C.H.A.N.O.S.

Controlled. Hydration. Automated. Nutrient. Optimization. System.

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Motivation and Background

- Gardening can provide joy, relieve stress, and build confidence
- Busy schedule of modern life and long work hours
- Disruption between people and nature ⇔ reduced cognitive function, increased anxiety and depression
- Many existing products do not emphasize low power consumption or alternative green sources of energy

Goals

- ❑ Basic Goals
  - ❑ Automatically waters and nourishes a plant
  - ❑ Automatic drainage of the water runoff
  - ❑ Adaptable to a plant of the user’s choosing
- ❑ Advanced Goals
  - ❑ Reduce the environmental footprint of the design
  - ❑ Low energy consumption and use of sustainable energy sources

Objectives

- ❑ Objectives for Basic Goal
    - ❑ Measurement of the soil moisture
    - ❑ Transport of the runoff from the pot to separate container
    - ❑ Design of a web or mobile app
- ❑ Objectives for Advanced Goal
    - ❑ Periodically sampling sensors
    - ❑ Selection of lower voltage components
    - ❑ Reuse of water runoff

Features

- Custom pot system/design
- Soil moisture sensor
- Solar/light sensor
- Water level (float switch) sensor
- USB Charging port
- Lithium-ion batteries
- Web application for user input/monitoring

Engineering Specifications

Parameter	Specification
Web data update frequency	20 - 25 min
Sampling of sensor data frequency	15 - 20 min
Power usage	<1.5Wh
Response time to user input on web app	< 5 mins
Cost of final design	< $75 USD
Battery life	21-27 hours
Time to activate water pump after timer wake-up	< 1 min
Temperature	21 C < temperature < 42 C (107.6 F)

Component	Parameter	Specification
Soil Moisture Sensor	Measurement accuracy	± 3% volumetric water content (VWC)
Soil Moisture Sensor	Standard deviation	± 5%
Soil Moisture Sensor	Measurement time	< 1 s
Water Pump System	Flow rate	0.5-1.0 L / Min
Solar Panel	MPower output	0.5-1.0 W
Ultrasonic Sensor	Water level accuracy	± 1 cm
Light Sensor	Resolution	± 10 lux
Light Sensor	Measurement Time	< 1 s

Comparison and Selection of Hardware

MCU v. MPU v. FPGA

	Microprocessor	Microcontroller	FPGA
Energy Consumption	Highest	Lowest	High
Cost	High	Lowest	Highest
Processing Speed	High	Lowest	Highest
Design Complexity	High	Lowest	Highest
Built-in Peripheral Support	Lowest	Highest	Low
Size	Large	Smallest	Largest

Microcontroller Products

	ESP32	STM32	nRF	CC3220	PIC32MZ
Built-in Wireless	Yes	No	No	Yes	Yes
Dev Kit Cost	$0	N/A	N/A	$47.99	$73.04
IC Cost (PCB)	$4.84-$5.71	N/A	N/A	$5.37	$4.31
Low Power Modes	3	N/A	N/A	4	4

Soil Moisture Sensor Technology

	Capacitive	Resistive	TDR	FDR
Cost	$1-$10	$1-$10	$100+	$100+
Accuracy	Moderate	Low	Very High	Very High
Speed	Slow	Slowest	Fastest	Fast
Susceptible to Corrosion	No	Yes	No	No
Calibration	Least	Low	High	High
Design Complexity	Low	Least	High	High

Soil Moisture Sensor Product

	STEMMA Soil Sensor	SparkFun	SunFounder	DFRobot
Cost	$7.50	$6.44	$6.39	$5.90
Interface	4-pin I2C	3-pin	3-pin	3-pin
Input Power	3-5 VDC	3.3-5 VDC	3.3-5 VDC	3.3-5.5 VDC
Coating of Probes	Metal probe not exposed	Electroless nickel immersion gold	Metal probe not exposed	Metal probe not exposed
Output Range*	200-2000	0-880 (5Vin)	N/A	0-520+

* Output range based primarily on example code and output provided by the manufacturer.

Light Sensor Comparisons

	How It Works	Pros/Cons	Common Uses
Light Dependent Resistor	Resistance decreases with light intensity	Very cheap, easy to use./Slow response, not very precise.	Used for night lights and basic light detection products
Photodiode	Semiconductor generates small current when photons strike.	Fast response, high precision, reliable./Very small output (needs amplifier).	Used in barcode scanners, smoke detectors, and various medical devices
Phototransistor	Like photodiode but with built-in amplification	Higher sensitivity, strong signal./Directional, doesn’t output lux without extra circuitry	Consumer electronics, light detection in automation
Digital Lux Sensor	Uses photodiodes + ADC to directly output lux values over I²C/SPI	High accuracy, calibrated output, wide measurement range./ More expensive than analog sensors,	Smartphones, agriculture systems, plant monitoring

Light Sensor: BH1750

- ❑ **Digital lux sensor** with built-in ADC (Analog-to-Digital Converter)
- ❑ Communicates through **I²C interface** (works well with ESP32)
- ❑ Measures light intensity in **lux** (1–65,000 lx range)
- ❑ **High accuracy** and pre-calibrated output , no need for complex conversion math
- ❑ **Low power consumption**, suitable for battery or solar-powered systems
- ❑ **Compact module**, easy to integrate into PCBs or breadboards
- ❑ Widely used in **plant monitoring**, smartphones, and display brightness control

Water Level Sensor Comparisons

	How It Works	Pros/ Cons	Common Uses
Float Switch	Mechanical float rises/falls with water, triggering a switch	Simple, low cost, reliable./ Only provides on/off	Water tanks, pumps, plant watering systems
Ultrasonic Sensor	Emits sound waves and measures reflection time to detect distance to water surface	Non-contact, works with various liquids./ More expensive, can be affected by turbulence or vapor	Reservoirs, fuel tanks, smart appliances
Pressure Sensor	Measures hydrostatic pressure at bottom of tank to calculate water depth	Accurate over large depths, continuous measurement./ Needs calibration for liquid density, more costly	Wells, deep tanks, industrial monitoring
Capacitive Sensor	Measures change in capacitance as water level changes	No moving parts./ Sensitive to liquid type, can be affected by dirt/minerals	Industrial tanks, beverage dispensers

Horizontal Float Sensor: Ximimark

- ❑ **Simple and reliable** sensor for detecting water level
- ❑ Works by a **mechanical float** that rises/falls with water, triggering an internal reed switch
- ❑ **Horizontal mounting** makes it easy to install on the side of a reservoir or tank
- ❑ Provides a **binary signal** (water present / not present) to the microcontroller
- ❑ **Low cost** and low power consumption ideal for small embedded systems
- ❑ **Durable design**, resistant to corrosion when used with water
- ❑ Perfect for preventing **pump dry-run** by signaling when the reservoir is empty

Pump Selection

	How It Works	Pros/ Cons	Common Uses
Peristaltic Pumps	Rotating rollers compress flexible tubing, pushing liquid forward	Accurate flow control, self-priming, can run dry/ Lower flow rate, tubing wears over time	Medical devices, dosing nutrients, small plant watering
Centrifugal Pumps	Spinning impeller creates centrifugal force to move liquid	High flow rate, simple design/ Cannot self-prime (needs priming), not ideal for low flow precision	Irrigation, water circulation, sump pumps
Submersible Pumps	Pump motor sealed and submerged directly in the liquid	Quiet operation, efficient for moving larger volumes / Harder to maintain, must be waterproof sealed	Wells and aquariums

Water Pump: Adafruit

- ❑ Flow rate: ~100 mL/min (depends on tubing and voltage).
- ❑ Operating voltage: Typically 6–12 V DC (works well with 12 V for higher flow).
- ❑ Self-priming: Can draw fluid without needing pre-filling.
- ❑ Fluid contact: Only the tubing touches the liquid → reduces contamination risk.
- ❑ Use cases: Dosing, aquariums, hydroponics, medical/lab equipment, beverage dispensing.

Battery Selection

Model	Capacity (mAh)	Max Discharge (A)	Protection Circuit	Voltage Range	Notes
Samsung 30Q [18]	3000	15	No	2.5–4.2 V	High current, unprotected
LG MJ1 [19]	3500	10	No	2.5–4.2 V	High capacity, low cost
Panasonic NCR18650B [20]	3400	4.9	Optional	2.5–4.2 V	Lower discharge rate
Panasonic/Sanyo NCR18650GA [21]	3500	10	Yes (Protected)	2.5–4.2 V	Selected: Best balance of capacity and protection
Shockli Protected 18650 (GA)	3500	10	Yes	2.5–4.2 V	Similar spec, less tested source

Solar Panel

Panel Model	Rated Power (W)	Open-Circuit Voltage (Voc)	Max Power Voltage (Vmp)	Size (mm)	Notes
Voltaic Systems P108	3.5 W	22.5 V	18.0 V	178 × 114 × 3	Compact, rugged ETFE coating, selected panel
Tycon Systems TPS-12-15W	15 W	22.1 V	18.0 V	340 × 230 × 17	Larger capacity, sealed frame
ACOPOWER HY-12P-35W	35 W	21.6 V	17.9 V	470 × 340 × 25	High output, bulkier footprint

Buck Converter

Part Number	Type	Output Voltage	Max Current	Package	Pros	Cons
LM2596-3.3	Buck (Fixed)	5 V	2–3 A	Through-hole	Easy to prototype, tolerant of wide input range	Lower efficiency, large footprint
AMS1117-3.3	Linear Regulator	3.3 V	~800 mA	TO-220	Plug-and-play, reliable for testing	Inefficient, not scalable
MP1584	Buck (Adjustable)	Adjustable	2–3 A	SMD	Compact and capable	SMD-only, noisier, limited support
TPS62162	Buck (Adjustable)	Adjustable	1 A	SMD (WSON)	High efficiency, low quiescent draw, clean output	Requires careful layout, SMD-only

Boost Converter

Part Number	Output Voltage	Max Output Current	Package	Pros	Cons
MT3608	Adjustable	~1–1.5 A (realistic)	SMD module	Small, cheap, easy to test	Underperforms under load, voltage sag
XL6009	Adjustable	~2 A	SMD module	Higher current handling, quick to prototype	Noisy output, low efficiency
TPS61088	Adjustable	2–3 A+ sustained	SMD (VQFN)	High efficiency, tight regulation, solid protection	Requires custom layout, SMD-only
LM2577	Adjustable	~1 A (continuous, practical)	TO-220 / TO-263	Easy to use, robust	Large size, lower efficiency, needs bulky external components

Solar Charger

Part Number	MPPT	Battery Chemistry	Max Cells	Input Voltage	Key Features	Limitations
CN3791	Yes	Li-ion	2S	4.5–28 V	Simple integration, few external parts	Limited control, fixed logic thresholds
BQ24650	Yes	Li-ion/LiFePO4/LA	Up to 6S	5–28 V	Highly configurable, robust protection, MPPT	More complex to implement, SMD-only
BQ24210	No	Single-cell Li-ion	1S	4.35–6.5 V	Compact, USB charging, low part count	Not compatible with 2S batteries or solar

USB Charging

Device	Input Voltage	Battery Type	Charge Current	Voltage Accuracy	SYS Output	Iq	Protection	Package	Notes
CN3302	4.5–6 V	2S Li-ion	Up to 2 A	±0.5%	None (battery only)	<200 µA	OVP, OCP, OTP	SOP-8	Simple, low-cost
MP2672A	4.5–6 V	2S Li-ion	Up to 2 A	±0.5%	Yes (3.4–4.4 V)	~100 µA	OVP, OCP, OTP, Input limit	QFN-16 (3×3 mm)	Power-path, load sharing

Comparison and Selection of Software

Internet Communication

	Wireless Communication	Wired (cable, fiber-optic, ethernet)
ESP32 WROOM 32 Built-In Support	Yes; IEEE 802.11, Bluetooth, ESP-NOW	No
Secure	Less Secure	More Secure
Consistent	Less Consistent	More Consistent
User Convenience	More Convenient	Less Convenient

	Bluetooth	IEEE 802.11 (Wi-Fi)
Network Range / Type	Personal Area Network	Wide Area Network
Power Usage (TX / RX) (mA)	130 / 95	180 / 95

	HTTP	MQTT	ESP-NOW
Overhead	Higher (with more messages)	Lower (with more messages)	Low
Familiarity / Documentation	Most	Less	Least
Common Use Case	Web Interaction	IoT	IoT

USB-UART Conversion

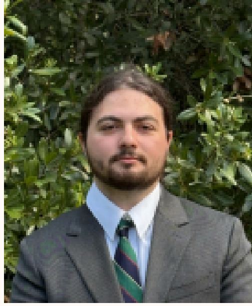
Schematic Source	sam_moshiri	Espressif / ESP32 Dev Kit	SparkFun
USB-UART IC	MCP2200	CP2102	FT231X
Compatible with ESP32	Unsure	Yes	Yes
Additional Functions/Subcircuits	Voltage regulator	N/A	Voltage regulator; Auto-reset
Recommended by Dr. Weeks	N/A	Yes	No

Embedded Software Language/IDE

	C/C++	Python
Framework	ESP-IDF/Arduino	MicroPython / CircuitPython
Abstraction	Lowest / Low	Highest
Performance / Overhead	Better	Worse
Memory Usage	Lower	Higher

	Arduino IDE	Visual Studio Code	Espressif IDE
Familiarity	Moderate	Most	Least
Support for ESP-IDF	No	Yes	Yes
Abstraction	Highest	Low	Lowest

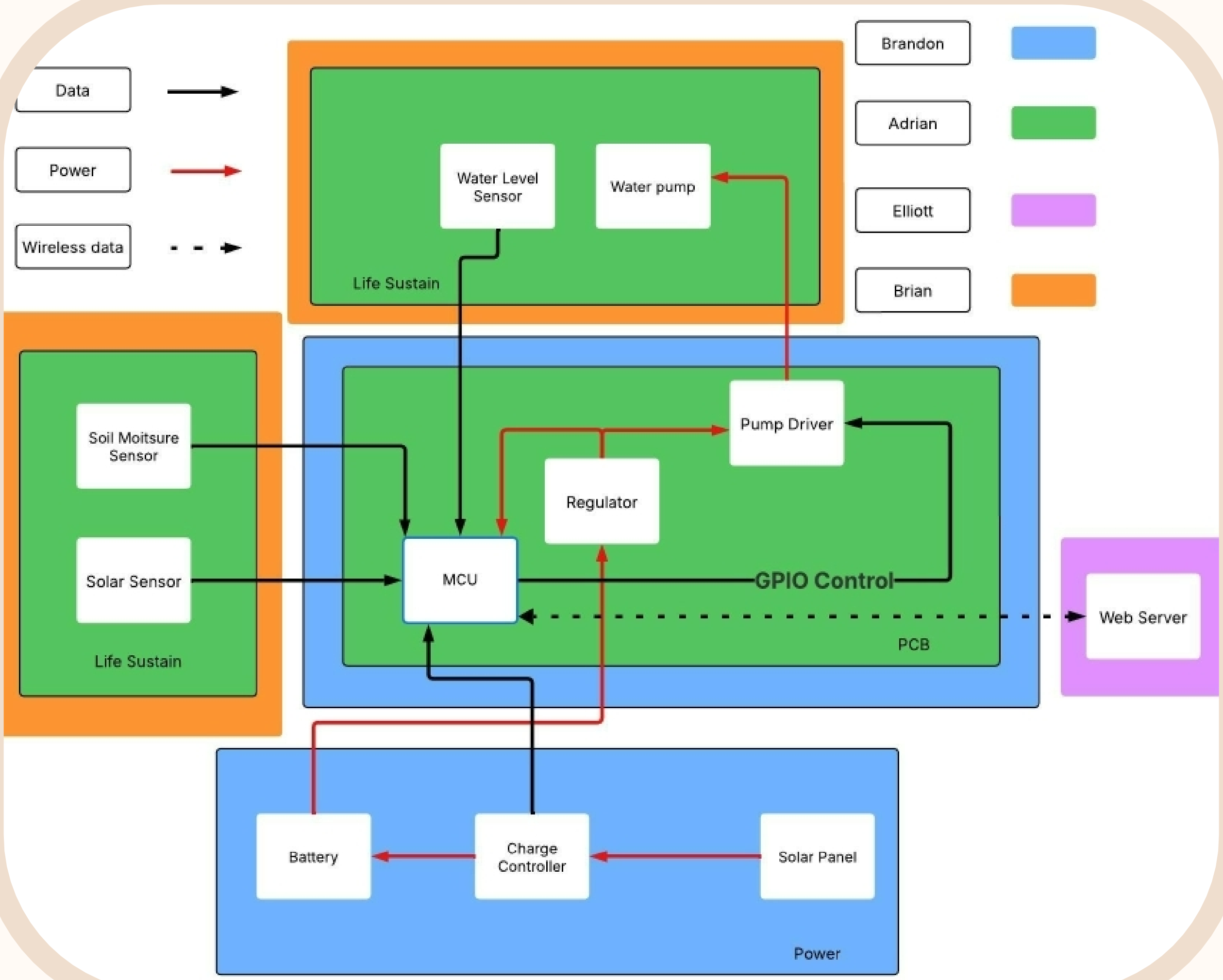
Web Stack Software



	Frontend	Backend	Database	Platform
LAMP	Simple, lightweight JS & HTML, not good for complex UI elements or animations	PHP; lightweight & simple language for manipulating backend data	MySQL; robust SQL-based DB that stores data in rows and columns, not very flexible	Lightweight Linux OS - wide variety of methods for maintaining dependencies
MERN	ReactJS; libraries that are resource heavy but easy to work with	ExpressJS; easy API creation and routing for requests	MongoDB; a flexible DB that stores data in a JSON-like structure	streamlined dependency management through NPM
PERN	same as MERN	same as MERN	Postgres; SQL-based robust DB similar to MySQL with added flexibility	same as MERN

Hardware Design / PCB Layouts

Hardware Design

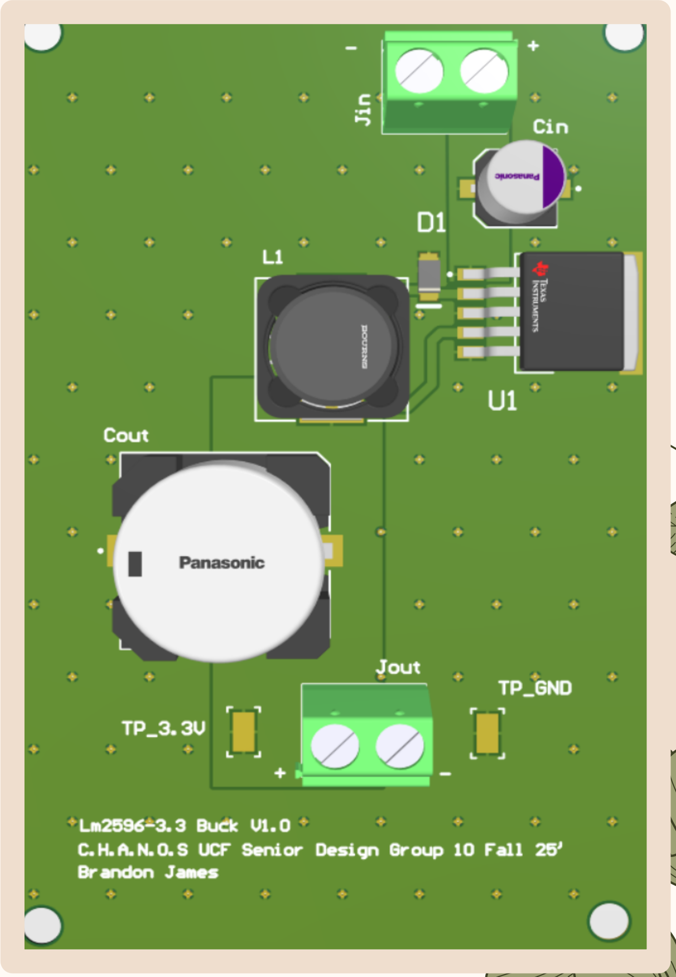


Power PCB Layout

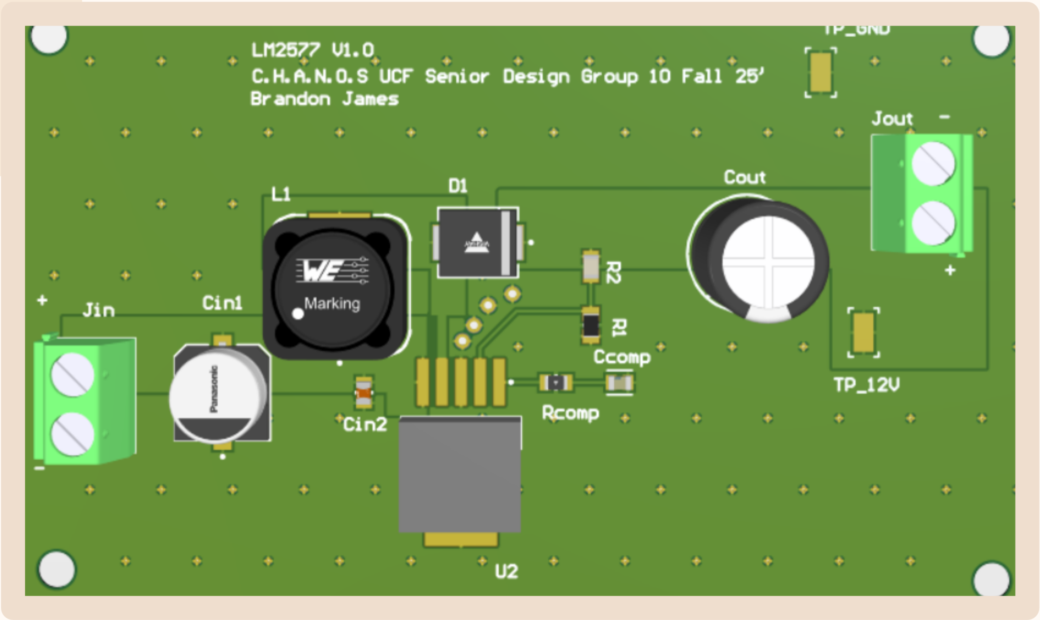
01 - LM2577 (Boost Converter)

02 - LM2596-3.3 (Buck Converter)

02

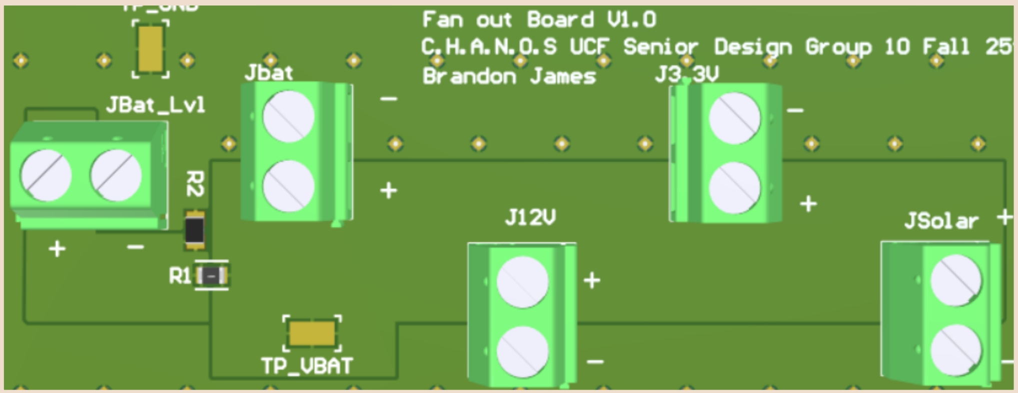


01



Additional Power

01

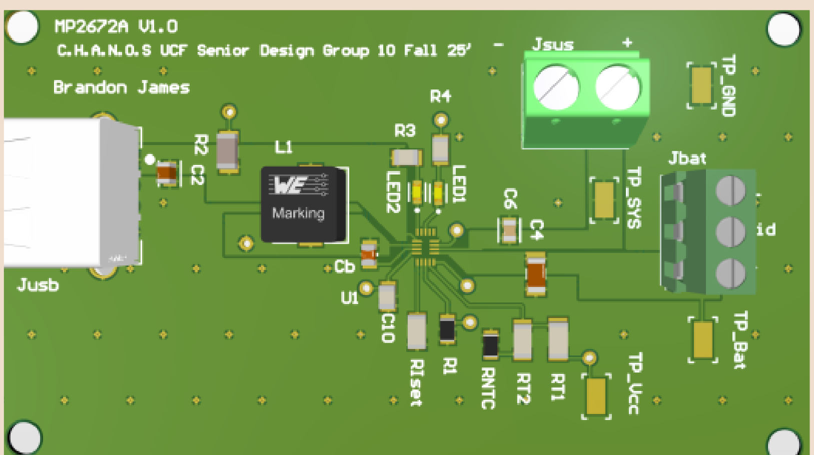


01 - Fan Out Board

02 - USB Charger

03 - Solar Charger

02



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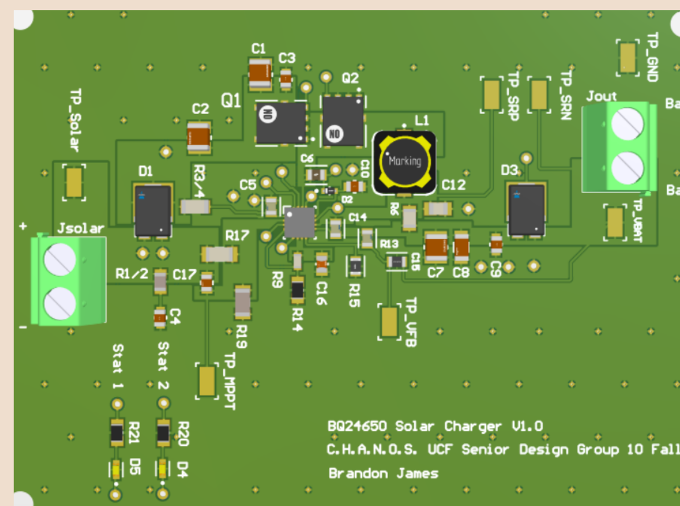
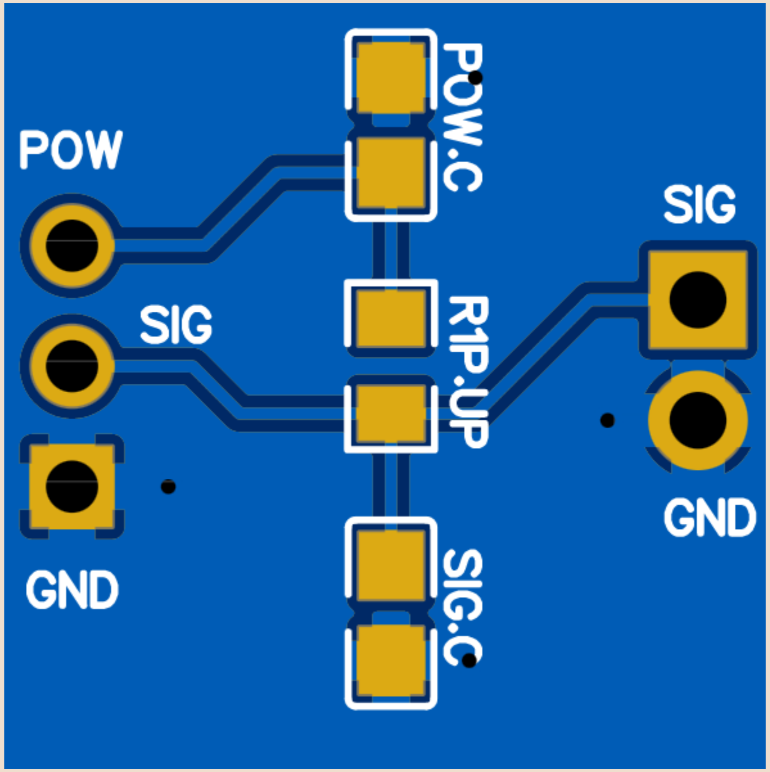
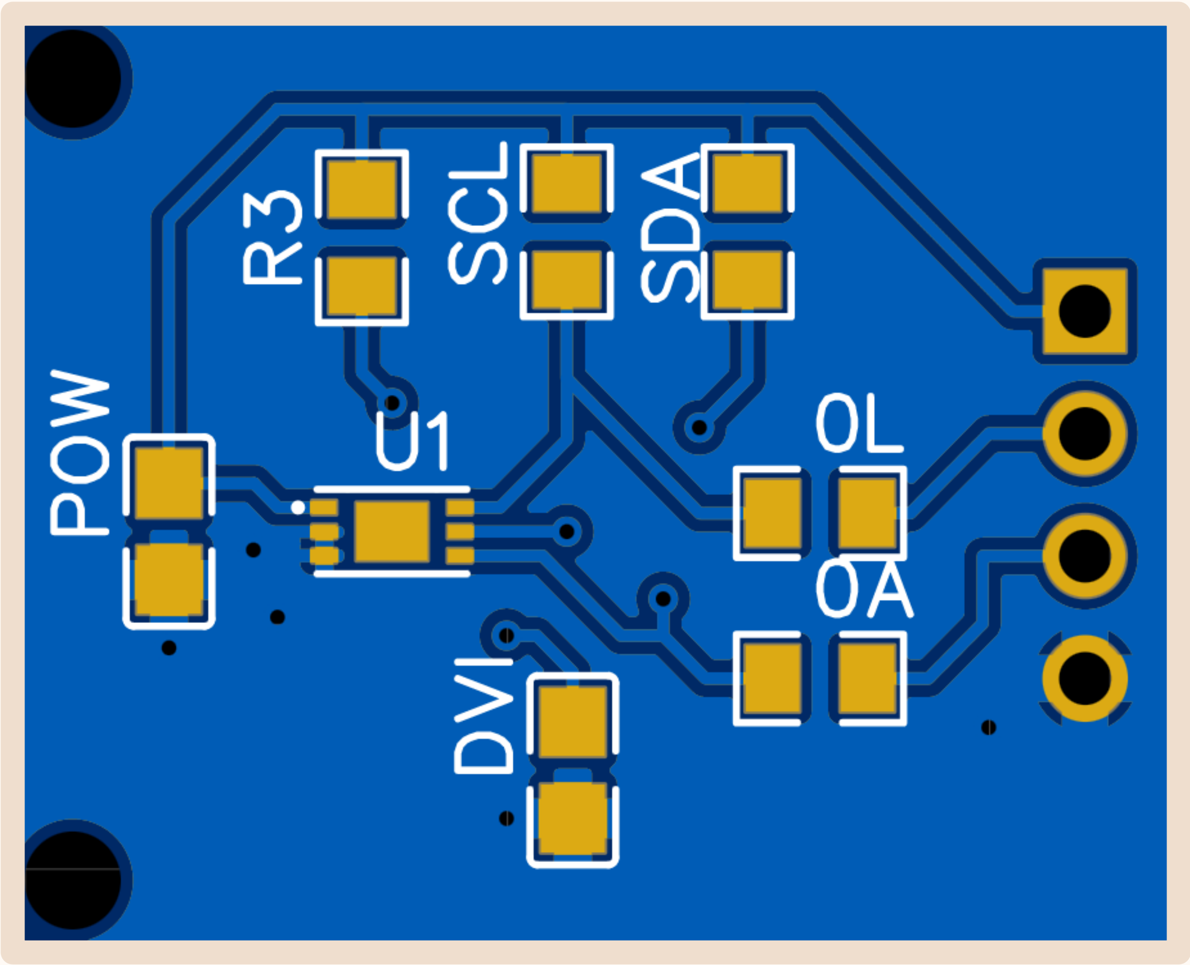


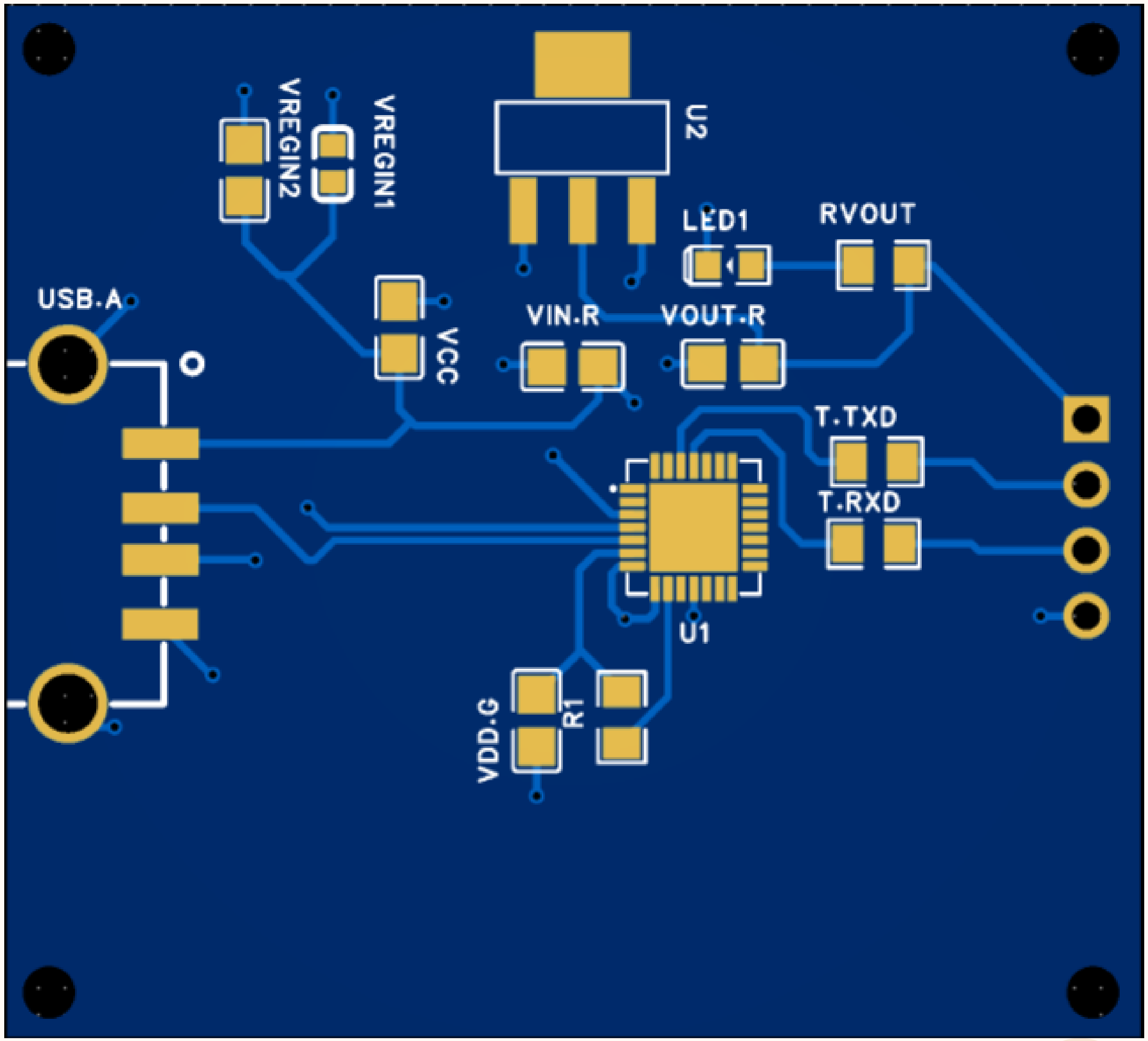
Water Level Sensor PCB



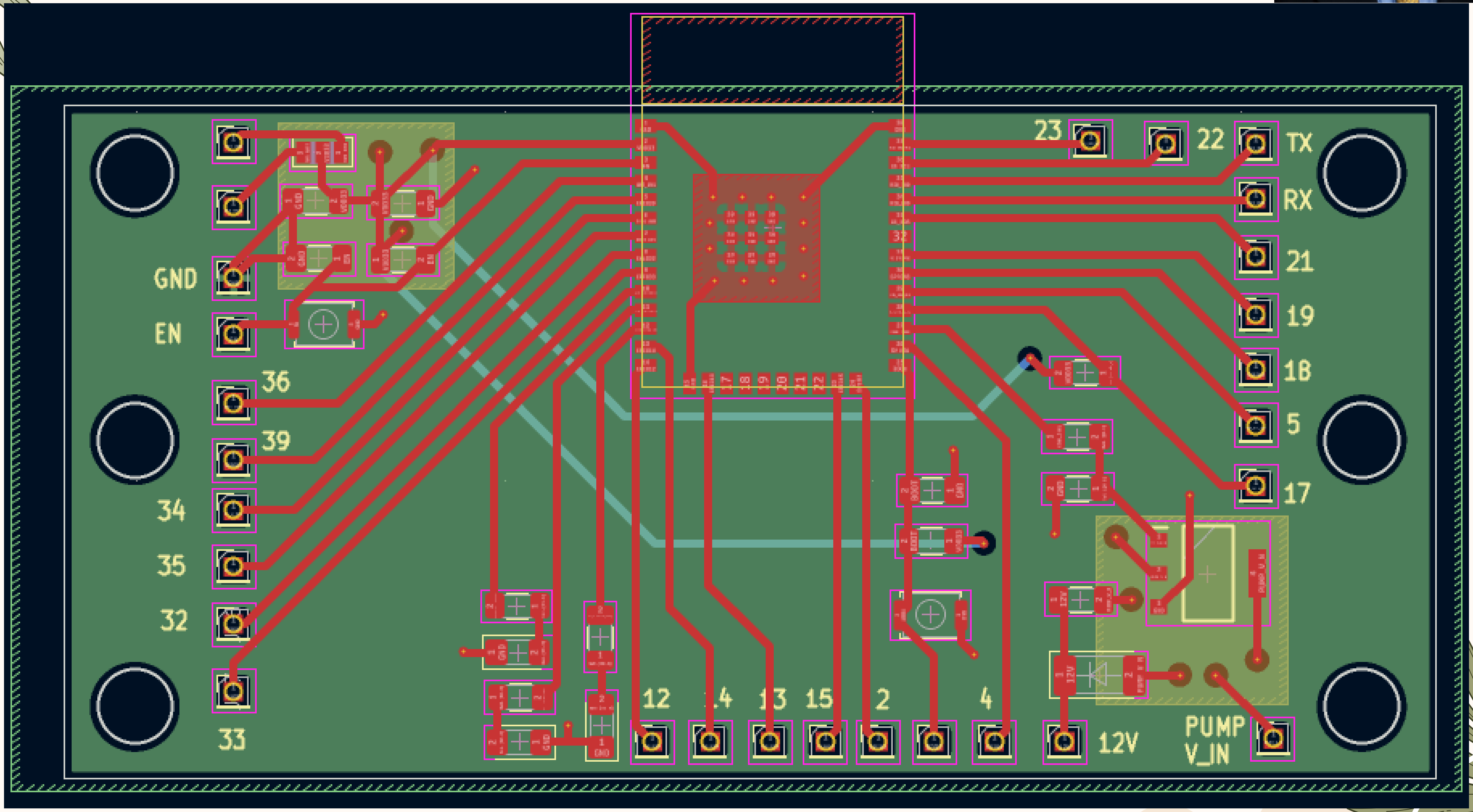
BH1750 Light Sensor PCB



UART - USB PCB

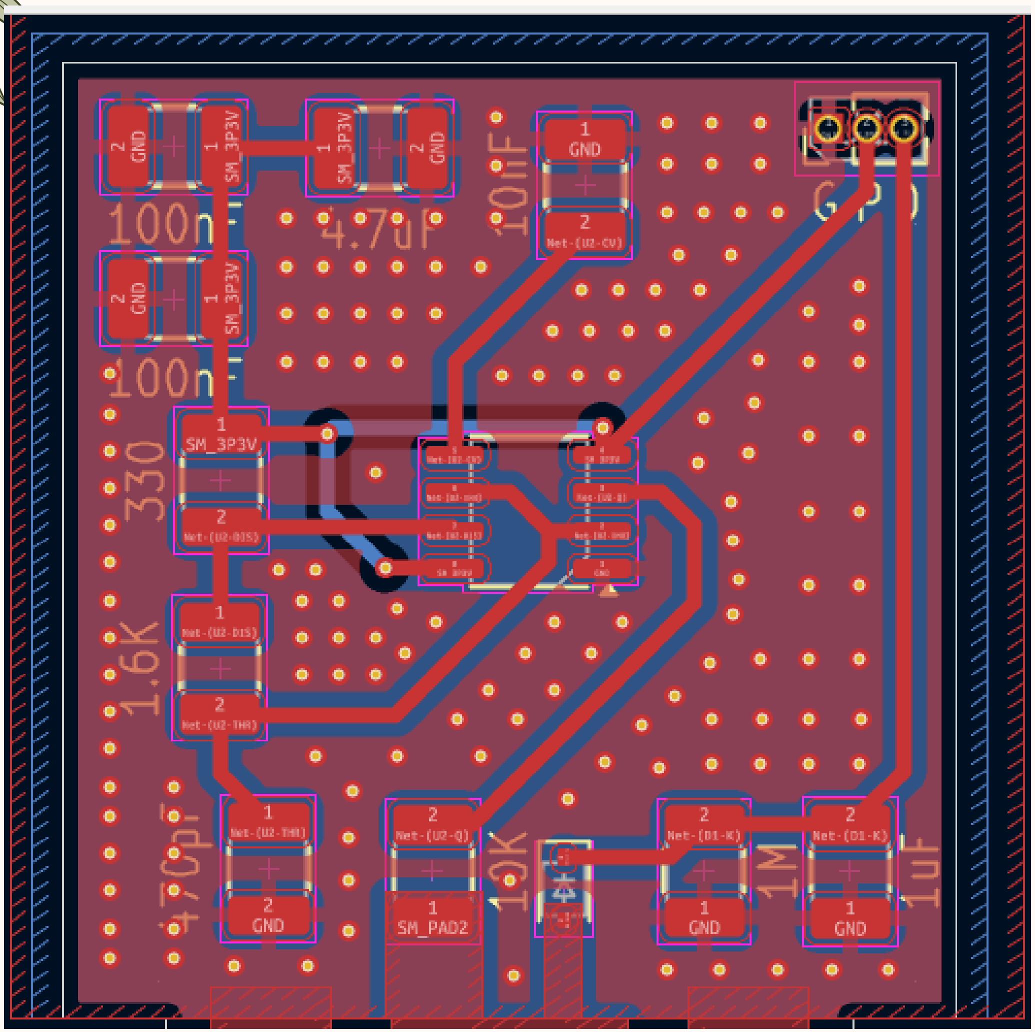

VREGIN2
VREGIN1
U2
LED1
RVOUT
USB.A
VCC
VIN.R
VOUT.R
T.TXD
T.RXD
U1
VDD.G
R1

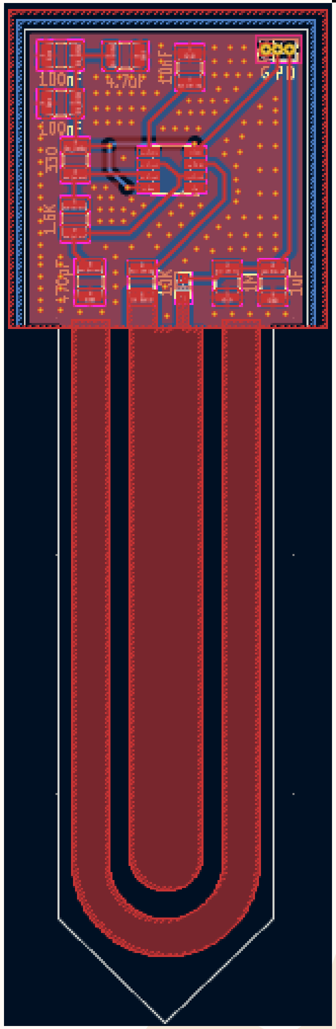
MCU PCB



23
22
TX
RX
21
19
18
5
17
GND
EN
36
39
34
35
32
33
12
13
15
2
4
12V
PUMP
V_IN

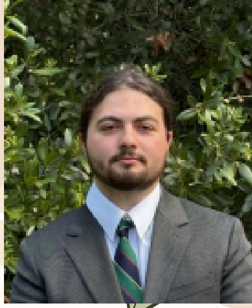
Soil Moisture Sensor PCB

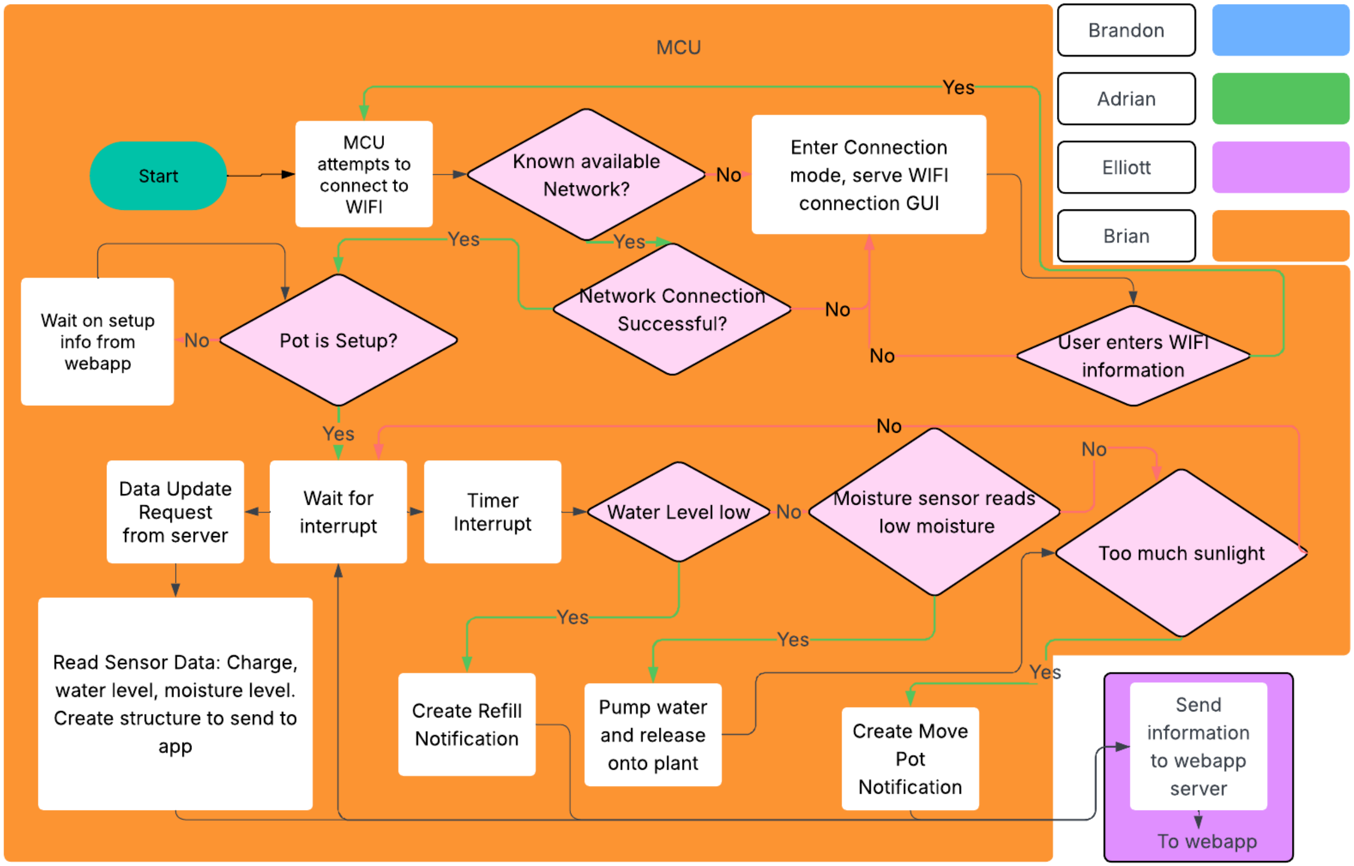




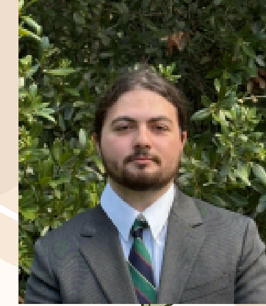
Software Design

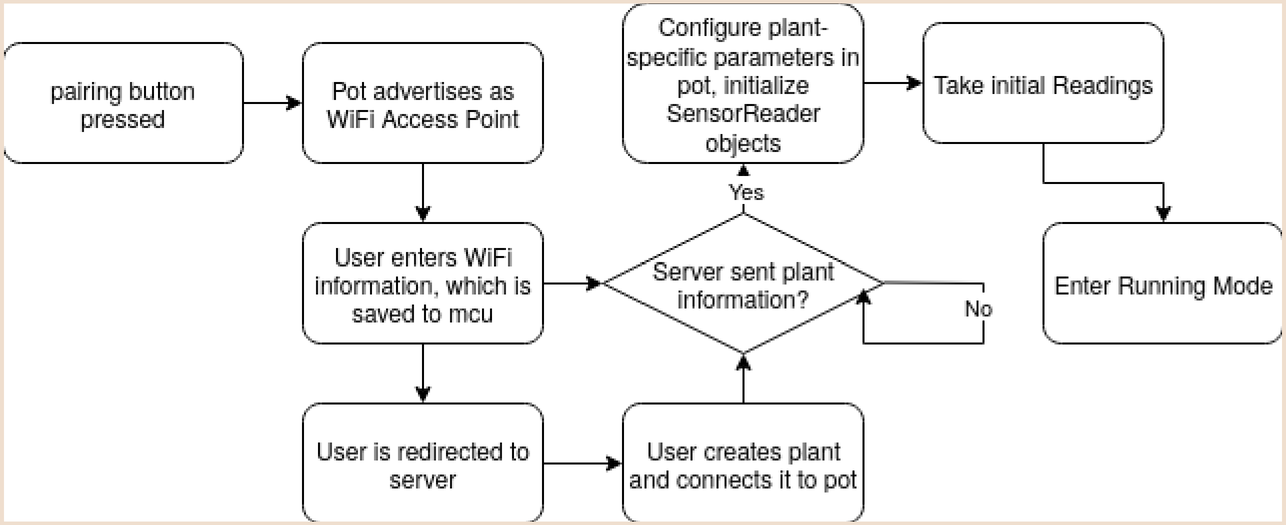
MCU Top Level Flowchart

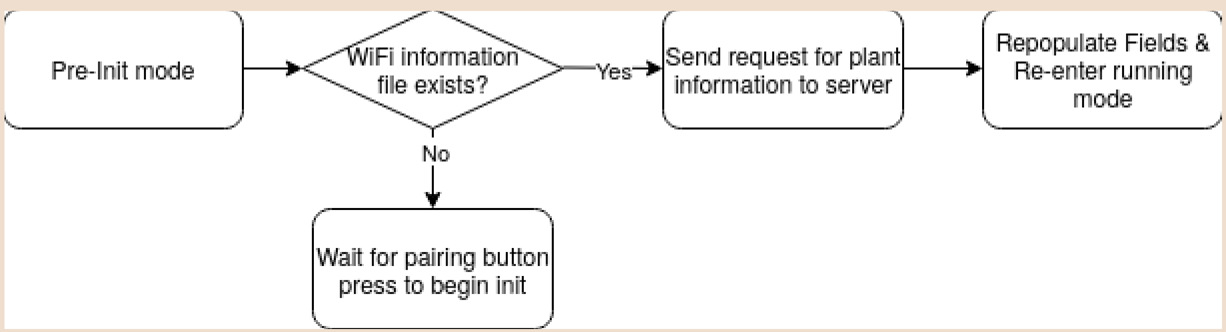




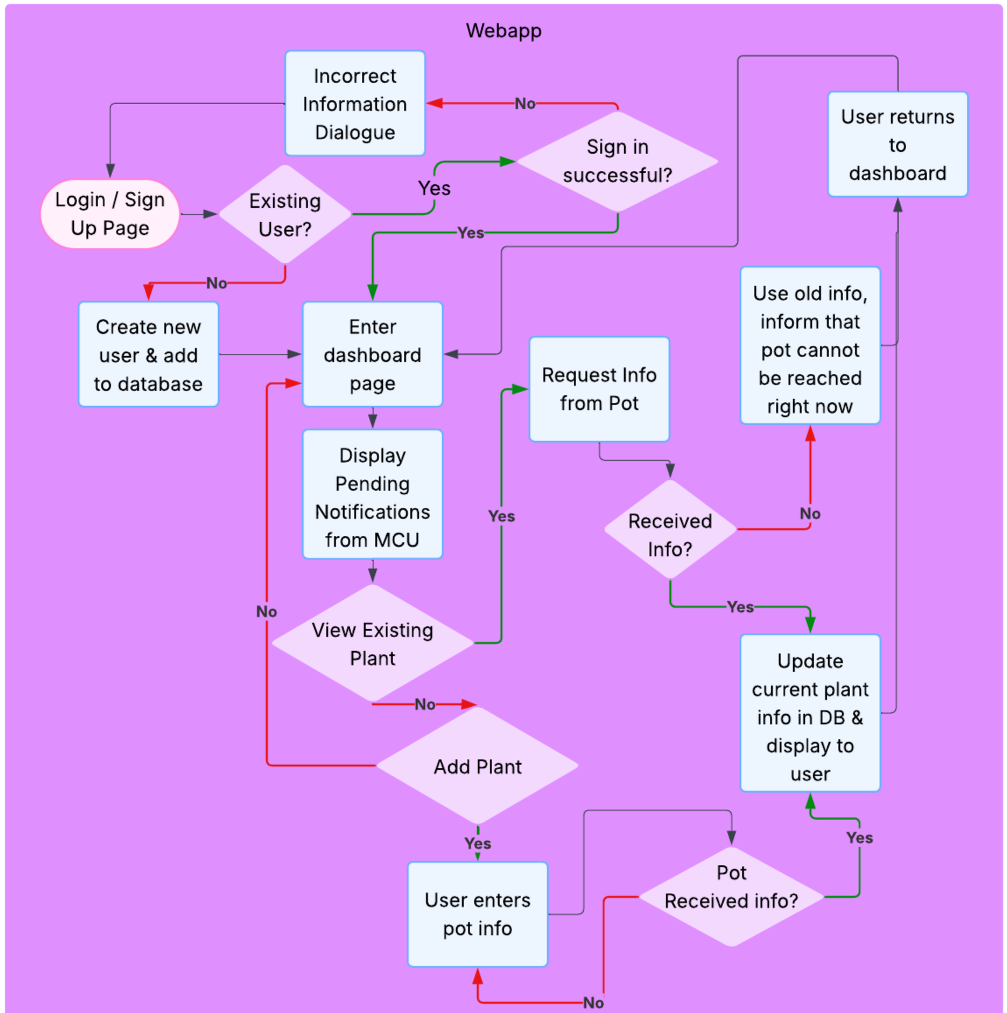
MCU Initialization Flowchart

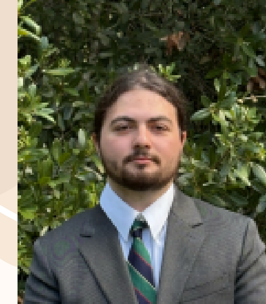




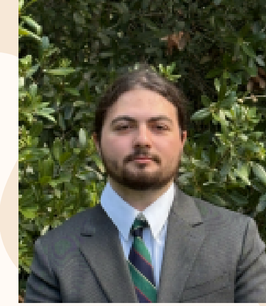


Web App Flowchart



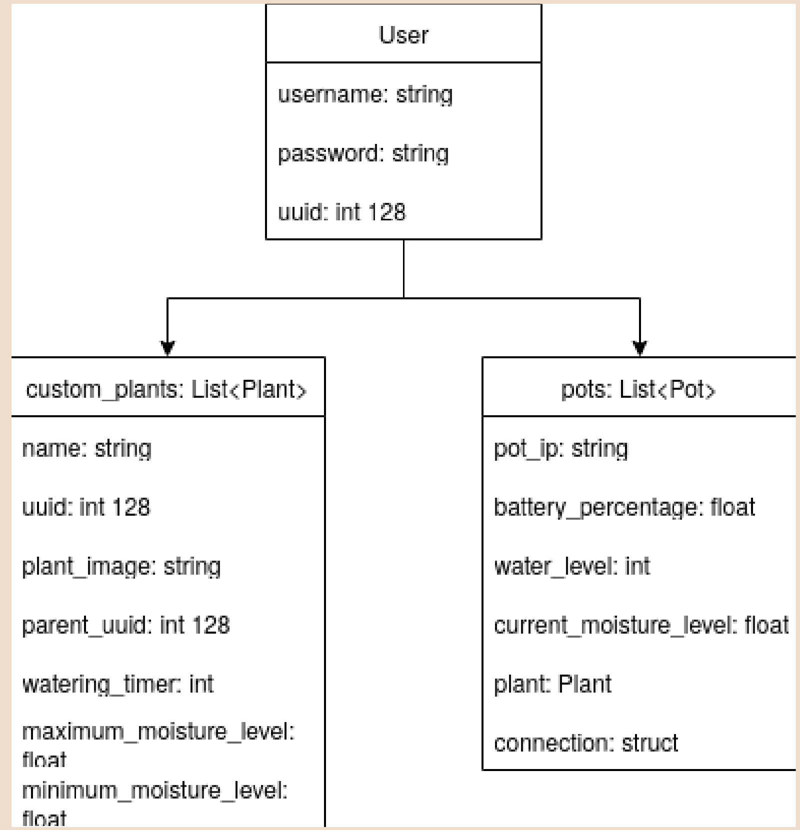


Software Data Organization

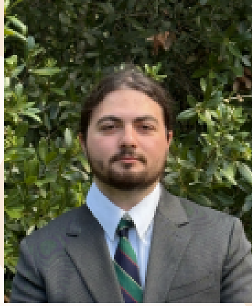


User data is at the top level

- ❑ Users can have multiple pots, each containing data from pot's embedded system
- ❑ User can also have custom, static plant information saved under their account
- ❑ Embedded system only concerns itself with pot data & some fields from plant, NOT user data or information

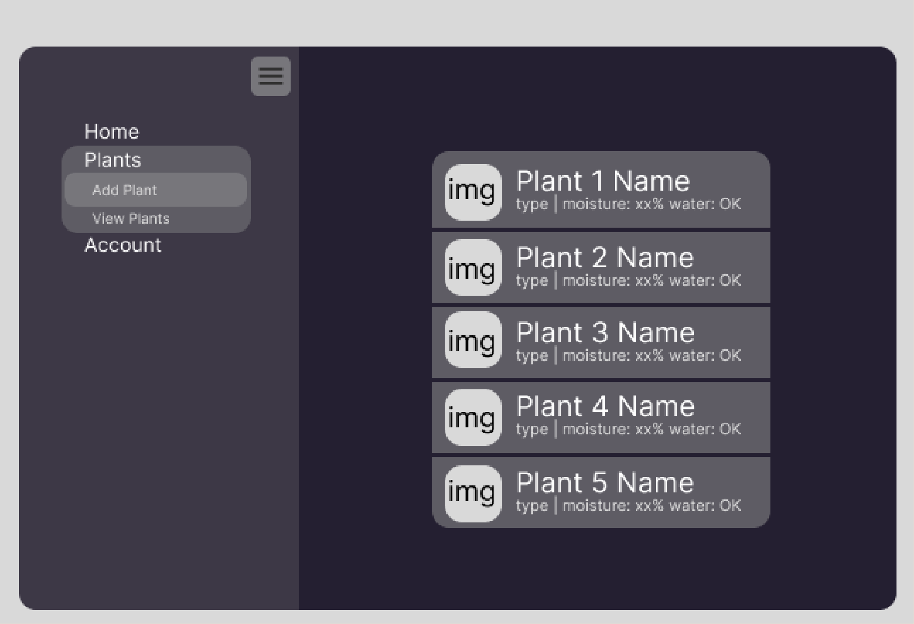


Software Webapp Design: Client

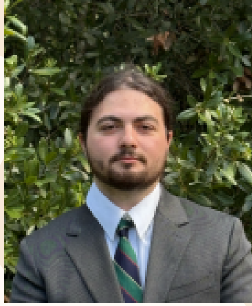


Focus on following design guidelines:

- ❑ Adaptability: Ensure that design can adapt to large number of screen sizes
- ❑ Content-Centric View: Limit use of tabs to separate content within a page, only use for separating ideas
- ❑ Readability: Small color palette with high contrast between foreground & background
- ❑ Accessibility: Enforce use of Alt text for images and robust navigation options



Software Web App Design: Server



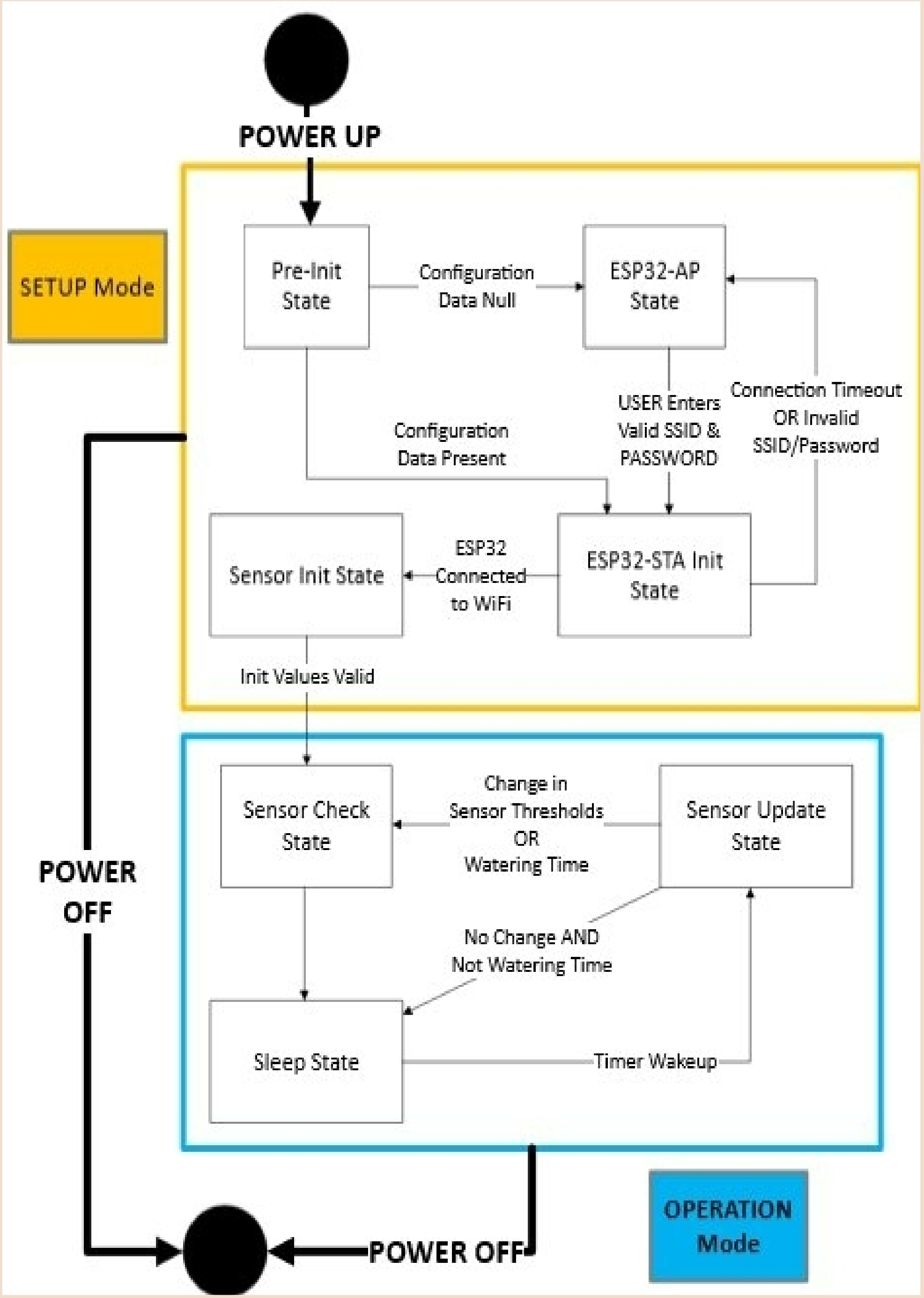
Communication will be done using HTTP Requests

- ❑ No communication between pot and client; all use server as middleman
- ❑ Server should not make many requests; mainly responds to requests from pot and client

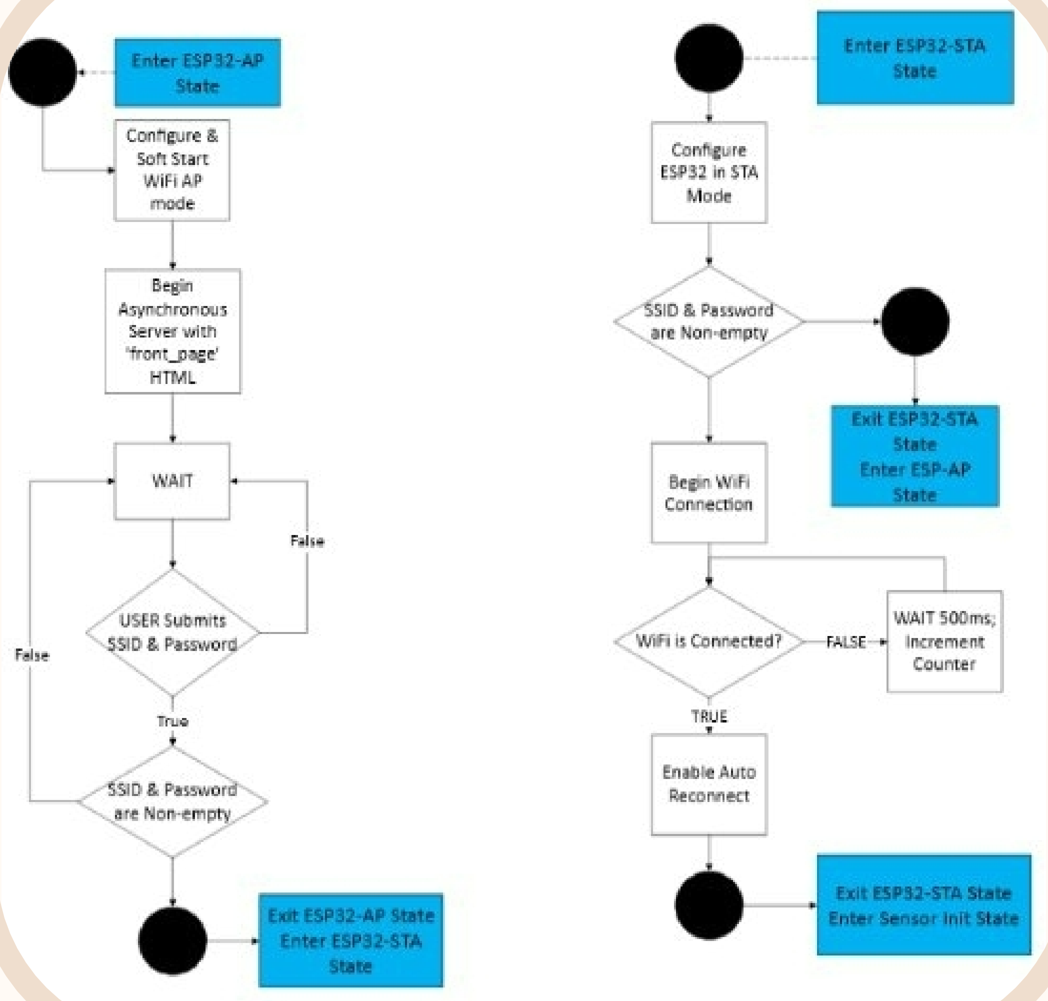
Organization of data will be accomplished through the use of Postgres

- ❑ Most data will be organized under the user
- ❑ Oauth (Google) will be used to authenticate the user before data is sent

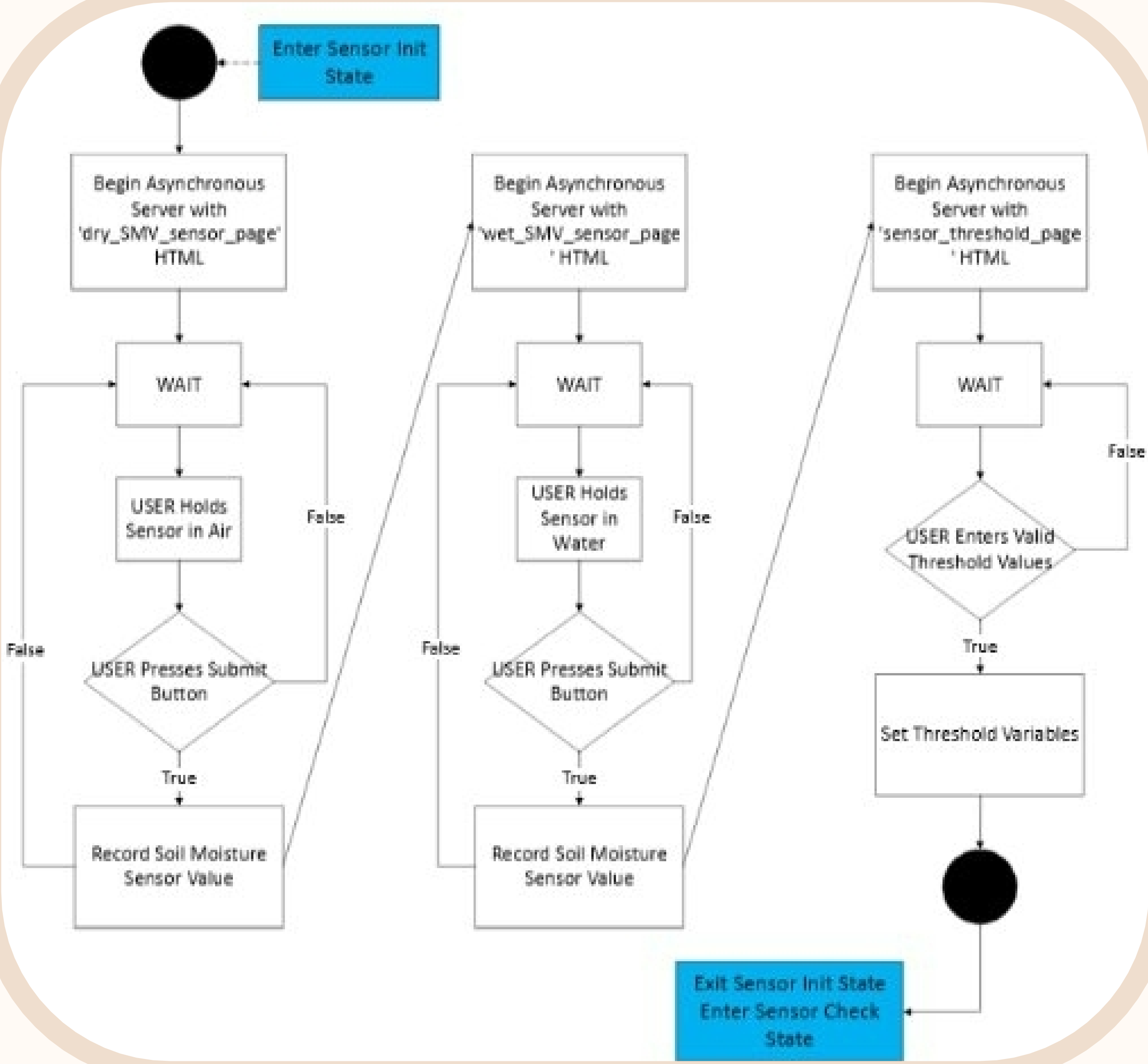
MCU Software Architecture



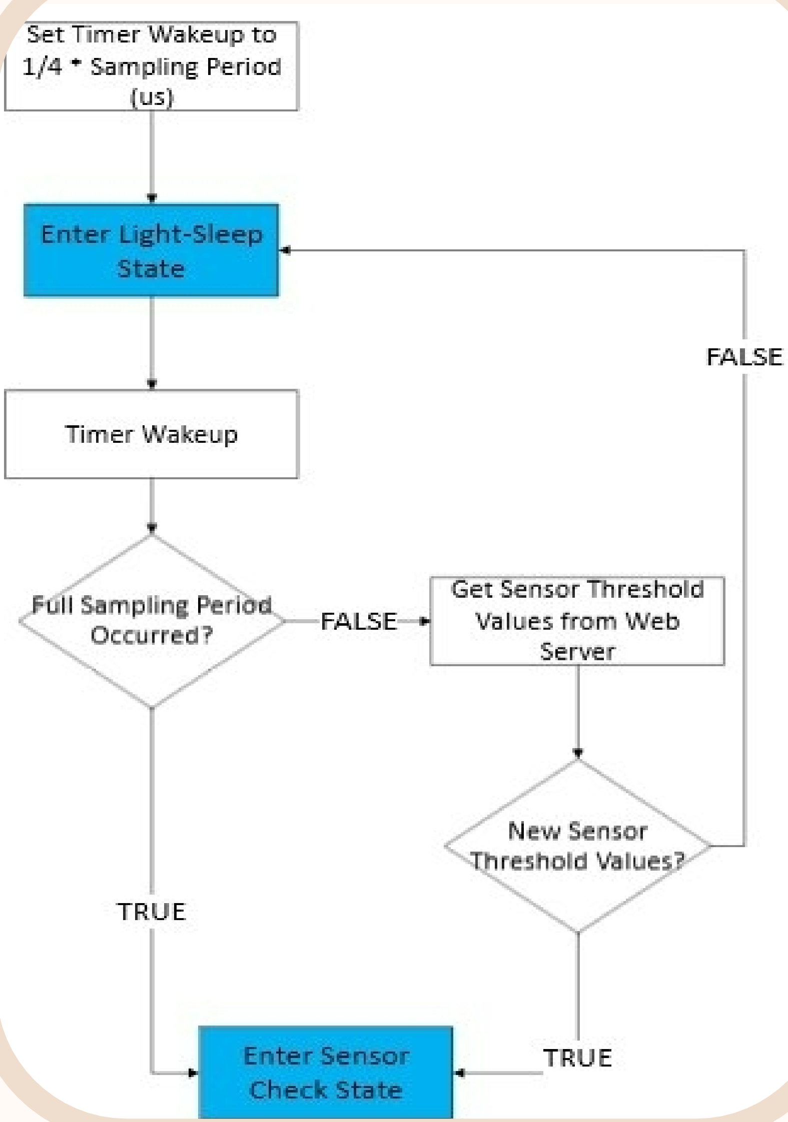
MCU Networking Software

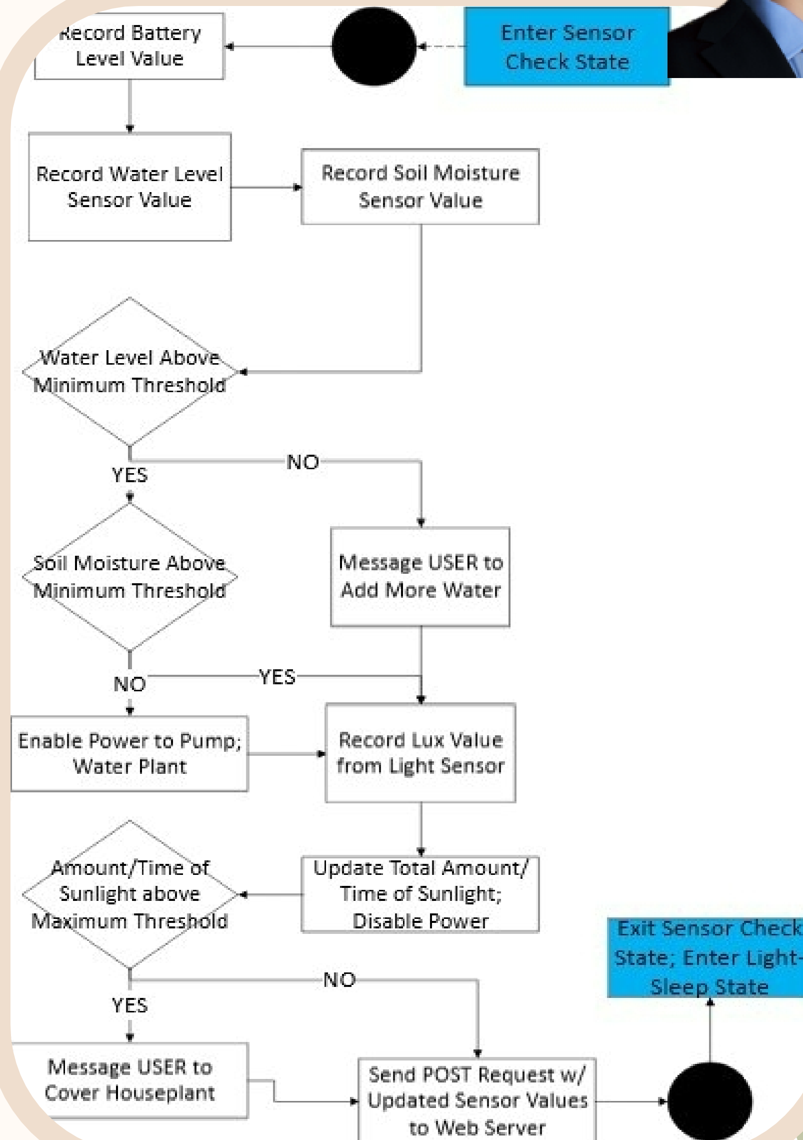


MCU Sensor Initialization Software



MCU Sensor Sampling Software





Prototyping & Testing

Soil Moisture Sensor Testing

Table 9.1.1.2.1 Soil Moisture Sensor Data Test Results.

Water Level/Content	Average Value		Standard Deviation			
	S1	S2	S1		S2	
0% (sensor fully dry)	2838.925	2838.11	12.63	0.88%	18.98	1.31%
25% Wet	1744.565	1760.125	11.02	0.76%	20.46	1.42%
50% Wet	1485.65	1492.915	14.75	1.00%	16.59	1.15%
75% Wet	1432.93	1427.46	12.45	0.86%	16.61	1.15%
100% (sensor fully wet)	1395.9	1394.285	18.29	1.30%	13.46	0.93%

Light Sensor Testing

The BH1750 sensor was tested using the ESP32 microcontroller over the I2C.

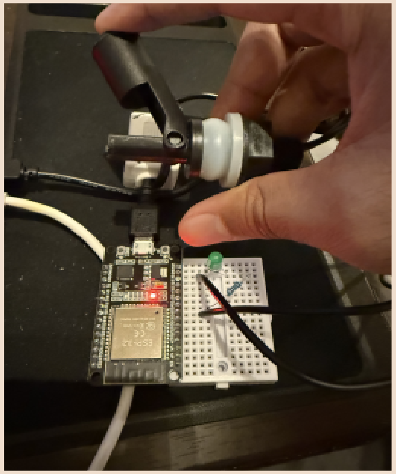
- ❑ Ensured proper wiring to SDA and SCL lines
- ❑ Confirming communication via the serial monitor
- ❑ The BH1750.h library was used to simplify code implementation.
- ❑ The sensor successfully initialized and produced real-time lux readings.
- ❑ Multiple lighting scenarios were simulated including
  - ❑ Direct light
  - ❑ Room light
  - ❑ Full darkness

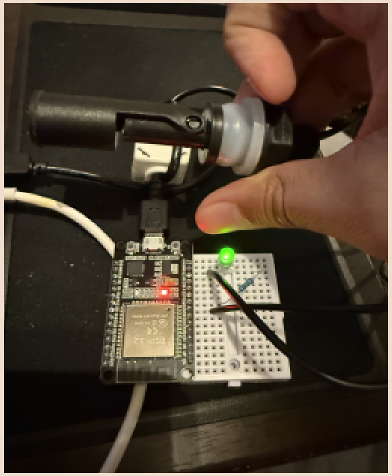
Sensor Readings 1 (Zero Light)	Sensor Readings 2 (Room Light)	Sensor Readings 3 (Flashlight)
0 lux	45.83 lux	33538.33 lux
0 lux	44.17 lux	33423.33 lux
0 lux	44.17 lux	33281.66 lux
0 lux	44.17 lux	33220.83 lux
0 lux	43.33 lux	33286.66 lux
0 lux	41.67 lux	33295.00 lux
0 lux	45.00 lux	33101.66 lux
0 lux	45.00 lux	33152.50 lux

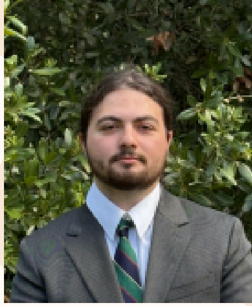
Horizontal Water Level Sensor Testing

The float sensor is a mechanical switch triggered by the raising and lowering of water levels.

- ❑ First tested out of water to confirm functionality
- ❑ An LED was connected to the ESP32 to indicate its status
- ❑ Low water level -> turned on
- ❑ High Water Level -> turned off



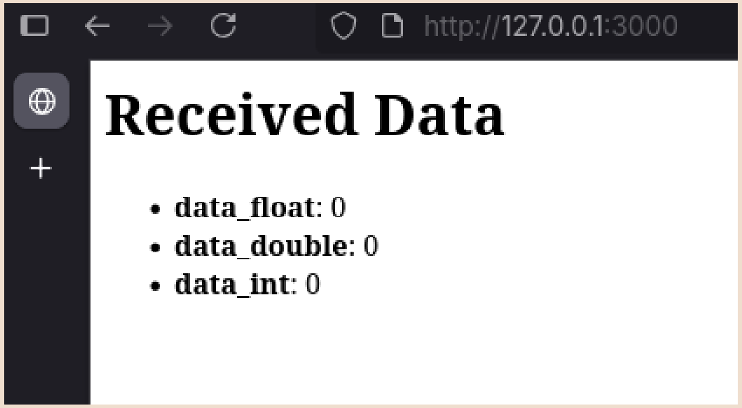




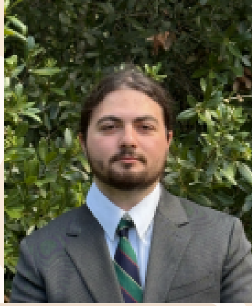
Software Testing

Moving Data from embedded device to server:

- ❑ ESP32 connects to WiFi network
- ❑ Sends data to IP address of server
- ❑ Server uses express to define HTTP requests it can handle
- ❑ server receives and displays data

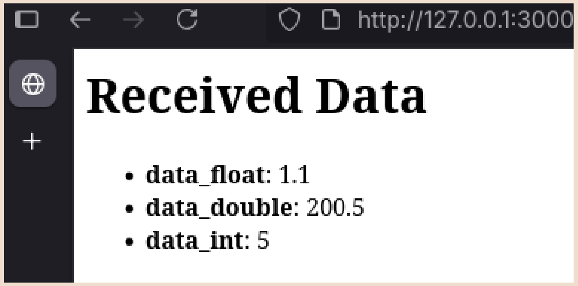


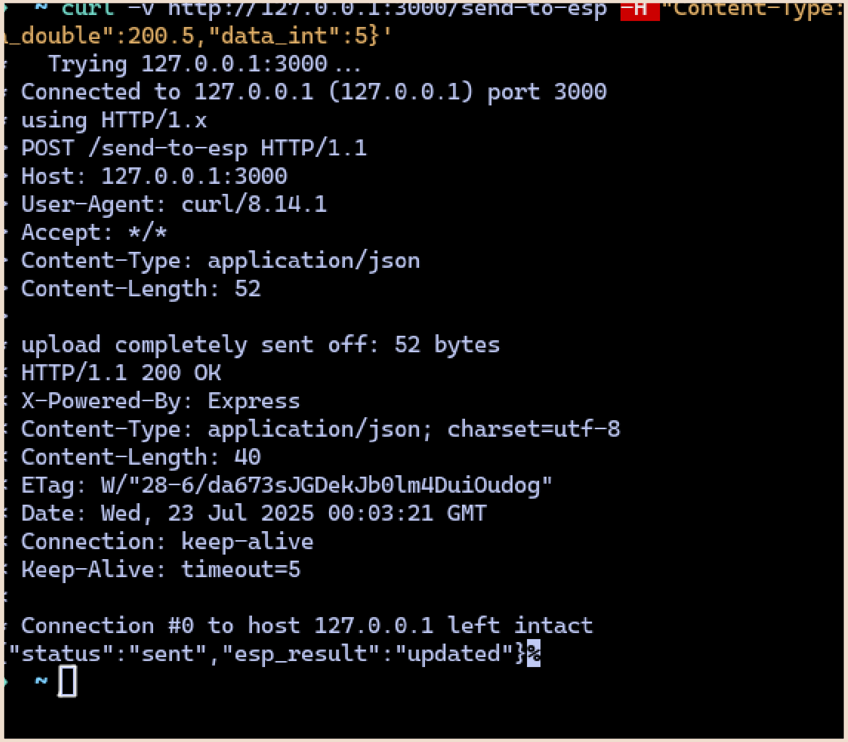
Software Testing



Moving Data from server to embedded device:

- ❑ Use curl to send JSON object to local server
- ❑ Server uses Express to handle data, sends to ESP32 with cached IP
- ❑ ESP32 updates data





Administrative Content

Distribution of Work

Electrical Engineering	Responsibility
Brandon James	PCB Design and fabrication
	Solar and other power delivery
	3d printing pot design
	Regulator Design

Electrical Engineering	Responsibility
Adrian Vergara	PCB Design and fabrication
	Water pump system
	Solar, soil moisture and water level sensor
	3d printing pot design

Computer Engineering	Responsibility
Brian Ericson	MCU software design
	Sensor design support; MCU/Sensor interfacing
	Web app support
	Smart home integration

Computer Engineering	Responsibility
Elliott D'Amato	MCU software design
	MCU/Sensor interfacing support
	Web app development

Progress and Plan for Completion

In Progress / Done

- ❑ Research - 100%
- ❑ PCB and Part Sourcing - 95%
- ❑ Prototyping - 30%
- ❑ Testing - 20%
- ❑ Overall - 60%

Major milestones remaining

- ❑ Verification and testing for PCB's
- ❑ Hardware integration
- ❑ Software integration
- ❑ Enclosure fabrication
- ❑ Final testing