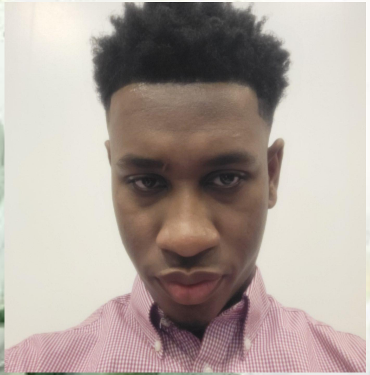
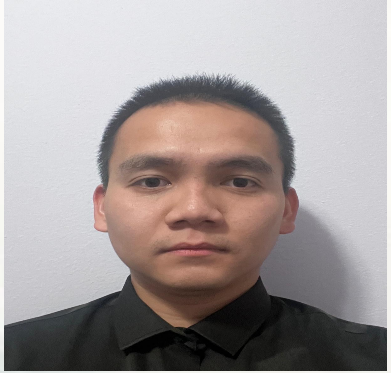
Bio-Sense Pot: Automated Plant Pot With Dynamic Lighting

Group 9



Brucely Charles
EE



Phuong Le
EE

Alex Beaufort
CPE

Ryan McDonnell
PSE

Motivation

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Charles

- **Busy Lifestyles:** Automate plant care tasks to support users who lack time for consistent maintenance.

- **User Error:** Reduce the risk of overwatering, poor lighting, or neglect through sensor-driven, automated responses.

- **Ease of Use:** Design an intuitive system that simplifies plant monitoring and care for users of all experience levels.

Goals

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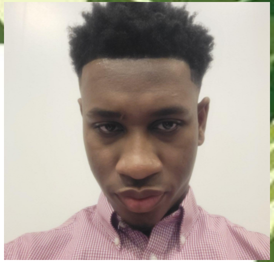

- **Basic Goals**
  - Implement light diffuser for even grow light distribution
  - Monitor temperature, soil moisture, and light intensity
  - Automate irrigation using real-time soil moisture data
- **Advanced Goals**
  - Automate watering and lighting based on sensor feedback
  - Dynamically adjust spectral light output for plant growth stages
  - Develop web/mobile interface for remote system monitoring
- **Stretch Goals**
  - Predict watering and lighting needs using historical data
  - Integrate LCD dome for dynamic ambient light shielding
  - Add AI assistant to interpret data and provide care recommendations

Objectives

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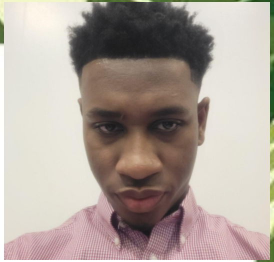

- **Basic Objectives**
  - Accurately monitor temperature, light intensity, and soil moisture with calibrated sensors
  - Calibrate moisture thresholds to prevent over/underwatering
  - Optimize energy use with low-power sensor cycles and fallback modes
- **Advanced Objectives**
  - Automate watering and lighting based on sensor data
  - Implement adaptive spectral control using multi-channel LEDs and sensor feedback
  - Use onboard spectrometer to optimize light wavelength selection in real-time
  - Develop web/mobile app for remote monitoring, alerting, and manual override
- **Stretch Objectives**
  - Train predictive models to optimize watering/lighting schedules based on plant history
  - Design LCD dome that dynamically shields excess sunlight via real-time sensor input
  - Deploy an AI assistant to analyze trends, send alerts, and guide user decisions interactively

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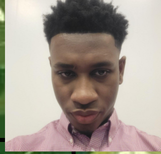
Specification



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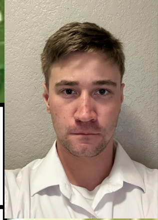
Specification	Value/Range	Description
Soil Moisture Response Time	<5 seconds	Time required for the soil moisture sensor to detect change and initiate a response.
Watering Automation Accuracy	±10% of the min and max threshold for the soil moisture sensor	Accuracy of automated watering based on live soil moisture readings. Also to avoid the overwater and reading data correctly
Spectral Lighting Adjustments	<5 seconds and accuracy up to 90%	Time for LED output to adjust in response to spectrometer data.
System Uptime	80% to 90%	Percentage of time the system operates without critical failure.
Humidity Temperature	20 to 90% accuracy	Accuracy for the temperature sensor
Remote Response Time (App or website)	<15 seconds	Delay from condition change to reflected update on mobile/web UI.

Specification	Value/Range	Description
Grow Light Output Spectral Ratios and Light Intensity Thresholds	Spectral Ratios: Red:Blue = 1:2 (Seedling) 4:1 (Vegetative) 5:1 (Flowering) Ratio Error = X ± 0.1 Light Intensity Threshold PPFD = 60–85 $\mu mol/m^2/s$ (Peace Lily)	Red:Blue photon flux ratios are preset for three plant growth stages and verified via spectrometer data. Target light intensity range of 60–85 $\mu mol/m^2/s$ at 6 inches from diffuser ensures healthy Peace Lily development during the demo. These values confirm both spectral targeting and intensity delivery within system limits
Spectrometer Response Time	< 5 seconds	Time to register and process spectral data for lighting feedback.
Light Intensity Control Resolution	5–10 $\mu mol/m^2/s$	Minimum increment of light intensity adjustment from software or automation.



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Ryan

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Design Approach

Design Approach

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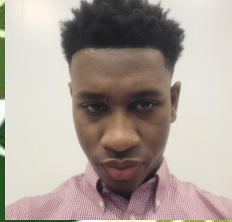
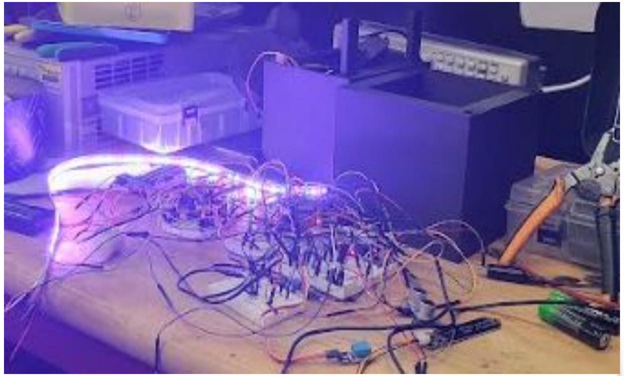
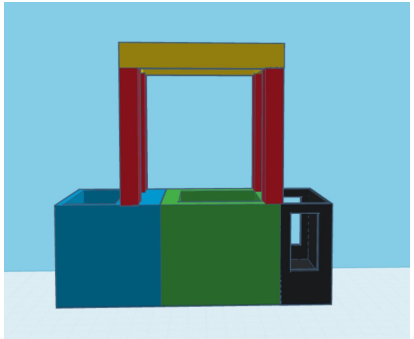
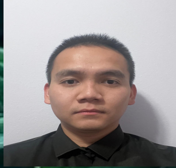


- Minimal-Intervention Design Goal
- Sensor Integration
- Structural Design for Growth Support
- Modular Housing Architecture
- Power Supply Challenges & Solutions
- Power Stability Enhancement
- Solar Charging Limitations & Resolution
- Final Charging Solution was External Battery Charger



- **Blue** – Water Container
- **Green** – Soil and Plant Area
- **Black** – PCB Board Placement
- **Yellow** – LED Light Surface
- **Red** – Structural Support Beams





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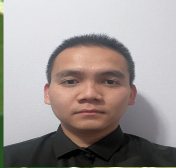
Constraints



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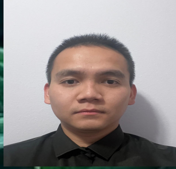
- **Power Constraints**: Limited by battery capacity and efficient voltage step-down for long autonomous operation.
- **Waterproofing and Safety**: Electrical and water systems required waterproof housing and careful separation to prevent leaks or short circuits.
- C**ost Constraints**: Project kept under ~$1000 part cost target to meet consumer affordability goals.
- **Thermal and Environmental Limits**: Components selected to operate reliably within typical indoor temperature and humidity ranges.
- **Size and Weight Limits**: Entire system must fit in a compact footprint and able to carry and use for indoor
- **Lighting Accuracy**: Spectral LED control and sensing had to maintain plant-optimized PAR range despite variable ambient lighting.
- **Modularity for Maintenance**: Subsystems (LEDs, pumps, sensors) designed to be easily replaceable for long-term usability.



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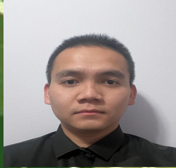
Hardware and Design

Subversive Water Pump

Feature	Mini Submersible Pump 5V	MakerFocus 5V Submersible	DC 5V USB Mini Water Pump (PL-USB 118)
Operating Voltage	**5V DC**	5V DC	5V DC
Current Draw	**180mA**	120–220 mA	~250 mA
Power Consumption	**0.91W**	1.1 W	1.25 W
Flow Rate	**100 L/h**	80–100 L/h	80 L/h
Waterproof Rating	**IP68**	IP65	IP65
Noise Level	**<35 dB**	~40 dB	~40–50 dB
Dimensions	**35×25 mm**	40×27 mm	~36×26 mm
Cost (approx.)	**$5–6**	$6.50	$8.99



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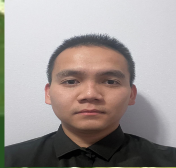
Soil moisture comparison

Feature	Capacitive Soil Moisture Sensor v1.2	Vegetronix VH400	Adafruit STEMMA
Accuracy	Moderate (±5% to ±7%)	High (±1% to ±3%)	High (±1% to ±2%)
Power Consumption	~0.05 W at 5V	Very Low (1mA to 3mA)	Low (1mA to 5mA)
Cost	Affordable ($5 to $7)	Expensive ($40 to $65)	Expensive ($25 to $50)
Additional Features	Wi-Fi enabled Waterproof, and corrosion proof	Moisture readings that are highly accurate	Multi-sensor support and integrated temperature sensor



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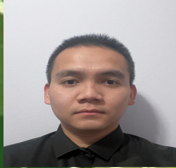
Microcontroller

Feature	ESP32	Arduino Uno (ATmega328P)	Raspberry Pi Pico (RP2040)	STM32 (e.g., STM32F103C8T6)
GPIO Pins	~34 total, ~25 usable	14 digital, 6 analog	26 total, 3 analog inputs	~37 total, ~10 analog
Analog Inputs (ADC)	18 channels	6 channels	3 channels	10 channels
Communication	UART, I2C, SPI, BLE, Wi-Fi	UART, I2C, SPI	UART, I2C, SPI	UART, I2C, SPI, CAN
Wi-Fi / Bluetooth	Built-in Wi-Fi + BLE	None	None	Usually external modules needed
Processor Speed	Dual-core 240MHz	Single-core 16MHz	Dual-core 133MHz	~72MHz
Memory (RAM)	520KB SRAM	2KB SRAM	264KB SRAM	~20KB SRAM



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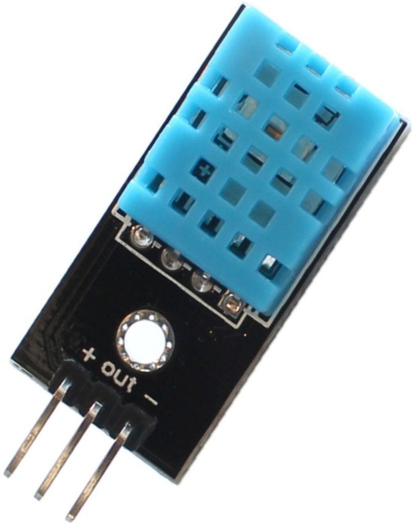
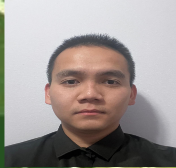
Temperature Sensor Comparison

Feature	DHT11	DHT22 (Selected)	LM35
Temperature Range	0°C to 50°C	-40°C to 80°C	-55°C to 150°C
Humidity Measurement	Yes up to 20% to 90%	Yes up to 0% to 100%	No
Accuracy (Temperature)	Plus or minus 2	Plus or minus .5	Plus or minus .5
Accuracy (Humidity)	Plus or minus 5%	Plus or minus 2%	Plus or minus 5%
Response Time	Slow in about 1 read per second	Moderate (about 0.5 to 1 seconds)	Fast (less than 1 second)
Output Type	Digital	Digital	Analog
Cost	Low ($1 to$ 4)	Moderate ($3 to $7)	Moderate ($5 to $10)
Ease of Integration	Simple single-wire interface	Simple single-wire interface	Requires ADC for digital integration
Best For	Basic smart plant monitoring, budget-friendly applications	High-accuracy smart plant monitoring, environmental control	Precision temperature measurement, industrial applications





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Schematic and PCB

Overall Schematic

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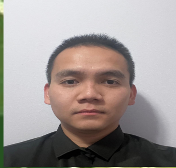

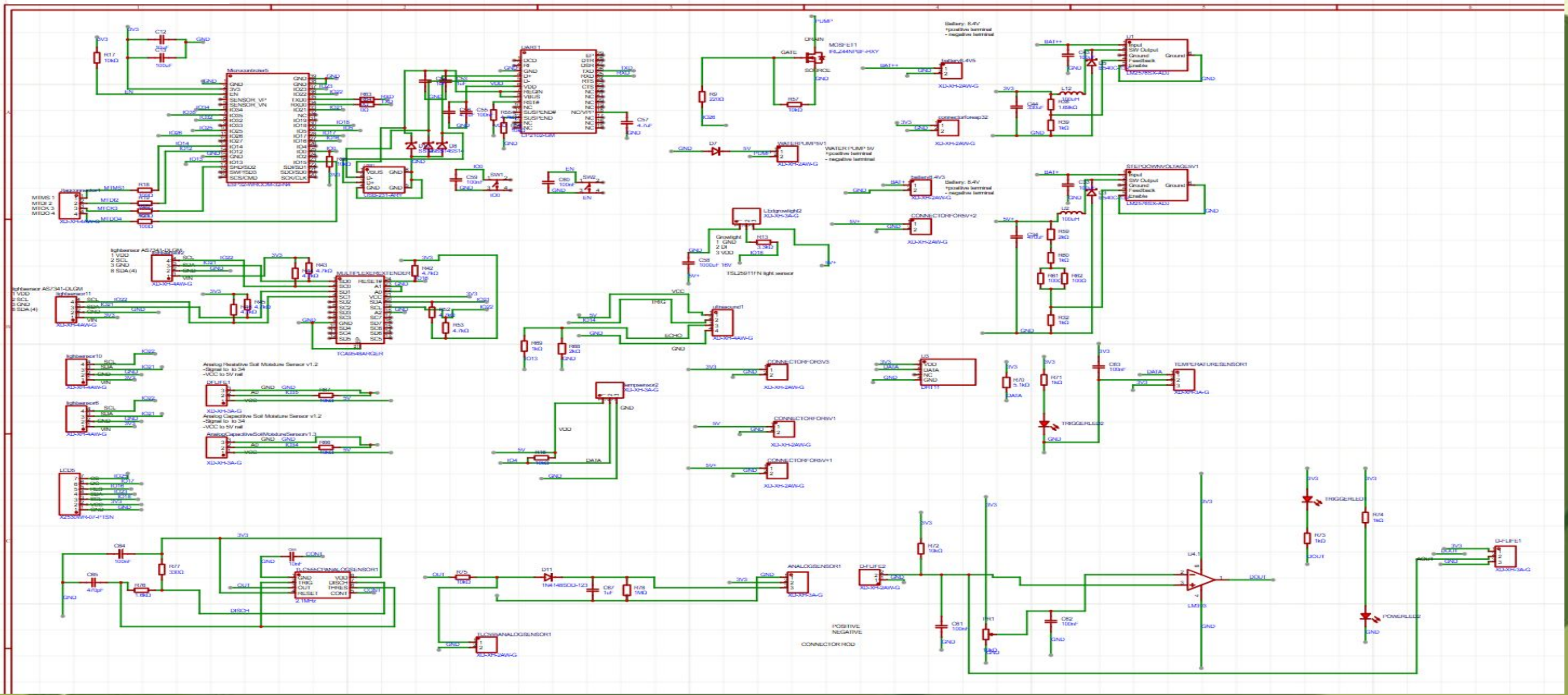

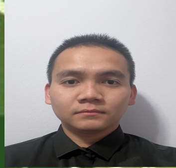

Irrigation and Moisture Sensing Subsystem

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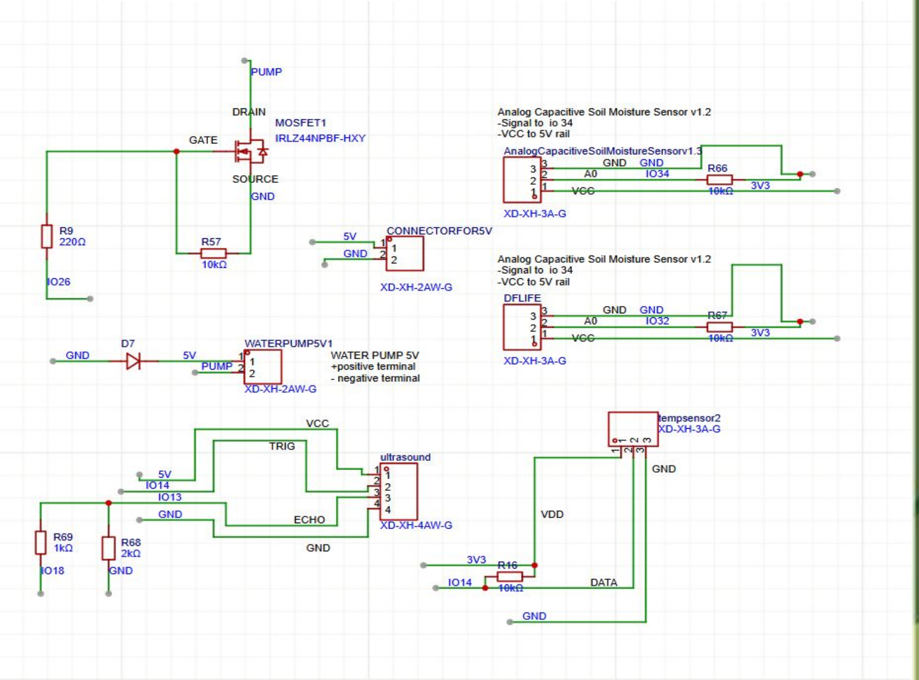
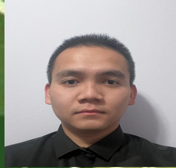
- Automated Water Pump Control Using MOSFET IRLZ44N
- Ultrasound sensor act as measurement for water level tank
- Temperature sensors and soil moisture sensors are for control mosfet switch on and off



Multiplexer and Light Sensors



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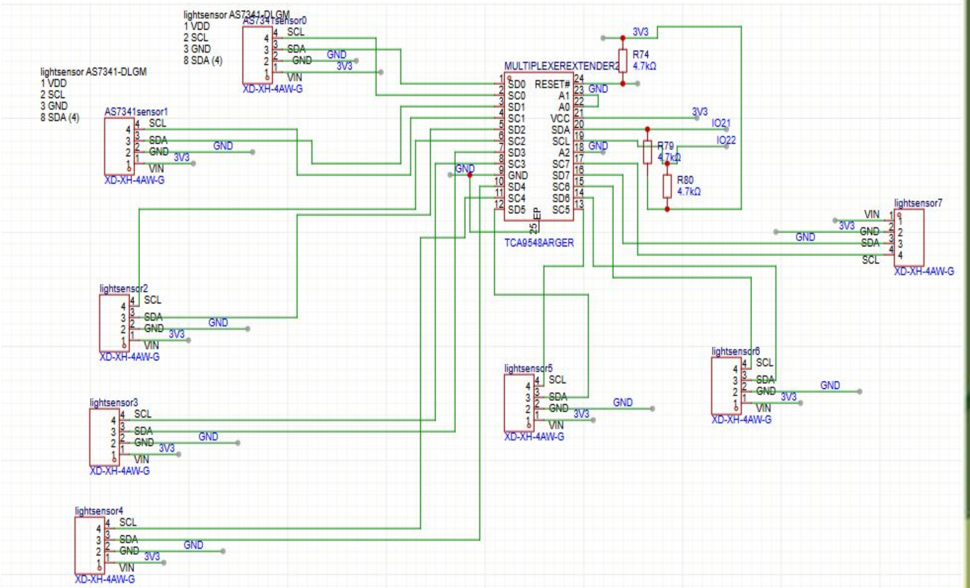
- Dual AS7341 Spectrometers with I2C Multiplexer
- Multiple Light Sensors for Adaptive Control
- Pull-up Resistors for I2C Bus Stability
- LED Grow Light



PCB main board

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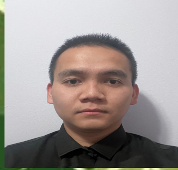
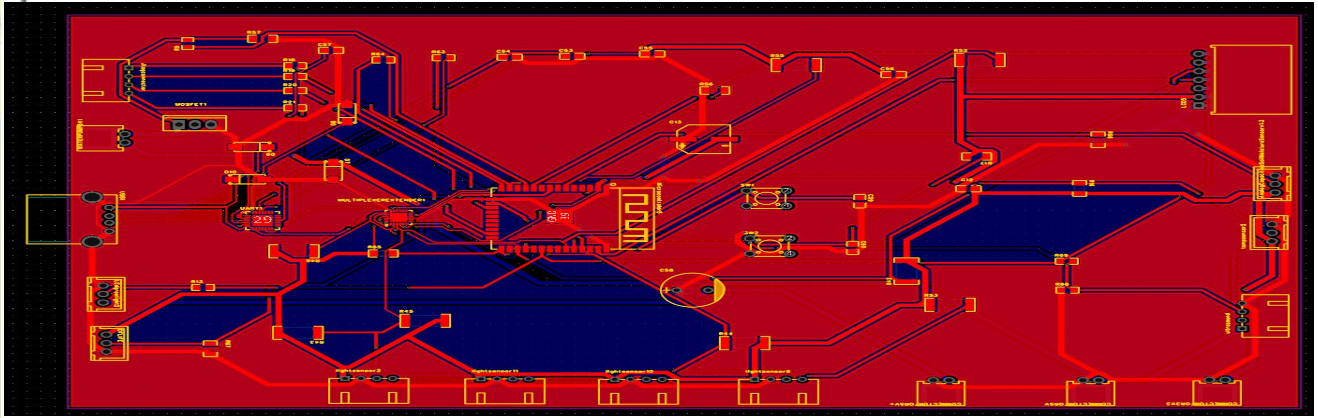
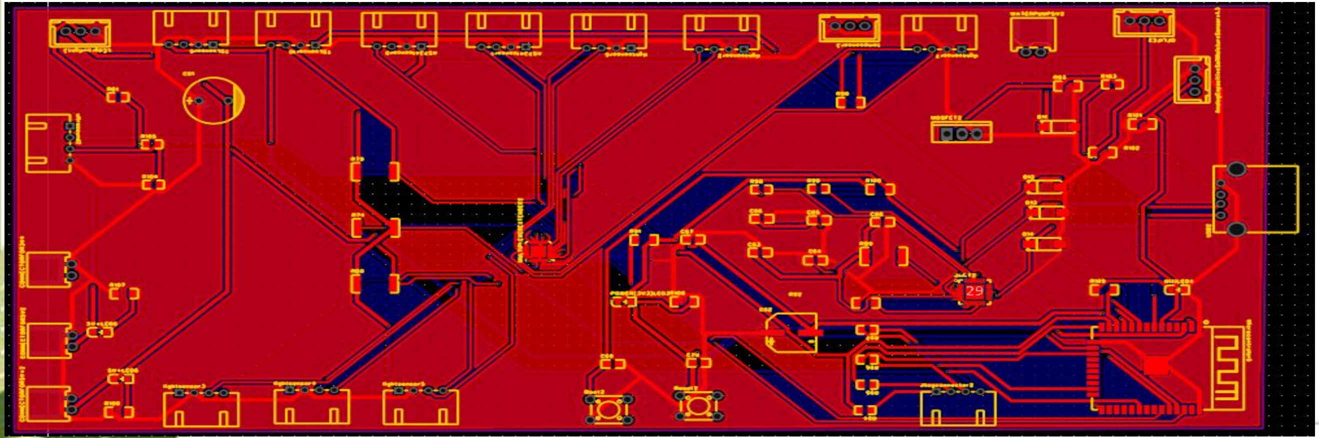




Old PCB board



New PCB board

Voltage Regulator 3.3V /5V

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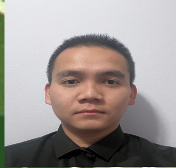

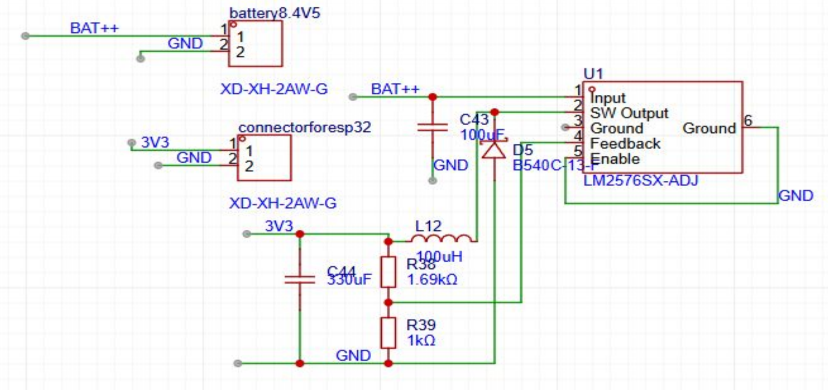

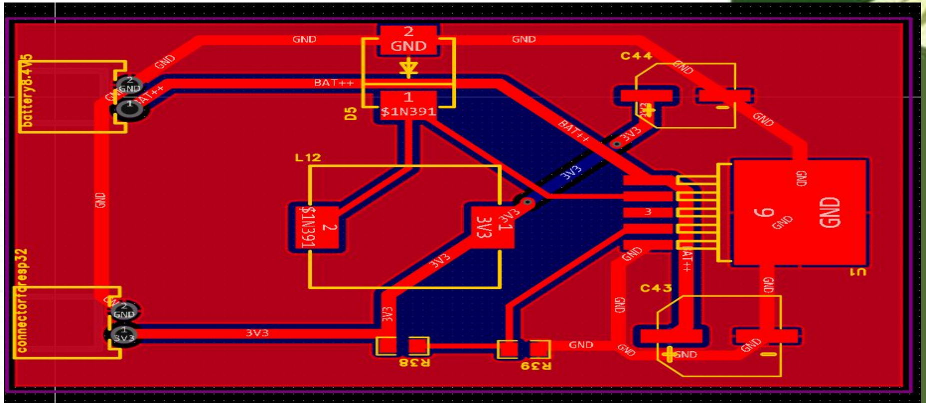

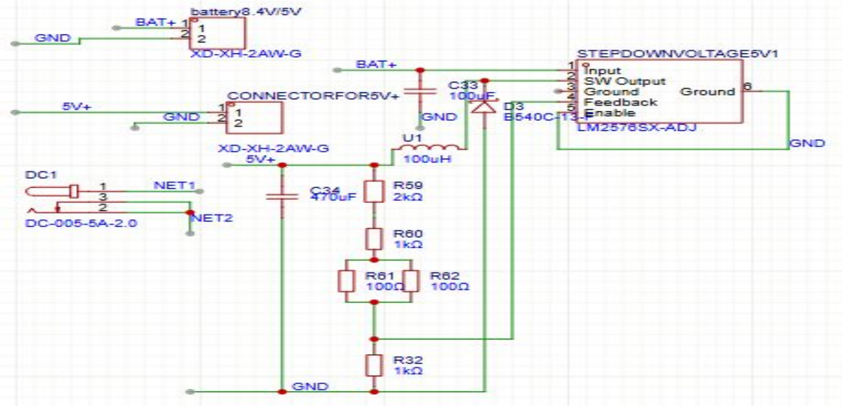

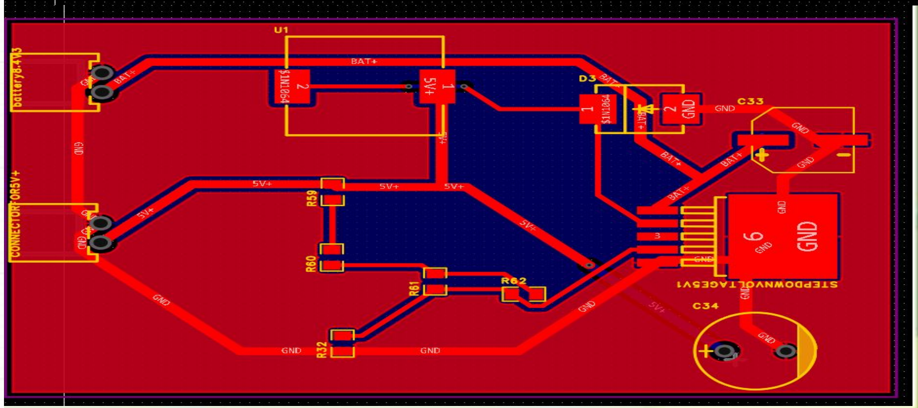

Temperature/Humidity Sensor +Soil Sensor

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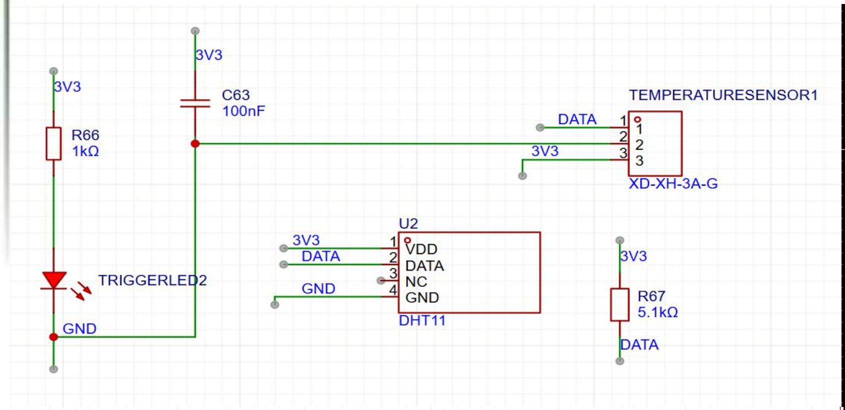

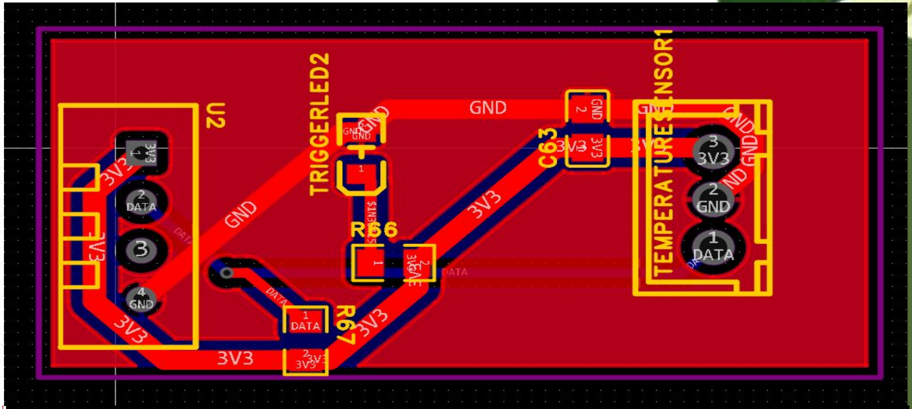

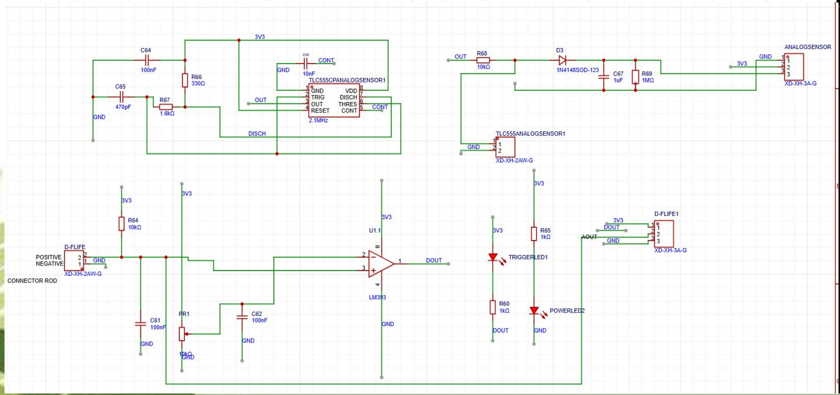

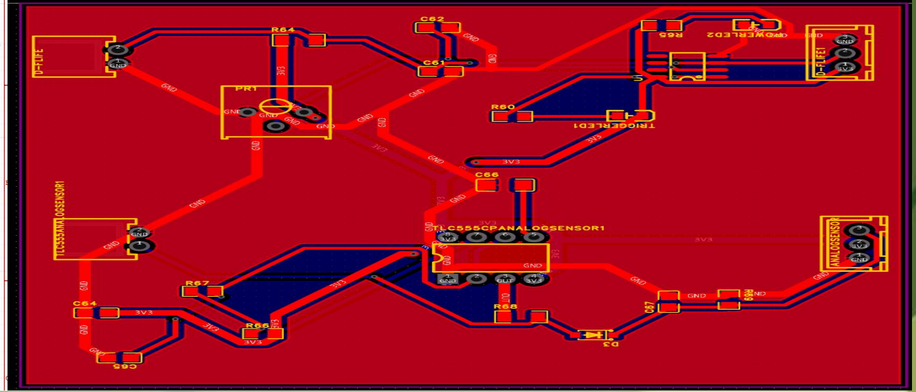

Block Diagram

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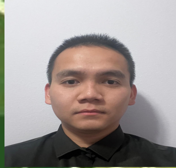

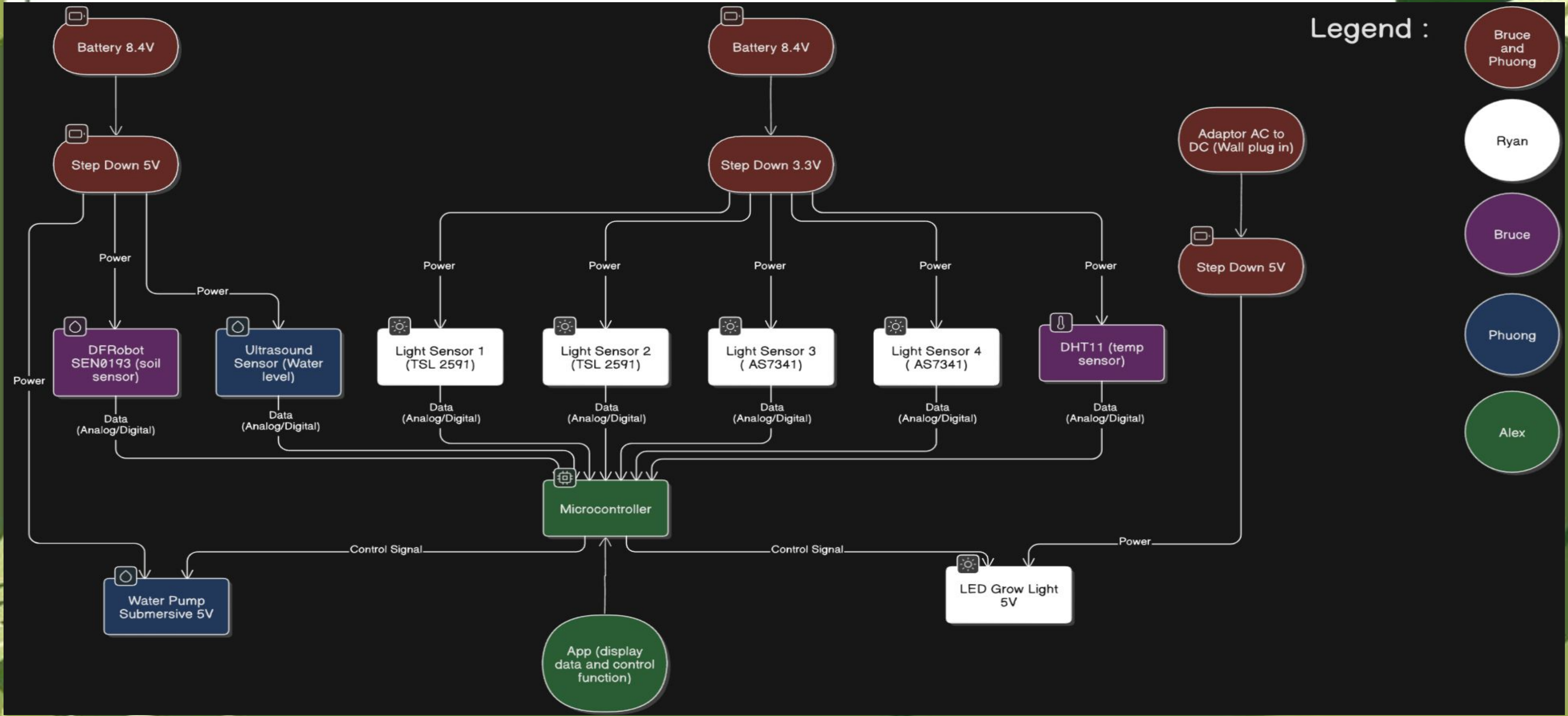

Optical Sensors and Systems

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Comparison of Light Source

Component/ Metric	Fluorescent Lamps	HPS Lamps	High-Power LEDs	Addressable RGB LED Strips (WS2812B, Selected)
Power Consumption (per ft^2)	20–40 W	40–60 W	15–35 W	7–14 W (based on density)
PAR Output ($\mu mol/m^2/s$ at 12")	~80–150	~150–200	200–400	~100-150
Thermal Output (Watts of heat)	Moderate (~50% radiant loss)	High (~70% radiant loss)	High (~60–70% efficient)	Low (~80% electrical efficiency)
Control System Compatibility	Low (manual only)	Very low	Medium (requires external driver)	High (direct ESP32 integration)

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Comparison of Addressable LEDs

Component/ Metric	SK6812	APA102	WS2812B
Power Consumption (per ft²)	~8.5 W	~10 W	7.5 W
PAR Output (μmol/m²/s at 12")	~85	~80	81.3
Control Type	Single-Wire, 5V	Dual-Wire, 5V	Single-Wire, 5V
LED Density (LEDs/m)	80	80	144

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Light Intensity Sensor Type Comparison

Component/ Metric	Integrated Circuit Sensor	Photodiode + Amplifier	Analog Light Sensor Module	Commercial Light Meter
Spectral Range	400–800 nm (VIS + IR)	280–1100 nm (depends on diode)	~400–700 nm	400–700 nm (PAR)
Size (sensor + circuit)	2–3 mm IC + breakout (~15×10 mm board)	~25–35 mm with op-amp and power	~20–30 mm module	~130×60×30 mm handheld unit
Power Consumption	1–2 mA active, ~0.2 mA idle	2–10 mA typical	~0.5–2 mA	Battery or USB powered (~30–50 mA draw)
Interface Type	I²C (digital)	Analog output	Analog output	Standalone display

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Light Intensity Sensor Comparison

Component/ Metric	TSL2591	VEML7700	BH1750	LTR-559
Saturation Point	>88,000	~100,000	~65,000	~60,000
Spectral Range	Dual photodiode (Visible + IR) (Separated)	Dual photodiode (Visible + IR) (Combined)	Visible only, ~560 nm peak	~100–150 (RGB combined)
Minimum Detectable Lux	~0.000377 lux	~0.005 lux	~1 lux	~0.01 lux
Power Consumption	0.4 mA active, <5 μA sleep	0.17 mA active, 0.5 μA sleep	0.12 mA active, 0.01 μA sleep	0.2 mA active, <1 μA sleep

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Spectrometer Sensor Type Comparison

Component/ Metric	Integrated Circuit Sensor	DIY Dispersive Spectrometer	Commercial Spectrometer Module
Spectral Channels	6–18 fixed channels (discrete bands)	Continuous, resolution depends on design	Continuous, typically 0.3–5 nm resolution
Size (sensor + circuit)	3–5 mm IC + breakout (~20×15 mm total)	~50–100 mm length (slit to sensor)	~60–150 mm module (varies)
Cost	$15–70	$50–150 (DIY parts total)	$200–$1500
Interface Type	I²C (digital)	USB or analog (if camera or linear sensor used)	USB, UART, or SPI

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Spectrometer Sensor Comparison

Component/ Metric	SparkFun Triad (AS7265x)	DFRobot Gravity	Adafruit AS7341
Cost (USD)	$65–75	$15–20	$20–25
Spectral Range	18 channels (UV to NIR: 410–940 nm)	6 channels (VIS only: ~450–650 nm)	11 channels (VIS to NIR: 415–940 nm)
Built-in Gain Control	Yes (configurable)	No	Yes (software-controlled)
Power Consumption	~10–20 mA active	~2.1 mA active, ~0.2 mA idle	~1.8 mA active, ~0.2 mA standby

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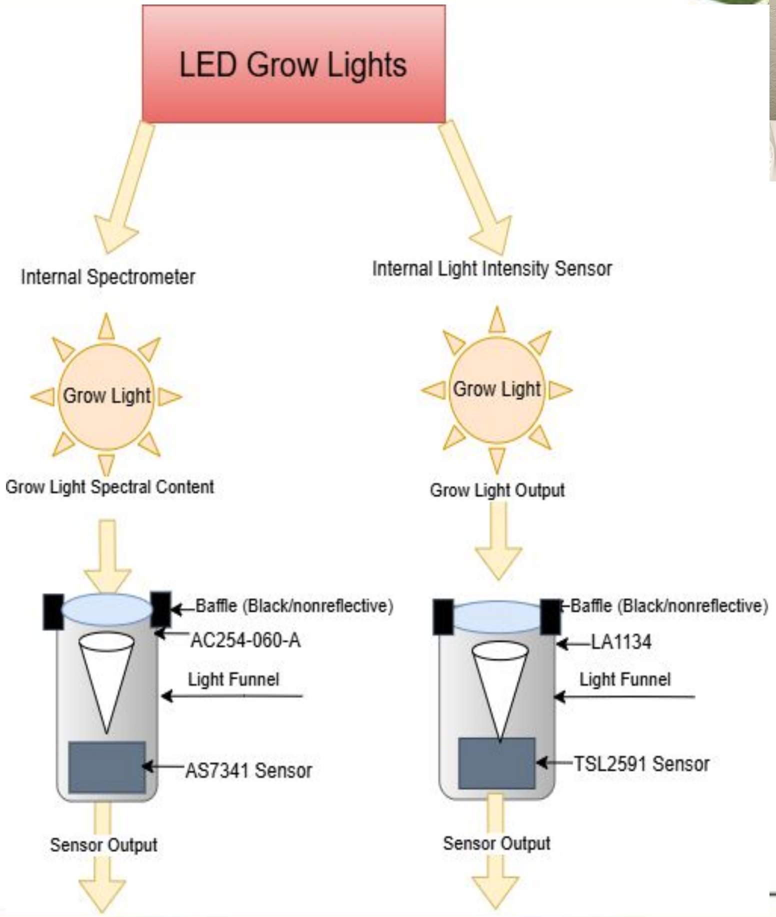
Internal Optical Systems

Component/ Metric	Spectrometer Collection Lens	Light Intensity Collection Lens
Cost (USD)	$95.34	$26.14
Lens	AC254-060-A	LA1134
Lens Type	Achromatic Doublet	Plano-Convex
Focal Length	60 mm	
Diameter	1”	



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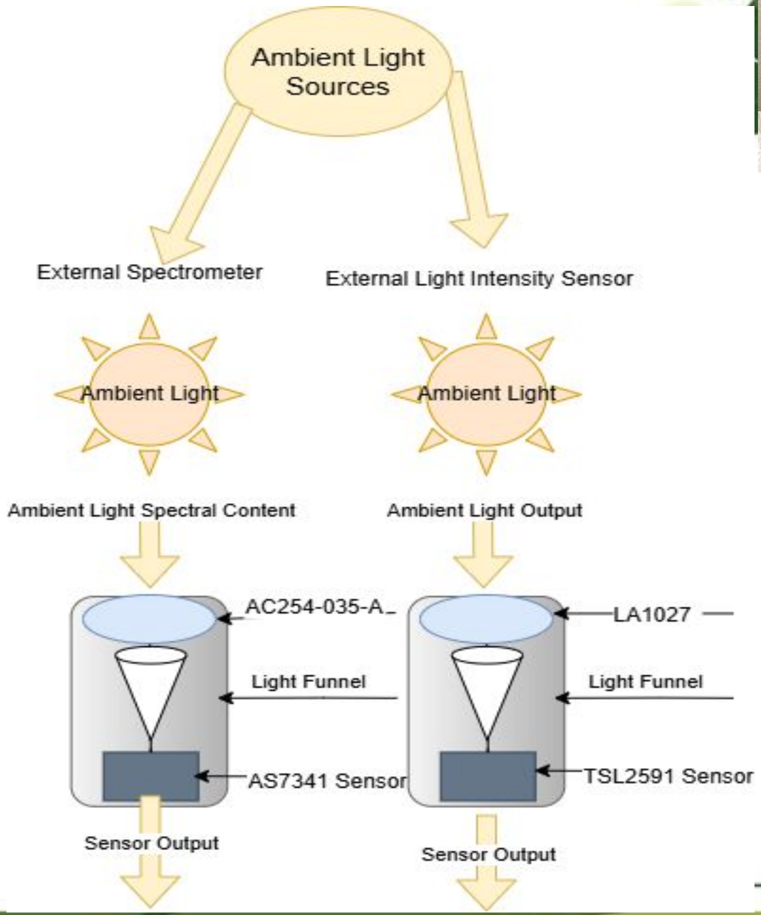
External Optical Systems

Component/ Metric	Spectrometer Collection Lens	Light Intensity Collection Lens
Cost (USD)	$102.96	$27.62
Lens	AC254-035-A	LA1027
Lens Type	Achromatic Doublet	Plano-Convex
Focal Length	35mm	
Diameter	1”	



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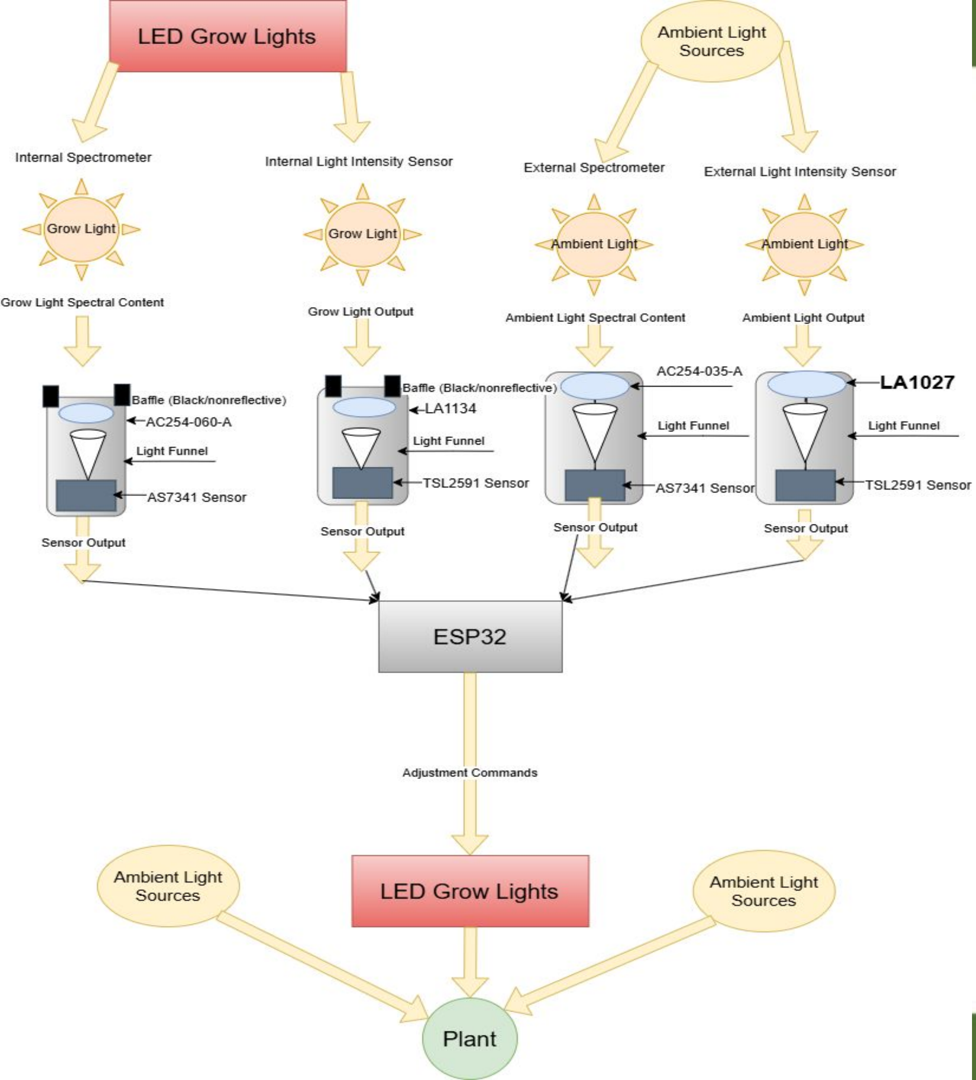

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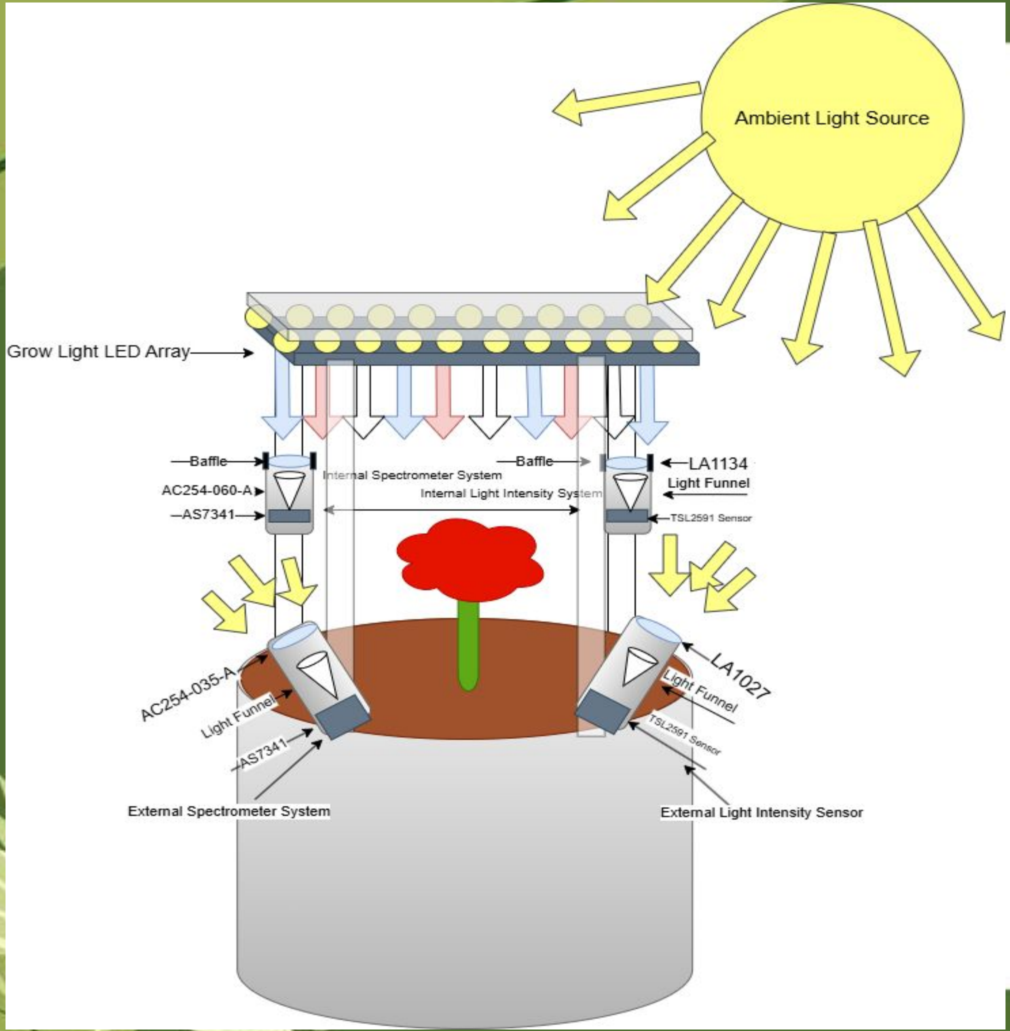
Full Optical Diagram



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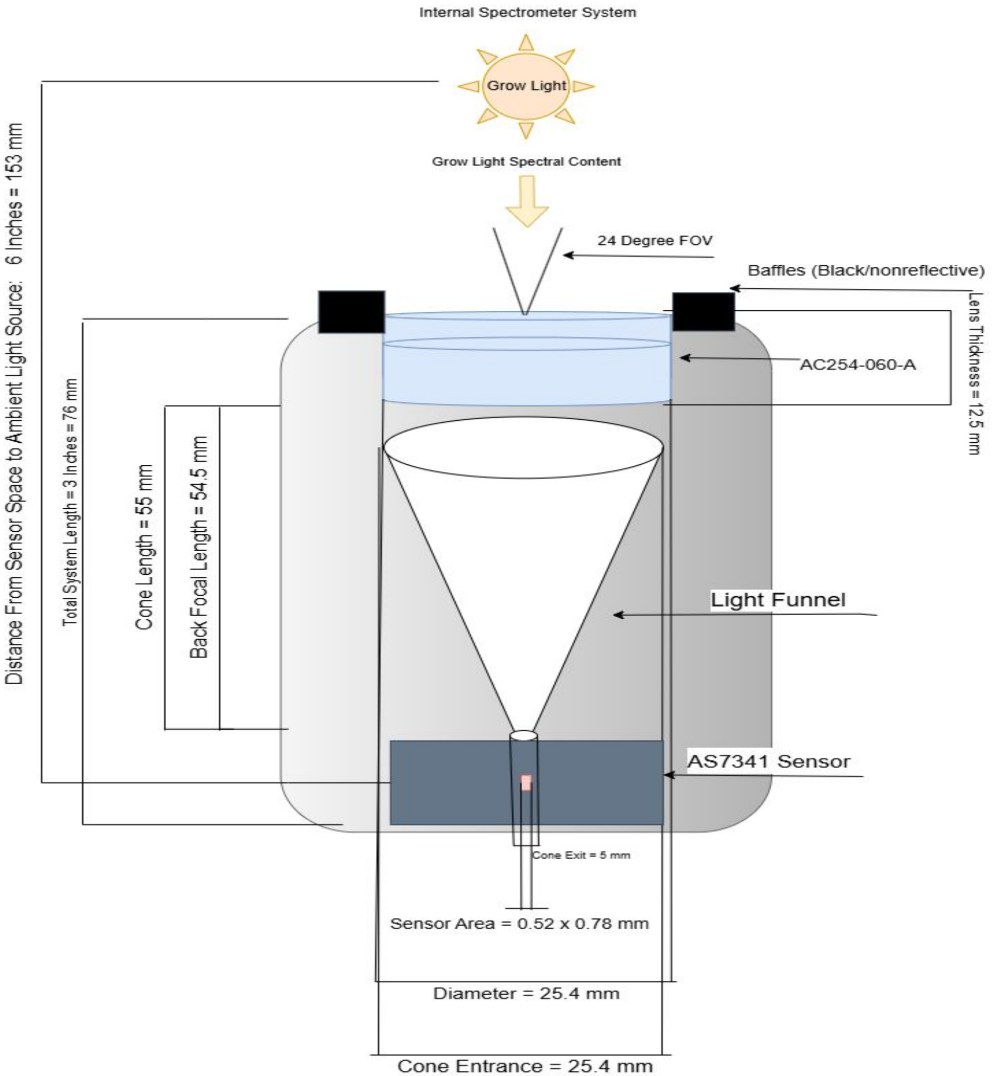
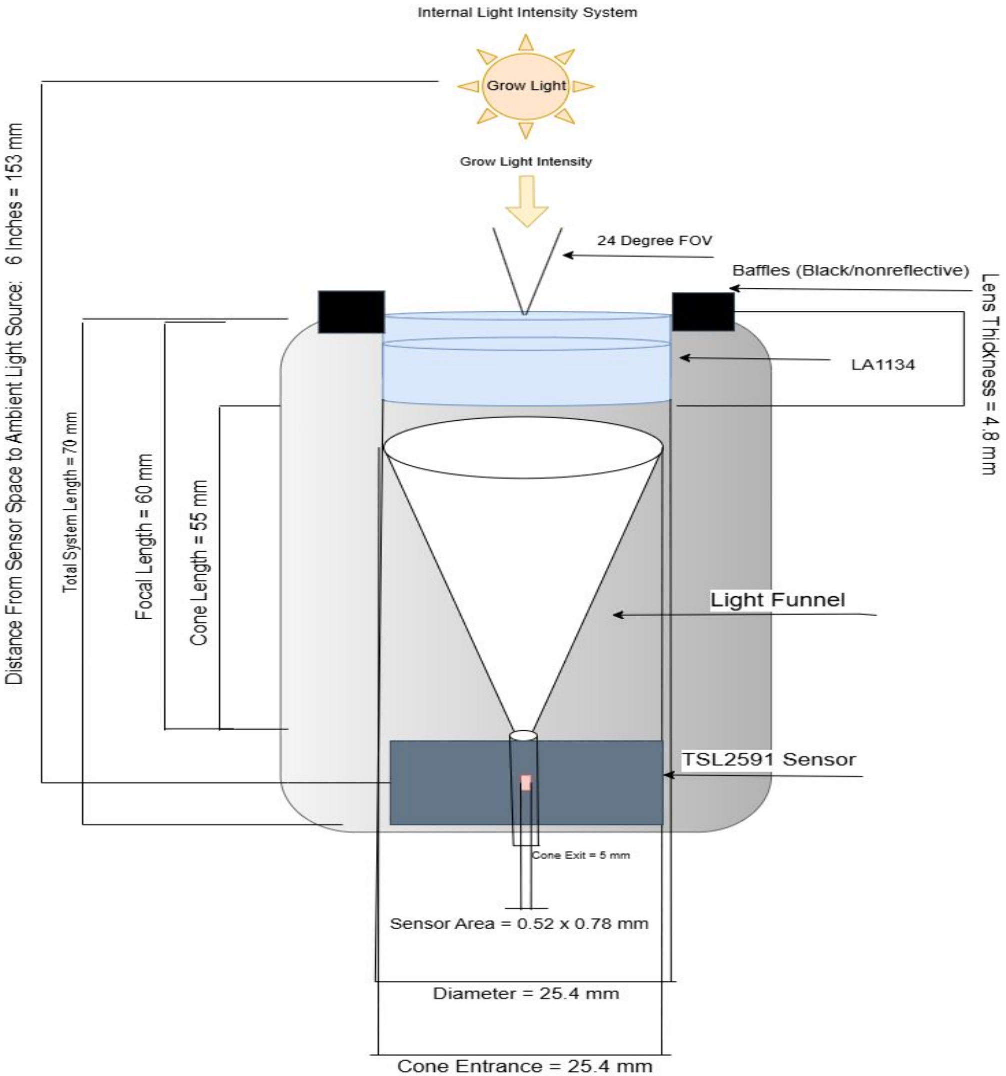
Ryan

Optics with Plant



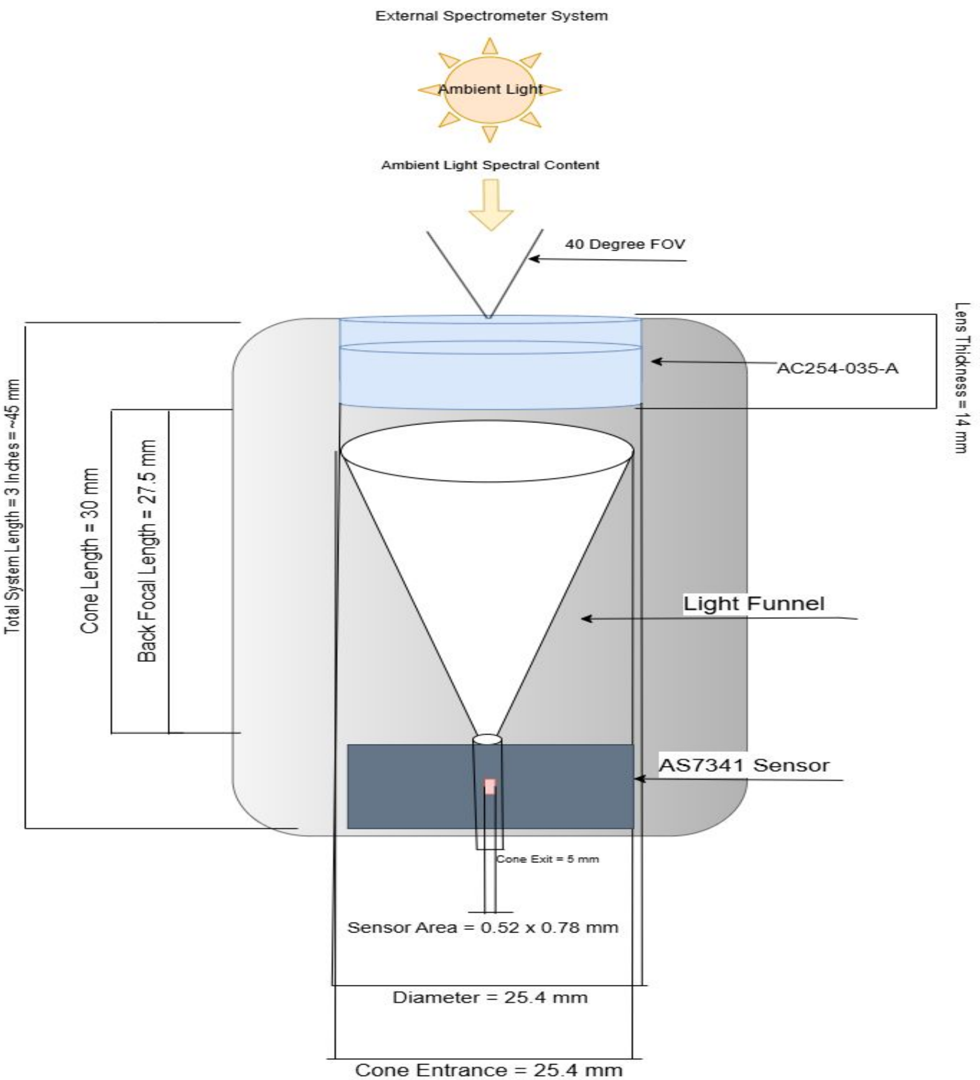
PSE, Ryan

Internal Spectrometer System



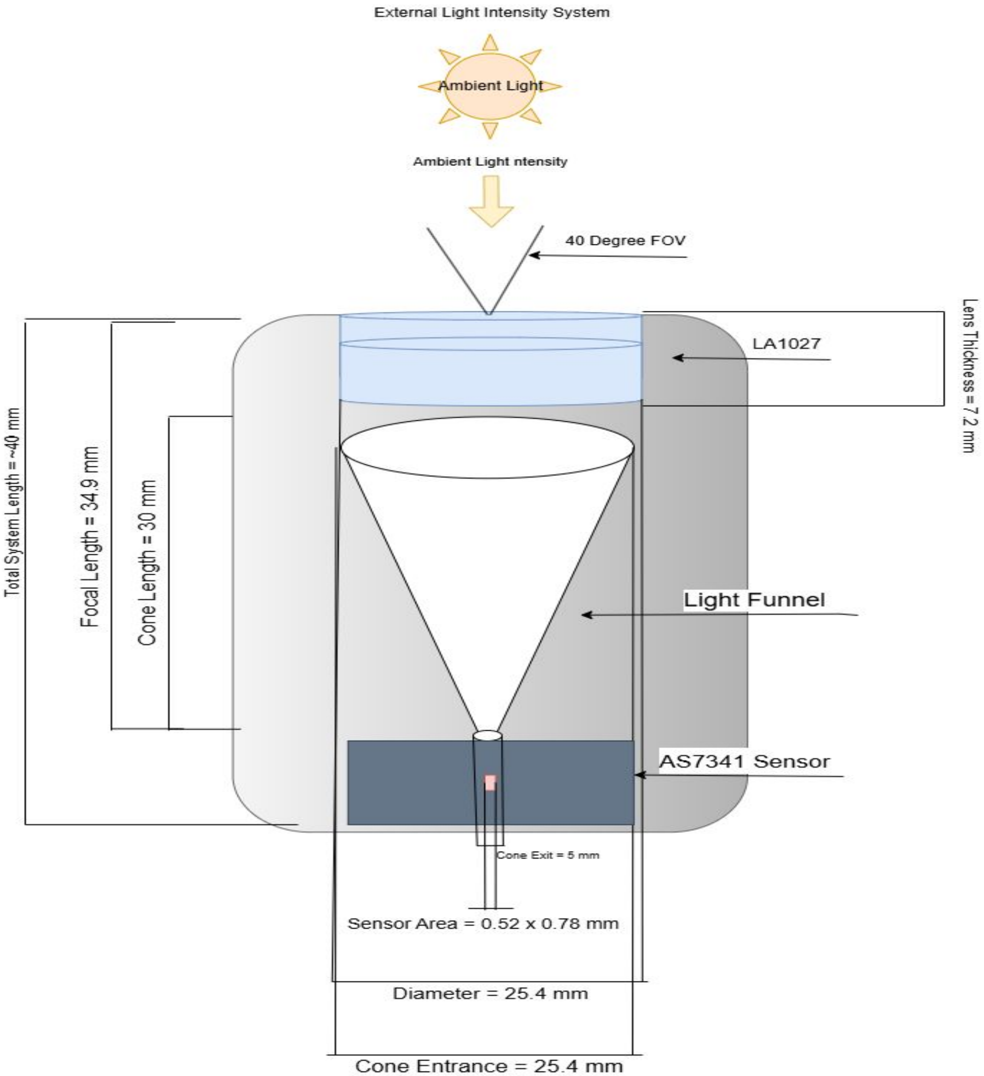
PSE, Ryan

Internal Light Intensity System



PSE, Ryan

External Spectrometer System



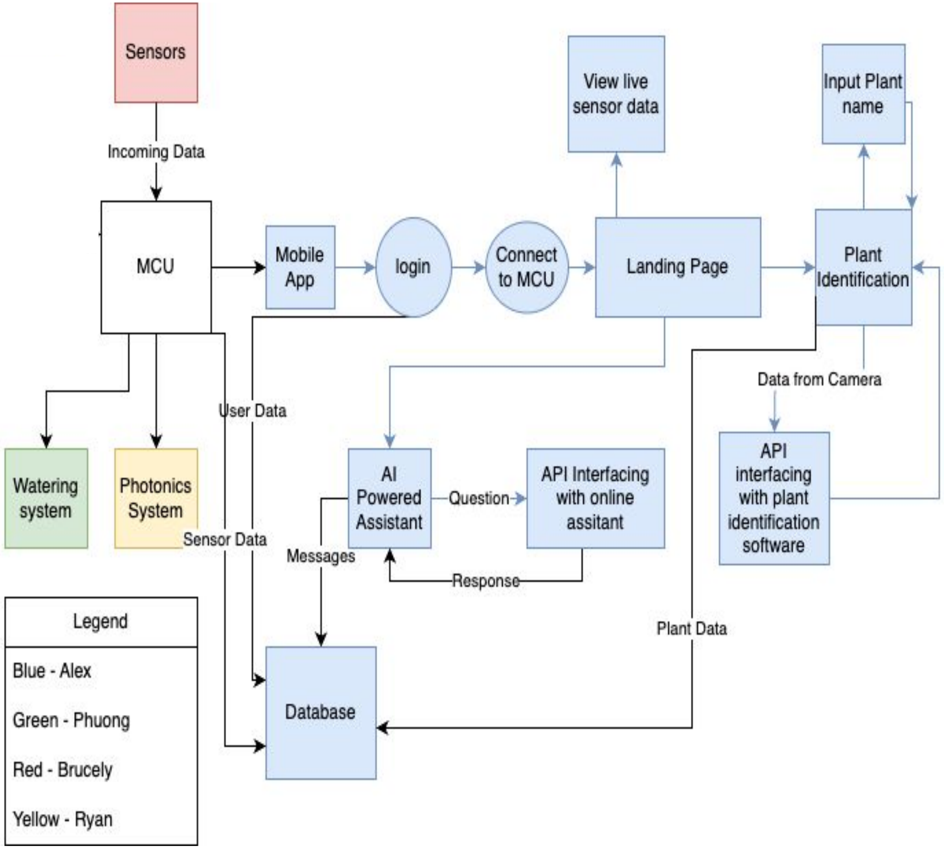
PSE,
Ryan

External Light Intensity System

Alex Beaufort
CPE

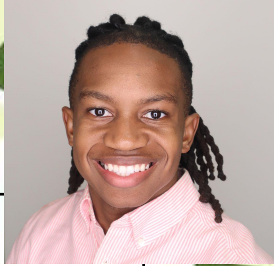
Software Design

Software/Data FlowChart



APP Technologies

Alex Beaufort, CPE



Criteria	Native (Swift/Kotlin)	Cross-Platform (Flutter/React Native)	Web App
Performance	optimized for platform	Good, near-native performance	Moderate, depends on browser performance
Code Base	Requires separate codebases	Single codebase for both platforms	Single codebase accessible from any device
Maintenance	High, separate updates for each platform	Easier, single update across platforms	Easiest, updates deployed directly to the server
Device Integration	Full access to native features (GPS, sensors)	Limited access, but supports most common features	Limited access, relies on web APIs
User Accessibility	Requires app installation	Requires app installation	Accessible from any device with a browser

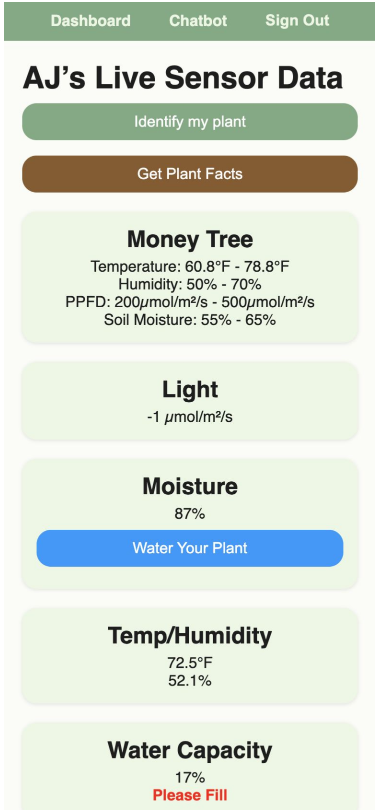
Backend Technologies

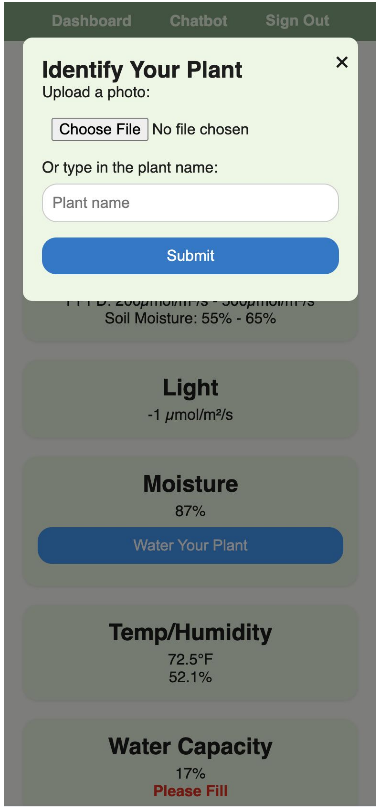
Alex Beaufort, CPE

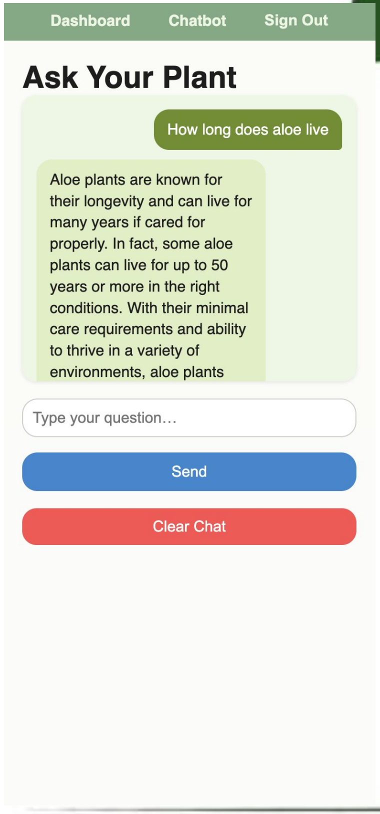
Criteria	Data Model	Scalability	Realtime Updates	Offline Support	Security & Authentication	Integration (Mobile/Web)	Maintenance
Firebase	Schema-less JSON (NoSQL); hierarchical structure	Auto-scaled by Google Cloud; handles large traffic seamlessly	Built-in realtime database and Firestore listeners	Client-side SDKs provide automatic sync when back online	Built-in Firebase Authentication; granular security rules	SDKs for iOS/Android/Web; deep integration with other Firebase services	Fully managed; automatic updates and backups
MongoDB	Document-based (BSON) flexible schema	Sharding available but requires manual setup	Requires additional libraries	Offline support via 3rd-party tools or custom sync logic	Authentication/authorization via MongoDB Atlas, role-based access	Drivers available for most languages; moderate setup for mobile/web	Managed via Atlas; users manage indexing and cluster scaling
SQL	Relational tables with fixed schema; rows/columns	Vertical/horizontal scaling possible but more complex	No built-in realtime; requires polling or additional services	No native offline sync; must implement custom caching	Depends on the provider (Google Cloud SQL, AWS RDS) for auth	Connectors exist for mobile/web, but require setup of middleware/API	Maintenance (patching, backups) handled by provider if managed DB

Web App

Alex Beaufort, CPE







Alex Beaufort,
CPE

Administration

BIOSENSE POT – WORK DISTRIBUTIO

Alex Beaufort, CPE

Water Pump + Tubing System
Primary: Phuong
Secondary: Brucely

Water Reservoir + Sensor
Primary: Phuong
Secondary: Ryan

Soil Moisture Sensor
Primary: Brucely
Secondary: Phuong

Ambient Temperature Sensor
Primary: Brucely
Secondary: Alex

Light Intensity Sensors
Primary: Ryan
Secondary: Brucely

Spectrometers
Primary: Ryan
Secondary: Alex

LED Grow Light Array
Primary: Ryan
Secondary: Alex

Spectral Lighting Control
Primary: Ryan
Secondary: Alex

Microcontroller & PCB Design
Primary: Alex
Secondary: Brucely

Growth Prediction System
Primary: Alex
Secondary: Ryan

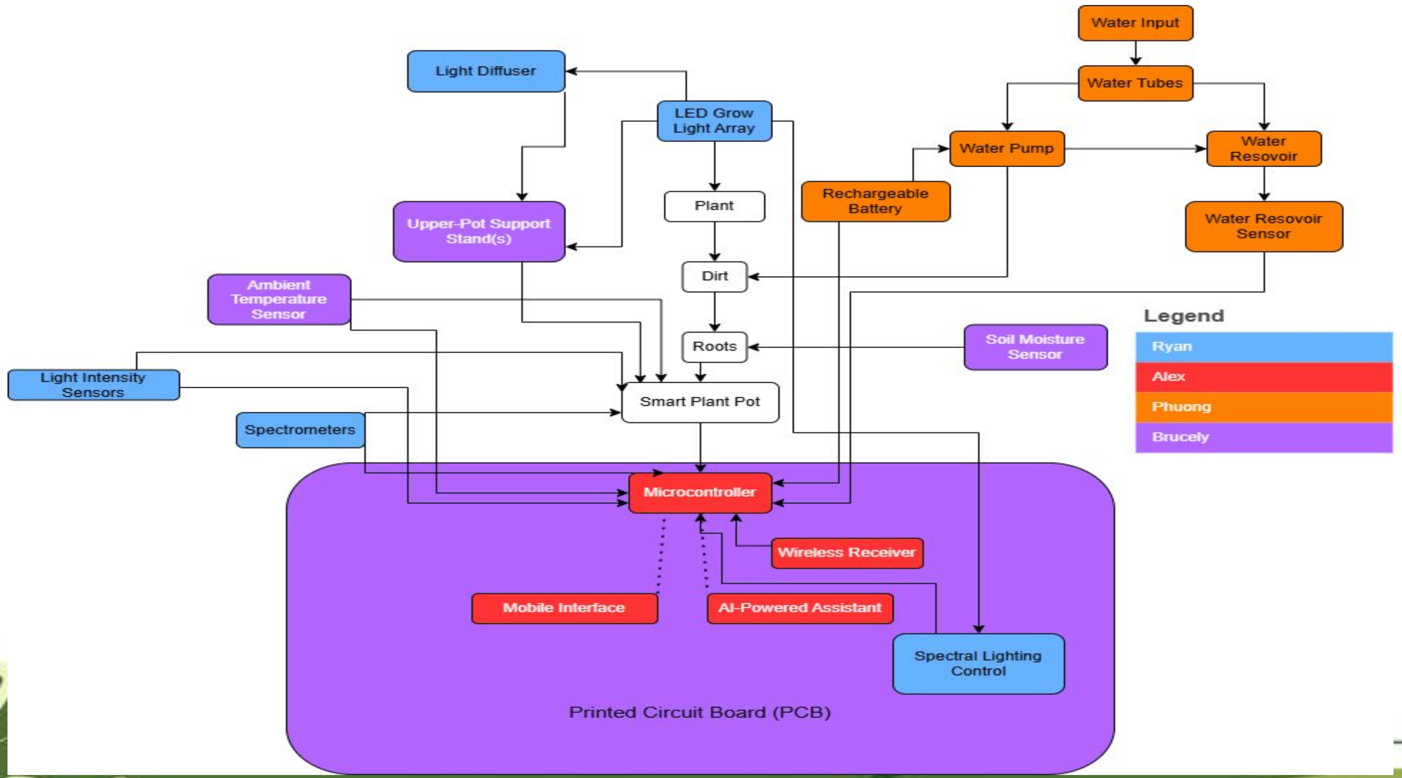
AI-Powered Assistant
Primary: Alex
Secondary: Brucely

Mobile Interface & Wireless
Primary: Alex
Secondary: Ryan

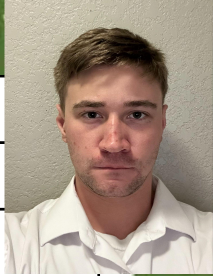
LCD Screen + Menu Buttons
Primary: Brucely
Secondary: Alex

Upper-Pot Support Structure
Primary: Brucely
Secondary: Phuong

Light Diffuser + LCD Dome
Primary: Ryan
Secondary: Brucely


Water Input
Water Tubes
Light Diffuser
LED Grow Light Array
Water Pump
Water Resovoir
Rechargeable Battery
Plant
Upper-Pot Support Stand(s)
Water Resovoir Sensor
Dirt
Ambient Temperature Sensor
Legend
Ryan
Alex
Phuong
Brucely
Roots
Soil Moisture Sensor
Light Intensity Sensors
Smart Plant Pot
Spectrometers
Microcontroller
Wireless Receiver
Mobile Interface
AI-Powered Assistant
Spectral Lighting Control
Printed Circuit Board (PCB)

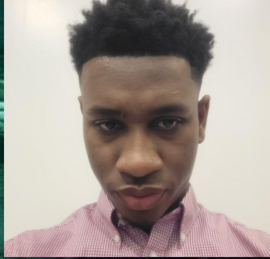
Budget & Financing



PSE,
Ryan

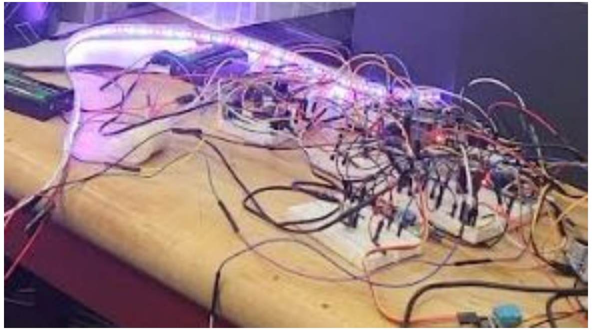
Product	Cost	Quality	Total cost
ESP32-WROOM-32-N4	$ 3.4762	1	$ 3.4762
DHT11 (temperature sensor)	$ 1.1182	1	$ 1.1182
Achromatic Doublet Lenses	$90 - $100	2	$198.3
Plano-Convex Lenses	~$25	2	$53.76
WS2812B IC RGB LEDs	$17	1	$17
Light Sensors TSL 2591	$6.95	2	$13.90
Light Sensors AS7341	$15.95	2	$31.90
Capacitive Soil sensors v1.2	$3.46	1	$3.46
Ultrasound sensor HC-SR04	$ 2.57	1	$2.57
Acrylic Sheet Diffuser	$10.95	1	$10.95
Passive component (resistors, capacitors, diodes, inductors)	$247.23	1	$247.23
Total Cost			$583.57

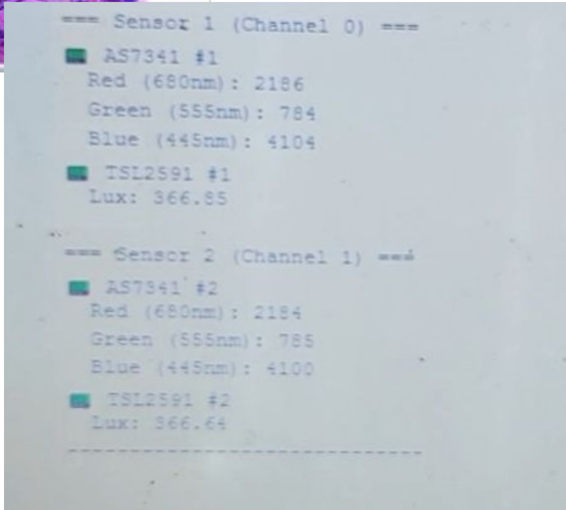
Testing and Progress



- Tested various configurations of LED grow lights under real system load.
- Found that capacitors were essential to stabilize voltage for LED operation.
- Observed that higher battery voltage (12V+) is more efficient — it reduces current draw.
- Determined that low voltage caused flickering or brightness inconsistency.

EE, Brucely Charles





=== Sensor 1 (Channel 0) ===

AS7341 #1
Red (680nm): 2186
Green (555nm): 784
Blue (445nm): 4104

TSL2591 #1
Lux: 366.85

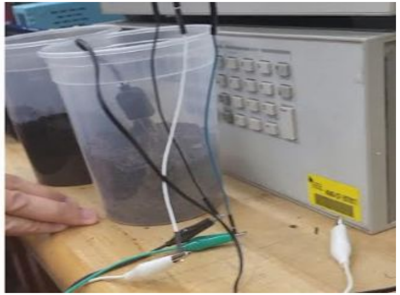
=== Sensor 2 (Channel 1) ===

AS7341 #2
Red (680nm): 2184
Green (555nm): 785
Blue (445nm): 4100

TSL2591 #2
Lux: 366.64

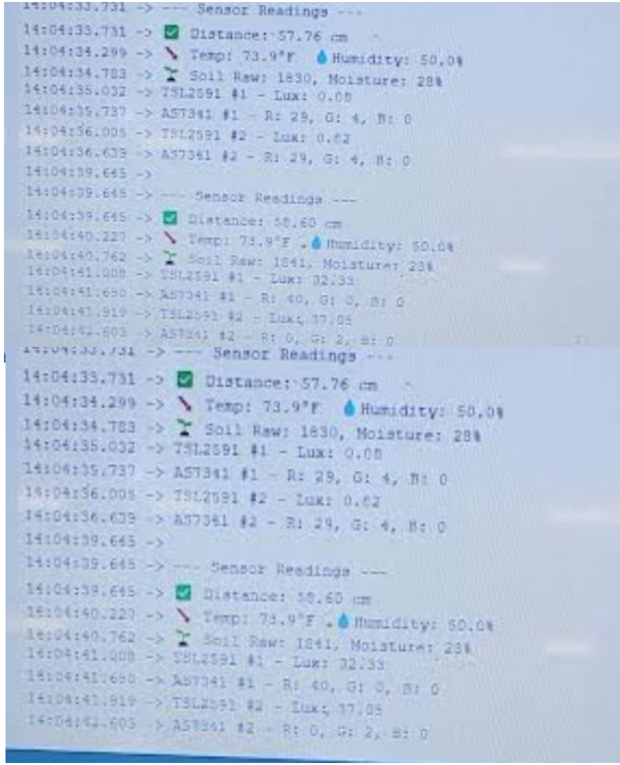
EE, Brucely Charles

- Verified water pump function and emphasized correct polarity and wiring.



- Linked pump control to soil moisture readings for automation.
- Observed that LED brightness could affect soil moisture sensor.

- Adjusted pump timing logic based on real world soil drying behavior.



EE, Brucely Charles

- Tested 3D-printed structure for thermal resistance using heated components.
- Applied thermal tape to reinforce areas exposed to heat (near LEDs).
- Found that the 3D printed reservoir leaked over time not watertight for long term use.
- Realized 3D printing is better for mounting electronics than storing liquids.

Trial Number	Reference Temperature (F)	Measured Temperature (F)	Accuracy (%)	Error (%)
Trial #1	73.4	73.2	99.7	0.3
Trial #2	73.8	73.2	99.2	0.8
Trial #3	74.6	72.5	97.2	2.8
Trial #4	73.7	73.8	100.1	0.1
Trial #5	74.9	73.8	98.5	1.5
Trial #6	73.5	72.5	98.6	1.4
Trial #7	73.1	72.8	99.6	0.4
Trial #8	73.1	72.6	99.3	0.7
Trial #9	73.7	73.0	99.1	0.9
Trial #10	73.2	72.82	99.5	0.5
Average	73.7	73.02	99.1	0.9

Temperature Video

https://youtu.be/0DZHQNTkoLk

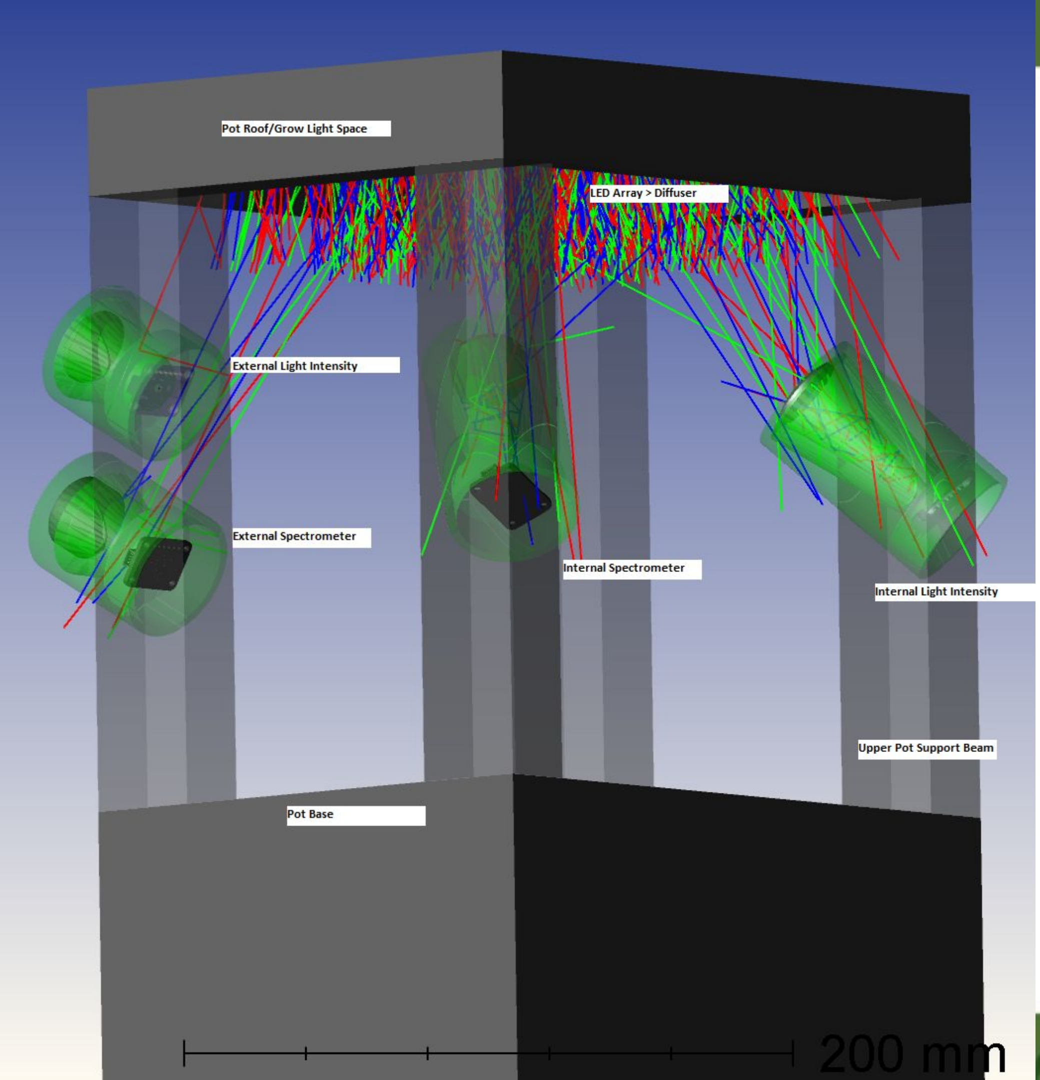
Time 21:25 - 22:50

Trial Number	Reference distance (cm)	Measured ultrasonic (cm)	Accuracy (%)	Error (%)
Trial #1	8	7.9	98.8	1.2
Trial #2	12	11.76	98	2
Trial #3	15	14.7	98	2
Trial #4	15	14.99	99.9	0.1
Trial #5	10	9.76	97.6	2.4
Trial #6	17	16.58	97.5	2.5
Trial #7	7	6.79	97	3
Trial #8	8	7.8	97.5	2.5
Trial #9	9	8.9	98.9	1.1
Trial #10	11	11.16	101.5	1.5
Average	11.2	11.03	98.5	1.8

Ultrasonic sensor Video

https://youtu.be/0DZHQNTkoLk

Time 22:50 - 24:30



PSE, Ryan

Prototyping and Testing

Prototyping and Testing

PSE,
Ryan

d_{total} = total distance from sensor to LED array

d_{lens} = distance from sensor to lens (focal length)

d_{diff} = distance from LED array to diffuser

t_{diff} = thickness of diffuser

$$z = d_{\text{total}} - d_{\text{lens}} - d_{\text{diff}} - t_{\text{diff}}$$

D_{lens} = lens diameter

f = lens focal length

$$r_{\text{footprint}} = \left(\frac{D_{\text{lens}}}{2}\right) \cdot \left(\frac{z}{f}\right)$$

$$D_{\text{footprint}} = 2 \cdot r_{\text{footprint}}$$

s_x = LED spacing along strip (long axis)

s_y = strip spacing (short axis)

x_i, y_j = coordinates of each LED

$$\sqrt{x_i^2 + y_j^2} \le r_{\text{footprint}} \quad \Rightarrow \quad \text{LED is captured}$$

$$N_{\text{captured}} = \text{number of LEDs satisfying condition}$$

N_x = LEDs per strip

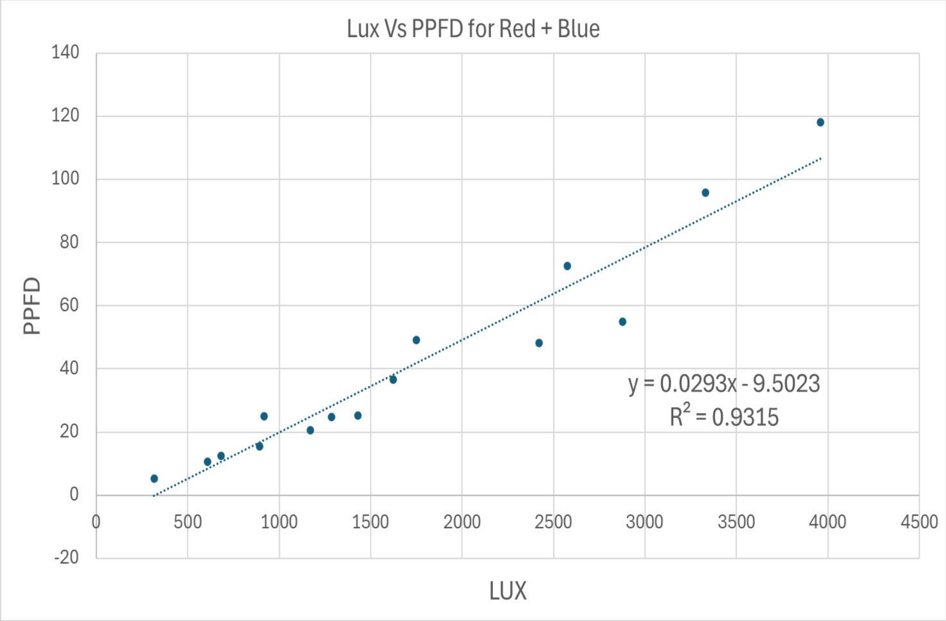
N_y = number of strips

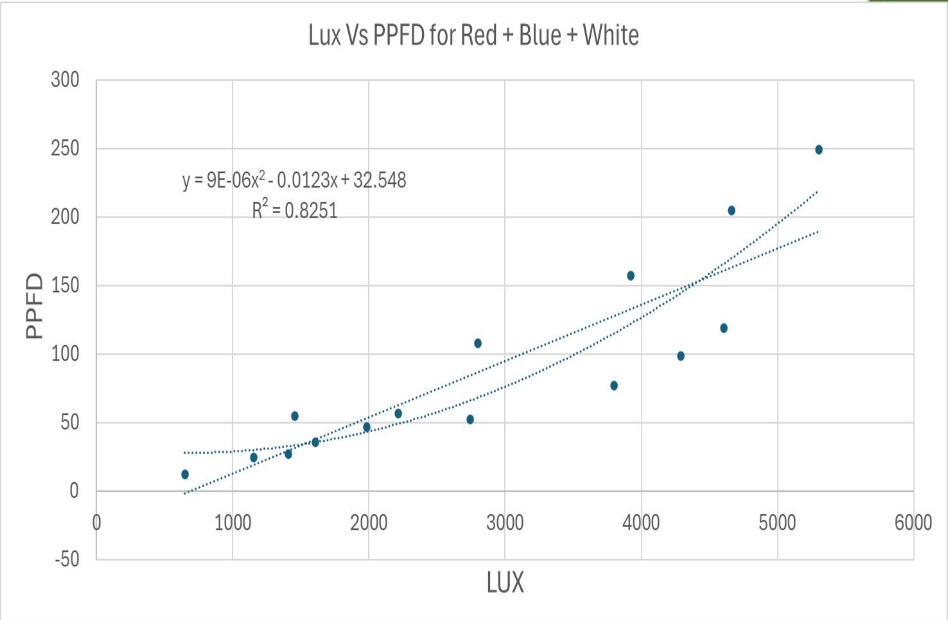
$$N_{\text{total}} = N_x \cdot N_y$$

$$\text{Scaling Factor} = \frac{N_{\text{total}}}{N_{\text{captured}}}$$

Prototyping and Testing

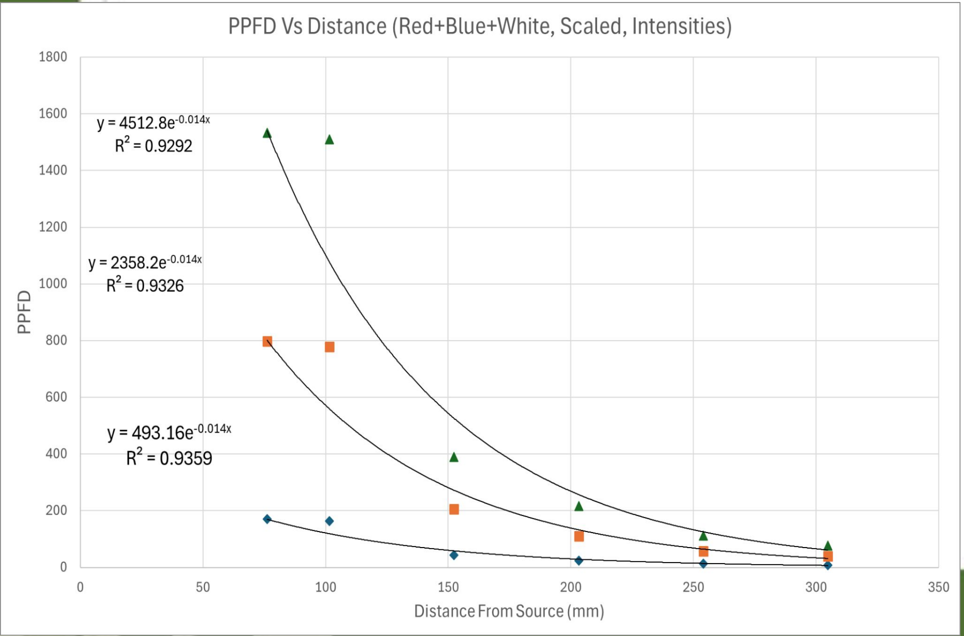
PSE,
Ryan

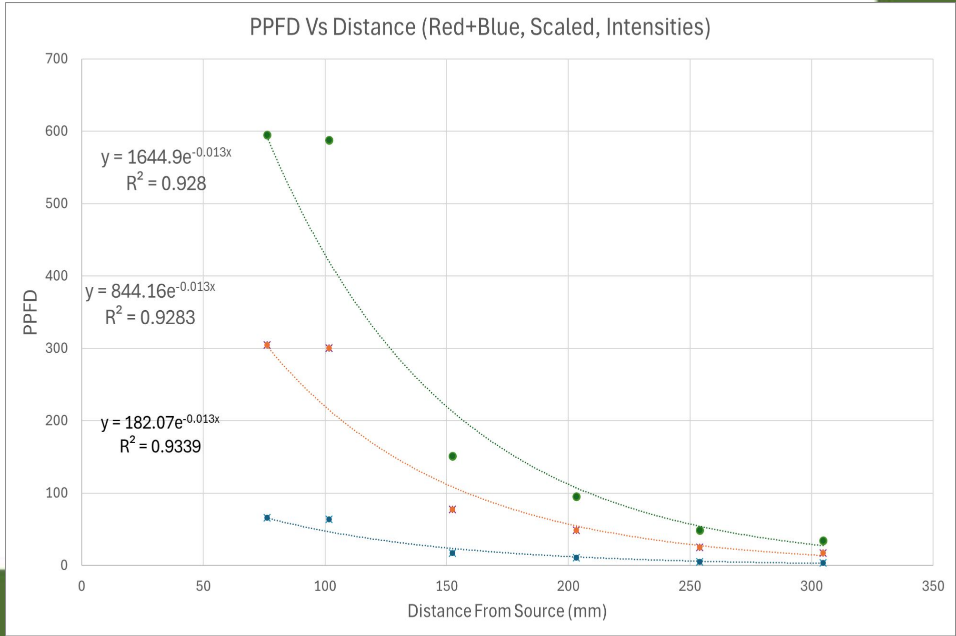




Prototyping and Testing

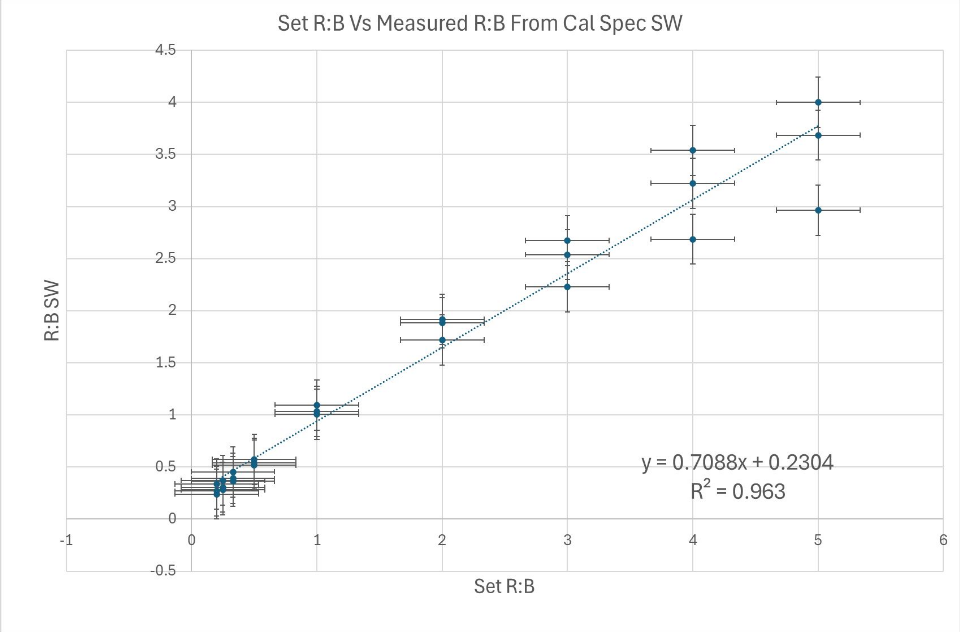
PSE, Ryan

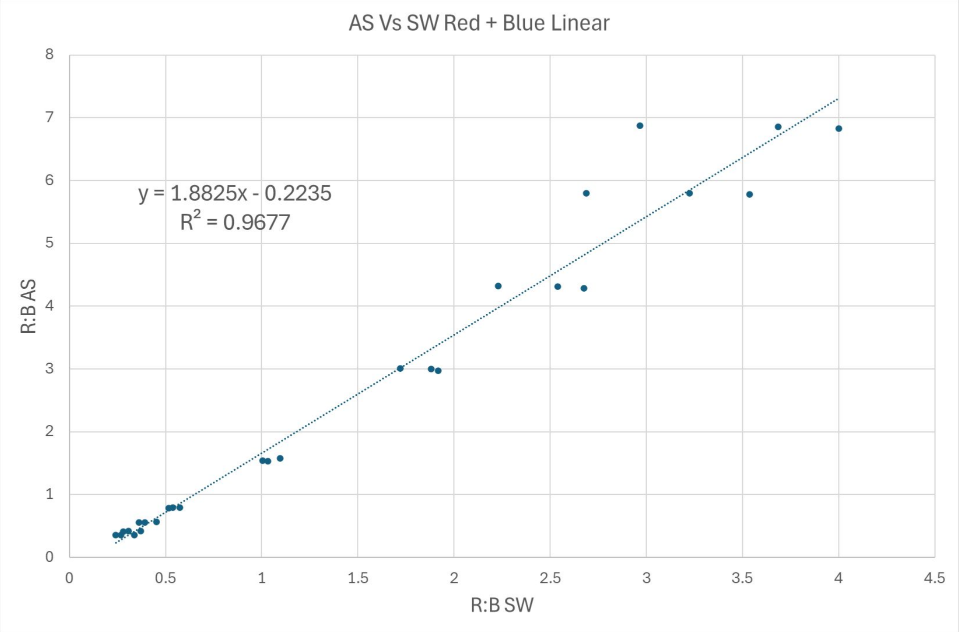




Prototyping and Testing

PSE, Ryan





Prototyping and Testing

PSE, Ryan

Plant-to-Opening Vertical Distance

$$d = |h - \Delta|$$

d = vertical distance from plant top to center of the opening (mm)

h = vertical distance from plant top to diffuser (mm)

Δ = vertical distance from center of opening to diffuser (mm)

Solid Angle of Rectangular Opening

$$\Omega_{\text{opening}} = 4 \cdot \sin^{-1}\left(\frac{a \cdot b}{\sqrt{(a^2 + 4d^2)(b^2 + 4d^2)}}\right)$$

Ω_{opening} = solid angle of the window as seen from the plant (sr)

a = width of rectangular opening (mm)

b = height of rectangular opening (mm)

d = from step 1

Cosine Correction for Sensor Tilt

$$\Omega_{\text{adjusted}} = \Omega_{\text{opening}} \cdot \cos(\theta)$$

Ω_{adjusted} = adjusted solid angle based on sensor's angular offset (sr)

θ = angle between sensor's viewing axis and the normal to the window degrees)

Solid Angle of the Sensor (Circular Cone View)

$$\Omega_{\text{sensor}} = 2\pi\left(1 - \cos\left(\tan^{-1}\left(\frac{r}{f}\right)\right)\right)$$

Ω_{sensor} = solid angle of the sensor system (sr)

r = radius of sensor lens aperture (mm)

f = focal length of lens in front of sensor (mm)

Scaling Factor Between Sensor and Window

$$\text{ScalingFactor} = \frac{\Omega_{\text{adjusted}}}{\Omega_{\text{sensor}}}$$

This tells how much more light the plant receives (through the opening) compared to what the sensor sees directly

Final Lux and PPFD Estimate

$$\text{ScaledLux} = \text{RawLux} \cdot \text{ScalingFactor}$$

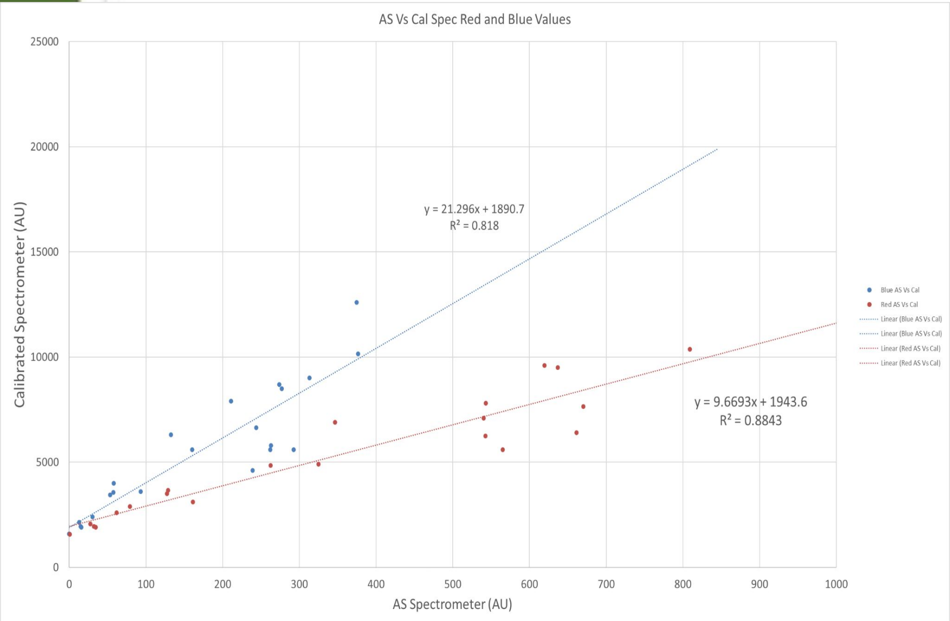
$$\text{PPFD} = m \cdot \text{ScaledLux} + b$$

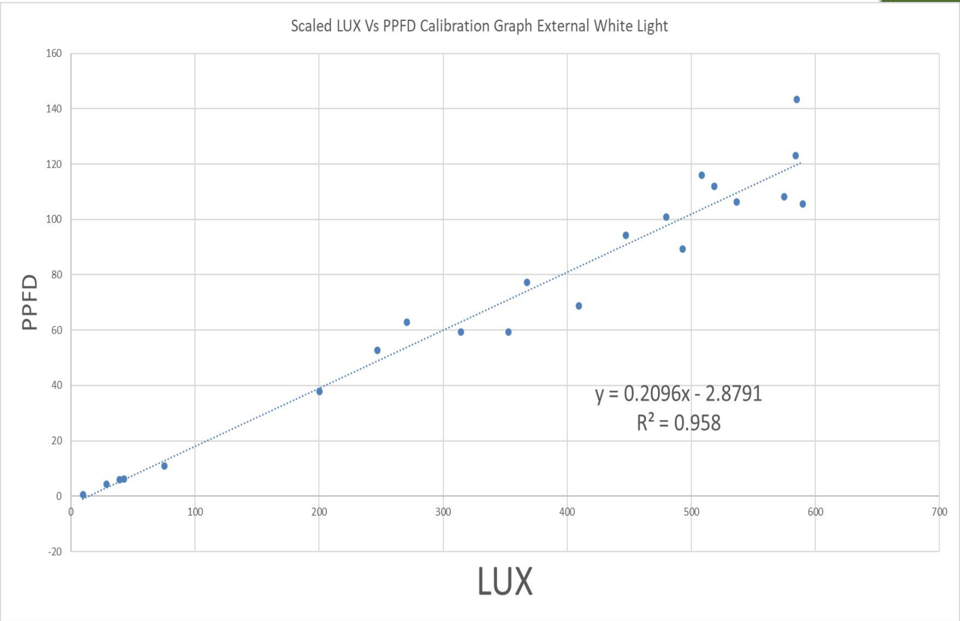
RawLux = Lux measured by the external sensor

m, b = constants from Lux-to-PPFD calibration (linear fit)

Prototyping and Testing

PSE, Ryan





Thank You