V.I.S.T.A

Vent Intelligence System for Temperature Adjustment

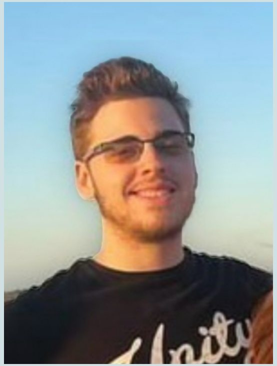
Senior Design Group 34

Sponsored by Dr. Qun Zhou Sun

The Team

Katerina Brown
Electrical Engineering

Alexander Hatzilias
Electrical Engineering

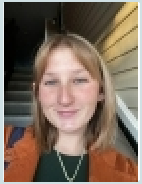


Luke Morrison
Computer Engineering

Isabella Polkey
Electrical Engineering

Motivation and Background

- Power and energy consumption
  - Heating or cooling unnecessary areas of a home or building
  - Different temperature preferences among people
- Smart thermostats
  - Typically an expensive solution
  - Difficult to install
  - Must fit exact measurements of an AC vent
- Fans/heaters
  - Inexpensive but unreliable
  - Electric fans circulate dust
  - Electric heaters are fire hazards
  - Window AC units are a security issue
- Why VISTA?
  - Combines the inexpensiveness of traditional methods with the sophisticated technology of a smart thermometer



Goals and Objectives

Main Objective: Create a semi-autonomous system that will decrease loss and overall energy cost of a home/building by responding to sensor data

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.

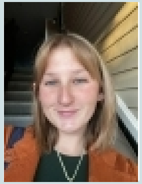
Objectives:

- Implement a mechanical device to open and close vent 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.

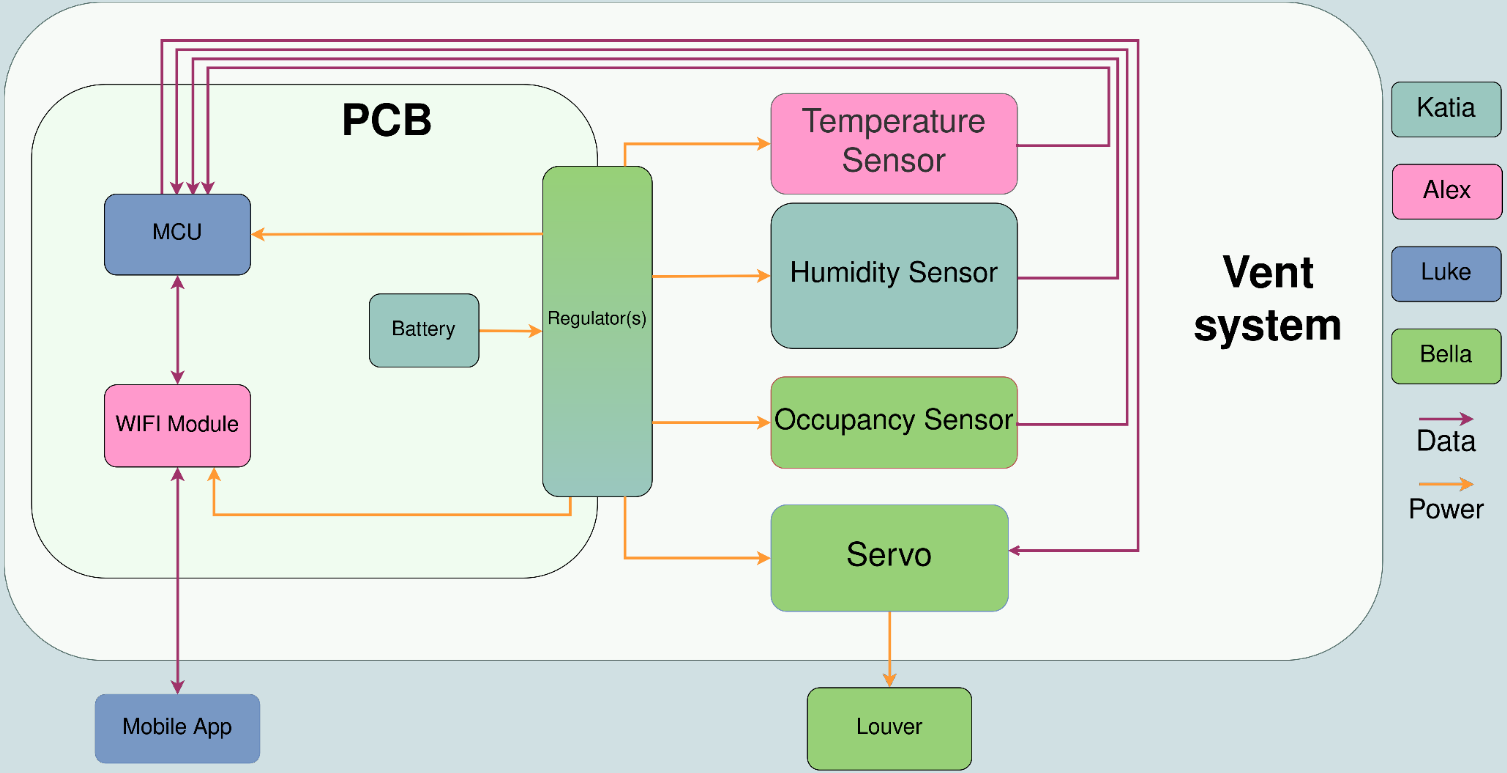
Engineering Specifications

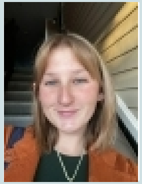
VISTA Specifications	
Hardware	
Room occupancy accuracy	Occupancy indication with 90% accuracy
Response time	Less than 5 minutes
Durability	Device lifetime greater than 2 years
Dimensions	Shall not exceed 11” x 3” x 9”
Weight	Shall not exceed 5 pounds
Affordability	Less than $600
Power supply	
Battery 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%

Hardware Comparison & Selection



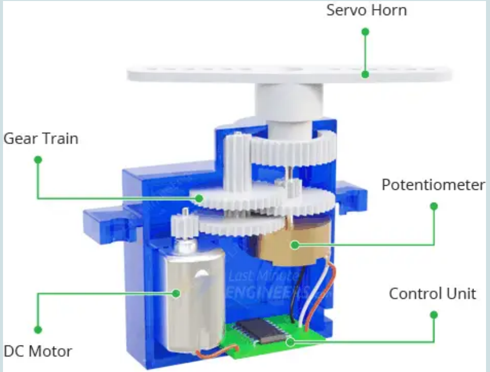
Hardware Diagram



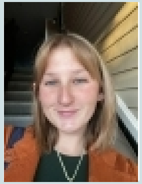


Hardware Comparison & Selection: Mechanical Control

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	



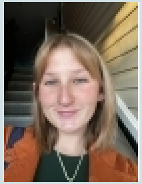
- Servo will control the opening and closing of the vent
- High speed, precision, and accuracy
- Biggest issue: energy efficiency. However, the servo will not be continuously running



Hardware Comparison & Selection: Mechanical Control: Servo

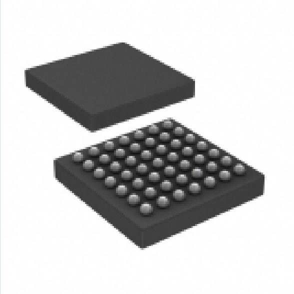
Comparison Criteria	SG90 Micro [79]	FS90R Micro [80]	SG92R Micro [81]	DS3218 [82]	ES08MAII [83]
Operating Voltage	4.8 V	4.8 V	4.8 V	4.8 V	4.8 V
Torque	1.8 kg/cm	1.3 kg/cm	2.5 kg/cm	19 kg	1.6 kg/cm
Operating Speed	0.1 s/ 60 degrees	0.5 s/ 60 degrees	.1 s/ 60 degrees	.16 s /60 degrees	.12 s / 60 degrees
Gear Type	Plastic	Plastic	Plastic	Metal	Metal
Rotation	180 degrees	360 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

- SG90 allows 90 degrees in each direction, giving exact positions in rotation cycles
- Lightweight, low cost, and power efficient compared to competitors

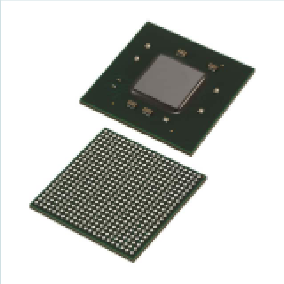


Hardware Comparison & Selection: Controller Type

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	



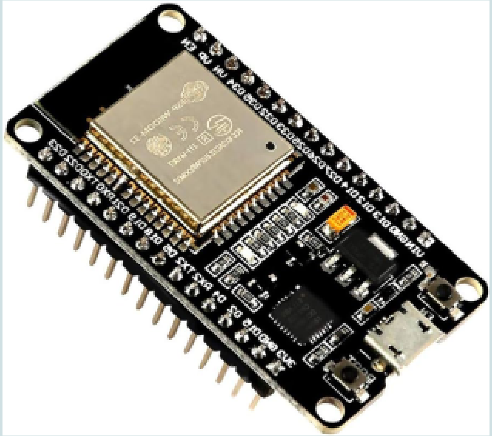
VS



- FPGA capabilities go beyond the needs of VISTA
- MCU is simple, small, and energy efficient

Hardware Comparison & Selection: Controller Type: MCU

Comparison Criteria	Arduino Uno	ESP32-D-WROOM	STM32L475VGT6	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℃	-40 - 125 ℃	-40 - 125 ℃	-40 - 105 ℃
Cost	$1.61	$3.05	$9.67	$7.27



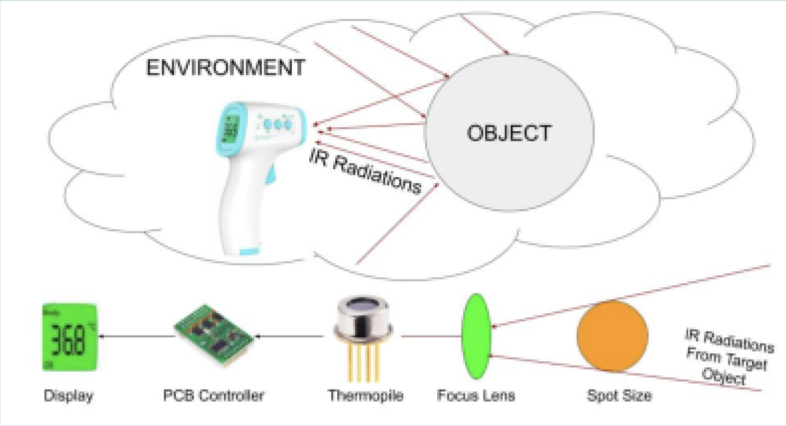
- Excellent wifi capabilities, supply voltage range fits needs of other components, inexpensive, high processing speed, many peripherals, development board makes testing and debugging easy

Hardware Comparison & Selection: Temperature Sensor

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		

Thermistor

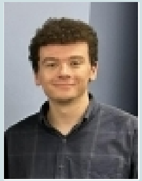
Semiconductor



Infrared

- Infrared: Thermopile sensor -> absorbs infrared energy radiating from bodies -> converts to heat -> converts to electrical signal

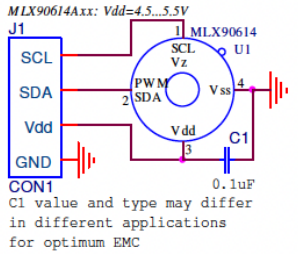
- Advantages: contactless, remote, no additional installation necessary



Hardware Comparison & Selection: Temperature Sensor: Contactless Infrared

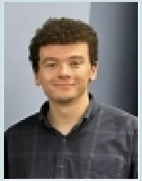
Comparison Criteria	Melexis Technologies MLX90640/90641 Series	MLX9061 Series	TE Connectivity G-TPMO-102
Accuracy	X	X	X
Interface		X	
FOV	X		X
Cost	X	X	X
Power		X	

- Low power capabilities < 2.5mA
- Different lens sizes available: from 35° all the way down to 5° (angle of view visible by lens)
- Small/compact design
- Simple schematic



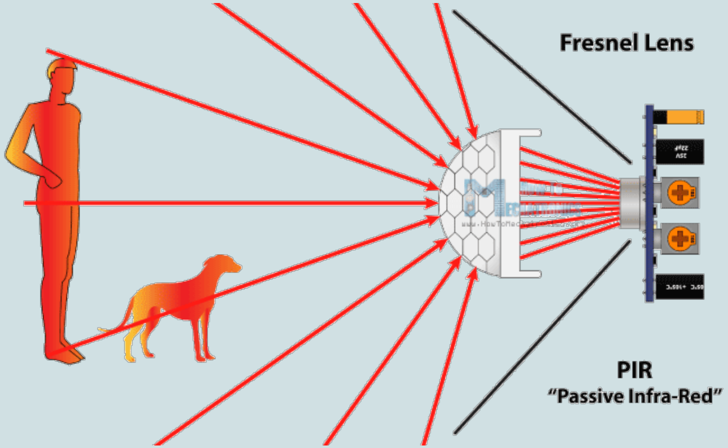
MLX90614 connection to SMBus

Figure 1: Typical application schematics

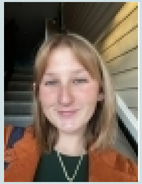


Hardware Comparison & Selection: Occupancy Sensor

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

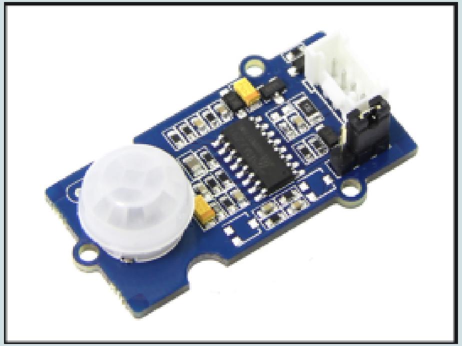


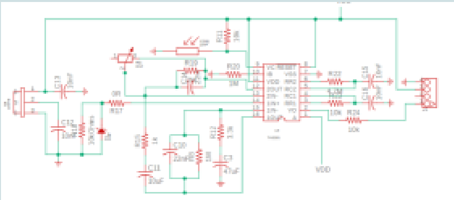
- HIgh accuracy in a wide range to capture an entire room
- Low power consumption (sleep modes)
- Simple, lightweight, easy to install



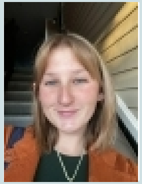
Hardware Comparison & Selection: Occupancy Sensor: Passive Infrared

Comparison Criteria	**AM312 mini [97]**	**HC-SR505 mini [98]**	**Grove PIR sensor**	**Adafruit Part 189 [100]**
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	150 uA	15 mA
Field of View	100 degrees	<100 degrees	120 degrees	120 degrees
Detection Range	3-5 meters	3 meters	6 meters	6 meters
Ambient Temperature Range	-20 to 85 C	-20 to 85 C	-20 to 80 C	-20 to 85 C
Object Temperature Range	-20 to 70 C	-20 to 70 C	0 to 80 C	-20 to 70 C
Integration	Through Hole	Through Hole	PCB daughter board	Through Hole
Price	$8.69	$9.50	$34.87	$9.95



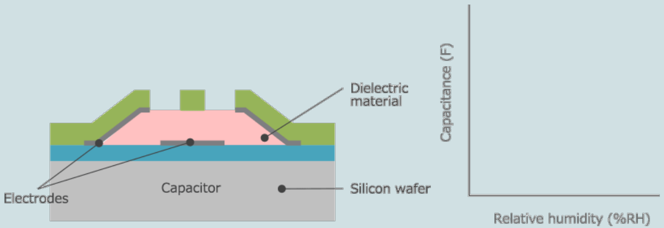


- Wide detection range
- Large field of view
- Easy integration to PCB



Hardware Comparison & Selection: Humidity Sensor

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		

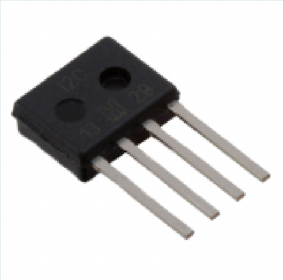


A visual representation of moisture absorption, resulting in a change in relative humidity therefore a change in capacitance

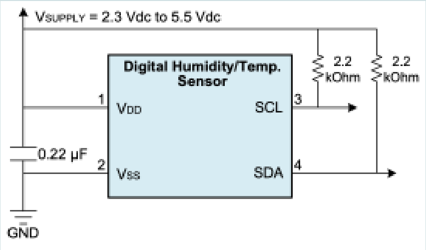
- High accuracy and stability
- Quick response time and recovery time

Hardware Comparison & Selection: Humidity Sensor: Capacitive

Comparison Criteria	HIH8120-021-001	SHT30-DIS-P2.5KS	HDC2080DMBR
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



HIH8120-021-001



SIP 4 Pin Typical Application Circuit

- Quick response time, large operating temperature range, suitable supply voltage range
- Despite the price, through-hole was preferred to allow room for error

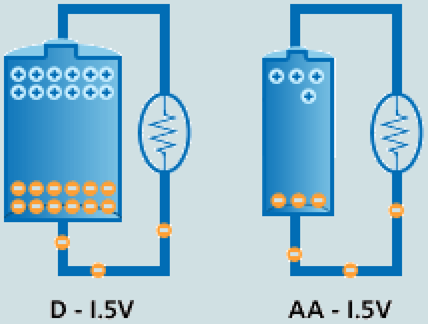
Hardware Comparison & Selection: Power Source

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

- High energy density meaning long shelf-life
- Safe/non-toxic, little erosion over time, temperature resistant

Hardware Comparison & Selection: Power Source: Alkaline Batteries

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

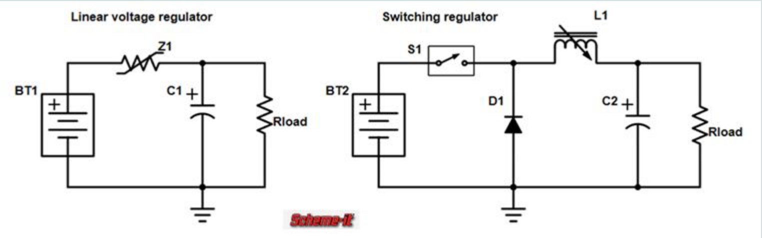


Lifespan difference between AA and D batteries

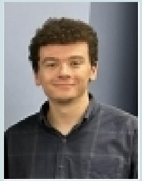
- Compact yet high voltage
- Rates similarly in other aspects in comparison with alternatives

Hardware Comparison & Selection: Regulator

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	$	$$	$



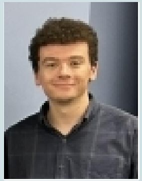
- Low power dissipation and efficient
- Allows for a wide range of voltages



Hardware Comparison & Selection: Regulator: Switching

Comparison Criteria	**TI TPS562201DDCR**	**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 µA	90 µA	70µA
Max Output Current	2 A	600mA	3 A

- High max output current
- High quality datasheet



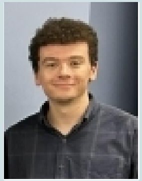
Hardware Comparison & Selection: PCB

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	$	$$	$$$	$$	$$$$

- Minimize cost
- Reliable under environmental fluctuations, enduring repeated heating and cooling from the vent.

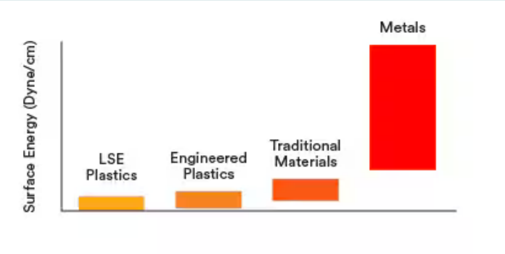
Comparison Criteria	PCBWay	JLC- PCB	Elecrow	Seeed Studio
PCB(s) Price	$5.00	$3.30	$6.90	$12.90
PCB Assembly Cost	$129.32	$0.00	$42.00	$25.83
Cheapest Shipping Cost	$23.21	$18.06	$10.35	$26.66
Discounts/Promotions	-$100.32 Assembly -$23.21 Shipping	Free Assembly on First Order	None	-$13.33 On Shipping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

- Minimize cost
- Fastest turn-around



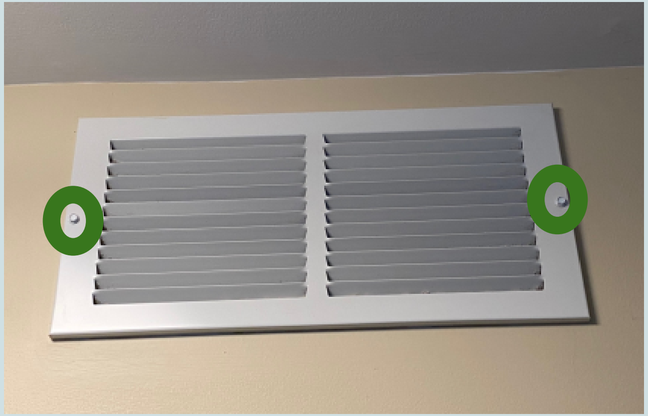
Hardware Comparison & Selection: Mounting

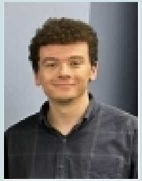
Comparison Criteria	Wood/Concrete Screws	Machine Screws (Pre-existing holes)	Rubber Adhesive	Acrylic Adhesive	Silicone Adhesive
Cost	$	$	$$	$	$
Strength	+++	+++	++	+	-
Ease of Installation	-	+	++	++	-
Durability	+++	+++	++	+	-



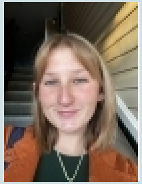
- Minimal installation complexity
- Adaptable to variety of existing vent designs
- Reliable for long term use

Utilizing existing mounting holes ensures the VISTA will comply to standard vent sizes
CommandBrand Adhesive Strips will ensure strong seal against frame of vent to reduce leakage





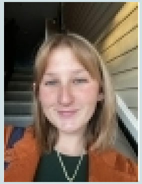
Communication Selection



Communication Comparison & Selection: Wireless

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

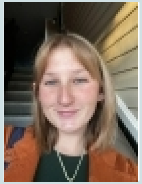
- Highest data transfer size
- Widest range
- Ease of use



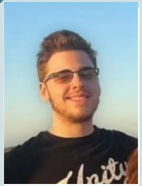
Communication Comparison & Selection: Wireless: Wifi

Comparison Criteria	**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

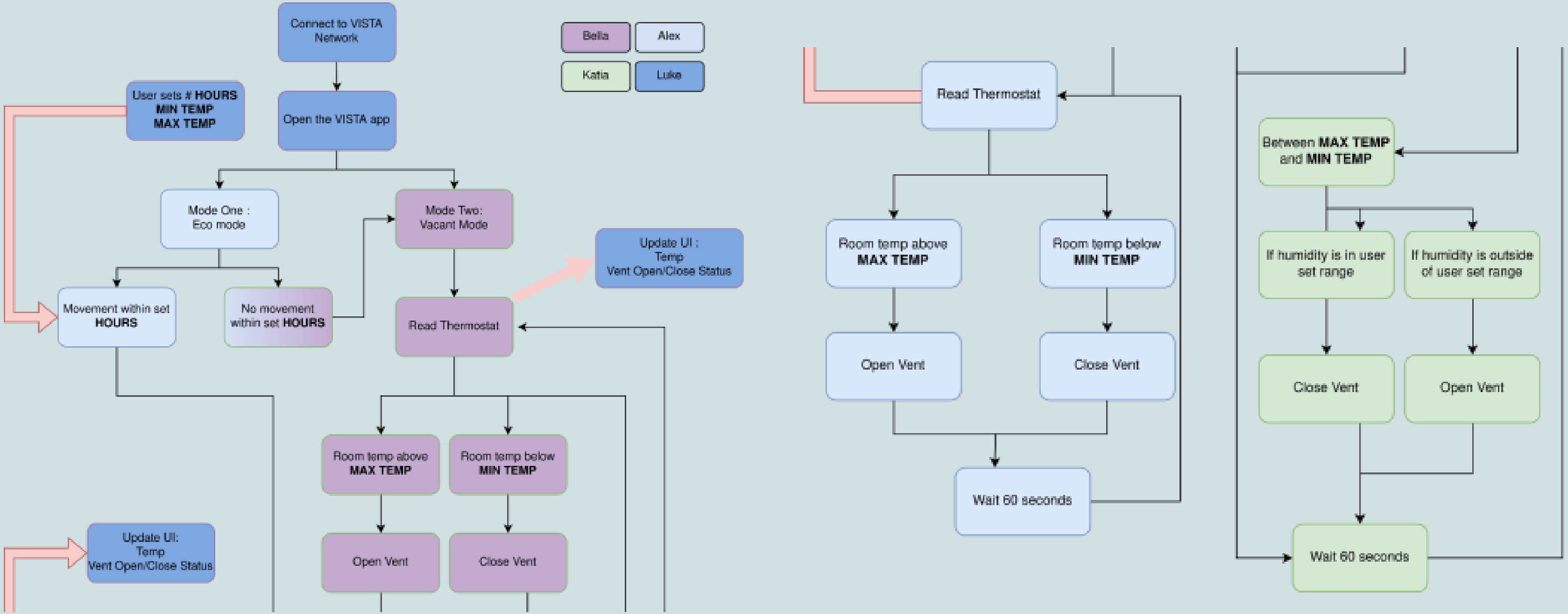
- Highest speed
- Smallest for PCB design
- Cheaper
- Overall best option

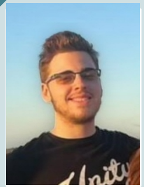


Software Selection



Software Diagram

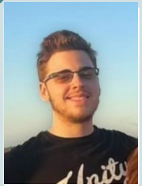




Software Comparison & Selection: User Interface

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

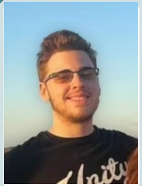
- Good balance between implementation and browser support.
- Quick development time, easy to learn



Software Comparison & Selection: User Interface: Javascript

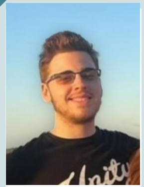
Frontend Framework	Performance Overhead	Maintainability	Library Support	Fast UI Updates
React.js	+	++	++	++
Angular.js	++	+	+	+
Vue.js	-	-	-	-

- Popular UI Library
- Extensive Support



Web App Technology

-Using Arduino WebServer library to service HTTP requests to the ESP32(from frontend or backend), and to send HTTP requests to backend.
-Chosen over ESPAsyncWebServer libraries due to implementation simplicity and asynchronous implementation already in place using FreeRTOS tasks.
-Also chosen over ESPAsyncWebServer because the device does not need to send/receive HTTP requests often enough to justify it.

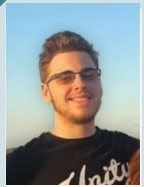


Web App Technology

Goal: Allow for VISTA communication to work during most browser configurations and internet connectivity status.

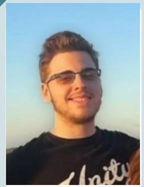
Some browsers restrict access for HTTP request to a local device on LAN (CORS Policy)

Solution: Forward requests through a Lightsail-hosted Backend



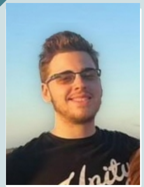
Web App Technology

-ESP32 will periodically send it’s local IP address to backend.
-Frontend will Periodically Retrieve local IP in case of dynamic IP reconfiguration.
-ESP32 will regularly check itself in with a “heartbeat” to the Backend by sending a request to an endpoint.
-Frontend will check device connectivity status to determine whether to begin backend forwarding or display a connectivity error.

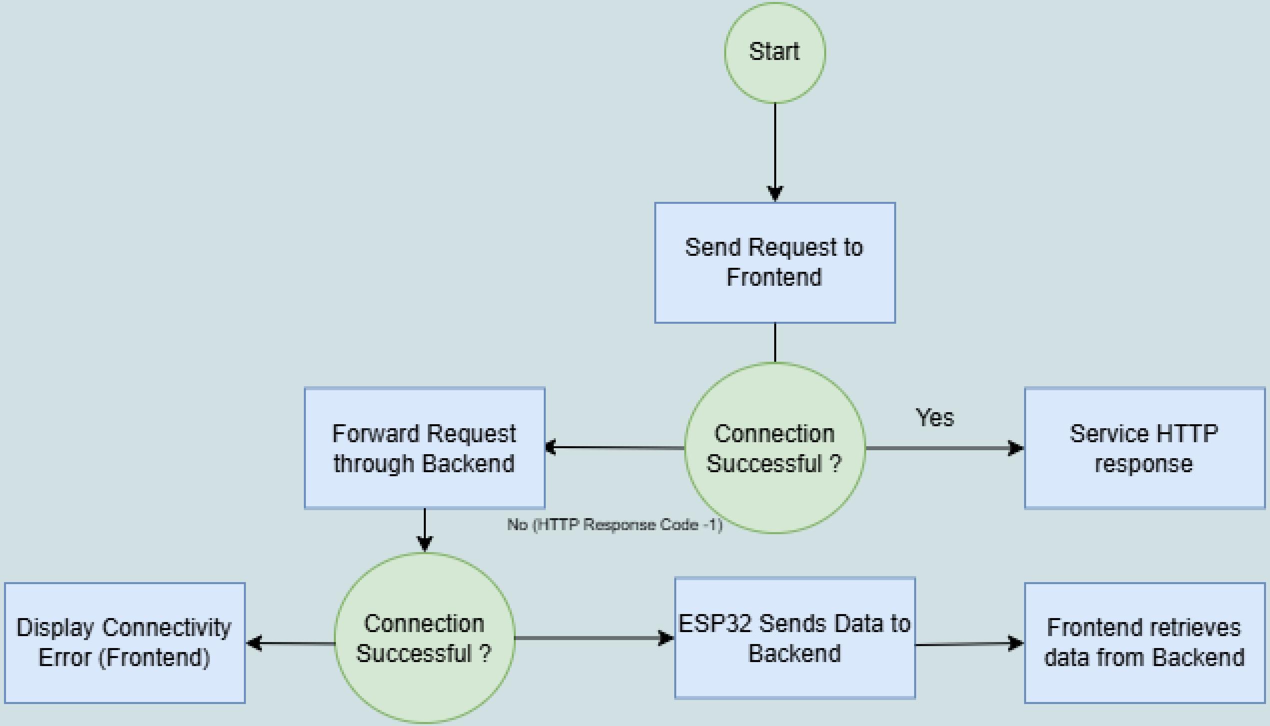


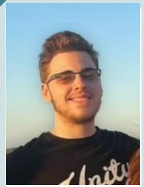
Software Comparison & Selection: Backend Javascript

-Lightsail amazon server will host the VISTA Backend using Node.js
-Backend will host various endpoints, such as the heartbeat endpoint, various data points (current temperature, device mode, humidity status)
-Backend will host a SQlite database for storing device name, IP address(for frontend connection), device connectivity status, and various data points
-On situation where ESP32 cannot connect to React frontend, the frontend will utilize this backend relay.



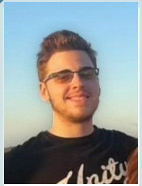
Web App Technology



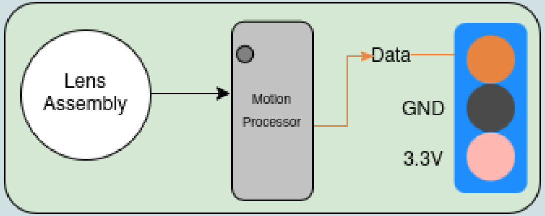


Software Comparison & Selection: Software Development: RTOS

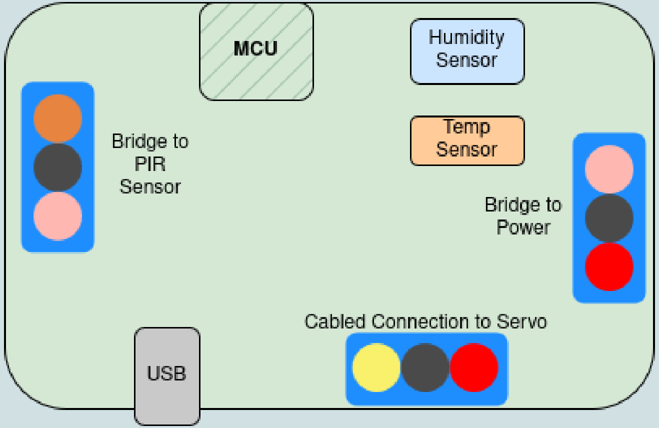
RTOS	Power Management	Memory Overhead	Performance Overhead	Extensive Documentation	HTTP Support
FreeRTOS	-	-	-	++	-
Zephyr OS	++	+	+	+	+
Mbed OS	+	++	++	-	++



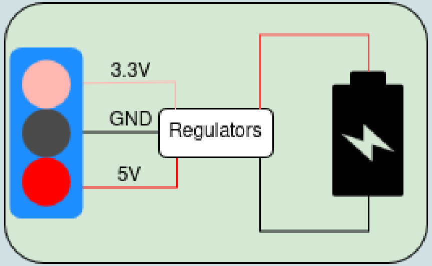
Hardware Design



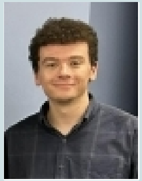
PIR Sensor Board



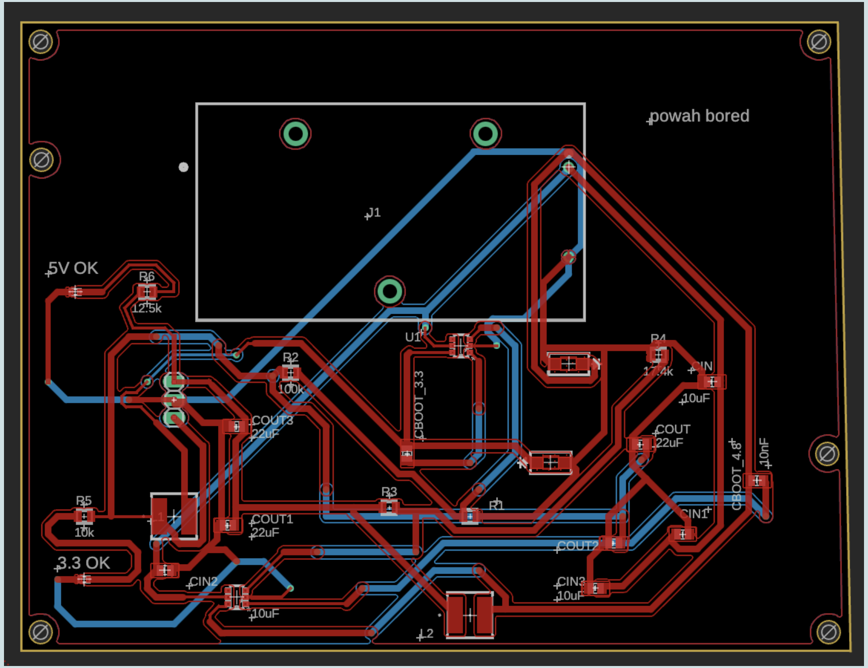
Main Components Board

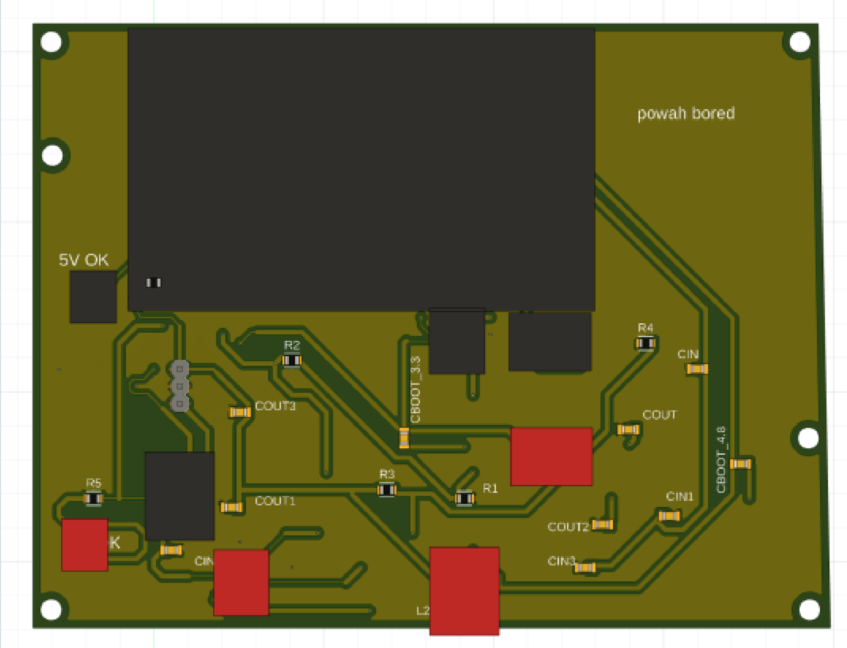


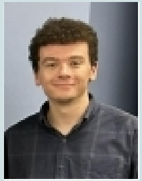
Battery



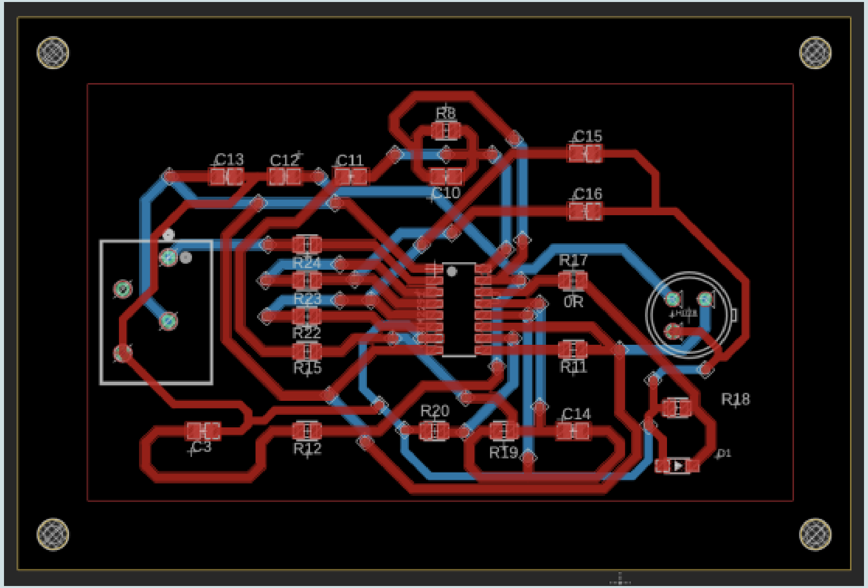
PCB Design- Power Board

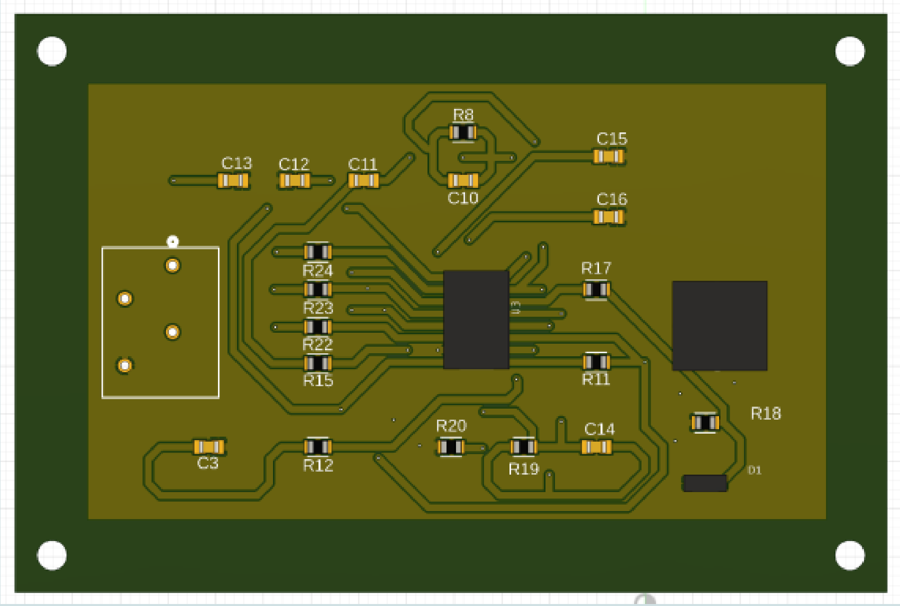


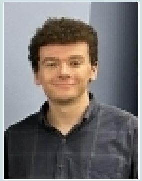




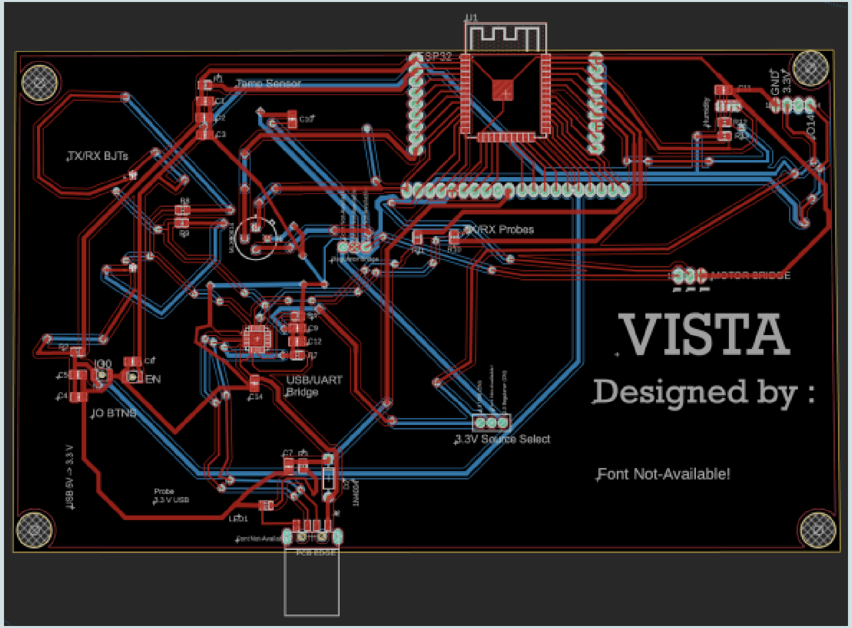
PCB Design- PIR Sensor

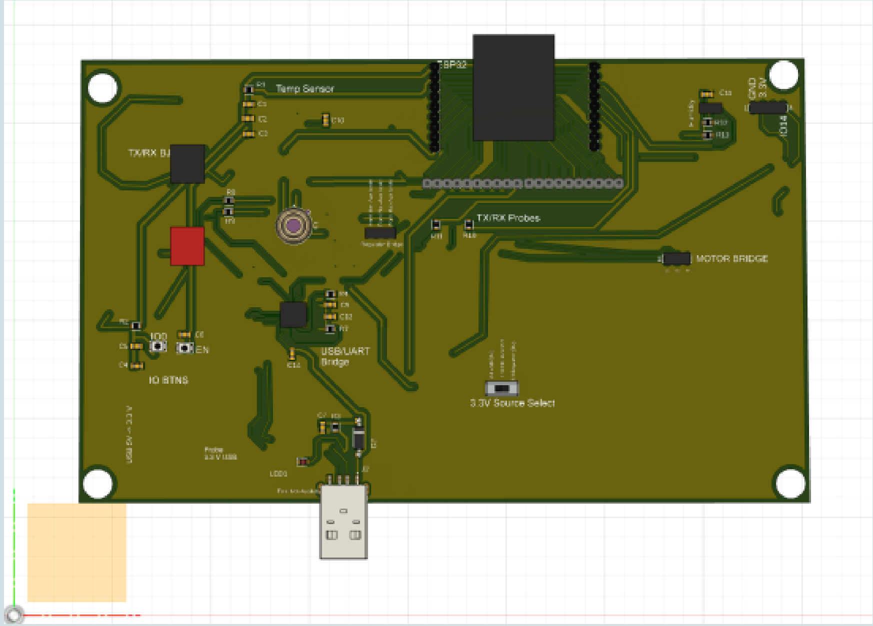


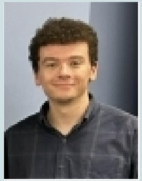




PCB Design- Main Components Board







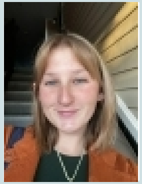
Prototyping and Testing

What we have currently tested:

- All of our components work, we have built all of the PCB boards.
- User interface: designed locally, UI features implementation in coordination with the hardware

What we will continue to work on:

- We are going to make a prototype of the ventilation system with plywood, blind, and housing for our PCB
- Making sure the PCB boards work completely and get them to interact with one another.
- Making the servo interact correctly with the blinds
- User interface: personal accounts and saved preferences.
- Building our final prototype



Administrative Content- Budget

Part Name	Company	Price
Original Components	Digi Key	$170
New Components with replacements	Digi Key	$110
PCB	JLC	$120
Vent/ Housing	Home Depot	TBD
Prototyping materials	Home Depot	TBD
Shipping	N/A	$28
Total Cost		$428

Administrative Content- Work Distribution

Electrical Engineering	Responsibilities
Katerina Brown	Hardware design- battery
	Hardware design- humidity sensor
	Hardware design- controller type
	Hardware design- vent system design

Electrical Engineering	Responsibilities
Alexander Hatzilias	Infrared sensor system
	Communication between thermostat sensor and vent PCB
	Hardware design- Mounting design and structure
	Hardware design- temperature sensor

Computer Engineering	Responsibilities
Luke Morrison	Operating system
	User interface that interacts with vent system
	API between the user interface and the vent system
	Software design- programming language

Electrical Engineering	Responsibilities
Isabella Polkey	Hardware design- regulator
	Hardware design- servo
	Hardware design- actuator
	Hardware design- occupancy sensor

Progress/Completion Plan

2/19

PCBs semi-working

Power board functional, PIR sensor board semi-functional, Main components board semi-functional. All boards fully soldered.

2/25

Software Stack Initial Build

ESP wifi communication established
Control logic developed

3/2

Mechanical Device Construction

Hardware/blinds apparatus is assembled and working

3/8

Hardware/Software Integration

PCBs assembled, integrated into hardware enclosure with mechanical apparatus
Software Stack status and control functional

3/14

Midterm Demo

Functioning initial build is demonstrably working

4/12

Final Review

Final fixes and tweaks are completed. VISTA functions as specified by project proposal requirements