mbps and 3.5 Gbps; while the latest wifi module, wifi 6 (802.11ax) can achieve rates as high as 9.6 Gbps [112], improving efficiency in high-density environments and overall better performance.

The chosen communication protocol can also affect the effective transmission speed. TCP/IP and UDP [113] are the main examples of different types of communication protocols. TCP is more reliable but may have higher overhead and slower transmission rates due to its error-check mechanism. While UDP offers fast speed but lacks reliability. Each communication has its own purpose, for our system a communication protocol such as TCP would be preferred as the system will have low data transfer and does not require fast transmission speeds.

The second factor to consider when picking a wifi module is the coverage of the module. Wifi networks have a range limited by frequency, transmission power, antenna type, and their environment [114]. Picking a module with enough coverage to communicate throughout the optimal use case is necessary. The frequency of the wifi signal can affect range, 2.4 GHz signals can travel about 60 feet through walls in indoor environments. On the other hand, the 5 GHz frequency band provides faster data rates but has a shorter effective range, about 45 feet through walls.

For our system, both frequency bands would provide adequate coverage for the system's operation within a small bedroom. However, if future applications or expanded functionality are anticipated, choosing a 2.4 GHz wifi module may make more sense. The extended range could benefit the system if interconnectivity between vents becomes a reality. It could also benefit the system if it were to become used in a more commercial space.

The third factor is power consumption, this is a big one as we want the VISTA system to be as efficient as possible. The power consumption of a module can vary depending on the model and if it supports operating modes. If a module does not have special modes of operation it will consume, on average, 30-40 milliamps. There are also modules that support a low power mode to help reduce power consumption [115]. This mode can reduce unnecessary power consumption of the module. Some modules not only are low power but also have inactive and active modes. All of these different adjustments to a general wifi module can help improve efficiency of the overall system [116].

The final major factor to consider when picking a wifi module is physical size. While size may not be a significant concern for large systems with ample space for components, it

becomes more critical when dealing with compact designs. In projects where multiple components need to fit onto a single printed circuit board, such as the VISTA system, the physical footprint of each component directly impacts the overall layout and design flexibility.

Choosing a wifi module that is small can allow for more use of the PCB space, the can accommodate for additional components or maintain the overall size requirements of the system. In cases such as ours, opting for a smaller module can help reduce the need for a larger PCB, helping to minimize production costs. Smaller wifi modules may also come with integrated antennas or reduced external parts which further helps in space management.

There are three different wifi modules that could be used to benefit the VISTA system, ISM43362-M3G-L44, SPWF04SA and WiFi HT40. The different specifications that each brings to the project will determine which is most suitable.

The ISM43362-M3G-L44 is an embedded wifi module that consists of a cypress CYW43362, an integrated antenna, and a STM32F205 host processor. This device has UART and SPI interface capability and requires no operating system. The system uses a TCP/IP stack that only requires a simple AT command to establish connectivity to the product. This module is ideal for low cost embedded wireless applications, it enables a quick, easy and cost effective method for adding wifi to a system [117].

The second potential wifi module is the SPWF04SA, it is a ready to use wifi module made for the Internet of Things. The module integrates a Cortex-M4-based STM32 MCU and a transceiver for a 2.4 GHz band. It is cloud compatible, and can operate in serial-to-wifi and standalone mode. The module is also lower power consumption and ultra-compact. This module is ideal for fixed and mobile wireless applications, as well as challenging battery operated applications [119].

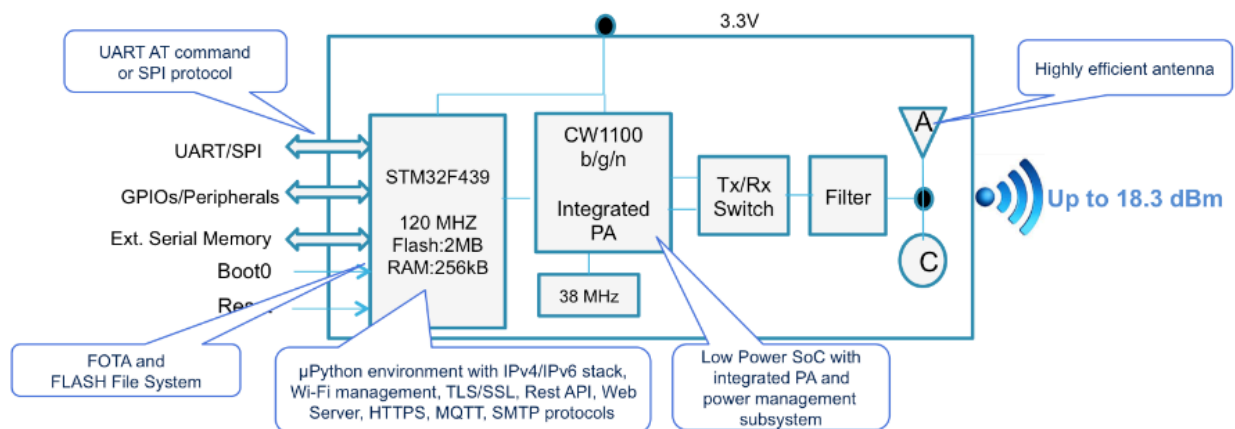


Figure 3.2.2.1: SPWF04SA/SPWF04SC schematic

The final wifi module option for the VISTA system is the WiFi HT40. This wifi module is embedded within the ESP32 MCU, it is beneficial because it can increase transfer speeds

by combining two 20 MHz channels together. While this is the most obvious choice for our system, it is important to also consider the possibility of external wifi modules.

Table 3.2.2.2: Wifi Module Technical Specifications Comparison

Technical Specifications	ISM43362-M3G-L44 [117]	WiFi HT40	SPWF04SA [119]
Standard	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n
Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Throughput speed	54 Mbps	150 Mbps	54 Mbps
Low Power Modes	Yes	Yes	Yes
IOT interface	Yes	Yes	Yes
UART/SPI	Yes	Yes	Yes
Size	14.5 x 30 (mm)	12 x 12 (mm)	26.92 x 15.24 x 2.35 (mm)
Price	\$10.33	Included in MCU price	\$8.95

All three Wifi modules offer valuable features for the VISTA system, the WiFi HT40 stands out as the most suitable choice. Its integration, high efficiency, and fast communication make it a great choice for adding wireless connection to the system. Additionally, the immediate communication between the wifi module and the MCU is a major advantage of this module. While the ISM43362-M3G-L44 and SPWF04SA offer strong IoT and cloud compatibility features, the WiFi HT40 strikes the ideal balance between simplicity and functionality, making it the optimal choice for the VISTA system.

3.3 Software Comparison and Selection

3.3.1 User Interface

One of the most important aspects of the V.I.S.T.A system is to be able to respond to the user's input. The V.I.S.T.A must be able to take direction from the user in order to set temperature settings, change from Eco mode to Bare minimum energy mode, and force open/close the vents. All of these tasks are performed via the User Interface. The User Interface for the V.I.S.T.A device, as stated in the Software section, will be controlled via a separate web application. The reason this was chosen was because of the flexibility a web app provides in comparison to a mobile app. For one, it will not require approval through an app store, and it will also allow for the V.I.S.T.A to be controlled through all devices that can support a WiFi connection. It is also preferred compared to creating a hardware-based remote control because of its simplicity. With this in mind, all web application development must begin with considering the frontend frameworks, as this is the framework where the user interface will be built on. Before the framework is chosen however, the best programming language must be chosen that includes available frameworks to be chosen from.

To begin development of a web-application frontend, it is important to determine what the best programming language should be. There are many available languages that exist which could fulfill the requirements of this project, but the chosen framework languages must fulfill certain requirements. Firstly, the frontend framework must be supported on all available web browsers, since this is the only way to interact with the V.I.S.T.A device. It must also be simple enough to learn in order to expedite development time. It is preferred that the chosen framework be known for its rich user interface elements, and is also preferred to achieve this without much performance overhead. The chosen frontend framework-type will have implications on all of these requirements. Some existing framework-types would be Javascript, as there are many existing Javascript frontend frameworks such as React.js, Angular.js, and Vue.js. Although Javascript is very popular, there exists alternatives which could offer benefits for this project. Another would be using the C# language, which would give other framework options such as WebAssembly and Blazor. Python could also be a useful language to use given these requirements, and would open up the use of the Flask framework.

Javascript is one of the largest web development languages and, because of this, offers very clear advantages. There are many helpful resources online to learn more about Javascript and it is native to all web browsers. It is known for its real-time HTTP communication and offers good state-management compared to other languages. The one downside of Javascript however would be its performance. All of the frameworks that are built on Javascript would offer significant performance overhead, despite the benefits listed. Whether or not Javascript would be the best language to choose from depends how much performance is a necessity for this project.

Utilizing C# in combination with other existing frameworks, such as WebAssembly, could be a viable alternative for this project. There would be some clear benefits to using C# as well. C# is commonly used for web development in the .NET framework, which is known for integrating the frontend and backend under one framework, leading to lots of

performance gains. It could be a great alternative to Javascript if the backend of the web development would sit outside of the V.I.S.T.A device. It has some clear drawbacks, however. Firstly, it is unclear whether a backend would need to exist outside of the V.I.S.T.A device, since the V.I.S.T.A device has its own WiFi module capable of sending/receiving HTTP requests. The V.I.S.T.A device could therefore set up its own backend, and it is unlikely that C# would work well with the chosen MCU. Even if the backend existed separately from the V.I.S.T.A, it would require a lot of development time to set up a .NET framework, and the performance gains would be the only viable reason to undergo this process.

Python is another possibility for this project, and it is clear that this could be the easiest to implement. Most people are familiar with the Python language, and it would also allow for simple backend implementation similarly to C#. However, it lacks significantly in performance considerations and also in browser support. Most browsers don't natively support python frontends, lacking a python runtime engine since most browsers opt for Javascript. Python would only be a viable choice if the development was really that much simpler compared to Javascript and C#.

With all of this in mind, the best web-development language would be Javascript. Despite its setbacks in performance, it would offer a moderately easy development, and it is available on all web browsers. It is then important to choose which Javascript framework best fits the needs of this web app for the frontend, and Javascript also offers a wide variety of frameworks that already exist.

Table 3.3.1.1: Javascript vs C# vs Python Comparison

Language	Performance Overhead	Development Time	Rich UI Elements	Browser Support
Javascript	-	+	++	++
C#	++	-	-	+
Python	+	++	+	-

3.3.2 Javascript Framework

With this web app comes the decision on what Frontend framework the user interface will be developed on. As stated, the user interface is a Javascript-based web application, so a Javascript framework will be chosen. There are many possible Javascript frameworks to choose from, but they must fulfill certain requirements. For one, this framework must be able to service HTTP requests to the backend, that in turn will communicate with the MCU software. It is preferred that the framework include support for the RESTful API or similar. This will also allow for easy error-handling and debugging when HTTP errors occur. It is also a requirement for this framework to support global state management. An example of a global state would be the current temperature. For example, this front-end framework should receive information from the backend such as the current temperature, and be

able to instantly update the global state and in turn update a temperature box on the user interface. Choosing a framework that is known for complex state-management is therefore preferred. Finally, the framework must be light-weight enough to optimize performance. With these framework requirements in mind, the best possible candidates would seem to be React.js, Angular.js or Vue.js.

Each of these front-end frameworks offers some or most of the specifications, but React.js offers most of the given requirements, therefore it will be chosen as the front-end framework. React.js is a relatively light-weight and easy to learn framework that also includes support for the RESTful API for HTTP requests. React.js also works well with other API's such as Context API for more complicated state-management procedures, such as changing the temperature reading on the user interface every time the VISTA device sends a new reading. Angular.js does however offer HTTP request support without the use of imported libraries, but at the cost of being a heavier framework compared to React.js. Vue.js also satisfies the HTTP request requirement but is not as well known for state management as React.js is. As an example, the Context API is very commonly used for state-management and this API is not available for Vue.js. Therefore, the React.js frontend framework was chosen for the web application.

Using this frontend technology, the user will be able to log into the web application and open a device portal to interface with the VISTA device. The user can set their desired temperature, change the mode of the device from Eco mode to Bare minimum energy mode, or force open/close the vents. The temperature will be able to be changed by a dynamic slider that can be set from the minimum temperature setting to the maximum temperature setting. The Eco mode and Bare minimum energy mode will be a toggle switch that can be switched to either mode when the user interacts with it. Finally, the vents can be open or closed simply by pressing a button. This information will then be communicated to the backend so it can be transmitted to the VISTA device.

Table 3.3.2.1: Javascript Framework Comparison

Frontend Framework	Performance Overhead	Maintainability	Library Support	Fast UI Updates
React.js	+	++	++	++
Angular.js	++	+	+	+
Vue.js	-	-	-	-

3.3.3 Software Development

The VISTA device will require an extensive software stack in order to implement all of its intended functions, and various software development strategies therefore must be employed to simplify this process. On top of this, the web application will include its own software stack that must be designed to be in sync with the VISTA device. The backend

for the web app software stack must be chosen to work effectively with both the V.I.S.T.A device's internal software and the frontend. The challenges for each software endeavor, the MCU software and the web app, must be tackled separately. For the MCU software, it is important to determine at what level of abstraction VISTA's internal software will be written in, as is the case for writing any embedded software. One of the main points of concern for VISTA's internal software is ensuring that the layer of software abstraction allows for more complicated procedures, such as sending HTTP requests to the backend, or being able to handle many processes. It might make sense to, for example, utilize the task-scheduling features of a RTOS to schedule an HTTP request when the single-core MCU is still busy. However, this must not also make the software too complex as to increase development time. It is also essential that VISTA's internal software allows for a connection to WiFi as this is the chosen communication method. Choosing the correct level of software development abstraction therefore depends on the complexity of these tasks.

Determining the level of software development abstraction is the first and perhaps most important step in beginning the development of VISTA's internal software. There are three common ways to develop embedded software. The first is using register-level software development, which can be the most complex but also can be the most effective at maximizing hardware-performance. The second involves utilizing an available Hardware-Abstraction Library which is often provided by the MCU vendor and exists for the STM32 MCU. This library abstracts away common requirements like setting up UART, I2C, or other communication protocols into simple function calls. Despite this, it will involve a modest amount of overhead and performance drawback compared to bare-metal register-level software programming. The final possibility would be to use an available Real-Time operating system for embedded devices such as FreeRTOS, Zephyr, or Mbed OS. Utilizing a RTOS will allow for the most amount of abstraction and will also enable other features, such as multitasking and task-priority scheduling. It will incur the most amount of overhead and performance drawback however. Selecting the best software development abstraction level will depend on the complexity of the project and the performance.

The register-level development involves utilizing no pre-existing libraries and creating a "super-loop" in which to run the main functions of VISTA's software. The super loop would be a C while loop that will contain all functions that would need to be performed, such as polling sensors and sending HTTP requests. It could also involve setting up hardware interrupts to perform an interrupt for when an HTTP request arrives, or when a thermal reading changes. The register-level development method means that all protocols such as UART and I2C, would have to be set up manually by placing numeric values in hardware registers. This is because there would be no libraries to perform these tasks. This method would allow for the most amount of performance since it would incur no library overhead. Despite this, it would likely be the most difficult to implement and require extensive reading of the data-sheet to determine the correct placement of values in hardware registers. It is by far not the favorite despite its extensive improvement in performance it would cause.

Utilizing a Hardware-Abstraction Library would be the second method which will improve on development time at the cost of performance. The Hardware-Abstraction Library available for STM32 series MCU's eases the implementation of common hardware protocols like UART and I2C. It also can set up other common MCU functionalities like creating timers and performing direct-memory access requests without placing values into hardware registers manually. This would allow for a much easier development cycle, because time would not be spent implementing all of these functionalities from scratch. It would also incur a small performance loss due to the overhead of libraries. Despite the fact that it would make development significantly easier compared to register-level development, it might not go far enough. Utilizing only a Hardware-Abstraction Library means that all functions would still sit inside of a super-loop, and sensor readings would still either be polled or occur through hardware interrupts. In general, utilizing only a Hardware-Abstraction Library would merely simplify the process of setting up hardware communication protocols and basic setup procedures, but is unlikely to go far enough in simplifying development.

With these considerations in mind, it is clear that using a RTOS will be the best method for implementing the V.I.S.T.A's internal software. This is because there are many scenarios that the V.I.S.T.A device will have to tackle that involve concurrency, task scheduling, and asynchronous events. For example, the VISTA device must be able to respond to incoming JSON data from an HTTP request, despite being in the middle of a sensor reading. Even though the chosen STM MCU is single-core, the task-scheduling functionality of a RTOS will simplify this process where there is data arriving asynchronously from the web-app backend. A RTOS can even allow for better power management by entering a sleep mode when all tasks are waiting on other components like sensor readings. This works best for the VISTA since it will likely remain idle for long periods of time. Reading the sensor, sending HTTP requests, changing VISTA's internal mode all can be made into tasks that can be at a lower or higher priority level depending on their severity. A RTOS then includes a basic scheduler that will handle all of the tasks in the task queue and pre-empt the task once it is done. The scheduler would then take the place of a super-loop, since all tasks would sit in the scheduler and be executed by priority level. Based on the Software Decision Tree in Figure 2.5.2, VISTA's internal software is expected to read the thermal sensor every 60 seconds. In order to do this without a real time operating system, it would likely require starting a timer and having sensor-reading inside of an interrupt. To make this process more simple, A RTOS allows the sensor reading to be placed into a separate task that is scheduled to run on a cycle of every 60 seconds. After reading, the sensor data could then be sent to the actuator control task. A RTOS would preempt other tasks running when the 60 seconds arrives without having to write the sensor reading function inside of an interrupt service routine. A RTOS would also allow for the use of dynamic memory functions in C to be utilized, in case they would be needed. Simply put, it would make the complex nature of interacting with the web-app backend and responding to asynchronous events much simpler. It does come with the notable drawback of a performance hindrance because of the large amount of overhead with a RTOS, compared to register-level. Yet, with the development cycle being made easier it is a worthy trade off, since the VISTA device does not need to meet specific timing requirements.

Using a RTOS will be one of the biggest components of technology for the V.I.S.T.A's internal software, however it is not the only technology to consider. This is because the VISTA software also needs to manage a WiFi connection in order to communicate with the web app. For simplicity, one of the responsibilities of the VISTA internal software will be to host the backend of the web app. Utilizing the WiFi modules built into TCP/IP stack, the VISTA software will set up a small HTTP server that will carry the responsibility of hosting endpoints, and sending HTTP get/fetch commands to the React.js frontend. This also allows for the React.js frontend to either be hosted on a local machine or in the cloud, such as Amazon's Web Service. However, because VISTA will host a small HTTP server, it must also be configured to connect to a WiFi network. This is challenging to do because it cannot be done simply through the React.js frontend. Instead, the VISTA device will have to communicate to another device to receive the SSID and password of an existing WiFi network. There are three possible ways to achieve this goal, with varying levels of difficulty and user-friendliness. One solution would be hard-coding an existing SSID and password combination directly into the MCU software. Another would be to set up Bluetooth low energy WiFi provisioning, and the last would be to have VISTA set up a WiFi access point.

To begin with, hard-coding the SSID and password combination into the V.I.S.T.A's internal software would be the easiest possible implementation. It would allow for simple debugging and not overcomplicate development by relying on Bluetooth protocol or creating an access point network. Yet, it will be the least user friendly option because this WiFi network would have to exist somewhere in proximity to the device. For this reason it will not be the chosen method of implementation but will be used for testing purposes only. Bluetooth low energy WiFi provisioning is often the most commonly used method for performing this task. Bluetooth low energy WiFi provisioning allows for the transfer of SSID and password combination through Bluetooth, commonly through a smartphone. It would be the most user friendly method, but would also be the most complicated implementation due to the nature of this product. It would require the introduction of a Bluetooth module which is not currently in consideration for VISTA. It would make the VISTA internal software more complicated by having to implement the Bluetooth protocol as well. This leaves the WiFi access point therefore to be the best method. The V.I.S.T.A device, during set-up, will create a WiFi access point that the user can connect to that will open a small HTTP-server, where the user will be requested to provide the SSID and password login to an existing WiFi network. Once this is done, the VISTA device will switch from Access-Point mode into Client mode, changing internal settings on the WiFi module, and will then operate as expected. The user will be able to re-active the Access Point network whenever they wish to connect to a new WiFi network. This provides a safe balance of user-friendliness and ease of use for the user. It will not require any new pieces of hardware like a new Bluetooth module, and will allow for the user to connect to any available WiFi network in vicinity.

Utilizing the software technologies of real-time operating systems, such as RTOS and Wifi Access-point networks will be crucial for the implementation of VISTA's internal software. A RTOS will allow for more complex task management, and will also make development

simpler and more modular. Features can be tested and debugged much more simply, without having to worry extensively on communication protocols and interrupt-management. For accessing a WiFi network, creating a WiFi access point for the user to connect to during setup seems to be the most efficient and user friendly method that would be less challenging to implement compared to Bluetooth.

Table 3.3.3.1: Software Development Comparison

Abstraction Level	Performance Overhead	Memory Overhead	Development Time	WiFi Support	Power Saving Features
RTOS	++	++	-	++	++
HAL Library	+	+	+	+	+
Register-Level	-	-	++	-	-

3.3.4 Real Time Operating System

Choosing the best real time operating system to run on VISTA's MCU will depend on several factors. It will mostly depend on the complexity of the software requirements for the VISTA device, and what benefits an embedded operating system would provide. An embedded operating system will provide task-scheduling, allowing for certain operations like reading the thermal sensor, to be scheduled while the MCU could be reading or sending a HTTP request. Some of the most common real time operating systems include FreeRTOS, Zephyr and Mbed OS. These operating systems all offer unique advantages and disadvantages. It is important to note what features would be most important to consider for the purposes of this project. A real time operating system must provide task-scheduling, built-in support for a TCP/IP stack, and task prioritization. Another important feature of an embedded operating system would be power management. This would allow for the MCU to enter a low-power mode when there are no important tasks to run, which is especially important given the power saving nature of this project. Some other features of an embedded operating system might not be required, such as task concurrency through the use of semaphores. This is because the chosen STM32 MCU is a single core processor, therefore they will not be discussed. With these features in mind, it is also preferred that the chosen operating system have little memory usage and performance overhead, and be easy to implement.

The FreeRTOS software is one of the most common real time operating systems for embedded devices. It has extensive developer support and documentation. It is known for being a lightweight and open-source operating system that offers solid STM32 integration. It is most commonly used on resource-constrained MCU, because it is known for being one of the most lightweight and performance-optimizing operating systems. Perhaps most importantly, it integrates well with the TCP/IP stack and is also commonly used for Internet of Things devices. Some of the drawbacks of FreeRTOS however include a lack

of support for dynamic memory management, and requires manual task management. Tasks within FreeRTOS must be created manually, and priority levels must be stated manually. This will also create some amount of development-overhead. Despite this, it is the most lightweight operating system to choose from and offers all of the most essential features.

Zephyr OS is another common operating system known for its more extensive feature set and modularity. Unlike FreeRTOS and Mbed, only the features the user wants can be imported into the project. Some of the possible features include more advanced security features, extensive power management, and libraries for driver support. Two examples of security include memory protection and TLS. Memory protection means that two processes cannot access the same memory and corrupt each other. With power management in mind, Zephyr's power management features are more configurable than the other alternatives. While all of the embedded operating system choices include a "tick-less" mode, where the CPU's internal clock can be disabled and then re-enabled through an interrupt, Zephyr goes further. It has power-awareness scheduling, enabling Zephyr to schedule tasks based on power management. None of these benefits come without trade-offs, however. With the given embedded operating system choices, Zephyr has the most memory and performance overhead especially compared to FreeRTOS. Most of the feature set of Zephyr is made for MCU's that have multiple cores and more available memory. For example, the memory protection is not a requirement when the chosen STM MCU only has one core. The Zephyr embedded operating system therefore could be a good choice if some of the more extensive power-saving features are determined to be worth the cost of a less supported development environment, and more extensive performance and memory overhead.

The last possible embedded operating system to consider would be the Mbed OS. It is the most common embedded operating system for Internet of things devices, making it an interesting consideration given the nature of this project. Its features include native support for common internet protocols like TCP and HTTP. It is known for its cloud configuration to services like Amazon's Web server. It provides built-in support for network stacks like TCP/IP and even cellular communication. It might seem that Mbed for these reasons alone would be the best choice for this project. However, given the fact that the WiFi module chosen for this project has its own co-processor, some of these features are redundant. The WiFi module in particular will be responsible for managing the TCP/IP stack, not necessarily the MCU. Therefore the attention is mostly on its performance and memory overhead. Because of Mbed's extensive overhead for internet-based features, it has the worst memory and performance overhead. This is particularly important for our chosen MCU with its limited memory. It does include a lot of power management functions, like a tick-less mode and a basic performance scheduler, but does not go as far as Zephyr. For these reasons it is a good choice for projects that want to handle all web communications through the MCU side, and lack a co-processor to perform these tasks.

With these options, and the nature of the chosen STM MCU, the best option would be FreeRTOS. This is because it is most important for the nature of this project, that the embedded operating system has little memory and performance overhead. It is also not

essential that it include extensive libraries for other services like web protocols since these tasks can be off-loaded to the WiFi coprocessor. It lacks some of the more advanced power management features of Zephyr, but these can still be managed through additional libraries or further implementation.

Table 3.3.4.1: Real-time Operating System Comparison

RTOS	Power Management	Memory Overhead	Performance Overhead	Extensive Documentation	HTTP Support
FreeRTOS	-	-	-	++	-
Zephyr OS	++	+	+	+	+
Mbed OS	+	++	++	-	++

Chapter 4-Standards and Design Constraints

4.1 Standards

4.1.1 Temperature Sensor Standard

Accurately sensing temperature is of course no easy task. Sensors must be configured and integrated to work in a wide variety of environments. A single sensor may advertise accurate readings in extreme heat or cold, contactless temperature sensor from a range of distances etc. ASTM E2758 [121], an international standard for the picking and employing contactless infrared temperature sensors. This provides key insight into integrating an infrared temperature sensor into the VISTA.

The key takeaways of relevance to implementation in the VISTA identify, temperature reading accuracy variations in different materials, calibration, and maintenance. Infrared sensors operate under the principle that all materials emit some amount of electromagnetic radiation, which is strongly related to the materials temperature. This blackbody radiation is emitted at different wavelengths, depending on the material. The emissivity of any object follows a known relationship to its temperature, which makes infrared sensing possible.

The emissivity of different materials can vary significantly. Specifically, metals do not emit blackbody radiation on the wavelengths infrared sensors are able to detect. Polished metals in particular emit even less radiation by orders of magnitude less than non-metal materials. The standard also provides procedural advisement in initial sensor calibration. The E2758 standard can serve as a basis for advising users of the suitable use conditions (not pointed towards metal) and configuration.

4.1.2 Passive Infrared Sensor Standard

Specification 26 09 23 [122] outlines passive infrared sensor usage conditions. There are many suitable use cases of passive infrared sensors, and the standard serves as a guide on different use case configurations. The majority of these use cases are slightly outside the scope of the VISTA; such as, security systems and light controllers. However, much of the documentation on the standards of the sensors themselves can serve as an invaluable resource when designing and integrating onto the rest of the VISTA. All sensors in compliance have some ability to toggle from active low to active high. Either by explicit programming or more commonly outputting a differential signal.

All sensors in compliance with the standard must in turn comply with National Electric Code (NEC) Class 2. NEC Class 2 is a separate standard for safety of residential devices. Specifically, low voltage devices hardwired in residential properties. Although the VISTA will not be hardwired so this compliance is not necessary, it ensures the device is tolerant to certain voltage levels. Specifically, five, 12 or 24 volt AC or DC.

4.1.3 USART Standard

USART is a serial hardware communication protocol that is often used for microcontroller applications. Its primary purpose is to allow the MCU to communicate with other hardware devices that are connected to the same embedded system. For example, the MCU must be able to communicate with other modules on the same board and send/receive data, such as the WiFi module receiving commands from the MCU. USART is a derivative of the UART protocol, the only difference being that USART allows for the communication to either be synchronous or asynchronous. The explanation for how the USART standard is implemented is below, however it is best to first explain how UART works and then elaborate more on how USART differs from it.

UART stands for Universal Asynchronous Receiver Transceiver. It allows for components to communicate with each other, either receiving or transmitting data, asynchronously. To accomplish this, UART involves a start bit, eight bit data, a stop bit, and an optional parity bit. A device that wants to initiate a communication with an outside module will first send a start bit. Importantly, when there is no on-going communication the signal line is set to high voltage (a logical 1 value). The start bit is sent to initiate a communication by pulling this line to logical zero (low voltage). After this bit is set, all voltage changes are recorded as data bits, waiting for 8 bits to arrive. In order for the bits to be interpreted correctly, it is important that both modules wishing to communicate agree on a baud rate. The baud rate determines how many bits are being sent per second. For example, a common baud rate for UART devices would be 9600 baud rate. This means that both devices should expect to receive 9600 data bits per second. This allows for both devices to determine when a full bit has been sent. After the start bit has been sent, eight bits are read with the corresponding baud rate. Depending on the UART configuration, a parity bit would sit at the end of the data lines. The parity bit is used for error detection. UART can be configured for either odd parity or even parity detection. This means that if the sum of all 1's in the sequence is supposed to equal an even number, the parity bit will get pulled to

zero. This can then be used to detect if the data bits are sent incorrectly if this does not line up with the sent data. Notably, the parity bit cannot be used to perform error correction, only error detection. The parity bit is the only optional bit in this sequence. Finally, at the end the stop bit is sent which is always a high bit to begin the idle sequence. Even with the baud rate, the UART protocol is an asynchronous protocol because there is no clock line sent in conjunction with the data. Notably, this is implemented through both a Transfer (commonly named TX) and a Receiver line (commonly named RX). For two components wishing to communicate, the RX line of one device will be connected to the transfer line of another device, and vice versa. The protocol explained above begins on either of these two lines. Therefore this makes the UART protocol a full-duplex protocol, since any device can transmit and receive information at the same time.

The USART protocol differs from UART only with respect to one feature, which is that it allows for synchronous communication. USART stands for Universal Synchronous Asynchronous Receiver Transmitter, highlighting this distinction. The USART protocol now includes the optional requirement for a clock signal if both modules wish to communicate synchronously versus asynchronously. This would remove the need for a common baud rate, since the clock signal would be shared between both modules. USART also allows for higher communication speeds since it would not be dependent on a baud rate. The most prominent use case for this is for the WiFi module, allowing for high-speed AT commands to be sent to the WiFi module for sending/receiving HTTP requests. The clock signal will act as the third shared signal between the two modules, besides the RX buffer and the TX buffer.

USART, similarly to UART, is considered an industry de-facto standard. It is not owned by any corporation and does not cost any money to implement. Its widespread adoption allows it to be utilized in a wide variety of projects and implementations, making it useful for the purposes of this project.

4.1.4 I2C Standard

In contrast to USART, I2C is a strictly synchronous serial data transfer hardware protocol. The I2C standard involves a Serial clock line (SCL), and a Serial data line (SDL). It is considered a multi-master and multi-slave hardware protocol. The difference between I2C and USART lies in that multiple devices can be connected to the I2C lines and share data at the same time. For example, the MCU can be configured to be the master and can send data to many different peripherals at the same time. The way that this is done is by first sending an address over the Serial data line. Acknowledgement and Non-acknowledgement signals are also used to coordinate responses between devices, and signal to the MCU or peripherals that data was received.

One of the benefits of the I2C protocol is its ability to communicate with multiple components. For the purposes of our project, the MCU could communicate with the occupancy sensor or the temperature sensor at the same time. The downside of this protocol is that it is typically slower than USART because it needs to send address

signals and acknowledgement signals, before data can be sent. Furthermore, the master device is held responsible for driving the Serial clock signal, and acts as the clock signal for all peripherals connected since I2C is a fully synchronous protocol. It is a half-duplex protocol, meaning that data can only be sent in one direction at a time. Unlike when utilizing USART, the MCU cannot send data and also receive data from a sensor at the same time. Its most common use is interacting with sensors, EEPROMS, and displays.

The I2C standard is considered a de-facto standard and is commonly used in industry. Despite the fact that NXP semiconductors holds the original patent, the patent has expired, allowing it to be used for commercial purposes. The only exception to this would be utilizing a fast-mode of I2C which is held by NXP semiconductors, although this will not be required for this project.

4.1.5 Wifi Standard

One of the primary responsibilities of the V.I.S.T.A device will be to communicate with the corresponding web app over WiFi. In order to do this, the V.I.S.T.A must work with the IEEE 802.11n standard for WiFi communication. It is important to first explain the IEEE 802.11 standard and then elaborate how 802.11n is different from it.

IEEE 802.11 is a family of standards that specifies how data is encoded, what frequency bands should be utilized to transmit the data through radio signals, and other hardware-specific features. All of these considerations create the physical-layer standard of IEEE 802.11. For IEEE 802.11, all data is sent through either 2.4 GHz or 5 GHz. It also specifies the specific data rate of up to 9.6 Gigabits per second in the newest revisions of 802.11. On top of the physical-layer standards, the 802.11 standard also specifies what is called the medium access control, or MAC for short. This specifies how other devices can actually access the network. For example, each network interface is assigned a MAC address. Afterwards, the router can identify which devices are connecting based on this address and can then initialize a connection. Other important components defined in the medium access layer include error correction and access control.

IEEE 802.11n is an extension of 802.11 that allows for higher data rates, improved signal strength, and allows for multiple data streams to be streamed simultaneously. The IEEE 802.11n allows for data rates up to 600 megabits per second. This is done through using multiple channels combined together to double the available bandwidth. In summary, IEEE 802.11n is a faster extension of 802.11 that is supported by the chosen WiFi module for this project.

In summary, 802.11n falls under the family of standards, 802.11, created by the standards developing commission of IEEE. Different from USART and I2C, it is considered a formal standard and not a de facto standard, since it is developed and expanded upon by the standards developing commission of IEEE. The use of this standard does not require explicit permission from IEEE, however any documentation of 802.11n must be purchased through the IEEE site.

4.1.6 Lithium-Ion Battery Standard

One important consideration for this project is that the V.I.S.T.A device will be a battery powered device. Because of this, it is important that proper safety is ensured for the device for both testing and performance. The IEC 61960-3:2017 and 62133-2:2017 specify the performance and safety requirements for lithium ion batteries. They are two separate standards, both requiring consideration for the purposes of this project.

IEC 61960-3:2017 specifies the testing and performance of lithium ion batteries and their applications to products. For performance criteria, it states what the acceptable levels of capacitance retention and degradation are acceptable for a lithium ion battery. The capacitance retention is an important metric because it exemplifies how well the battery can store and deliver energy. The standard also states how the lithium ion battery must be able to keep a certain percentage of its rated charge capacity over a period of charging and discharging cycles. This essentially states the level of acceptable degradation of a battery after a number of charging and discharging cycles. Finally, the standard specifies how well the battery must be able to perform under specific circumstances like extreme heat and current load.

IEC 62133-2:2017 differs from the previous standard in that it outlines the safety requirements for a lithium ion battery. Importantly, the standard outlines the extent of conditions that the lithium ion battery must be able to endure without hazardous conditions occurring, such as a fire or an explosion. The standard outlines the requirements overcharging/over-discharging, short circuit conditions, and temperature conditions. This standard states to what extent these conditions can occur without a hazardous condition, as opposed to the previous standard, which only states to what extent each situation can occur without a performance degradation. The standard states firmly that the lithium ion battery must be able to withstand a short circuit without a fire, or without explosion. The lithium ion battery must be able to handle overcharging without resulting in a hazardous condition. Finally, the lithium ion battery must withstand certain extreme temperature conditions without a hazardous condition.

Similarly to IEEE 802.11, the specifications listed above are private and are created by the International Electrical Commission, or IEC. The standards are considered formal standards and are used internationally to ensure the safety and reliability of consumer products that use lithium ion batteries.

4.1.7 PCB Design Standard

The IPC-2221 standard is a PCB design standard that ensures the quality of a PCB design to withstand various considerations, such as temperature conditions and vibration [161]. There are many standards relating to PCB design, some are more focused on rigid PCB design or multi-layer PCB designs, however IPC-2221 is a generic standard that applies to all PCB types. One aspect of the standard is it outlines the acceptable levels of trace width and spacing for the conductive material inside of the PCB. This can be adjusted using any PCB design software such as Eagle. Another attribute to the IPC-2221

standard is what materials are acceptable for the PCB design. It provides a guideline for what material to select for the PCB depending on the application. This can be selected from any PCB manufacturing vendor such as PCBWay, or in this project's case, JLCPCB. Finally, the standard specifies the conductive material types for surface mount components to ensure electrical reliability and mechanical reliability. Following this standard ensures that the VISTA PCB design will be high-quality and reliable.

The IPC-2221 Standard is an industry standard and is not free to use. It is developed and expanded upon by the IPC standards development commission, which is known for creating standards for OEM and PCB manufacturers for safety and reliability purposes [162]. Utilizing this standard for PCB design will be essential in constructing the VISTA.

4.1.8 Servo Standard

The Servo will be the main way to control the levers of the air vents, responsible for letting cold air in depending on the status of the thermal sensor. Therefore, due to the importance of the servo for this project, it is important to consider the standards for it. It is important to note that there exists many types of servos, for various applications. There exists large scale servos for automotive and aerospace, and smaller servos like the one used in our project. There exists standards for the more high power servos like in aerospace, such as IEC 61800, but these do not fit the purposes of our project. Therefore for our servo, there are not any standards developed by an organization, such as IEC. This means that all of the standards listed here will be considered De Facto standards.

Firstly, one of the most common de facto standards for servos is that it utilizes a Pulse Width Modulation signal for controls. This is done because it is an easy way to control both the direction and speed information into one signal line. It is also easily configured with a microcontroller such as an ESP32. On top of the pulse width signal, servo's typically include a DC power input for turning on the servo.

For the purposes of our Servo, the FS90R, it has an operating voltage range between 4.8 to 6V, and a pulse width range between 700 and 2300 microseconds. This means that our servo's maximum frequency is around 333 Hz, since the minimum and maximum pulse width range added together represent the maximum period supported by the servo. Various pulse width lengths and duty cycles will change the speed and direction of the servo, which is typical operation for other existing servos [163].

In conclusion, it is essential to consider the requirements of the FS90R servo, including the operating voltage range and the maximum frequency length. Utilizing the pulse width signal in combination with a DC voltage source are both considered de facto standards utilized in virtually all small-scale servos, like in our project, but the exact specifications for the Servo are determined by the manufacturer.

4.2 Design Constraints

4.2.1 Time

Underclassmen are often given advice to design their schedules to work around senior design. Senior design is often described as a dark and gloomy storm that will suck away all one's time. This is because time is perhaps the most critical constraint in all of the design process. Not only are deadlines around every corner, but delays in shipping, PCB construction, etc. are all likely to occur. Significant cushion must be given to avoid any potential setbacks.

Resultantly, the ideal time management strategy is precrastination. In other words, start and complete all necessary work as early as possible. A deadline must not be regarded as a regular due date. The "due date" can be thought of as weeks before required deadlines to account for tweaks, fixes and the aforementioned potential delays. For example, our senior design group set deadlines for each chapter or even subsections of chapters. This helped keep everyone on time and accountable. This also made our lives easier if one member could not work as hard due to tests in other classes or personal situations, the other members could pick up the slack with their extra time. Without these preset deadlines the group would have waited until the last minute and ended up with a poorly written report.

Adhering to this constraint is of the utmost importance. Incompleteness may result in a low grade in the class, unfair workloads for members, stress, or even all members of the senior design group needing to reattempt senior design. If members wait until the last minute to finish sections or other work relating to the paper, they will end up completing the remaining work in a rushed manner, which will diminish the quality of the overall product. Procrastination can also result in an unfair workload of members. If some members work on time, or even ahead, they may feel inclined to do other members' sections in order to avoid the situation mentioned above. This will result in inequality of paper count, stress, and workload. The ultimate consequence of procrastination is the worst, failing senior design. If the report is not completed or is very bad, the teachers have no choice but to fail students. This could result in an extra two semesters of school, even if not all students in the group deserved it. This is an important consideration when choosing your group or even deciding to put off writing your section; while in most classes procrastination only affects you, in senior design it affects the whole group.

Time management is the single most crucial factor to focus on throughout the senior design process. The pressure of deadlines, combined with the unpredictability of setbacks, means even small missteps can snowball into major issues throughout the rest of the design process. Procrastination only compounds these challenges, leading to unbalanced workloads, rushed work, and possibly even failure of the entire project. Ultimately, managing time effectively could mean the difference between completing a well put together project or being forced to extend your academic career by two semesters.

4.2.2 Financials

The VISTA project was originally proposed and created by Dr. Qun Zhou Sun. She then thought it would be a nice idea to integrate her idea into the senior design class and give students the opportunity to make her idea come to life. Dr. Sun has specific knowledge and interests in many different fields including Smart energy infrastructure, energy data analytics, bayesian methods and application in energy systems, and optimization under uncertainties. She also operates the Smart Infrastructure Data Analytics Lab at the University of Central Florida. Her involvement with this lab could help the VISTA reach one of its stretch goals, being grid integrated and interactive. Her vast technical knowledge and previous experience has given our group a foundation of confidence and overall vision for the VISTA system.

Since the project was her idea, her lab became its sponsor. Part of this sponsorship includes covering the cost of the development and final product. The overall project restraints and requirements are set by Dr. Sun. She is the originator of the idea and therefore has ultimate creative freedom on the final product; Although she is very generous with letting the senior design group make most of the decisions when it comes to specific parts and technologies. The sponsorship will cover up to \$2000 of costs for the project. Exceeding this cost is not a hard limit, as a portion of the development could be self-funded, although this would be unideal. Our estimated budget at this time is closer to \$300. This implies there should be no issue with the sponsorship amount. As long as we are conscious of our technology and supplies selection.

4.2.3 Demonstrability

Although the intended use of VISTA is to autonomously operate based on onboard sensor inputs, the additional functionality of manually activating the mechanism is necessary for demonstration purposes. This constraint is exclusively applicable to the software/control aspect of the design, and has no impact on the physical design of the VISTA. The necessity of this constraint is driven by requirements of the final grading criteria, and are not necessary for the design to succeed. At the end of the senior design two semester we will be expected to demonstrate our prototype to our board of professors. This will include the mentor, review committee, and sponsor for the project.

We will present this prototype at the UCF campus which may not have the type of vent we designed for easily accessible. Because of this, a mock environment is needed. This mock environment must contain a traditional air vent mounted on a surface of similar characteristics to common interior surfaces. This is necessary because without the mock environment the mechanical operations and mounting techniques could not be observed. There is another demonstrability constraint that needs to be considered. Without the ideal environment of the VISTA system present, the spatial constraints cannot be observed. While this constraint could be added to the mock environment it is not one of the most important components of the overall system so it is not necessary on testing day.

Ultimately, these adaptations are crucial to meet the requirements of the final grading process and to provide a working prototype to the final grading committee.

4.2.4 Remaining Constraints:

4.2.4.1 Sustainability

Sustainability in the context of constraints refers to the several factors that will influence the design and manufacturing of V.I.S.T.A device to make it acceptable for environmental and social concerns. Some of these factors include maximizing energy efficiency, optimal material selection, and minimizing electronic waste. Ensuring that these constraints are met will allow the VISTA device to operate in the global marketplace with acceptance.

Maximizing energy efficiency for VISTA will involve reducing the energy footprint by ensuring that all components chosen are low-power. This has been taken into consideration for the parts, as the chosen MCU is known for its low power management and can be placed into low power modes using real time operating systems. For material selection, utilizing renewable and recyclable materials will be essential to reduce carbon footprint and ensure that the product is socially acceptable. The use of PETG plastic for the 3D print of the surrounding case will be an acceptable material, as it is recyclable plastic. Lastly, to reduce electronic waste it is important to implement a modular design in the V.I.S.T.A so that repairs can be done on the product without requiring the replacement of the whole device.

With these constraints in mind, VISTA will be an environmentally and socially friendly device for all consumers. Utilizing low power components such as the MCU will ensure compliance with energy efficiency standards and constraints. Furthermore, the PETG plastic selection will allow for an environmentally safe product that can be recycled and not contribute a carbon footprint. Finally, the use of a modular design will facilitate an easy repair process and not contribute to electronic waste.

4.2.4.2 Compliance (Legal)

Some constraints must be upheld in order to avoid significant legal repercussions. As the VISTA will be necessitating the use of wireless communication, a lengthy amount of code and regulations must be adhered to. The primary area of concern in the VISTA project is the selected operating frequency. The Federal Communications Commission (FCC) controls the use of the entire EMF spectrum in the United States [124]. Lower frequencies may inherently use less power and traverse a further range, making a lower frequency communication system more attractive for use in the VISTA. However, much of the commercially available systems for these lower frequencies are regulated, restricted and often necessitate special licensing from the FCC [123]. This added complexity not only necessitates more attention in the design process, but additionally introduces an immense amount of liability. To avoid this liability, the VISTA will only utilize wireless communication devices operating in unrestricted frequencies, such as those authorized inside the ISM (Industrial, Scientific and Medical) spectrum [124].

4.2.4.4 Manufacturability

Manufacturability and time work together in this project. While a group may find the perfect technology for a project, it will only work if it can also get here in time. This is one of the two main constraints within manufacturability, the other being resources.

Time is a huge constraint of the entire project but it is especially evident within manufacturability. If there is a part that the system needs but it cannot be ordered or shipped in time, the manufacturability of the product becomes much more complex. Having to find replacement parts that can arrive within the correct scope of time could cause issues within a system. When part selection was being conducted for the VISTA system, this deliverability was accounted for within each part. If a part was perfect but would not get here in time, it was automatically cut from the running. By accounting for this manufacturing issue ahead of time, the VISTA has avoided the predictable manufacturing issues. There are always the unpredictable setbacks but those have to be dealt with head on.

Another manufacturing constraint is the resources of the project, specifically the ability to acquire/print/make the parts needed to complete the project. Our system implements a plastic louver that is screwed over an existing vent. There are many ways to acquire a louver that we design, the main being a 3D printer. This is not an issue if we can acquire access to this resource. The issue being if we cannot there will be a delay in manufacturing. To account for this, other methods of getting the louver were researched and taken into account. While 3D printing would be the most unique and adjustable source of the covering, other similar items can be purchased online.

While there will always be unexpected manufacturing risks related to a project, the VISTA system will avoid any predetermined manufacturing risks due to proper research ahead of time.

4.2.4.3 Health and Safety

While the VISTA system does not have major health and safety risks, there are always some concerns that should be taken into account when planning and implementing the system. The main safety concerns are data and privacy, Air quality, and Overheating. These risks will be discussed and solved with low impact on the integrity of the system as a whole.

When using wifi in any capacity there is a risk for data and privacy leaks. Some wifi modules are built to be more secure but are then generally more expensive or fall short in other categories. The wifi module that the VISTA system uses does have software to mitigate data hackers and such, but it is not a module designed specifically for data protection. The module picked is best for low power and long operational systems; these specifications are more important to the overall goals of the VISTA system and therefore were held at a higher weight when choosing the best module for the project. The system

will also not be using very private information about the user, it should only need name, email, and maybe phone number just to identify which user is setting specifications for their home. Due to how public that information is, our system is low risk when it comes to data privacy and risk.

Air quality is a health concern for the vista system; while it is noted that the system could cause poor ventilation, the goal of the system is to improve ventilation. If the system is causing insufficient air flow, then there is a bigger problem with the technology of the project. Insufficient air flow could result in the buildup of allergens, pollutants, and possibly fungus, potentially impacting the health of occupants. As a result of this concern, maintaining balanced airflow has become a goal of the VISTA system.

The last health and safety constraint is overheating. This is a concern of many systems where electrical components are involved. Ours is special because it is also near a vent which could help to produce moisture near or on the electrical components. This is a very valid concern as we do not want any damage to come to the users of the VISTA system. To mitigate this constraint, thermal management systems to displace heat could be useful for making sure the design has enough ventilation around the electrical components.

These health and safety restraints are very reasonable concerns for the project, but with the proper research they can be accountant for and managed before they even arrive. These risks will still be prevalent in the VISTA system but at a much lower percentage with all of the mitigations found used to improve the system.

Chapter 5-Comparison of ChatGPT with other Similar Platforms

5.1 Comparisons and Limitations

Artificial intelligence is a widespread and rapidly growing source of obtaining information quickly and easily. The technology is becoming so advanced that it is able to solve problems and write thought out responses for users, as well as generate images and presentations. This raises a great deal of concern regarding reliability of the AI as well as plagiarism. For many applications, the use of AI is considered cheating as the extremely advanced software is able to answer nearly any question and can generate entire essays or reword articles to avoid getting caught for plagiarism when copying directly from a source. This began causing a great deal of issues, particularly in school settings, due to the inability to detect the use of AI. There are now specific programs that do detect AI in students' work, which helps teachers in eliminating the use of plagiarism, however accurate they may be.

For the purpose of senior design, AI software such as ChatGPT is encouraged to use, due to the need to research many specific technical specifications and in depth research on parts and technologies. Utilizing AI and comparing to traditional search methods can result in a great deal of benefits for researchers. But there are many things to consider

when using AI. Unlike humans, AI is unable to distinguish between biased and unbiased opinions from sources when generating responses to user prompts or questions. The responses generated from artificial intelligence are often worded very confidently and matter-of-fact, which discourages people from questioning the validity of the results. In contrast, the AI does not know for sure what is true or not, instead simply gathering all information from credible and non-credible sources alike, to compile into an all-encompassing responses that may please the user. It is up to users to take the responses with a grain of salt, do their own investigation, and determine credibility of the sources that AI uses to produce responses.

ChatGPT is an AI (artificial intelligence) software that can understand and generate text to respond to questions and comments by a user. Since its official launch in November of 2022, ChatGPT has been a growing tool that many people- and particularly students- use to either pass time or obtain information quickly. Though AI can be extremely useful in getting information quickly, it is important to note that much of its technology is fairly new and therefore at least somewhat experimental. While ChatGPT offers accurate information on most topics, its training data is from 2021, so much of the information could be outdated or not fully-accurate [125]. However, users can ask for the chatbox to provide its sources, and from there on can determine the validity for themselves simply by taking a couple of extra steps. By researching the provided sources, users are doing their due-diligence when utilizing AI softwares. It is crucial to do your own investigation for credible sources since AI is unable to detect opinion from not and determine whether the information it is gathering is in fact all true and useful to the user.

GoogleAI is another technology that uses AI to generate summaries gathered from multiple sources based on the question that is searched on Google. The accuracy of the responses depends mainly on the validity of the sources that it pulls from, which can be checked by clicking the link button next to each summary statement. So similar to ChatGPT, while this platform may also not be completely accurate, it is easy to check the sources that it is pulling from and then decide for oneself whether or not the information is reliable. The summaries pulled from many different websites are extremely helpful when trying to gain a generalized understanding of knowledge on certain topics. GoogleAI is particularly useful when researching things like advantages and disadvantages of a certain technology or part, determining the most popular options for a technology or part, etc. The AI does an exceptional job at pulling together all the key information, which gives users a really convenient starting point to base the direction of the more in depth research. For example, by listing out some of the potential pros and cons of a product, it is easier to refine search criteria when then looking to expand upon those ideas to actually write about them in an assignment. Once again, it is a user's responsibility to do their own background investigation of the sources used and determine the overall validity and reliability of the generated summaries and responses.

The most common method of finding information for any given assignment is by simply using Google and finding credible sources on your own. While GoogleAI may pull together helpful information quicker, it is still very useful to simply go through all of the search-generated websites and determine which ones are useful for whatever the

purpose may be. The issue that sometimes comes up with simply using the Google search engine however, is that oftentimes none of the sources are not very credible, many of them simply being blogs and opinionated articles that may not pull information from credible sources themselves. When trying to gain an accurate understanding about a topic in order to relay the information in a paper or other assignment, it is crucial to ensure that such research information that is being gathered is, of course, actually true. This is why finding sources of information that are verified and from valid and trustworthy sources is an important step in writing assignments that require research. These types of sources typically include but are not limited to research papers, government funded websites, organizational websites, etc. A good indicator of whether or not a website is credible comes down to the fundamentals of choosing sources. This can be determined by the domain extension (.org, .gov, .com) as well as the appearance of the website- particularly pertaining to the amount of ads, grammar mistakes, whether or not it says 'blog' at the top, etc. Finding accurate and trustworthy sources can oftentimes prove to be a more difficult task than one may expect it to be. This leads to a final option for search platforms: Google Scholar.

Google Scholar is an extension of Google that searches only for scholarly articles. This can be extremely useful when writing research based papers or other assignments, particularly when looking for credible sources that are based on factual information and real research by accredited authors. All the results shown by Google Scholar are published papers or articles that are based on research and math/science as opposed to possibly opinionated information. Many of the authors are oftentimes researchers working at universities or other funded- or not funded- organizations, scientists, authors of research papers for conferences, etc. Their motivation for posting their findings is typically to simply share their results with colleagues and other researchers in order to progress in their field. Other times many researchers post papers for conferences, where they can present their finding a go network with others in their field or similar ones. Therefore, the use of Google Scholar is extremely useful in determining reliable sources and information, as the motivations behind the sources are purely research and knowledge based, all deriving from factual results and mathematical calculations in addition to simulations or real-life test runs. The only downside to using this platform may be that scholarly articles are sometimes too in depth with specific research topics and can prevent users from understanding background knowledge or being able to fill in certain gaps in their understanding of the content. In these cases, it can be very helpful to use Google or AI platforms to fill in those gaps and achieve an overall understanding. This in turn can help with writing about topics more efficiently and learning more accurately. Hence, it is crucial to rely on many different platforms when conducting such in depth research and trying to gain such vast understanding of specific topics and how to incorporate them into projects. All different sources of information provide very different results oftentimes, and it is left up to the researcher to compile those results and determine the correct information from the incorrect. That way it is easier to tell what should be included in an essay or project and what should not.

With all of these different platforms for searching the same information, it is important to keep in mind the advantages and disadvantages of using each and how that may affect

the resulting paper or assignment that is being written, as discussed above. This can cause great impacts in the credibility of such projects or assignments. The following case studies highlight the difference in information that is obtained through these different search platforms and how that can impact the knowledge of the user if not used carefully. Additionally, the following section delves into the effect of having so many platform options and the impacts that it can make on learning. It proves why it is so crucial to rely on many different sources of information rather than just one, and why students and researchers should all be extremely careful when using AI platforms for research due to possible inconsistencies or falsifications in information. With such quickly advancing autonomous technology, it is difficult to be able to tell the truth from the not when asking for answers to such technical knowledge especially.

5.2 Impact on Learning

Case Study 1: Smart Vents

For the purpose of planning VISTA, it was very useful to do research on other smart vents that were available to determine a suitable set of requirements and objectives for the project, as well as highlight certain capabilities that either are or are not important to take into consideration when starting preliminary design steps. Using ChatGPT to generate this response is helpful in giving a direction to go in for research purposes, such as which smart vents to look into from different companies. However, this response only gives a basic amount of information and does not provide details about the different options. In order to do a thorough investigation on the functionalities and specifications of each, it is necessary to utilize other platforms like Google to obtain further information on the smart vents from the actual manufacturers websites or others.

Additionally, some of the information provided by ChatGPT is potentially outdated, as discussed previously. Through doing further research on the listed companies using Google, it was determined that Keen Home and Ecovent are now merged into the same company (although separate products are still technically available), while ChatGPT lists them as separate options. This highlights the importance of taking responses provided by AI platforms with a grain of salt, and putting in the time to actually do further research to validate the information it gives. Though the response is not inaccurate and gives a good starting point to conduct further research, it does not give users enough information to write about the different options or choose one for purchase.

For this prompt in particular, searching through Google did not give any GoogleAI results. And while Google Scholar is a great resource for in depth research, this platform would likely be useful if needing to go more in depth about the specifications of the smart vents and why certain functionalities would be useful to include when manufacturing a new design. For the purpose of simply researching other options as opposed to VISTA itself, Google Scholar goes beyond the scope of what is needed in this case.

Case Study 2: Alkaline Batteries

Through comparing the two responses from both ChatGPT and GoogleAI, many of the advantages are the same in each, but there are still a couple from each that are not present in the other. Therefore, when looking for a fully encompassing answer, you really are not going to get all possible answers from either platform. This proves why it is so advantageous to utilize multiple different sources or platforms when conducting research. By choosing to only use one of the two AI platforms, some additional advantages of alkaline batteries are missed out on. While it may seem that this would have a negligible effect, depending on the project specification, one of the advantages that are missed out on could be extremely helpful in deciding on one type of battery technology or another. Hence, it is crucial to explore all possible extents of the benefits of alkaline batteries, or any subject for that matter.

While ChatGPT and GoogleAI are so useful in providing basic advantages for alkaline batteries, similar to case study 1, the information provided is still a very small amount of information. Thus, further research is certainly necessary, and using Google and Google Scholar will allow for gaining a great deal more knowledge and understanding on the topic. The AI platforms also have the option of providing the sources they used to gather the advantages, so by visiting those websites users could in turn determine the credibility and authenticity of each point as well as learn further background information or some more specifics. Then, doing some google searches could result in even more extensive and in-depth research and knowledge. Finally, Google Scholar would be a useful resource for this prompt, as some scholarly articles that go in depth to study the characteristics and functionalities of alkaline batteries could prove useful in determining whether or not alkaline batteries are actually the most suitable choice for VISTA.

Case Study 3: Infrared Sensors

Both platforms answered the prompt in its entirety, they both gave advantages of different types of sensors and answered the original question of which type of sensor would be best for the given application. ChatGPT focused more on comparing many different sensors, giving users a wide variety to choose from. While Google AI focused on the overall necessities of the given system and then gave more examples of specific sensors. When doing the research to find a sensor for the system both platforms would be helpful individually, but they would be even more helpful working together.

ChatGPT gives five different specific types of sensors that could be used in a low power, long operational system. The platform then delves further into each type of sensor giving the “Best for” operation, advantages, and use case. This platform is extremely helpful if you already have a good sense of the project you are asking about. If you went to ChatGPT with little background information it would not be as beneficial when it starts talking about technical specifications. When I was researching I found it more helpful to have some background knowledge on sensors and their specifications before using a platform like ChatGPT for more information.

Google AI is a great starting platform, it is very helpful when trying to look at a broader scope of a project. The google AI response first gave key points of self-powered sensors, then other sensor types, and finally factors to consider when choosing a sensor for a

low-power system. This last section specifically is unique, as it gives more than what the prompt in asking. This could be helpful if the researcher does not yet know what specifications they should keep an eye out for. Another unique factor of Google AI is the links attached to the answers. Each answer that the platform gives has a link attached with the website where they found said information. I love this feature as it gives researchers a resource for even more information. This can help accelerate the researching stage of a project, it can also help researchers feel more comfortable with the site in which they are receiving their information.

Overall, both platforms are outstanding tools to utilize within the research stage of a project. Each offers a different scope of the prompt given, so depending on your base knowledge and what type of answer you are looking for, either platform could aid research. ChatGPT gives very specific answers to the prompt, while Google AI will give one or two answers to the prompt and then expand on related concepts. Picking the best platform depends on the users preferences. For this specific prompt ChatGPT gave a more exact and relevant answer.

Case Study 4: Mounting

ChatGPT gave a very clear and concise answer to the prompt. It touched on five different methods on installing a register over an existing vent, each having a different level of permanence. Each answer also had its “Best for” case, steps, pros, and cons. All of the different sections of the answer helped this platform's answer to differ from other artificial intelligence platforms. The steps on how to use it may not be the priority for our application, but it is still relevant and useful information for the prompt. The tips section was also unique, it was surprising to see the tips section and the sign off from ChatGPT as normally its answers are straight to the point and formal. The tips section is useful, and the sign off may help those who are nervous to use AI feel more comfortable. Even though a comparison could not be made on this specific use case, Google AI and ChatGPT are both well known and liked platforms for artificial intelligence.

Using a variety of research platforms can help enhance the depth and breadth of knowledge on specific prompts and topics. Each platform provides unique insights, scopes, and data, allowing for a more comprehensive study of the topic at hand. The case studies presented and emphasized the role that thorough and diverse research plays in achieving and making well informed conclusions. This multifaceted approach not only deepens one's understanding but also helps mitigate the risks of bias or incomplete information. It also helps researchers to make confident decisions regarding their research topics. By leveraging all available platforms such as Google AI, Google scholar, and ChatGPT, project members are better equipped to identify the best answers to a specific project topic or question.

Chapter 6-Hardware Design

6.1 Regulator Design

The power delivery for VISTA primarily draws its power from 9V alkaline batteries. Some components of the vent system, including the temperature, occupancy, and humidity sensors, the servo, and the wifi module require step-down regulators in order to draw appropriate levels of voltage to withstand operation. Two different regulators are required, a 3.3V regulator and a 4.8V regulator. The 3.3V regulator will be used for the humidity, temperature, and occupancy sensors; it will also be used for the MCU and wifi module. The 4.8V regulator will be used only for the servo. Each of the regulator values had to be checked against the operating values of the components. Luckily, most of the components operate under similar voltage levels so numerous different regulators are not required.

Table 6.2.1: Component Voltage Input

Component	MG90S Micro	G-TPMO Temp Sensor	STM32L475VGT6	Adafruit Occupancy Sensor	HIH8120-021-00 1 Humidity Sensor	ISM43362-M3 G-L44 Wifi Module
Input Voltage	4.8 V	3.3 V	3.3 V	3.3 V	3.3 V	3.3 V

In the documentation, the 3.3V regulator values of the resistors, inductors, and capacitors are given within the ideal regulator circuit. This was used for reference when making the regulator schematic. [139]

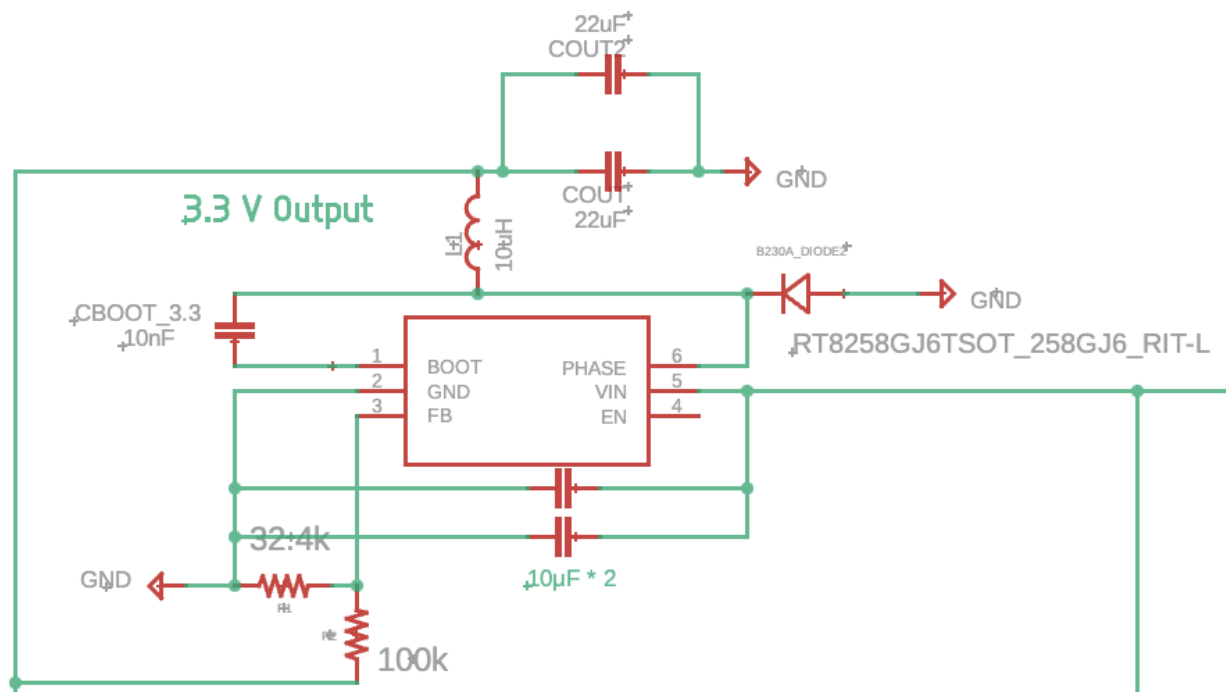


Figure 6.2.2 : 3.3V Regulator Schematic

The 3.3V component values and general schematic were derived from the regulator documentation as shown in the schematic above. The 4.8V regulator component values and schematic were not provided in the documentation, therefore the equations derived

from the ideal regulator circuit, shown in Figure 6.2.3 and discussed further below, were utilized in order to solve for the appropriate resistor and inductor values.

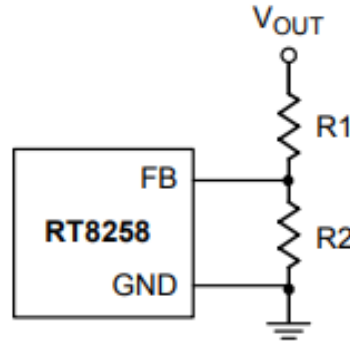


Figure 6.2.3: Output Voltage Setting [139]

The appropriate resistor value for R_1 of the 4.8V regulator was derived from the recommended component selection table from the documentation, shown in Figure 6.2.3. The appropriate resistor value for R_2 of the 4.8V regulator was solved for by utilizing the equation shown in the calculations below. In these calculations, V_{FB} is the feedback reference voltage which is set at 0.8V, and V_{out} is the desired 4.8V.

V_{OUT}	1.2V	1.5V	1.8V	2.5V	3.3V	5V	8V	10V	15V
R_1 (k Ω)	100	91	91	100	100	91	91	91	120
R_2 (k Ω)	200	100	75	47	32.4	17.4	10	7.87	6.8
L (μ H)	3.6	3.6	4.7	6.8	10	15	22	22	33
C_{OUT} (μ F)	22	22	22	22	22	22	22	22	22

Figure 6.2.4 : Recommended Component Selection [139]

$$V_{OUT} = V_{FB} \left(1 + \frac{R_1}{R_2} \right)$$

$$9V = 0.8V \left(1 + \frac{91k\Omega}{R_2} \right)$$

$$R_2 = 18.2k\Omega$$

The appropriate capacitor values were determined to be kept as the same values provided for the 3.3V regulator in the documentation. The appropriate inductor value, similarly to the R_2 resistor value, was solved for using equations derived from the ideal regulator circuit as shown in the calculations below. For the ripple current selection, the value of $\Delta I_L = 0.34(I_{MAX})$ is given. The largest ripple current occurs at the highest V_{IN} , so to guarantee that the ripple current stays below the specified maximum, the inductor

value should be chosen according to the following equation as provided by the documentation.

$$L = \left(\frac{V_{OUT}}{f \times \Delta I_L} \right) \times \left(1 - \frac{V_{OUT}}{V_{IN(max)}} \right)$$

$$L = \left(\frac{4.8V}{700kHz \times 0.34\mu H} \right) \times \left(1 - \frac{4.8V}{9V} \right)$$

$$L = 9.4\mu H$$

Inputting all of the component values for the 4.8V regulator derived by all the equations and concepts discussed, the final schematic can be configured in Fusion360. The necessary component values shown and discussed above all come together to make up the power board as shown below. This is a crucial part of the hardware design of VISTA, as it controls the voltage levels to ensure that components do not get overloaded. From looking at the datasheets of all the different parts, it is found that the components all have specified ranges of voltage input that the parts can withstand.

It is necessary to follow specified voltage guidelines to ensure the proper functionality and longevity of VISTA. Failure to do so can result in a great deal of issues within any application. Devices can get damaged due to overloaded circuits burning out and smaller components failing. Additionally, it can cause erratic behavior in devices due to thermal instability or inadequate noise filtration. Overall, this can greatly impact the efficiency and lifespan of a device and cause safety issues.

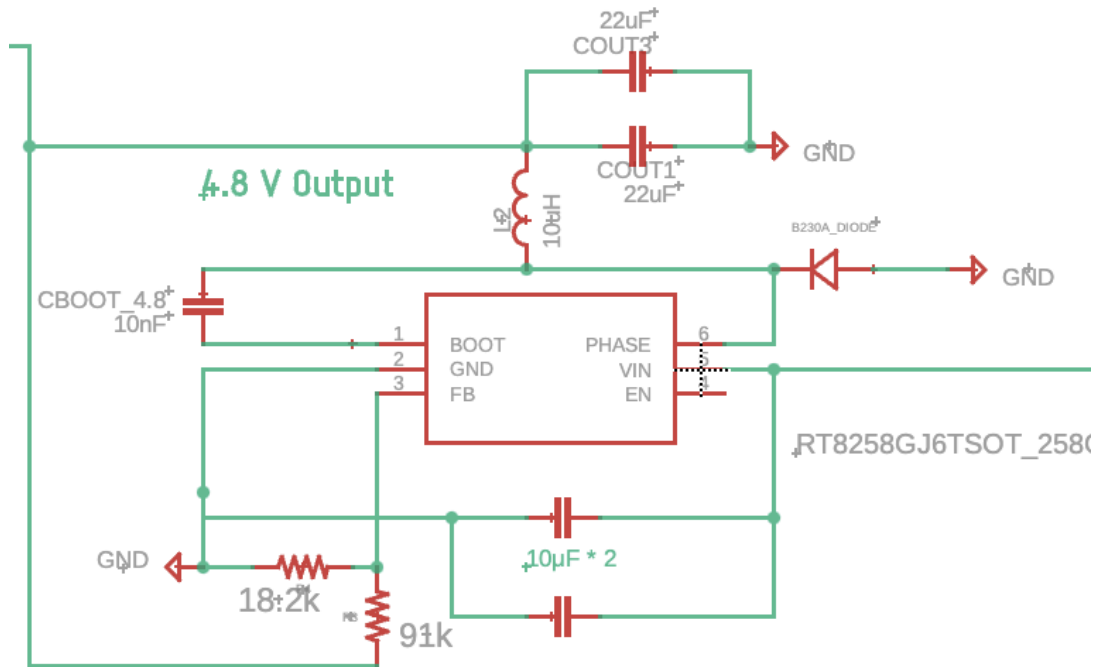


Figure 6.2.5: 4.8V Regulator Schematic

Once both of the regulators have been configured, they can both be connected to a 9V battery as the chosen power source and 1x3 header pins to finalize the appropriate connections for optimal functionality. It is important to have a schematic of both regulators connected in the same system to ensure that the subsystems will work both independently and cohesively. To facilitate this design, a three pin male header is mounted to the power supply board with a corresponding three pin female header on the main component board. The three pins are +3.3V, +4.8V and a common GND.

Based on specifications derived from the regulator datasheet, it is crucial for the functionality of the design for the decoupling capacitors to be as close as possible to GND and V_{in} . Additionally, pins on the feedback pin should be as close as possible, and there should be nothing near the switching load pin (PHASE pin). Both regulators share a common input, as shown in the combined schematic below, which can range between 5-12V depending on the applications. In this case, VISTA is powered by a 9V battery. The two decoupling capacitors shown on each are used for noise reduction and signal stabilization. CBOOT is a bootstrap capacitor that provides the gate driver voltage for the high side MOSFET [139]. The feedback networks of resistor dividers set the output voltage of each regulator by connecting to the FB (feedback) pin of the regulator. The inductor regulates the output current for each, providing a steady DC output. The Schottky diode provides a fast and efficient path for the current to flow from the inductor and then back through it during the switch off cycle [146].

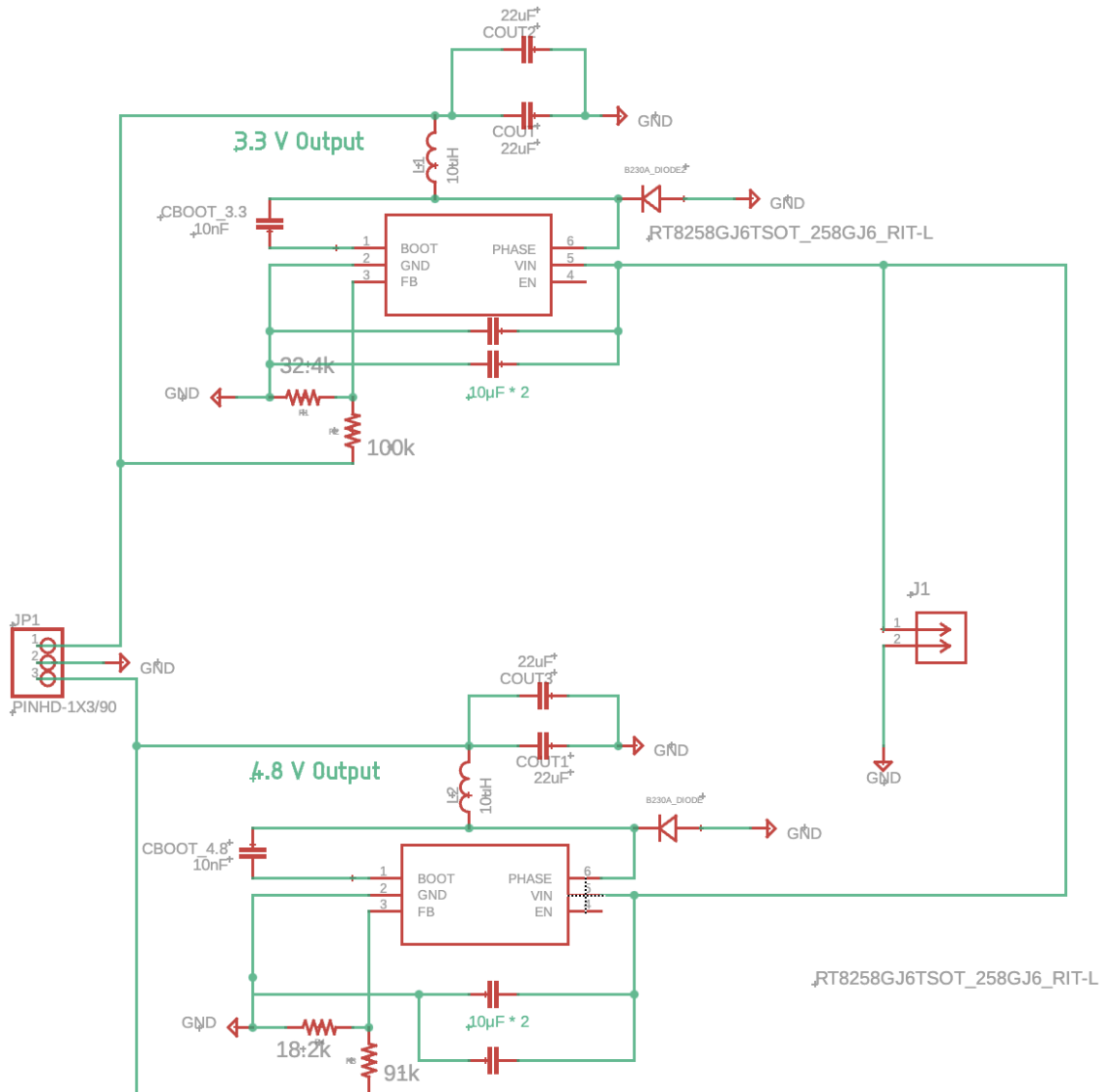


Figure 6.2.6 : 3.3V (Top) and 4.8V (Bottom) Regulators Schematic

The overall schematic of the 3.3V and 4.8V step down regulators connected to a 9V battery operated power source makes up the entirety of the power board schematic which is to be converted to a PCB layout in Chapter 8 of this documentation. The regulators both take the 9V inputs and step them down to appropriate voltage levels to then be supplied to external devices like sensors and other components of VISTA. The outputs of the two regulators connect to a set of header pins that are then connected to consequent header pins in the main components board shown and discussed in the section below. From those header pins, the voltage inputs can be supplied to all necessary components to power VISTA and all of its required capabilities. This lays out the fundamental hardware design of the project and highlights the importance of power regulation in applications like VISTA.

6.2 Main Component Design

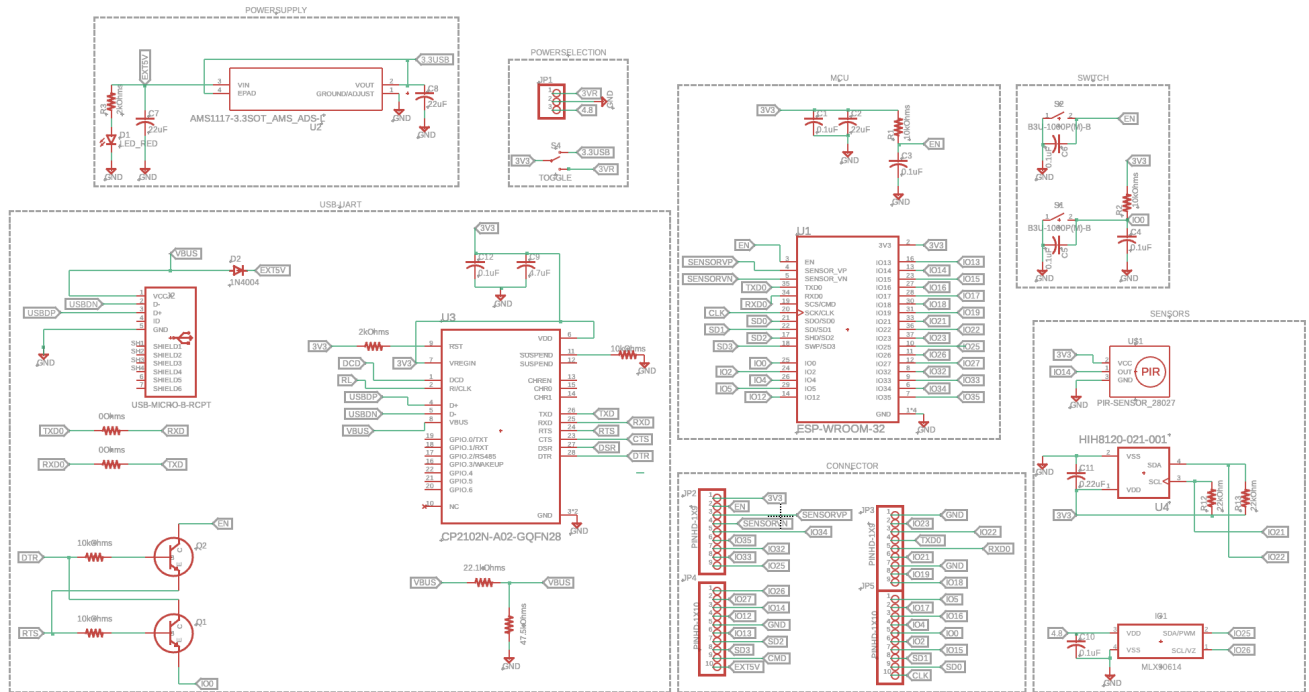


Figure 6.3.1: Schematic of MCU Connected to Sensors, Servo, and Wifi module

The ESP32 microcontroller requires multiple different connections to perform its necessary functionalities. One of the schematic subgroups includes all of the necessary components and schematic connections for USB (or 5V external power) to UART conversion.

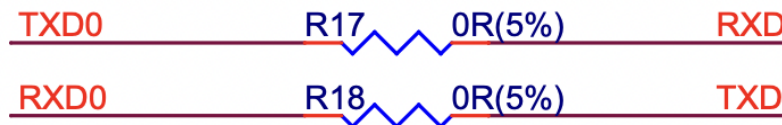


Figure 6.3.2: ESP32 UART Transmit and Receive Lines Schematic [147]

The 5V or USB to UART conversion schematic configurations include transmit and receive lines with resistors, which connect transmit and receive pins on the ESP32 to transmit and receive pins of an external device. This allows data to flow either way to ensure proper communication. The resistors have nominal resistance values of 0 ohms and tolerances of 5%. Therefore, for this design, the resistors are essentially placeholders in the schematic, however they still serve useful functionalities like easy circuit modification. Utilizing a zero ohm resistor in lieu of directly connected with net also adds some ability to act as a probing point for debugging purposes.

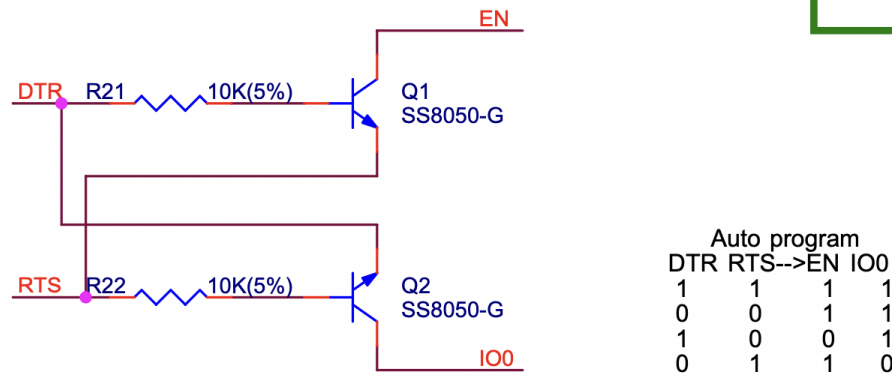


Figure 6.3.3: ESP32 UART DTR and RTS Signals Schematic [147]

Another section of the schematic is used for automatic programming or microcontroller resetting. DTR and RTS signals are logical inputs controlled by UART communication. The two resistors limit the base current for the BJTs (bipolar junction transistors), and then the transistors act as switches to control the output states for EN and IO0. To expedite the development and debugging process, a Micro-USB port is also included onto the board. This allows an interface between an external device and the ESP by using an intermediary bridge. The bridge will handle all interfacing and translation internally. As a result, reprogramming the MCU only requires the necessary output from the configuring device. Common IDEs are capable of flashing in the correct format. The bridge is connected to the differential data pins from the USB port on one side, and then processes and outputs the corresponding data over its output DTR and RTS pins.

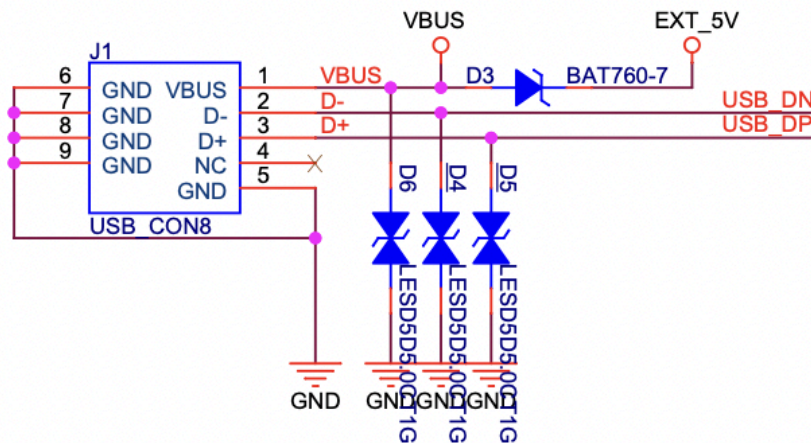


Figure 6.3.4: ESP32 UART USB Connectivity Schematic [147]

This schematic section shows the USB interface for UART on ESP32 in order to properly handle USB communication and power regulation between the ESP32 and an external device. The D+ and D- lines are data signals, and the D4-6 diodes are for protection against electrostatic discharge or voltage spikes to ensure proper communication [141]. For the purpose of VISTA, however, including these protective diodes is not a necessary requirement. The VBUS line is for USB power supply, receiving 5 V externally. Similar to

the other diodes, the D3 protects from voltage spikes on the VBUS line. The USB_DP and USB_DN lines connected from D+ and D- connect to a separate USB to UART peripheral as another schematic part of the ESP32. All the ground pins (GND) are tied together to denote a common ground for the circuit schematic.

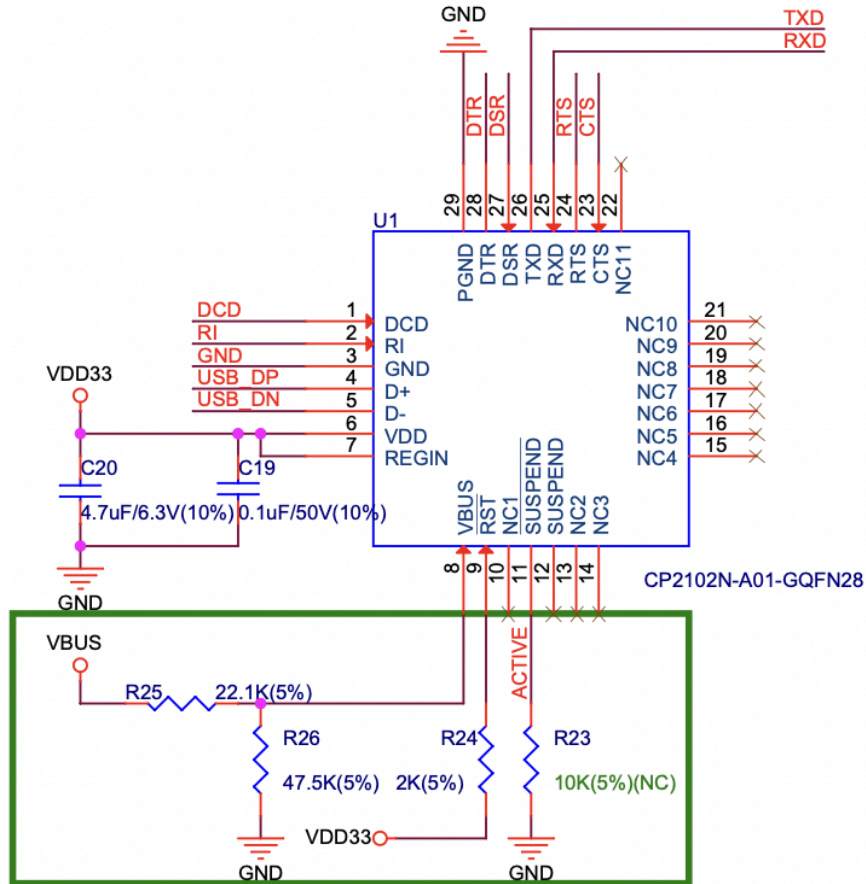


Figure 6.3.5: ESP32 USB to UART Conversion Schematic [147]

The final USB or 5V to UART section schematic is the configuration of the CP2102N chip that converts the input USB or other power into UART. The chip's interface between external USB and ESP32's UART allows for communication for programming, debugging, and exchange of data [142]. In the green box shown in the schematic figure above, the input 5V from VBUS is stepped down to 3.3 V at pin VDD33 and regulated to provide stable power supply for the chip. The pull up and pull down resistors in this section ensure proper functioning for detection of the VBUS as well as the chip's power state logic. Pin 11, labeled as ACTIVE, indicates the active state of the USB connection. An active USB connection refers to an active cable with a circuit that amplifies the signal and maintains integrity of the data, particularly over longer distances. The decoupling capacitors C19 and C20 connecting from VDD33 and into pins VDD and REGIN act as stabilizers for power and aid in noise reduction. The overall larger functionality of the CP2102N chip is to receive data from the USB data lines USB_DP and USB_DN and convert them into

UART signals for the ESP32 through pins RTS, CTS, TXD, and RXD. The DTR and DSR pins are used for reset and boot mode selection for ESP32 programming purposes.

Another subgroup of the ESP32 overall schematic is the power supply section. This is another crucial part of the ESP32 schematic for later PCB design, particularly for testing purposes.

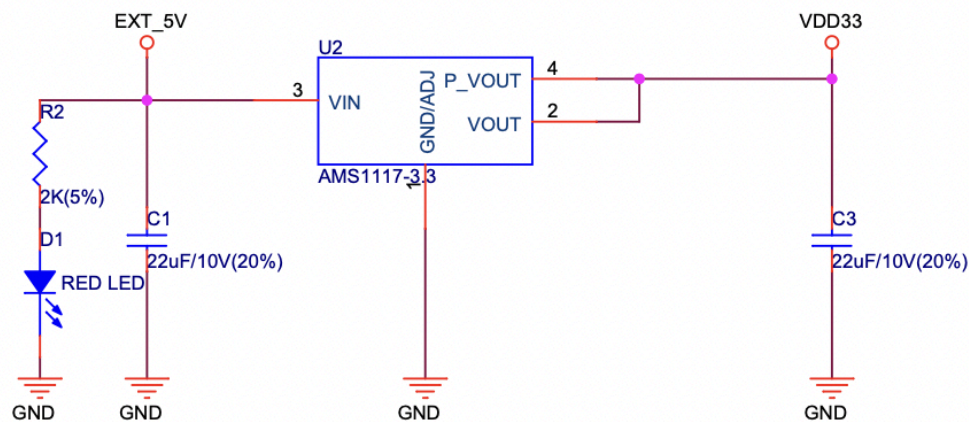


Figure 6.3.6: ESP32 Power Supply Schematic [147]

This section of the ESP32 schematic is for voltage regulation. The ESP32 has a built-in voltage regulator, although the 3.3V regulator schematic shown in section 6.2 of this report is still connected by a jumper, so that the resultant overall circuit may switch between using the built-in regulator for USB connection or the external voltage regulator for battery powered operations. Since VISTA is powered by a 9V battery for all of its functionalities, the built-in regulator is used for testing purposes. The regulator shown above takes in 5V of power from an external source and steps it down to 3.3V to provide suitable power supply for the ESP32 without overloading. The C1 and C3 capacitors work to reduce noise and stabilize the voltage, placed on the input and outputs of the voltage regulator. The RED LED (D1) lights up to indicate whether or not the circuit is being powered from the input voltage, and the resistor in series (R2) works as a current controller to prevent overload and burning out of the LED.

Another crucial schematic subgroup includes the push buttons for reset and boot modes of the ESP32. This is a necessary part of programming and testing, particularly.



Figure 6.3.7: ESP32 Switch Buttons for Reset and Boot Modes [147]

SW1 is a boot button that, when pressed, pulls GPIO0 (general purpose input/output 0, labeled as IO0 in the schematic) down to ground, which allows users to enter programming mode. This in combination with a reset is used to enter bootloader mode for the ESP32. This is a necessary functionality that allows for flashing new firmware onto the ESP [143]. Many physical switches can bounce after being pressed for longer than it takes for logic devices to respond. Even though the difference is imperceptible fractions of a second, the difference results in the bouncing that is left unaccounted for causing false triggers and useless outputs. The appropriate debouncing circuit, in this case the C15 capacitor, eliminates the bouncing and filters out noise to provide a clean, steady data signal [144]. SW2 is a reset button that, when pressed, pulls EN down to ground, which resets the ESP32 and its operations. Similar to the boot switch schematic, the C14 capacitor in the reset switch schematic is used for debouncing purposes. It is important to note that the schematic shown is missing a vital part of the debouncing circuit, which is shown in Figure 6.3.9 and discussed below.

Another important subgroup of the ESP32 schematic includes the unassigned pins, mostly including I/O pins that can be arbitrarily assigned based on the needs of the user.

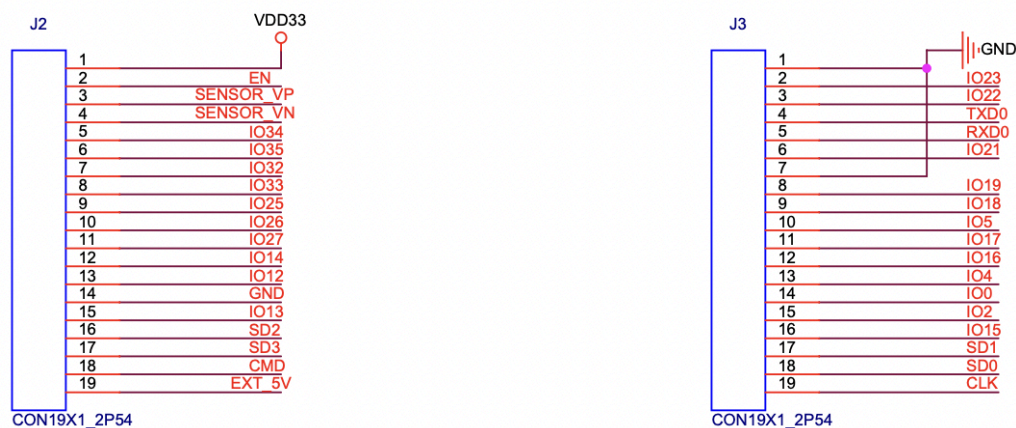


Figure 6.3.8: ESP32 Header Pins Schematic [147]

The header pins schematics are primarily useful for organizing the leftover pins for interfacing the ESP32 with peripherals, such as sensors. For the use of VISTA, some of the unused pins are necessary for connecting the occupancy sensor, temperature sensor, humidity sensor, and the servo. The pins in this schematic include the TXD0 and RXD0 (transmit and receive) pins for UART communication, SD card interfaces, sensor inputs, SPI interfaces, and other GPIOs for general purposes. Organizing all of these pins is useful not only for interfacing purposes, but makes it a great deal easier to facilitate connections and create specific hardware designs.

The final subsection of the ESP32 overall schematic is the ESP32 module itself and its necessary components. This section brings together all of the other subsections into a cohesive system functionality of ESP32 and combines all of its built-in capabilities.

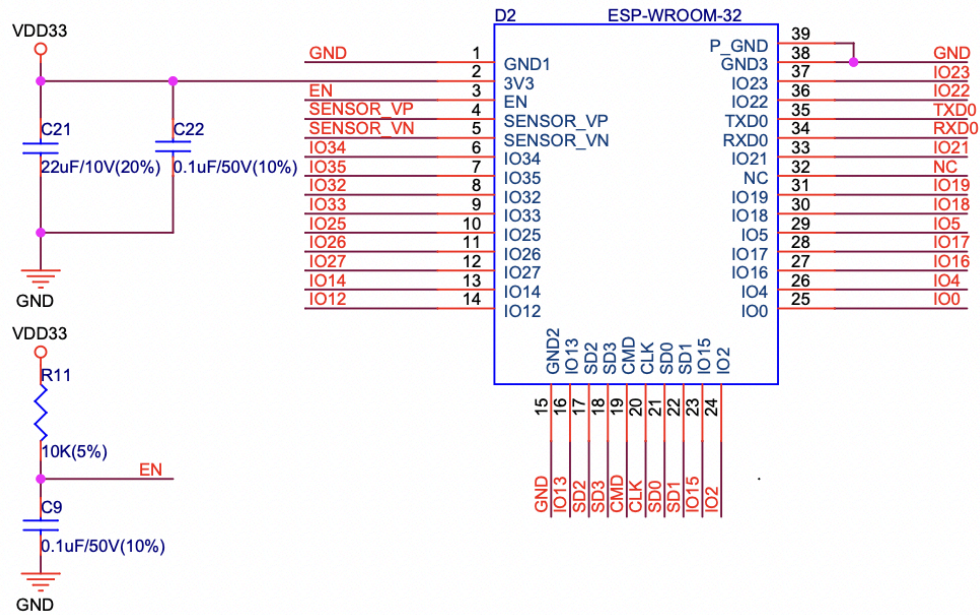


Figure 6.3.9: ESP-WROOM-32 Module Connections Schematic [147]

This subgroup schematic shows the direct connections for the ESP-WROOM-32 module. It received 3.3V of power from the step down regulator through pin VDD33. The parallel decoupling capacitors C21 and C22 then stabilize the input power by reducing noise, before the signal can reach the ESP module through pin 3V3. The circuit configuration containing the R11 resistor and C9 capacitor performs pull-up and debouncing functionalities. The pull-up resistor ensures that the ESP32 is enabled by default by connecting to the EN (enable) pin. Additionally, the debouncing capacitor filters unwanted noise before the signal reaches the EN pin. This resistor and capacitor configuration should also be connected to the switch buttons for proper debouncing and filtering, though it is not included in the schematic of Figure 6.3.7. The rest of the pins include configurable functionalities like UART, SD cards, general use GPIO, ADC inputs, and a common ground. The overall schematic shows how to power the module, reset or enable the module through the EN pin, and how to access other pins for interfacing external devices such as sensors and servos or other peripherals [145].

Connecting external devices or other peripherals is a crucial functionality of the ESP32 module. VISTA's capabilities include sensing and responding to information like occupancy, temperature, and humidity levels of the room. Additionally, there are some modules that are not included in the ESP32 that are necessary for the operation of VISTA such as the servo and the wifi module. The rest of section 6.3 shows all of the additional devices connected to the ESP32 module and discusses their schematic design and functionality as well as the overall purpose of each.

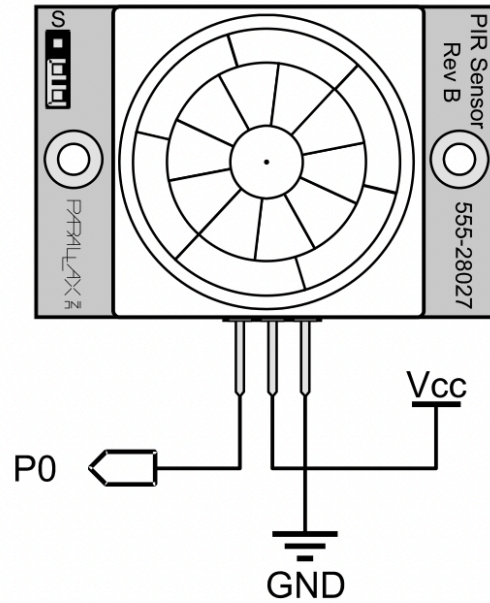


Figure 6.3.10: Occupancy Sensor Schematic

The occupancy sensor is an important aspect of VISTA's capabilities. The schematic shown above displays the basic connection necessities in order for the room occupancy to be accurately measured. The module includes a Fresnel lens that focuses infrared radiation onto the sensor [150]. The VCC pin receives 3.3V of power from the step-down regulator to properly function. The ground connection is a common ground shared with the rest of the schematics, and the P0 pin provides a digital output signal relaying either high or low (1 or 0) depending on whether motion is detected or not. This data is then fed to an I/O pin on the ESP32 microcontroller module in order to process the information and respond accordingly.

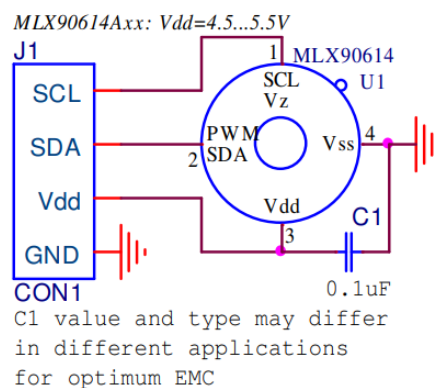


Figure 6.3.11: Temperature Sensor Schematic [154]

The chosen temperature sensor, the MLX90614 is perhaps the most vital component in the entire VISTA design. The four port connections consist of just power (4.8V), GND, and an SMBus interface. A coupling capacitor is needed to reduce noise and interference

from any AC component of the power input. The GND pin will be attached to the ground plane. The sensor can additionally be interfaced with via PWM, in a similar manner to the aforementioned servo. Under standard configuration, the sensor will output a 10 bit reading via PWM every 1.024 ms. To preserve power this can be configured to record temperature readings at a much slower rate.

To configure the sensor into low power mode, the device must be sent a command, '0xFF' via SMBus or PWM.

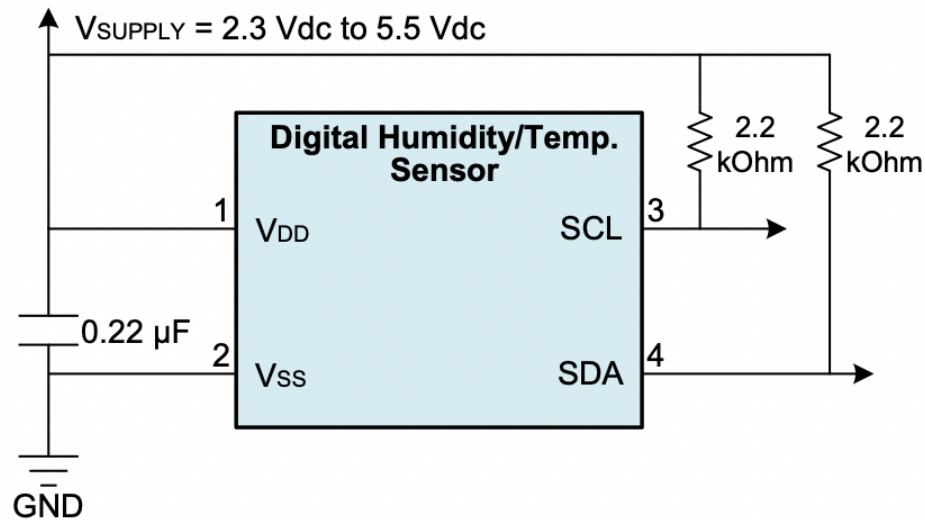


Figure 6.3.12: Humidity Sensor Schematic [148]

This schematic, as provided by the chosen humidity sensor's datasheet, the HIH8120-021-001, shows the proper way to connect the part to ensure proper communication and power supply. The sensor receives 3.3V of power from the step-down regulator discussed previously through the VDD pin. The decoupling capacitor between the VDD and ground (VSS pin) is used to filter out unwanted noise in order to stabilize the input power supply signal. This ensures proper and reliable functionality of the sensor. The sensor then outputs digital data over the SCL (serial clock line) and SDA (serial data line) lines. The SCL line provides the clock signal for synchronous communication, while the SDA line deals with the transfer of data between the sensor and the ESP32 microcontroller. The output data lines both have pull-up resistors attached in order to ensure the lines remain high, or 'on', when no device is actively pulling them low [149]. Overall, this humidity sensor has a fairly simple schematic that is easily integratable into the main components board schematic design.

The FS90R is an independent servo, which implies that it does not need to be built out in the schematic like that other components do. The servo needs to be incorporated in order to show the functionality of the whole project, but it will only be connected by three header pins. These pins are ground, V_{in} , and data. These pins will be connected to the MCU to control speed and position, it will be connected to the I/O pins on the MCU.

The HT40 wifi module is built-in to the ESP32 module, and therefore does not have a schematic or require any extra connections. The pins are hardwired internally, so the registers will be accessed through software interfaces as discussed in the software section of Chapter 9.

6.4 3D Louver & Housing

The main structure of the physical smart vent is the system of registers and louvers. Research from Chapter 3 determined that the optimal choice for building the structure was 3D printing using PETG plastic filament. The figures below show the 3D model/design for the vent system consisting of the register, or vent cover, which contains “louvers”, or vent slats, that, in this model, slide as one piece over the register to limit or allow air flow into a space based on how much of the opening are covered or not.

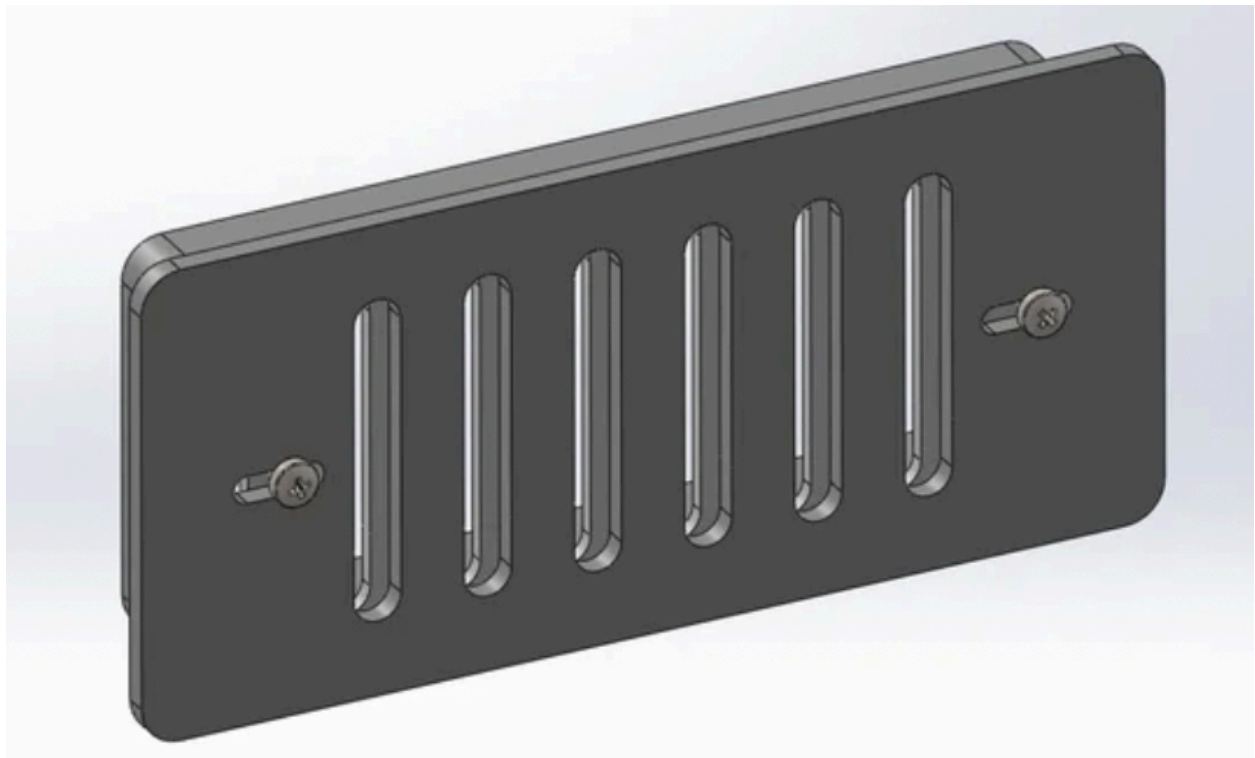


Figure 6.4.1: Register and Louver 3D Model [140]

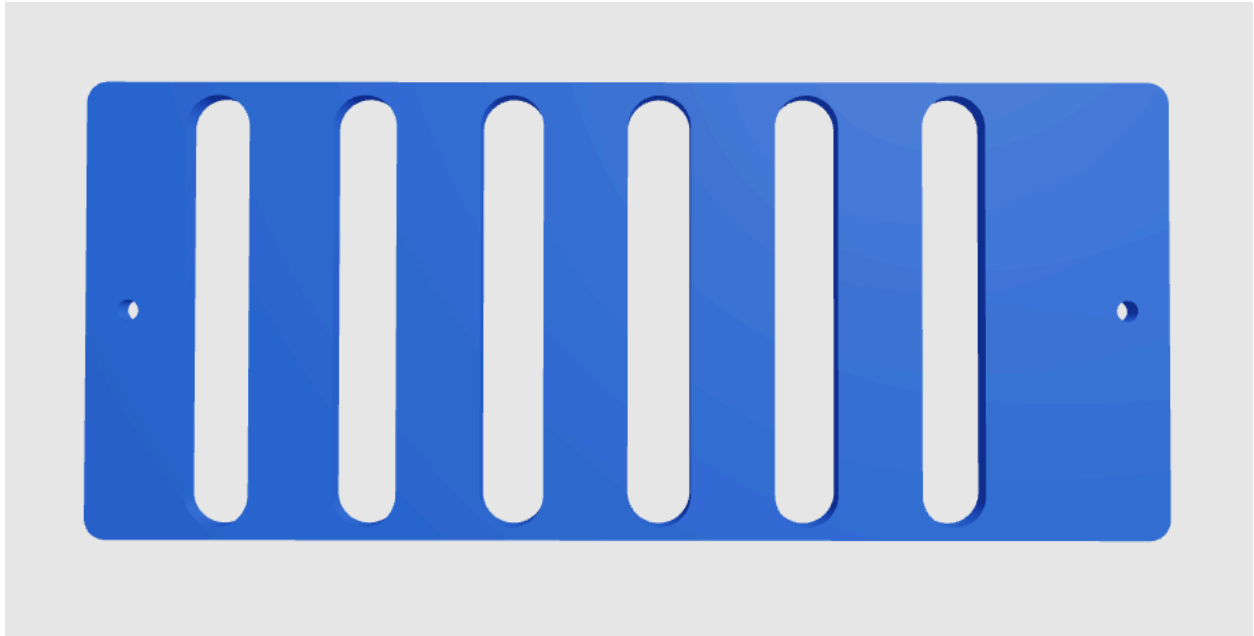


Figure 6.4.2: Register 3D Model [140]

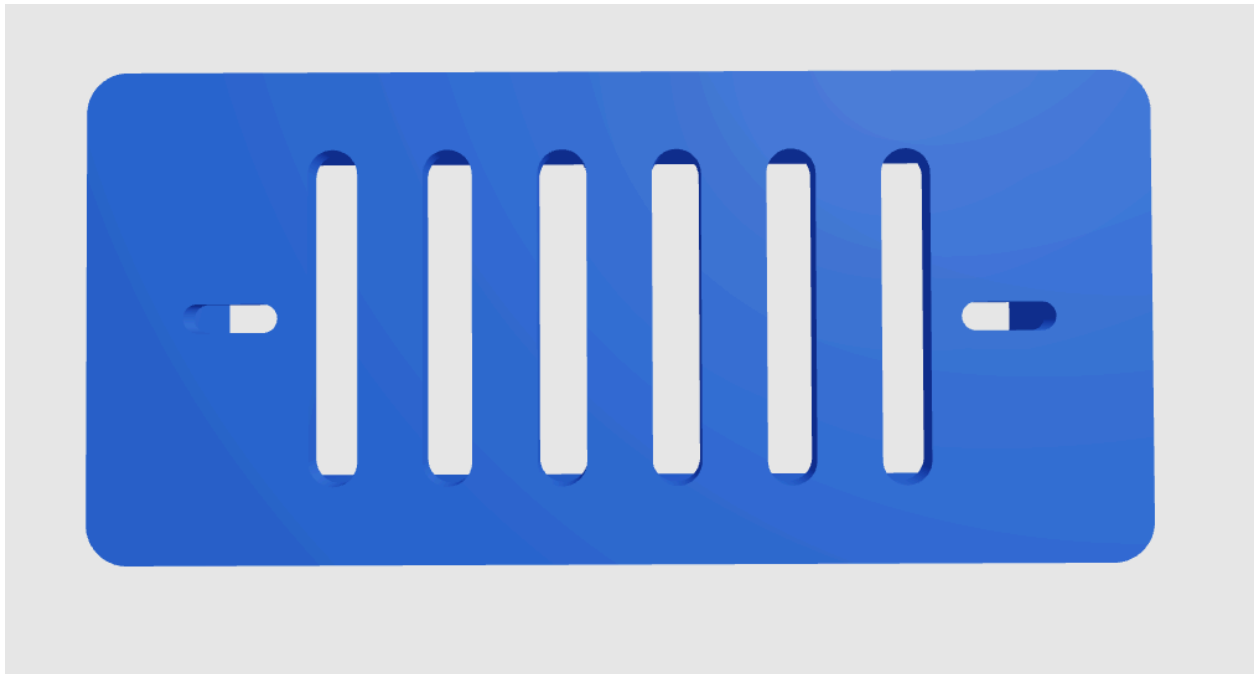


Figure 6.4.3: Louver 3D Model [140]

In order to use this device, there must be a mechanism constructed that will support the servo for the movement of the vent. The easiest option would be a rectangular piece, also 3D printed, that could attach to the front of the louver. This piece would require two holes on each side of the piece, one should be large enough for a shallow screw to fit through, while the second only needs to be small enough to connect the servo. This adaptation is

not shown in the 3D model above, but will be represented in the final model for the 3D printer.

The design will also require a housing to protect the components from dust, condensation, or accidental impact. The housing will serve both functional and aesthetic purposes, creating a polished and visually appealing device that integrates seamlessly into its environment. The housing will also be made of Plastic and will be 3D printed. It will be slightly larger than the final width and length of the PCB to provide adequate space for components while maintaining its compact design. The most important component of the housing will be the placement of the sensors, our design has three sensors: a temperature, occupancy, and humidity sensor. The temperature and occupancy sensors require an unobstructed line of sight into the room to deliver accurate readings. The humidity sensor, while less dependent on placement, will still require adequate ventilation to measure conditions correctly. These constraints will require the housing to either have holes in it where the sensors can peek out from or a way to mount these sensors on top.

Both the servo support mechanism and housing will undergo extensive prototyping to ensure alignment with the PCB and overall device design. Special attention will be paid to ensuring that the assembled unit operates smoothly and remains durable over extended use. The finalized 3D models will be evaluated for structural integrity and printed using high quality materials for maximum reliability.

Chapter 7-Software Design

7.1 WiFi Connectivity Flowchart

One of the key challenges for this project is ensuring that the V.I.S.T.A device be in constant communication with the corresponding web app. In order to do this, both the web application host and the V.I.S.T.A device must be connected to the same WiFi network. On top of this, the process of ensuring connection between the V.I.S.T.A device and the frontend must be user-friendly. Both the MCU software and the web app, therefore, must go through a software routine to ensure that they are connected and can begin sending or receiving HTTP requests upon startup. First the wifi module will start up and check for the user's information. If the user has logged in before their username and password will be saved within the memory of the wifi module. If the user has not logged in before, the module will take extra time to save their information; this makes future logins simpler. Next the wifi module will try to establish an access point, if the module is connected to the module it will continue on to the task, if it is not it will display an error message for the user. The next step in the connectivity presses is for the module to check the port broadcast from the backend, if that is successful the module will send the IP address. Upon completion of the connection the HTTP terminal will check if a request was sent, if it was it will be sent to the module to update internal variables and state management. Figures 7.1.1 and 7.1.2 will give visual representations for the wifi module's internal commands and decisions.

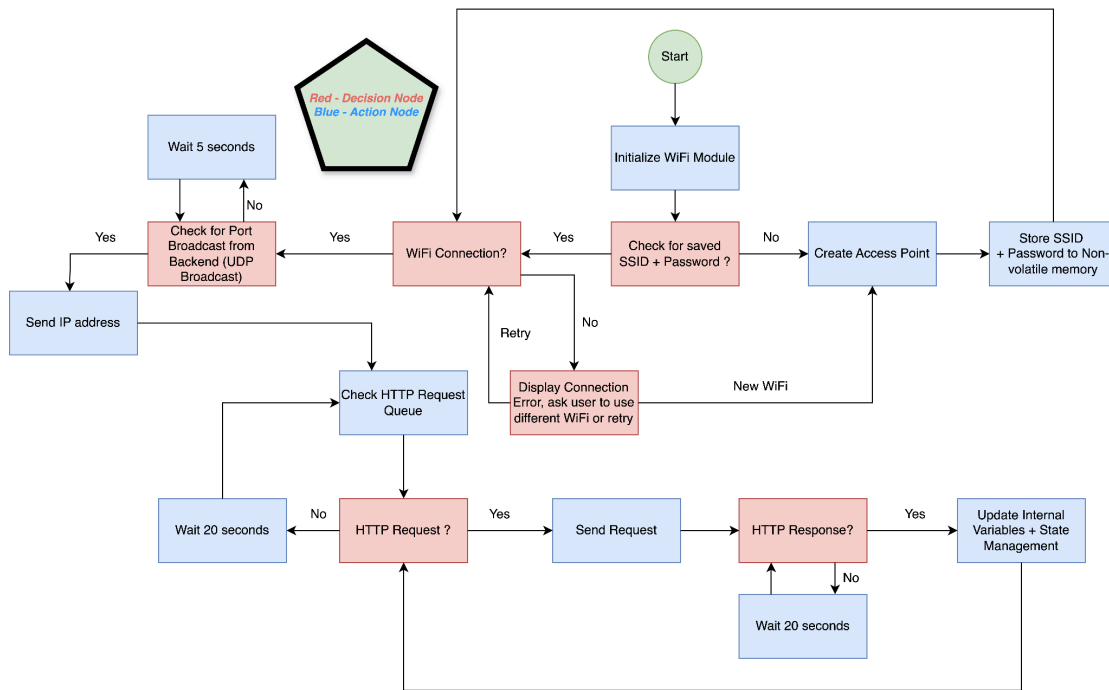


Figure 7.1.1: MCU Program WiFi Connectivity Flowchart

Next the wifi module will work to connect to the app that way users can interact with the VISTA device. First the module will send a broadcast request over the discovery IP to check for connectivity. It will wait for a request before continuing in its line of command. After it receives a request it will send an initial HTTP request, it will need to wait to ensure no requests are lost or skipped. After the response is recognized the connection is successful!

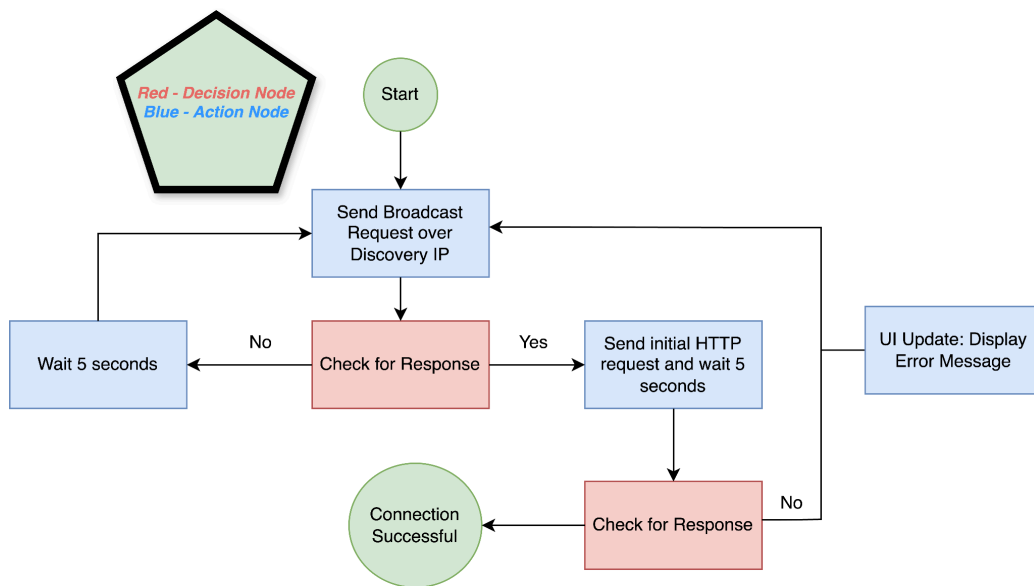


Figure 7.1.2: Web App WiFi Connectivity Flowchart

7.2 Occupancy Mode State Diagram

The VISTA comes with two programmable modes that allows for different functionalities and purposes. The two modes are the Eco mode and the Vacant mode, and are linked to the occupancy sensor. The user is allowed to initiate either of the two modes at their own discretion, however the VISTA will change modes depending on information from the sensor suite.

Eco Mode is the mode that the VISTA system will be in a majority of the time. The use of this mode is for users to specify the temperature in which they would like their room to remain. In eco mode the user will first set the temperature within the app they would like the room to be set at, and then the system will do the rest of the work. The system will first communicate with the occupancy sensor, if there has been movement within the amount of hours specified by the user then it will remain in eco mode. If there has not been movement within the set amount of hours the system will transition to vacant mode; but when there has been movement the system will next connect to the temperature sensor to read the current temperature of the room. If it is above or below the desired temp the system will connect to the servo to move it the appropriate way. After it moves the app will update with the new status of the vents.

The second mode that either the user can pick or that the system can automate to is the vacant mode. The vacant mode incorporates temperature and humidity unlike the eco sensor which only incorporates temperature. In vacant mode if the temperature is above or below the set temperature range it will have the same functionality as eco mode; but if the temperature is within the set range of temperatures the system will then move on to

checking the humidity. If the humidity is within the user set range the vent will close to keep that same level of humidity while if it is outside of the range it will do the opposite. An important thing to note is that all of these functionalities with asterisks in the figures will do the opposite in the winter when the AC system is using heat rather than cold Air conditioning. Figures 7.2.1 and 7.2.2 showcase when it is appropriate for the system to switch from the Eco friendly mode to the Vacant mode, and vice versa, depending on incoming data from the occupancy sensor.

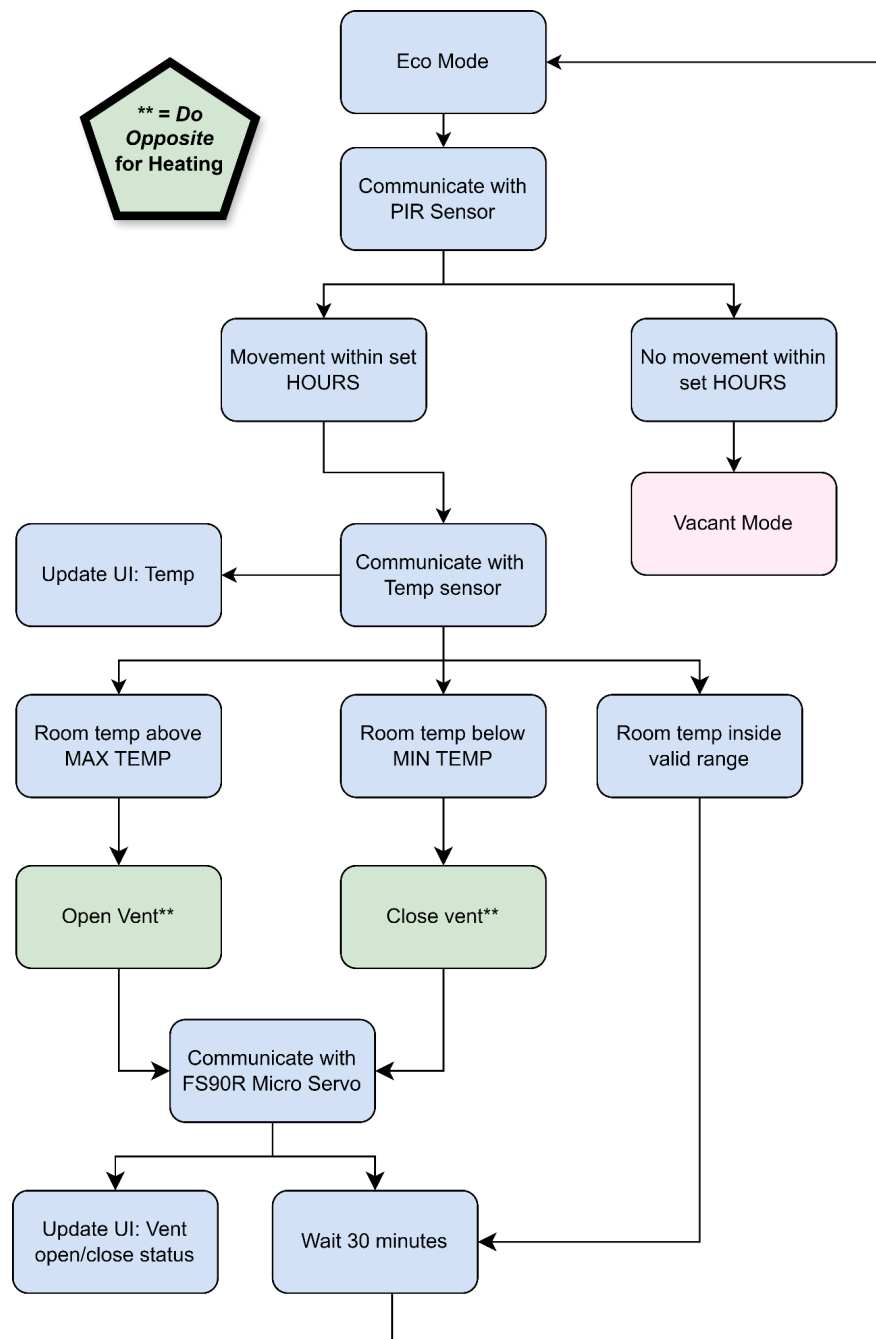


Figure 7.2.1: Eco Mode Flowchart

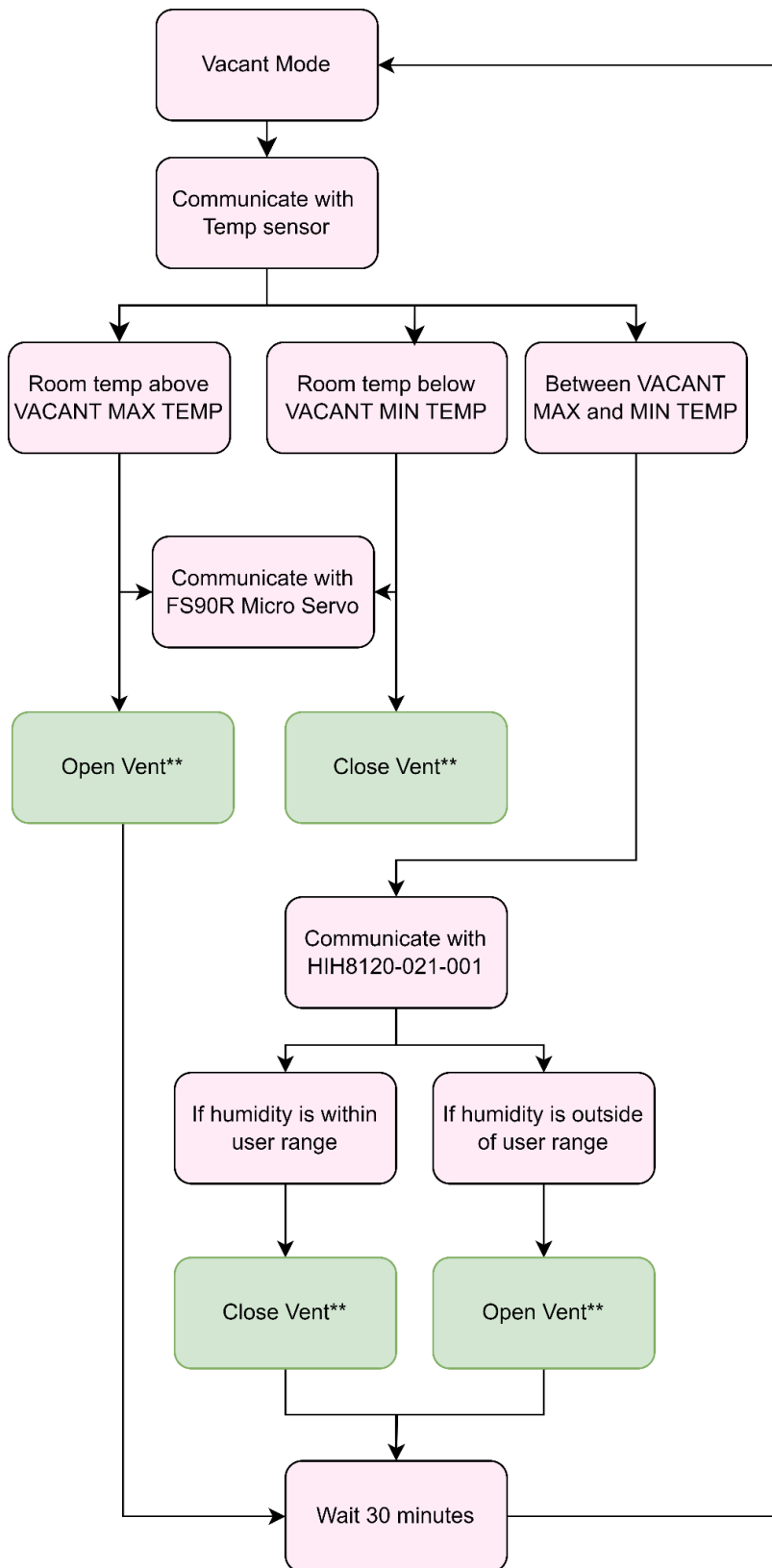


Figure 7.2.2 : Vacant Mode Flowchart

7.3 UI Update Table

As stated previously, the web app must be in continuous alignment with the V.I.S.T.A hardware, and therefore the application will be able to respond to changes in the V.I.S.T.A's internal state, and changes in the environment. For example, the web app must be able to receive information from the V.I.S.T.A's thermal sensor and display the current temperature. The V.I.S.T.A must be able to respond to these changes and display them on the user interface. For simplicity of implementation, it is best to poll the status of endpoints rather than using event-driven updates. This means that the React frontend will poll HTTP endpoints, and the most critical information, like the current temperature, will be polled more frequently. Below is a table describing when a variable should be polled.

UI Element	Purpose	Endpoint Name	Polling Frequency
Connectivity Status	Detect Connectivity between frontend and V.I.S.T.A device	/status	Every 60 seconds
Room Temperature	Measure the temperature of the outside room	/temperature	Every 5 seconds
Device Mode	Display if V.I.S.T.A device is configured to Eco mode or Vacancy mode	/mode	Every 30 seconds
Occupancy Status	Display Occupancy status read from V.I.S.T.A	/occupancy	Every 60 seconds
Humidity Status	Display Humidity status read from V.I.S.T.A	/humidity	Every 60 seconds

Figure 7.3.1 : UI Update Table

7.4 Servo Interfacing

The FS90R servo has multiple input parameters to modify the behavior of the device. Interfacing with the servo is done via a single data line [153]. The specified pseudo-protocol, PWM, is easily altered to manipulate the mechanical behavior of the device. Although PWM can be configured to communicate more efficiently by varying pulse width and frequency, the added complexity is thankfully not necessary for the servo. By varying the pulse width between five and ten percent, the speed and direction can be

modified. With a duty cycle of exactly 7.5%, the motor is in a neutral state, no turning force is applied and the wheel does not turn. Any duty cycle above 7.5% results in the wheel turning counterclockwise. The magnitude of the duty cycle exceeding 7.5% linearly increases the speed of the rotations until it is capped at 10%. The opposite behavior also applies- any duty cycle below 7.5% results in the servo rotating clockwise. Between 5% and 7.5%, the speed of the rotation is linearly correlated to the magnitude of the duty cycle away from 7.5%.

The FS90R is known for producing a reasonably loud sound when operating. To reduce this effect, the servo will be driven at the lowest possible speed in the corresponding direction. When accounting for the 0.15% duty cycle tolerance on the servo at 50 Hz, and a 0.1% tolerance on the MCU's GPIO pins, the total tolerance and input cushioning needed is 0.25%. This equates to driving a PWM signal with duty cycles of 7.75% and 7.25%.

All of these features of the FS90R can be controlled through arduino code on the ESP32. This interface makes communication with this device so much simpler.

Chapter 8-System Fabrication/Prototype Construction

8.1 PCB Layout

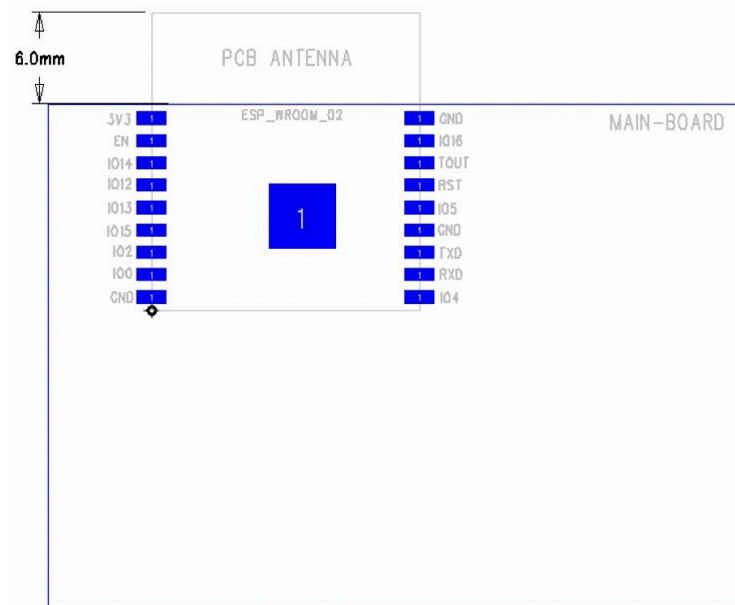
After designing the schematic in fusion 360, the next step is to create the PCB design within fusion 360. While trying to lay out the PCB schematic for the first time, some issues were encountered.

First, the inductors were the incorrect value and package. This was prevalent in the PCB design because the inductors took up much more space than any other component or even group of components on the PCB. The second issue encountered was the capacitors on the power schematic. Originally the number of capacitors was incorrect, so that needed to be adjusted before the layout could continue.

Although there were many issues, that is part of the learning process. Everyone in group 34 has had minimal experience with PCB design so mistakes were expected. Luckily all of the mistakes were small and fixed in a quick amount of time.

While designing the schematics to then convert to PCB layout, there are a lot of different factors to take into consideration. 0805 circuit components, like resistors and capacitors, are the ideal choice due to their widely available manufacturing and their ideal size. The 0805 components are small enough to fit many on a PCB while also large enough to solder on without much difficulty. When using solder paste, the 0805 stencil is a commonly used size, which also aids in the ease of use.

Another important design characteristic of the PCB is the trace width of the wires, which were originally set to the standard width of 6 mil. After further consultation with Dr. Weeks, it was determined that the wires were required to be at least 20 mm. There are many different reasons why it is important to have thicker trace widths, primarily because if there is a flaw in the design, wider traces can be removed and resoldered while with thinner ones it would be nearly impossible. Additionally, thicker trace widths result in more effective heat dissipation from resistance, as they can handle larger currents. Wider traces minimize the resistance and ensure voltage levels stay more consistent throughout the PCB.



↑ Option 2. Placing at the edge with the antenna outside of the host board

Figure 8.1.1: ESP32 PCB Placement for Antenna [152]

The ESP32 module has a large antenna that protrudes from the rest of the chip. Due to this, there are specific ways in which the PCB can be designed in regards to the location and orientation of the antenna that must be chosen from. The ESP32 has a document that depicts the different configuration to be chosen from, which consists of placing the module near the edge of the board with the antenna either facing outward at the edge or hanging off the edge. Essentially, it is recommended that the module be mounted on the edge of the host PCB with the antenna exposed to free space [152]. The figure above shows the configuration that was chosen for the PCB design of VISTA. This is an important PCB design characteristic to reduce noise interference and allow for optimal signal performance. This will allow better communication range and performance by Wifi or bluetooth, as well as the strength of the signals.

Location and orientation of main hardware components and connection components is another crucial characteristic to take under consideration when designing the schematic

and PCB layouts. Header pins are placed near the ESP module to route the connection through to other hardware components. It is important to select header pins with an appropriate amount of pins to fit the design needs, as well as pins that are at a 90 degree angle from the PCB in order to allow for proper connection space for jumpers. For the USB connection, it is necessary to ensure that the chosen component is a micro USB and that it is placed at the edge of the board to allow for external connection. Similarly, the PIR occupancy sensor must be placed at the edge of the board to allow for proper field of view to obtain accurate readings.

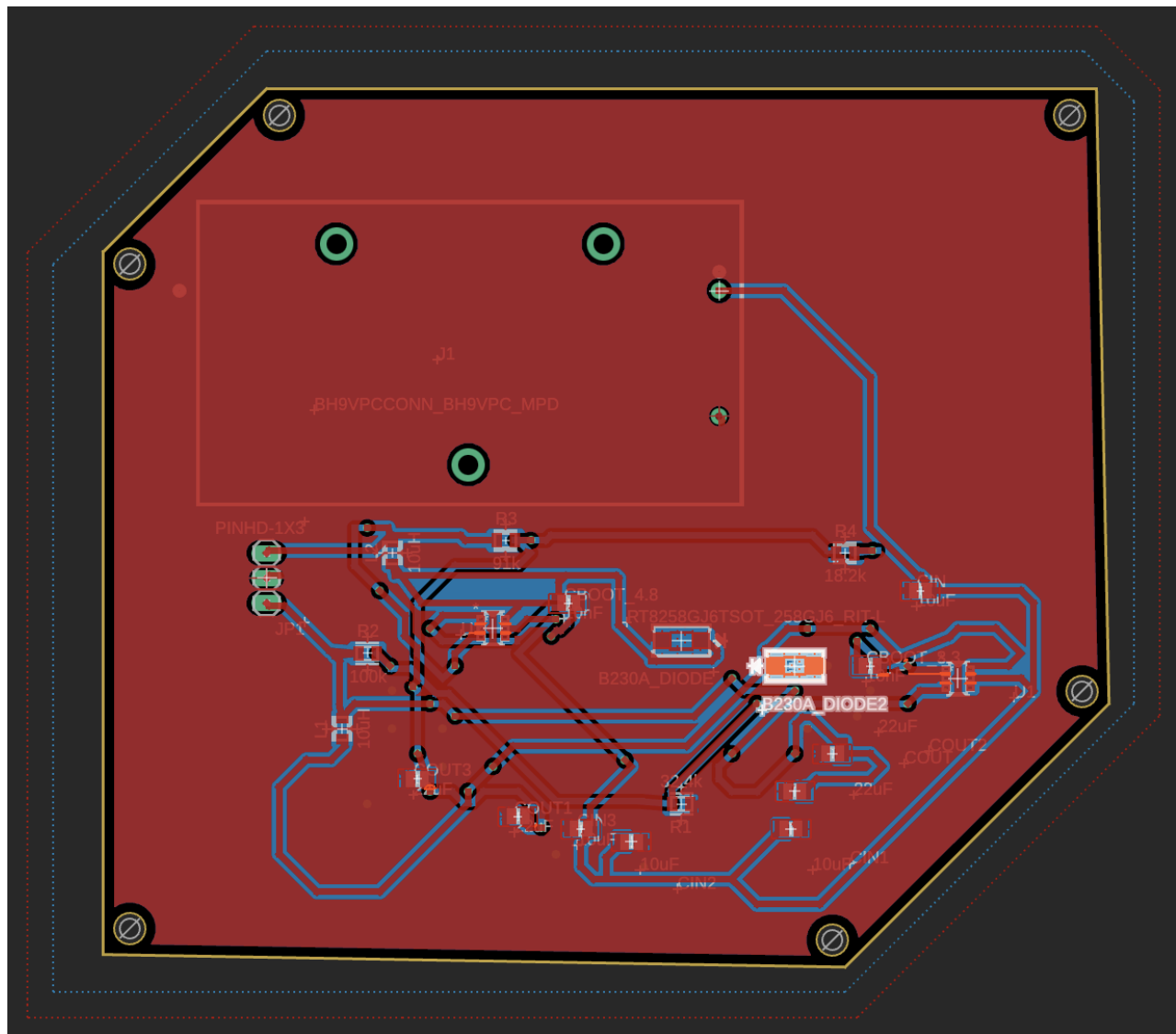


Figure 8.1.2: Power Board PCB

The power board can be thought of as three sequential sections flowing from right to left. The first section contains just the battery and outputs two signals: Vin and GND. These then flow into the middle section, which contains the regulators themselves and all the aforementioned components to operate the devices. This middle section contains many nets which stay internal. The output of the middle section to the final section is simply the

+3.3V, +4.8V and GND. The final section contains only the header pins which then are able to connect out via jumpers or female header pins to the main components board.

This PCB is a crucial component of VISTA, as it powers all of the functionalities and capabilities of the system through the input 9V battery and the step-down regulators to regulate the voltage levels of each hardware component. Through using header pins and jumper cables, the two PCBs can be easily connected in order to build the final product of VISTA.

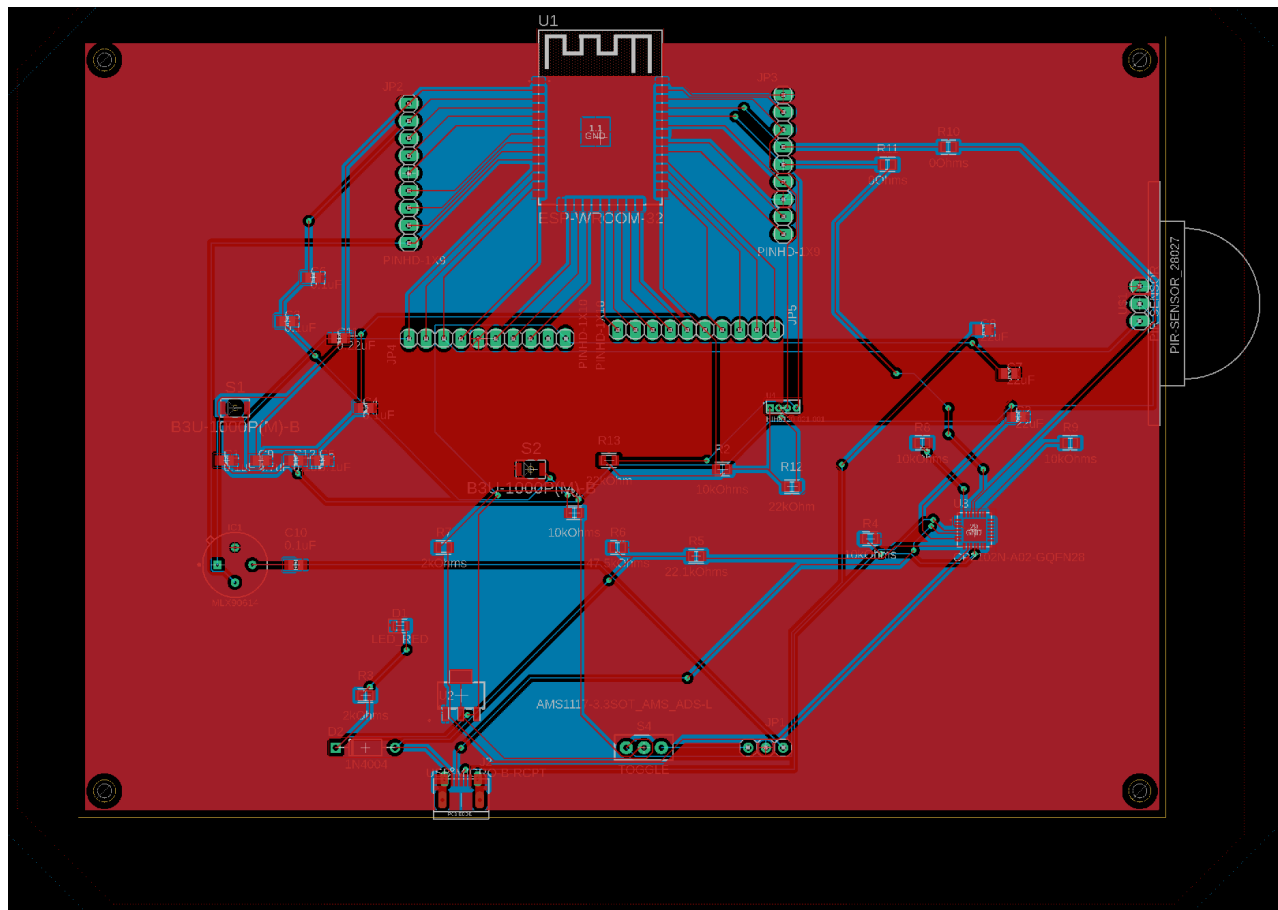


Figure 8.1.3: Main Components Board PCB

The main components board features the sensor suite, MCU, USB interface and a connection to the power supply board. As discussed previously, there are a multitude of design characteristics that are important to take into consideration when designing both PCBs. With all of these factors evaluated and integrated, the final PCB designs as shown above allow for all of the VISTA capabilities discussed throughout the report.

Chapter 9-System Testing and Evaluation

9.1 Hardware Testing

9.1.1 ESP32

Originally the VISTA system was being designed with a STM32 board. This MCU option was adjusted after advice from Dr. Weeks in the Senior Design Lab. This guidance will be essential to our success in senior design two, as the project would have continued down a much more difficult path without the input. While the STM32 was the best MCU from research alone, Dr. Weeks' practical knowledge helped us see that it was much more difficult to use than the ESP32. The STM32's biggest issue was interfacing it without other components; while it is possible it is no easy feat. Our group was also fortunate enough to communicate with group members in Senior Design II who are currently using the STM32, and they warned the group against it and recommended the ESP32.

Originally, this was troubling news, as we only had the STM32 ordered to test. Our group was worried about being able to complete the mini demo video in time for the final report submission. Thankfully, Dr. Weeks in the senior design lab loaned us an ESP32 to use for our demo testing. Since we had just been introduced to the controller with very little background knowledge, Dr. Weeks helped set up our arduino terminals and helped guide the connectivity with the first component. To test the functionality of the microcontroller, the ESP32 development board was connected to a USB-C power source. Even though we will not be using the dev board in our final design, we used it during testing for simplicity's sake. The simplicity of our design still showed components that the system will use in the final project and still fit in the scope of the demo testing video. A simple blinking LED program was uploaded to the board, the success of the blinking led design showcased the ability to connect, interface, and program the ESP32. It additionally proved the functionality of the GPIO, timer, clock, and internal power mapping was working as expected. Further testing of the software functionality of the ESP32 is discussed in a later section.

9.1.2 FS90R

In order to test the functionality of the servo, the FS90R part was connected to a DC Power Supply (Agilent U8002A Single Output DC Power Supply) to provide 4.8 V of power that, in the actual project applications, will be supplied from the 4.8 V step-down regulator. The servo was also connected to a waveform generator (Keysight EDU33212A Waveform Generator) supplying an amplitude of 4.8 Vpp, a frequency of 50 Hz giving a 20 ms period, and a varying duty cycle to change speed and directions. A digital multimeter (Rohde & Schwarz Digital Multimeter) was used to test the input power and verify that the servo was receiving 4.8 V. The following table displays the effect on the servo based on the changing duty cycle of the waveform generator.

Table 9.1.2.1: Duty Cycle Effect on Servo Movement

Pulse Width	Duty Cycle	Servo Position	Movement Direction
-------------	------------	----------------	--------------------

1 ms	5%	0°	CW
1.5 ms	7.5%	90°	N/A
2 ms	10%	180°	CCW

It is additionally important to note that moving away from the neutral midpoint of a 7.5% duty cycle (around 7.8% in actual experimentation), the speed of the servo rotations increases as the duty cycle either increases to 10% (rotating CCW) or decreases to 5% (rotating CW).

For the application of the servo within the final project, it will not be controlled by the waveform generator. It will instead be controlled by the arduino code within the MCU. Due to the scope of Senior Design I, this functionality has not yet been tested.

9.1.3 MLX90614 Temperature Sensor

The temperature sensor was successfully tested using the ESP32-WROOM dev board and the SMBus Arduino library. This library was a significant advantage of the ESP32 platform, as it allowed for efficient integration of components without requiring manual interfacing and leveraging pre-built functionality created by the developer community. The MCU first wrote the 0xFF command to send the temperature sensor into low power mode. The MCU then continually reads the PWM output of the sensor. The two SMBus lines can be connected to any GPIO pins on the dev board and operate in a similar fashion to I2C but with a smaller frame size.

To ensure reliable performance, the sensor can be calibrated by comparing the recorded temperature to the known ambient temperature. For implementation in the VISTA, a reasonable degree of accuracy can account for small discrepancies. As part of the testing process, the sensor was exposed to a lit candle and an ice tray to verify that it responded appropriately to varying temperature extremes. Confirming its functionality and suitability for integration into the VISTA device.

9.1.4 HIH8120-021-001

The humidity sensor has been incorporated into the schematic and PCB design and is currently awaiting final integration. Due to the sensor's extremely small through-hole components, testing it directly on the breadboard is impractical. To address this, the sensor will be ordered presoldered in an SMT package alongside the PCB fabrication. This approach ensures that the sensor is securely mounted and ready for testing upon delivery of the PCB. Although this testing method is less than ideal, it poses minimal risk due to the extensive research and validation performed during the design process, with input and verification from peers and mentors. Once the PCB is received, the humidity sensor can be thoroughly tested within the full system, ensuring proper functionality and calibration before the final system is built.

9.1.5 Adafruit Part 189 (PIR)

The occupancy sensor has given our group many issues. The first was discovered while trying to create the whole system's schematic; all of the sensors that were found (including the one already decided from the research) had no schematics included; or they had super complicated schematics that were mistranslated and could not be used. The other issue with all of the occupancy sensors was the ones with simple/understandable schematics did not have a matching footprint on any known website such as "ultralibraian". These two issues combined, caused issues with many possible components for the occupancy feature. Then the Adafruit PIR sensor part 189 was found. It is on a mini dev board that includes all of the complicated schematics associated with every other sensor. In most senior design projects, the use of pre-built boards is discouraged, as professors typically expect students to design and implement components at the fundamental level using individual parts. However, a key realization during the later stages of this project was that the majority of practical occupancy sensors are only available as pre-built modules. Despite our initial efforts to avoid reliance on mini development boards, the integration of this sensor necessitates the use of such a module to achieve the desired functionality.

The Adafruit 189 PIR sensor has a simple testing procedure. The sensor outputs a simple digital on/off signal when occupancy or motion is detected. There are only three pins connected between the sensor and MCU: +3.3V, ground, and the data pin. Because of the simplicity of the sensor, there is no communication protocol or handshake procedure required to interface with the device.

Once the power and ground are connected, the data pin can be connected to any GPIO pin on the ESP32. To read the value of the sensor, the ESP32 Arduino library contains a built in `digitalRead()` function which will return a value of either HIGH or LOW. To test if the sensor accurately reads LOW, the device can be covered with an opaque material, such as a blanket or box enclosure. Based on the configuration of the sensor on the development board, a new reading is processed every 4 seconds. To then test if the sensor will accurately read high, removing the covering and simply waving a hand close to the device to retrigger should result in a digital HIGH output.

9.2 Software Testing

9.2.1 ESP32

After successfully testing the basic hardware functionality of the ESP32, further testing of the software features was necessary. The ESP32 contains many on-chip functions and the development board being used allows the ability to test these functions. A significant advantage is the extensive support provided by the Arduino library, which includes numerous features that align with our project requirements. Key functions such as reading digital pins, interfacing with I2C lines, and connecting to the wifi module, are all undoubtedly going to be incorporated into the design. To test that these functions are at the very least compatible with the specific ESP32-WROOM-S model we will be using, the

necessary functions must be able to compile with the part number selected.

While compiling confirms compatibility between the Arduino library and the selected hardware, it does not guarantee functionality. To address this, a series of dedicated test programs must be written for each component, carefully designed to validate the operation of the relevant functions and classes. These programs will then be uploaded and executed to confirm that the hardware and software interact as intended, providing a robust foundation for the final implementation.

9.2.2 Development Environment

It is important to create a small test program to ensure that the development environment is set up correctly for the ESP32. There are many different ESP32 variants that exist, therefore writing a simple program ensures that the current development environment is compatible specifically with the ESP32-WROOM-32. One example of a simple program would be printing to the terminal using the Serial library, and configuring the LED lights to turn on. This is an easy task and shows that the development environment is functional because it is capable of configuring UART on its own, and is capable of configuring the pinouts of the ESP32 to turn on an on-board light.

With the success of this program, it shows that the development environment is set up correctly for development on this specific ESP32 module. The chosen development environment is PlatformIO because of its compatibility with many microcontroller applications. Specifically, PlatformIO has built in tools for uploading data to non-volatile memory for the ESP32, which is essential for hosting websites.

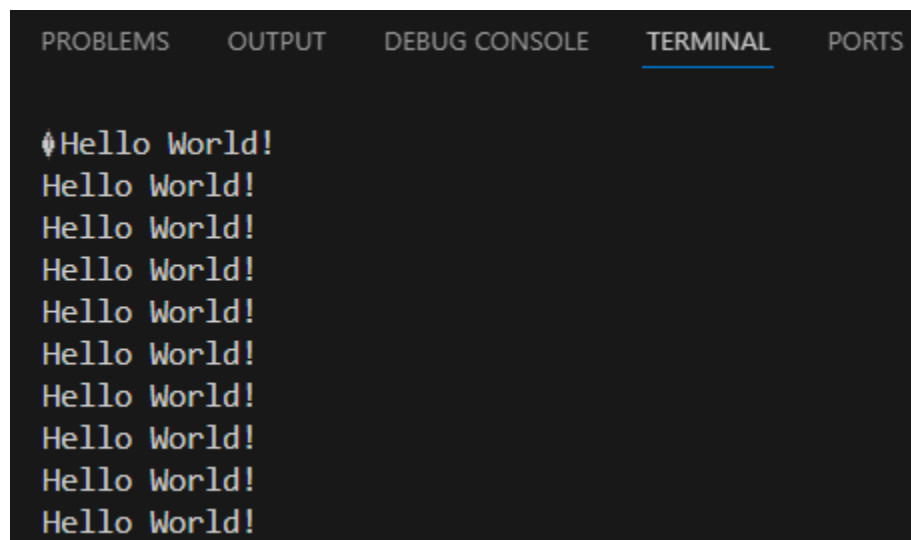
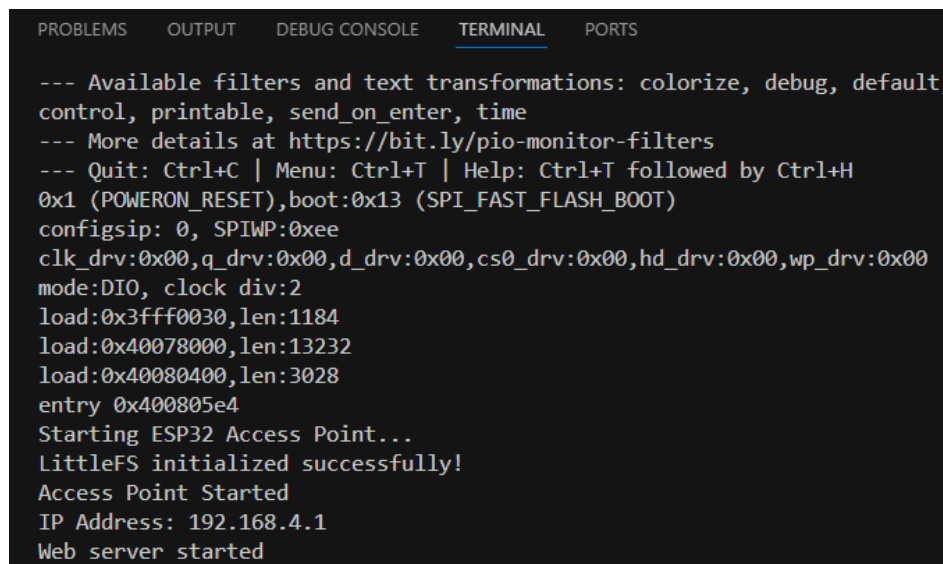
A screenshot of the PlatformIO IDE's terminal window. The window has a dark background with a light gray header bar containing five tabs: 'PROBLEMS', 'OUTPUT', 'DEBUG CONSOLE', 'TERMINAL' (which is selected and underlined), and 'PORTS'. The terminal area displays ten lines of text, each starting with a blue prompt character '❖' followed by the text 'Hello World!' in a light gray monospace font. The lines are stacked vertically, showing the output of a program running on the ESP32.

Figure 9.2.2.1 Serial Output for Test Program

9.2.3 WiFi Code Example

One of the main reasons for switching to an ESP32 is its easy to use and wide-ranging WiFi library. The built-in WiFi module is capable of being configured to either host an

access point, or connect to an existing WiFi network. Both of these can be done with one function call on using this WiFi library, and both will be required for the purposes of this project. More importantly, utilizing the WiFi access point is required for connecting to the setup web page, this website being built using React.js. The ESP32 will host a small HTTP server that any user can connect to, that will simply ask the user for a SSID and password login. The microcontroller will attempt to connect to this WiFi network and, if successful, will display a success message. It is important first, however, to test the functionality of the built-in WiFi module. This can be done by setting up an access point and seeing if the ESP32 assigns itself an IP address. Below is an output of a test program ensuring this very functionality.



```
PROBLEMS  OUTPUT  DEBUG CONSOLE  TERMINAL  PORTS

--- Available filters and text transformations: colorize, debug, default,
control, printable, send_on_enter, time
--- More details at https://bit.ly/pio-monitor-filters
--- Quit: Ctrl+C | Menu: Ctrl+T | Help: Ctrl+T followed by Ctrl+H
0x1 (POWERON_RESET),boot:0x13 (SPI_FAST_FLASH_BOOT)
configsip: 0, SPIWP:0xee
clk_drv:0x00,q_drv:0x00,d_drv:0x00,cs0_drv:0x00,hd_drv:0x00,wp_drv:0x00
mode:DIO, clock div:2
load:0x3fff0030,len:1184
load:0x40078000,len:13232
load:0x40080400,len:3028
entry 0x400805e4
Starting ESP32 Access Point...
LittleFS initialized successfully!
Access Point Started
IP Address: 192.168.4.1
Web server started
```

Figure 9.2.3.1: Serial Output for Test WiFi Program

With this output, it is clear that the ESP32's WiFi module is functional. It is capable of creating an access point and assigning itself an IP address, as shown from the output. There were no compilation errors, indicating that the development environment recognizes the Arduino's WiFi library and can respond to all of the function calls, such as "softAP()" to create an access point WiFi network.

9.3 Overall Integration

9.3.1 WiFi Setup Website

The WiFi Setup Website will be used to communicate with the VISTA device before launching the user interface. It establishes a WiFi connection that the user wishes to connect to, and can store other information like the user's name and other setup information. With the React development environment established, this showcases the integration between a web application and the VISTA device in action, notably that the ESP32 can respond to information sent between the web application and the device. This is crucial for establishing a connection between the frontend Javascript web application

and the VISTA device for communicating live temperature readings, changing the current device mode, and other important functionalities when creating the user interface website. Finally, when the VISTA device successfully connects to an existing WiFi network, the setup website leaves gracefully and would redirect to the user interface. Notably, the Setup Website would not appear again unless the user explicitly selects a button to change any of the internal settings, such as the WiFi login information or the user's name.

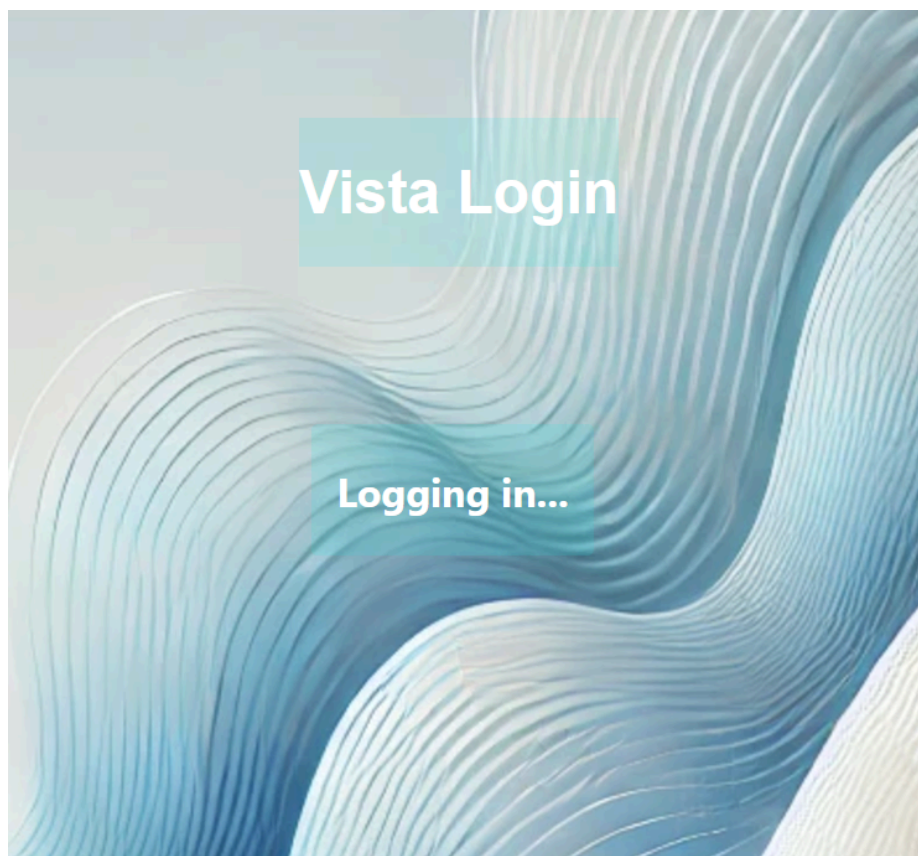


Figure 9.3.3.1: Vista Setup Website

Chapter 10-Administrative Content

10.1 Budget and Financing

VISTA is sponsored by Dr. Qun Zhou Sun. The maximum budget for this project given by Dr. Sun is \$2000. From estimation of costs, coming from a variety of factors based on the need of the project, the group set an estimated needs-based budget of \$400. The main components for VISTA, including technological, physical, manufacturing processes, etc. can be split up into multiple different sub-groups as seen below.

Table 10.1.1: Budget

Component	Cost
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Vent Mechanical Device(s)	\$100
Vent component enclosure	\$50
Power supply (battery)	\$20
PCB Printing	\$50
Components	\$100
Total Cost	\$320

Considering the budget for the project is \$400, the group has wiggle room to design VISTA. This will account for errors in estimation as well as roadblocks we may encounter as the project progresses. This can occur due to a wide variety of factors, which is why it is so crucial to plan the budget over the expected amount. As with most engineering, projects are oftentimes not in perfect working condition the first time around, so things must be reworked and redesigned in order to get fully operating conditions with all parts working correctly individually and together as a whole.

10.2 Bill of Materials

Part Name	Component Name	Part Number	Price
Servo	FS90R Micro	1528-1501-ND	\$7.50
Occupancy Sensor	Arduino PIR part 189	1528-1991-ND	\$9.95
Temperature Sensor	G-TPMO-102	223-1894-ND	\$24.66
Humidity Sensor	HIH8120-021-001	480-5706-1-ND	\$16.87
MCU	ESP-WROOM-32	1188-1178-ND	\$21.99
PCB			TBD
Vent/ Housing			TBD
Shipping	N/A	N/A	\$21
Total Cost			\$101.67

10.3 Distribution of Worktable

To ensure a proper work distribution among group members, the table below organizes general tasks of the project under each member. Specific tasks are assigned to different

members, although collaboration among all project sections is necessary to create a proper workflow and produce a successful final project.

Table 10.3.1: Distribution of Work

Electrical Engineering	Responsibilities
Katerina Brown	Determine and implement the most efficient battery for the hardware design
	Determine and implement the best humidity sensor for the hardware design
	Determine and implement the most suitable controller type for the hardware design
	Design and implement the 3D model for the vent system of registers and louvers
Electrical Engineering	Responsibilities
Alexander Hatzilias	Design and execute infrared sensor system
	Determine and implement how to communicate between thermostat sensor and vent PCB
	Determine and implement the most suitable mounting design and structure for the hardware design
	Determine and implement the best temperature sensor for the hardware design
Computer Engineering	Responsibilities
Luke Morrison	Design and implement the operating system
	Design and implement a user interface that interacts with vent system
	Implement and design the API between the user interface and the vent system
	Determine and implement the best

	programming language for the software design
Electrical Engineering	Responsibilities
Isabella Polkey	Determine and implement the best regulator for the battery loads versus component input allowances for the hardware design
	Determine and implement the best servo for the hardware design
	Determine/design and implement how the actuator will interact with the existing vent lever for the hardware design
	Determine and implement the best occupancy sensor for the hardware design

10.4 Milestones

In order to execute a successful project, it is important to meet regularly with group members. To complete steps in a timely manner, a breakdown of the meetings and general timeline of Senior Design I and II is shown below.

Table 10.4.1: Senior Design I Milestones

Senior Design I	
Week	Task
0-1	Group formation, Research and discuss initial project ideas
2	Decide on final project idea, Begin Divide & Conquer
3	Form review committee, Complete Divide & Conquer- Due 9/6/24
4	D&C group meeting on 9/11/24, Begin 60-Page Report
5-6	Update and upload D&C Report on group website- Due 9/27/24, Continue 60-Page Report
7-10	Complete 60-Page Report- Due 10/25/24, Begin 120-Page Report
11	60-Page Report Group Meeting, Continue 120-Page Report
12	Update and upload 60-Page Report on group website- Due 11/8/24,

	Continue 120-Page Report
13-14	Complete 120-Page Report (SD1 Final Report) & Mini Demo Video- Due 11/26/24

Table 10.4.2: Senior Design II Milestones

Senior Design II	
Week	Task
1	Revise 120-Page Report as needed, Order parts
2	Research building methodology, Start putting together PCB
3-5	PCB building & testing
6-9	System integration research & testing
10-12	Practice Project Demo, Finalize documentation
13	Practice Final Presentation
14	Final Presentation- Date TBD

Chapter 11-Conclusion

The VISTA project, sponsored by Dr. Q.Z. Sun at the University of Central Florida, is a unique solution that drives to solve temperature preferences in different rooms of the same home or building, in an effort to achieve the overall goal of energy consumption reduction. Through a specifically engineered design of adjustable louvers to limit or allow airflow and the inclusion of temperature, occupancy, and humidity sensors, the scope of the product goes beyond the simple functionality of the physical system. Thus, VISTA is a complex design that achieves many useful objectives which are appealing to a wide range of customers. The system works with many components in order to properly respond to temperature and humidity levels in order to aid in comfort as well as save on energy bills. This is in addition to responding to occupancy levels and adjusting accordingly, using a vacancy mode when rooms are empty for longer than specified lengths of time to save energy and money.

Particularly concerned with both comfort and environmental factors, VISTA stands apart from other options on the market due to the widely applicable design and many useful features incorporated. Many existing products lack the qualities that VISTA contains, including the many sensors that initiate responses from the system to optimize both comfort levels and spending. Additionally, the specifically engineered design that allows the new vent system to be placed over a pre-existing vent cover results in a widely applicable product that does not have to be specific to vent size. This shows unique

innovation as VISTA takes extra steps beyond currently available products to increase both marketability and engineering specifications. Additionally, the VISTA design can easily be modified to become manufactured in a variety of sizes not available on competing products.

The primary function of the VISTA is to reduce energy consumption. This is accomplished by dynamically reacting to localized environmental demands. The inherent nature of an air-conditioning system dictates the air outlets across different rooms and environments, will result in the unnecessary overcooling/heating of a portion of the overall building until the air directly surrounding a standard AC thermostat sensor reads a user set temperature. The VISTA solves the issue imposed by the weakest link of rooms driving unnecessary power to overcool/heat the entire environment.

VISTA utilizes different modes based on room occupancy levels and the temperatures and humidity levels of a room. The vent slats open to allow more cold air flow when the room temperature reaches above the user-set maximum, and close to limit cold air flow when below the user-set minimum. Similarly, the slats open/close to adjust humidity levels to prevent mold growth and damage to nearby furniture. VISTA responds to occupancy by entering vacancy mode when there is no detection of occupants in the room for over a user specified amount of time in order to save on energy.

Additionally, VISTA stands apart from other smart AC units due to its user interface and software capabilities. The use of a web app allows for the VISTA to be controlled anywhere in the home, from a smartphone or laptop, for convenience purposes. The web app will respond in real-time to changes in environment, such as changes in occupancy or humidity, and can be viewed without being in proximity to the device. This is different from other commercially available smart AC units, some of which require a remote control, or on-panel interface, in order to be operated.

This final project document outlines the in depth design, research, characteristics, and functionalities of VISTA. Continuation of the production and further research of VISTA and other smart vent systems aids in the continual building of knowledge of smart vents and all of the factors that go into the production and use of them. Particularly concerned with both comfort and environmental factors, VISTA stands apart from other options on the market due to the widely applicable design and many useful features incorporated. Moving forward, the VISTA project provides a great deal of knowledge and experience that will be highly beneficial to future applications or projects and aid in the overall understanding and progress of automated smart vent systems.

Appendix A-Reference

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Appendix B-Copyright Permission

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Appendix C-ChatGPT Prompts and Outcomes

Case Study 1:

Prompt: What are some existing smart vent options currently available for purchase?

ChatGPT Response: There are several smart vent options available on the market that can help optimize your HVAC system. Here are a few popular ones:

1. **Ecovent:** These vents can be controlled via an app and can help balance the temperature in your home by opening and closing based on the temperature of individual rooms.
2. **Nest Temperature Sensor:** While not a vent itself, it works with compatible systems to help your Nest thermostat manage temperatures more effectively by providing readings from different rooms.
3. **Smart Vents by Keen Home:** These vents allow for individual room temperature control and can integrate with various smart home systems.
4. **AirPatrol:** This system includes smart vents that can be controlled via an app, and it allows for monitoring and adjusting temperatures remotely.
5. **Flair Smart Vents:** These vents can be controlled through an app and can learn your preferences to optimize airflow throughout your home.
6. **Zonex:** This system allows for zoning control and can be integrated with smart thermostats to manage airflow in different areas of your home.

Before purchasing, it's a good idea to check compatibility with your existing HVAC system and consider factors like installation ease and additional features.

Case Study 2:

Prompt: What are the advantages of alkaline batteries?

ChatGPT Response: Alkaline batteries offer several advantages:

1. **Long Shelf Life:** Alkaline batteries can last for several years when stored, making them reliable for emergency use.
2. **High Energy Density:** They provide a high voltage and longer run time compared to many other battery types, which makes them ideal for high-drain devices.
3. **Widely Available:** Alkaline batteries are commonly found in various sizes (AA, AAA, 9V, etc.) and are available in most stores.
4. **Cost-Effective:** They are generally affordable, providing a good balance of price and performance for everyday use.
5. **Environmentally Friendly:** While not rechargeable, alkaline batteries are less toxic than some other types, and many are recyclable.
6. **Stable Performance:** They maintain consistent voltage output over time, which is beneficial for many devices.
7. **No Memory Effect:** Unlike some rechargeable batteries, alkaline batteries do not suffer from memory effect, allowing for full discharge without reducing their capacity.

Overall, alkaline batteries are a versatile choice for a variety of devices, especially those that require reliable, long-lasting power.

GoogleAI Response: Alkaline batteries have many advantages, including:

Long shelf life

Alkaline batteries can retain their charge for years without use. They can last up to seven years unused, losing about five percent of their energy every year.

High energy density

Alkaline batteries have double the energy density of a similarly sized zinc-carbon battery.

Safe to handle

Alkaline batteries are less hazardous to handle and use than other types of batteries. They are non-toxic and do not contain heavy metals such as cadmium or mercury.

Operates in extreme temperatures

Alkaline batteries can operate well in both hot and cold temperatures.

Cost-effective

Alkaline batteries are relatively inexpensive compared to other types of batteries.

Wide availability

Alkaline batteries are readily available in various sizes and brands.

Easy to incorporate into designs

Alkaline batteries come in standard sizes, making them easy for engineers and product developers to use.

Can be connected in a series

Alkaline batteries can be connected in a series to produce higher voltage arrays.

However, alkaline batteries do have some disadvantages, including:

- They can be bulkier than lithium alternatives.
- They can explode when charging with a faulty charger.
- Over time, they can leak a corrosive liquid that damages devices.

- High internal resistance reduces output.

Case Study 3:

Prompt: What is the best type of sensor to use within a low power system that needs a long lifetime?

ChatGPT Response:

For a **low-power system** that requires a **long operational lifetime**, the ideal type of sensor should be highly energy-efficient, have low standby power consumption, and be capable of operating effectively for extended periods on minimal power. Here are a few sensor types that excel in low-power applications:

1. Passive Infrared (PIR) Sensors:

- **Best for:** Detecting motion or presence.
- **Advantages:** PIR sensors are extremely energy-efficient, as they only consume power when detecting changes in infrared radiation (such as human movement). They typically operate in the **microamp (µA) range** during standby, making them ideal for battery-powered systems.
- **Use Case:** Great for occupancy detection in systems like lighting control, security, or HVAC management, where the system needs to operate efficiently for long durations.

2. Capacitive Proximity Sensors:

- **Best for:** Detecting nearby objects without physical contact.
- **Advantages:** These sensors can be configured to have low power consumption and are very durable, as they don't rely on mechanical parts. Capacitive sensors can enter low-power sleep modes and only wake up when proximity is detected.
- **Use Case:** Useful in touch-sensitive interfaces, low-power switches, or devices where non-contact interaction is required.

3. Temperature Sensors (e.g., NTC Thermistors or Digital Sensors):

- **Best for:** Monitoring environmental temperature changes.
- **Advantages:** Digital temperature sensors like the **DS18B20** or **NTC thermistors** are low-power and highly efficient, requiring very little energy to operate. Many temperature sensors operate in a sleep mode and only activate periodically, further conserving power.
- **Use Case:** Ideal for long-term environmental monitoring in energy-efficient HVAC systems, smart thermostats, or data logging devices.

4. Light Sensors (e.g., Photoresistors, Photodiodes):

- **Best for:** Detecting changes in ambient light levels.

- **Advantages:** Light sensors, particularly **photoresistors** or **photodiodes**, consume minimal power and are ideal for systems where the detection of light intensity changes is required, such as in automatic lighting control.
- **Use Case:** Useful in systems that adjust lighting based on ambient conditions, which need to function on low power for long durations.

5. Low-Power MEMS Sensors (e.g., Accelerometers, Gyroscopes):

- **Best for:** Detecting motion, orientation, or acceleration.
- **Advantages:** Modern **MEMS (Micro-Electro-Mechanical Systems)** sensors can be designed to operate on minimal power, often in the range of microamps during standby. Many include sleep modes and can wake up only when significant motion or activity is detected.
- **Use Case:** Common in wearables, fitness trackers, and smart devices where long battery life is critical.

Recommendation:

For a low-power system requiring long operational life, **PIR sensors** are often the best choice, especially for **occupancy detection**, due to their ultra-low power consumption in standby and long-lasting performance. If other parameters like temperature or proximity need to be monitored, pairing PIR sensors with **low-power temperature** or **capacitive proximity sensors** would provide efficient, long-term functionality.

GoogleAI Response:

For a low power system requiring a long lifetime, the best type of sensor is typically a "self-powered" or "energy harvesting" sensor as it doesn't require a battery, meaning it can operate continuously without needing replacements, making it ideal for applications where battery replacement is difficult or impractical; examples include piezoelectric sensors for vibration, solar cells for light, or thermoelectric generators for temperature differences.

Key points about self-powered sensors for long lifetime applications:

- **No battery needed:** Eliminates the need for battery changes, significantly extending operational lifespan.
- **Suitable for remote locations:** Can be used in hard-to-reach areas where battery replacement is inconvenient.
- **Environmentally friendly:** Reduces waste from discarded batteries.

Other sensor types to consider depending on the specific application:

- **Low-power MEMS sensors:** Micro-Electro-Mechanical Systems (MEMS) based sensors like accelerometers and gyroscopes often have very low power consumption, making them suitable for battery-powered systems with long lifetime requirements.
- **Passive infrared (PIR) sensors:** For motion detection, PIR sensors can be very power-efficient.

- **Thermistors:** Can be used for temperature sensing with relatively low power consumption, though their accuracy might be limited compared to other types.

Factors to consider when choosing a sensor for a low-power system:

- **Power consumption:** Choose a sensor with minimal power needs to maximize battery life.
- **Accuracy requirements:** Balance the desired accuracy with power consumption.
- **Environmental conditions:** Select a sensor that can withstand the expected temperature, humidity, and other environmental factors.

Case Study 4: Mounting

Prompt: What is the best mounting technique for adding a register over an existing vent?

ChatGPT Response:

To mount a register over an existing vent, the technique you choose will depend on the vent material, the register design, and how permanent or adjustable you want the installation to be. Here are some common and effective techniques:

1. Screw Mounting (Permanent)

- **Best For:** Registers that come with screw holes.
- **Steps:**
 - Align the register over the vent.
 - Use a pencil to mark where the screw holes are.
 - Drill small pilot holes if necessary, especially if the wall or floor is made of drywall, wood, or metal.
 - Secure the register with screws.
- **Pros:** Provides a strong, permanent hold.
- **Cons:** Requires drilling and leaves holes if removed.

2. Magnetic Registers (Non-Permanent)

- **Best For:** Metal vents (common with ductwork in many homes).
- **Steps:**
 - Buy a magnetic register cover.
 - Simply place it over the metal vent, and the magnets will hold it in place.
- **Pros:** Easy to install, adjust, or remove.
- **Cons:** Only works on metal vents.

3. Adhesive Strips or Velcro (Semi-Permanent)

- **Best For:** Plastic or non-metallic vents, or for those who don't want to drill holes.
- **Steps:**
 - Clean the surface around the vent.
 - Attach double-sided adhesive strips or Velcro strips to the register and corresponding points around the vent.

- Press the register firmly onto the vent area.
- **Pros:** No drilling required, easy to remove.
- **Cons:** Adhesive may lose strength over time or damage surfaces when removed.

4. Spring-Loaded or Pressure-Fit Registers (Temporary)

- **Best For:** Floor or wall vents.
- **Steps:**
 - Buy a spring-loaded or pressure-fit register that fits snugly into the vent opening.
 - Slide the register into place, and the springs or pressure will keep it secure.
- **Pros:** No tools or adhesives needed, easy to install and remove.
- **Cons:** Might not provide as firm a fit as screws or magnets.

5. Clips or Brackets (Custom Solution)

- **Best For:** Unique or custom vent sizes and shapes.
- **Steps:**
 - Use metal or plastic clips/brackets to secure the register over the vent.
 - Install the clips onto the wall or floor around the vent, then slide or snap the register into place.
- **Pros:** Customizable to your needs.
- **Cons:** Requires some assembly and could be more complex to install.

Tips:

- **Measure Carefully:** Before purchasing or installing a register, make sure it matches the vent size.
- **Check Vent Material:** Ensure that the method chosen is compatible with the material of the vent and surrounding area.

Let me know if you have a specific type of vent in mind, and I can help tailor the advice further!