GreenSync

A Smart Home Plant Care Optimization System

Group 12

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Our Team

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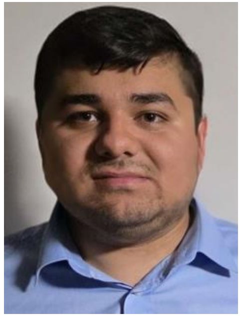

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CPE

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Project Motivations

- Houseplants are more popular than ever for aesthetics, air quality, and stress relief
- Many die each year from **overwatering, underwatering, or poor sunlight**
- These challenges discourage casual plant owners
- Our team is inspired to design a **smart, reliable care system**
- Applies our ECE skills: microcontrollers, sensors, power, and system integration
- Personal connection: we've all struggled with plant care ourselves
- Broader value: supports wellness, sustainability, and future scalability

Project Goals

- Provide an efficient, reliable solution for indoor plant care using automation
- Reduce daily burden of watering through smart sensing & control
- Monitor moisture, sunlight, and growth with real-time feedback
- Enable user engagement with camera-based tracking and time-lapse
- Deliver an intuitive mobile app interface for data & care profiles
- Integrate hardware + software into a modular, extensible system
- Promote sustainability and support scalable multi-plant expansion

Objectives & Features

- 💧 **Watering System**
- Compact relay pump controlled by the MCU
- Responds to soil moisture levels, avoids overwatering
- 🔆 **Lighting System**
- LED grow light for low-sunlight environments
- Automated activation using light sensor input
- 📷 **Camera System**
- Captures daily images with timestamps to create a visual time-lapse
- Enables plant growth tracking with livestream capabilities
- 📱 **Mobile App**
- Displays moisture/light readings + history log
- Plant database with optimized care profiles
- Bluetooth data sync from microcontroller
- 🔌 **System Integration**
- ESP32 manages sensors along with mobile app communication
- Modular design for future expansion into stretch goals

Stretch Goal Features

- **Notifications & Alerts** – Mobile alerts for moisture, light, or stress conditions
- **Environmental Expansion** – Add temperature & humidity sensing
- **Enclosed Growth Environment** – Mini greenhouse with climate control
- **Edible Plant Support** – Profiles for fruits, vegetables, and herbs
- ▯ **Modular Scalability** – Multi-plant setups to create a full home garden
- **AI Plant Identification** – Auto-recognize species & load care profiles
- **Cloud Integration** – Remote monitoring, backups, and trend analysis
- **Growth Analytics** – Predictive care suggestions from sensor + image data with AI

Engineering Specifications

CATEGORY	PARAMETER	REQUIREMENT
Water System	Soil Moisture Polling Rate	Once per hour
	Watering Activation Delay	Less than 3 seconds after threshold is crossed
	Water Delivery Accuracy	±5% of target watering duration
	Water Pump Response Time	Less than 5 seconds
	Moisture Sensor Lifetime	At least 6 months (under standard use)
	Moisture Sensor Accuracy	±5% volumetric water content
Light System	Light Sensor Polling Rate	Once per 3 hours
	Grow Light Power Consumption	Less than 20 Watts
	Grow Light Response Time	Less than 5 seconds
Camera System	Image Capture Frequency	Once per day
	Image Resolution	Minimum 1080×720 pixels
	Image Storage Capacity	At least 30 days of daily images (locally)
	Timestamp Accuracy	Within ±1 minute of scheduled capture
	Camera Wake & Capture Time	Less than 10 seconds
User Interface	Data Sync Interval	At least once per hour
	Supported Plant Profiles	Minimum of 5 preloaded species
	Sensor Data Display Delay	Less than 15 seconds after MCU transmits
System Power	System Power Source	12V DC adapter (baseline configuration)
	Operating Temperature Range	10°C to 40°C

Microcontroller Comparison

MCU	CORE & SPEED	WIRELESS CONNECTIVITY	GPIO & ADC	EASE OF DEVELOPMENT	KEY PROS & CONS
Arduino Uno (ATmega328P)	8-bit @ 16 MHz	None	14 GPIO, 6 PWM, 6 ADC	Very High (beginner-friendly, Arduino IDE)	Great community support, but no Wi-Fi; limited speed and RAM
Raspberry Pi 4 Model B	Quad-core Cortex-A72 @ 1.5 GHz, up to 8 GB RAM	Built-in Wi-Fi & Bluetooth	40 GPIO (digital), no native ADC	High (Linux-based OS, Python, C/C++, huge ecosystem)	Extremely powerful for multimedia & networking, supports high-res camera; higher cost & power usage
ESP8266	32-bit @ 80–160 MHz (Tensilica L106)	Wi-Fi only	Fewer GPIO, 1 ADC	Medium (Arduino & ESP-IDF)	Good for simple IoT, but lacks Bluetooth and limited multitasking
STM32 Blue Pill (STM32F103C8T6)	32-bit @ 72 MHz (Cortex-M3)	None	37 GPIO, 10 ADC channels	Medium–Low (STM32CubeIDE, more complex setup)	Powerful and flexible, but no built-in wireless; higher development complexity
ESP32	Dual-core 32-bit @ up to 240 MHz	Wi-Fi + Bluetooth	Many GPIO, ADCs, PWM, capacitive touch, etc.	High (Arduino, ESP-IDF, camera & sensor support)	All-in-one solution, fast, wireless-ready, multitasking; efficient for IoT like GreenSync

MCU Selection:

ESP32 and Raspberry Pi 4

- ESP32 chosen for **sensors, pump, and grow light control**
- Built-in Wi-Fi & Bluetooth, low power, real-time performance
- Raspberry Pi 4 chosen for **high-resolution camera and streaming**
- Powerful quad-core CPU, strong multimedia and networking support
- Dual-board setup balances **efficiency and advanced processing**
- Scalable design supports **future AI/vision features**

Moisture Sensor Technologies

SENSOR TYPE	MEASUREMENT PRINCIPLE	ACCURACY / PRECISION	DURABILITY	COST & COMPLEXITY	BEST SUITED FOR
Capacitive Sensor	Dielectric permittivity	High	High (non-corrosive)	Low cost, easy integration	DIY & microcontroller projects
Resistive Sensor	Electrical resistance	Low to Moderate	Low (corrodes over time)	Very cheap, very simple	Education, hobby projects
Tensiometer	Soil water tension (suction)	Moderate	Moderate	Moderate cost, analog data	Agricultural studies
TDR/FDR Sensor	Electromagnetic reflection	Very High	High	High cost, complex circuit	Precision irrigation research
Gypsum Block Sensor	Resistance via gypsum block	Low to Moderate	Moderate	Low cost, old tech	Basic systems, field demos
Sensor Array / Multi-Point	Spatial moisture sampling	Varies (multi-point)	High (varies by sensor)	High cost, advanced logic	Greenhouses, large plots

Moisture Sensor Technologies Selection

Capacitive Soil Moisture Sensor

- Chosen for the best balance of **accuracy, durability, and easy integration**.
- Measures moisture via **dielectric permittivity** (no metal-to-soil contact), unlike corrosive resistive probes.
- **Long-term reliability** with reduced maintenance needs.
- **Fast response** and **stable readings** for real-time irrigation control.
- **ESP32-friendly**: works at low voltage with simple **analog/PWM outputs**, streamlining design.
- Though slightly pricier, its **accuracy, robustness, and low power** make it the most **practical, future-proof** option.

Grow Light Technologies Comparison

TECHNOLOGY	ENERGY CONSUMPTION	LIFESPAN	COST	HEAT EMISSION	LIGHTING CONTROL
Fluorescent	Medium	10,000–20,000 hrs	Low	Low–Medium	Limited (On/Off only)
HID (MH/HPS)	High	10,000–24,000 hrs	Medium	High	Limited (Manual Dimming)
LED	Low	50,000+ hrs	Medium	Very Low	Excellent (PWM, Smart Control)
Incandescent	Very High	~1,000 hrs	Very Low	Very High	Minimal (On/Off only)
Plasma	Very High	30,000 hrs	Very High	High	Limited (Complex Drivers)
Infrared (IR)	Medium (Supplemental)	30,000 hrs	High	Medium	Moderate (Spectrum Blending)

Grow Light Technologies Selection

LED

- Chosen for **energy efficiency, long lifespan, and automation compatibility** in a compact smart garden.
- Use **significantly less power** than fluorescent/HID while providing **consistent intensity** and **customizable spectra**.
- **Low heat output** reduces or eliminates extra cooling—ideal for small enclosures.
- Support **PWM dimming** and smart integration for **precise, sensor-driven light scheduling**.
- Enable **fine control of light quality** to promote healthy growth across plant stages.
- Though pricier upfront, their **durability, efficiency, and flexibility** make LEDs the most **practical, future-proof** choice for GreenSync.

Grow Lights

MODEL	POWER DRAW	SPECTRUM	COVERAGE AREA	PROS	CONS	COST
Roleadro LED Grow Light Panel	~45W	Full Spectrum (Red + Blue)	~2' × 2'	Energy-efficient; Good light intensity; Affordable	No dimming control; External timer needed	$30–$40
GE BR30 LED Grow Light Bulb	~9W	Full Spectrum	Single Plant	Compact; Fits standard sockets; Low cost	Limited coverage; No dimming; Low intensity	$10–$15
Spider Farmer SF-1000	~100W	Full Spectrum (Premium diodes)	Up to 2' × 2'	High-quality light; Dimmable; Great for automation	High cost; Large for small systems	$120–$150
PicoFarm LED Grow Light Panel	18W	Full Spectrum (36 LM301b LEDs)	Single Plant	Compact (11×10 cm); High efficiency (220 lm/W); PWM/analog control; Low heat	Limited coverage area (best for single plant)	~$60–$70

Grow Light Selection:

PicoFarm LED Grow Light Panel

- **Compact design** (11×10 cm) ideal for single-plant setups
- **Low power draw (18W)** with high efficiency (220 lm/W)
- **Full-spectrum LEDs (36 LM301b)** support all growth stages
- **Onboard driver** allows PWM/analog control via ESP32
- Backed by a **mini sponsorship** from PicoFarm, providing hardware support,

  THANKS PICOFARM!!! :D

PicoFarm

Camera

COMPONENT	RESOLUTION (STILL/STREAM)	INTERFACE	CONNECTIVITY	EASE OF INTEGRATION	PROS	CONS	COST
ESP32-CAM (OV2640)	2 MP / ~640×480 stream	UART / SPI	Built-in Wi-Fi & BT	Medium (requires flashing)	Integrated MCU + camera; Wireless; Includes microSD storage	Limited resolution; setup requires flashing	Low ($8–$12)
Arducam Mini (OV2640)	2 MP / ~640×480 stream	SPI	None	Medium-Low (external MCU)	Compact; Flexible for modular systems	Needs separate MCU; extra wiring & coding	Low-Med ($12–$18)
OV5640 Module	5 MP / ~720p–1080p stream	DVP / MIPI	None	Low (special drivers req.)	Higher resolution; Better low-light performance	Complex integration; high processing needs	Med-High ($20–$35)
1080P HD USB Webcam	2 MP / 1080×720 stream	USB	USB	Very High (plug-and-play)	Full HD; Wide-angle; Auto light correction; Built-in mic & cover	Limited to USB hosts (e.g. Raspberry Pi 4)	Med ($25–$40)

Camera Selection:

1080p HD USB Webcam

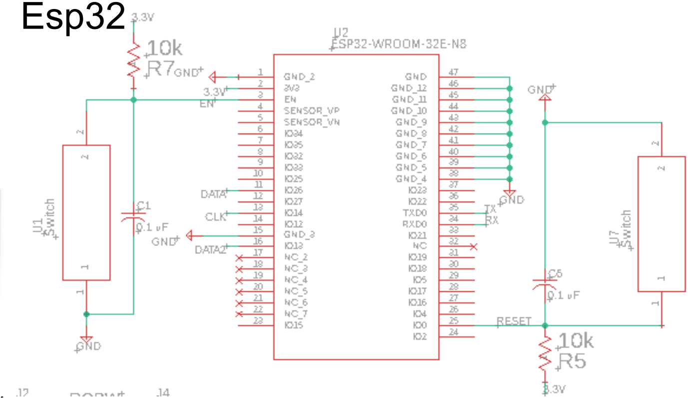
- **1080×720 resolution** for clear plant monitoring
- Wide-angle lens + auto light correction
- **Plug-and-play USB** → simple integration with Raspberry Pi 4
- □ Privacy cover + built-in microphone for flexibility
- Reliable streaming without burdening the ESP32

Hardware Flow

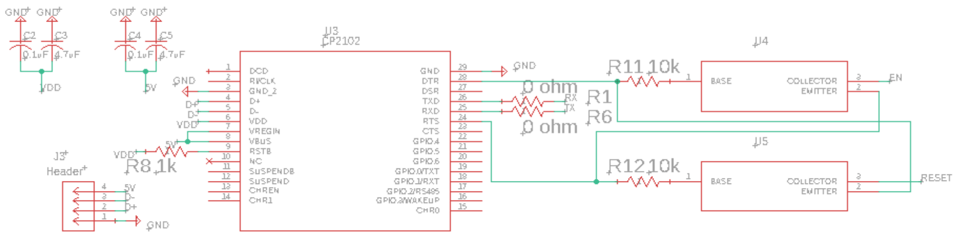
- Moisture Sensor → ESP32 reads soil hydration → triggers **Water Pump** if below threshold
- □**Light Sensor** → ESP32 measures ambient light → activates **Grow Light** when insufficient
- **ESP32** → central controller for sensors, pump, and light → transmits data to **Mobile App** via Wi-Fi/Bluetooth
- **Camera (USB Webcam)** → connected to **Raspberry Pi 4** → handles high-resolution image capture & streaming
- **Raspberry Pi 4** → sends camera data and processed information to the **Mobile App**
- **Mobile App** → displays soil moisture, light levels, and live images → allows user monitoring & interaction

Main Board

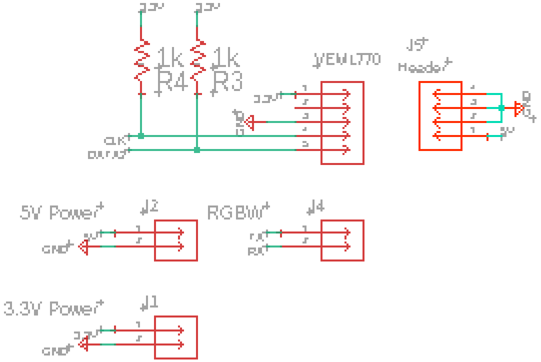
Esp32



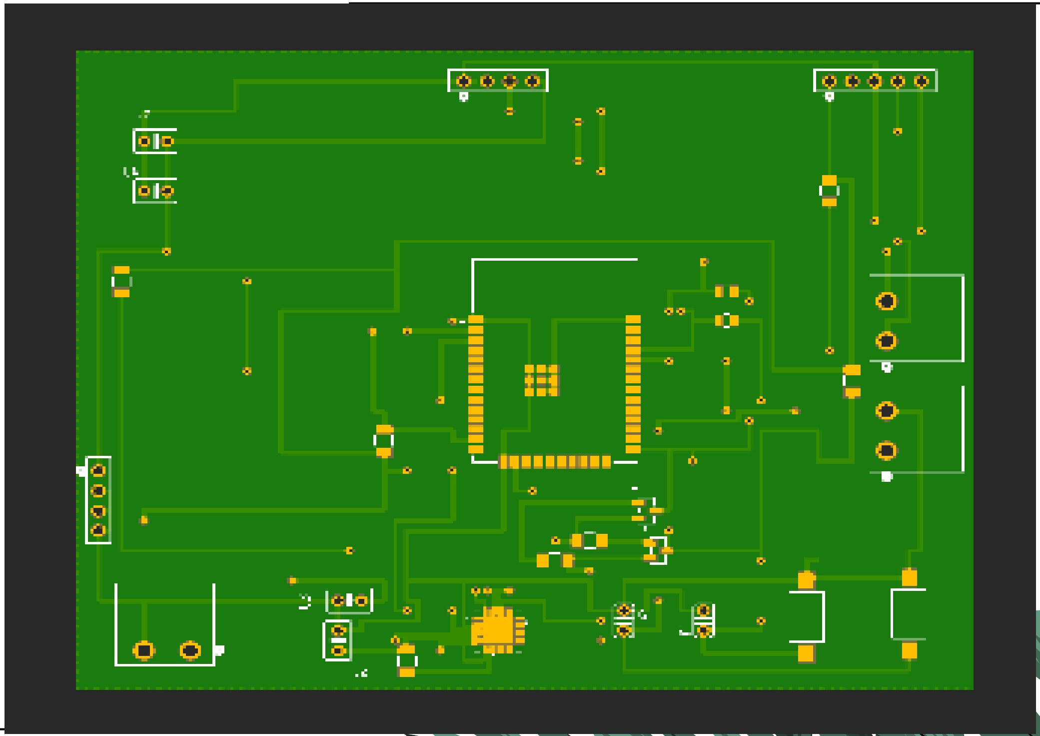
USB to UART



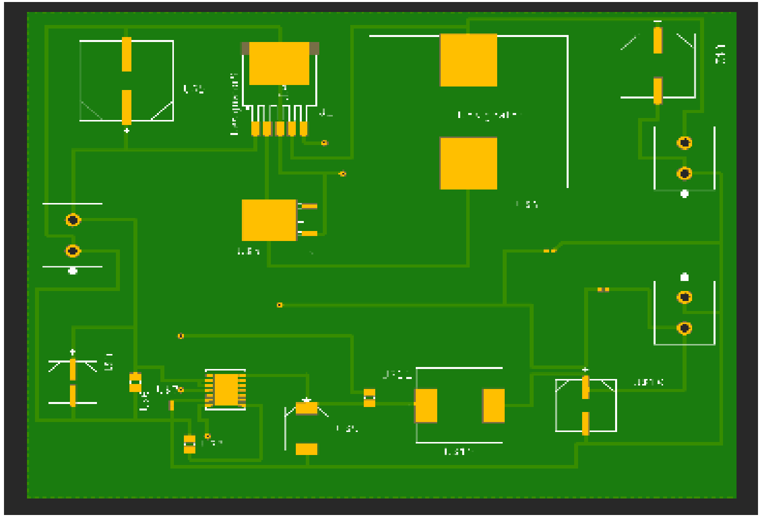
Connectors



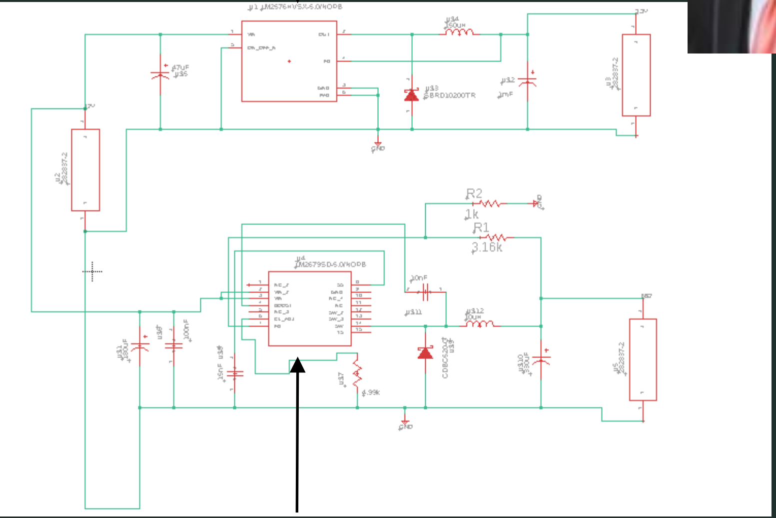
Main Board Layout



Power Supply



LM2576

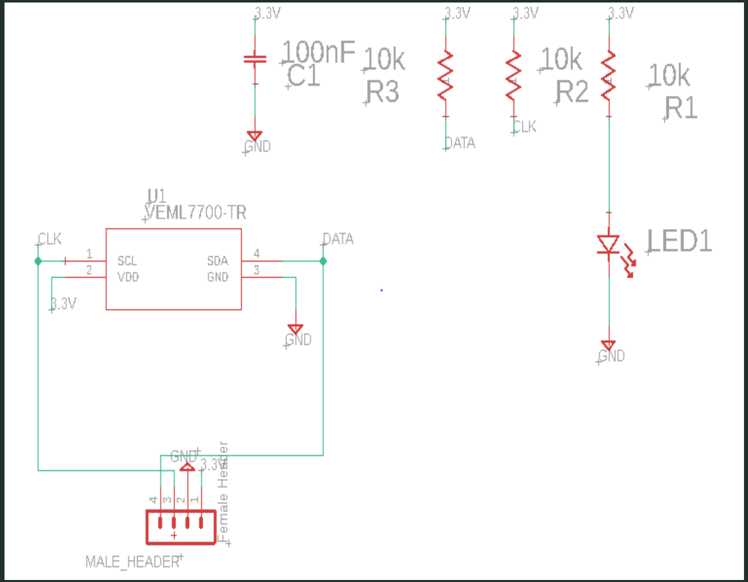


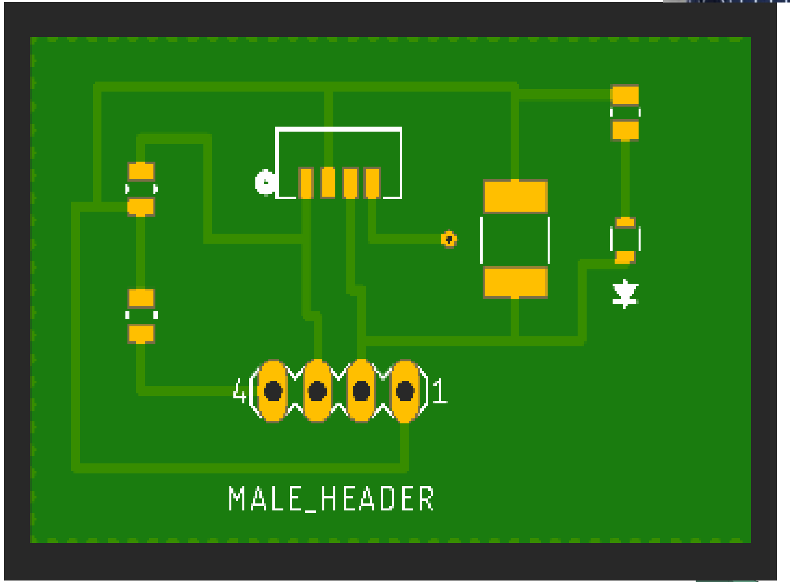
LM2796

Power Distribution Table

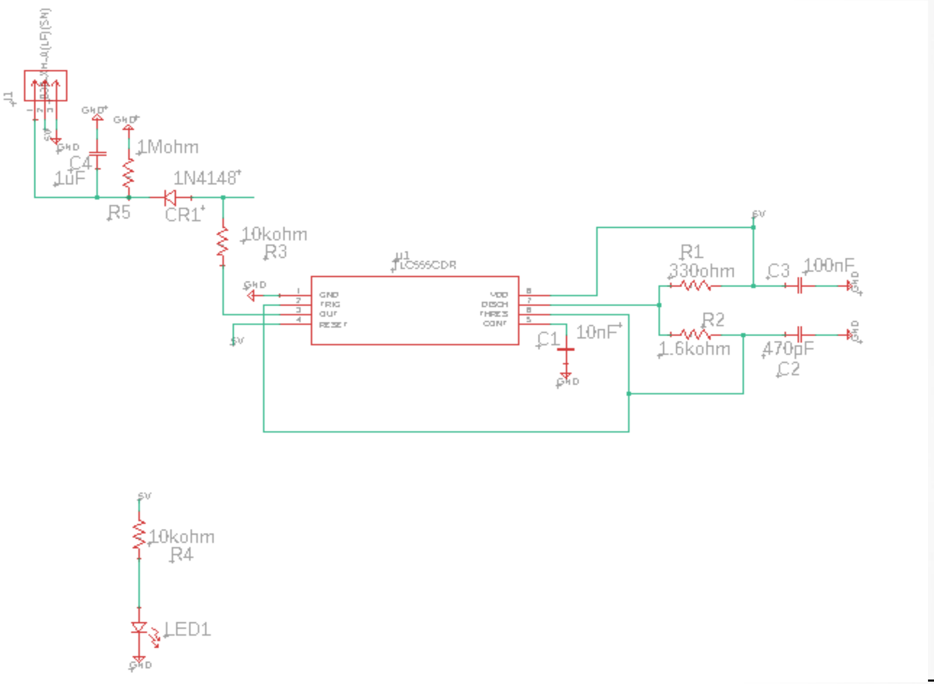
CATEGORY	LOAD / MODULE	VOLTAGE	TYPICAL CURRENT	PEAK CURRENT	EST. POWER
💡 LED Lighting	PicoFarm LED (solo panel)	5 V	3.5 A	3.5 A	~18 W
🧠 Main Controller	Raspberry Pi 4 Model B	5 V	1.5 A	3.0 A	~7.5–15 W
🚰 Water Pump	Mini Submersible Pump	5 V	0.3–0.6 A	0.8 A	1.5–3 W
⚡ Microcontroller	ESP32 (controller)	3.3 V	0.1 A	0.25 A	~0.5 W
💧 Moisture Sensor	Capacitive Moisture Sensor	3.3 V	0.01 A	0.015 A	~0.03 W
🌞 Light Sensor	Ambient Light Sensor	3.3 V	0.0002 A	0.001 A	~0.001 W

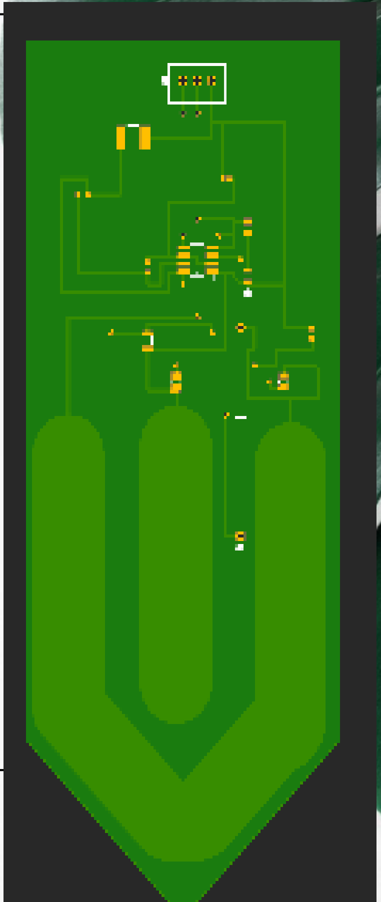
Light Sensor





Moisture Sensor





Hardware Selection: Water Pump

Water Pump Selection Summary:

- Selected Pump: Amazon Mini Water Pump
- Supply Voltage: 5V DC
- Flow Rate: 80 – 120 L/Hour
- Pump Type: Submersible DC Pump
- Maximum Lift: 40 – 110 mm
- Cost: $6.97 for four pumps
- Trade-Offs Considered: Maximum lift affects flow rate, but if pump is leveled it fits design limits
- Reasoning: Selected for cost, ease of use, and performance based off requirements

Mobile App integration

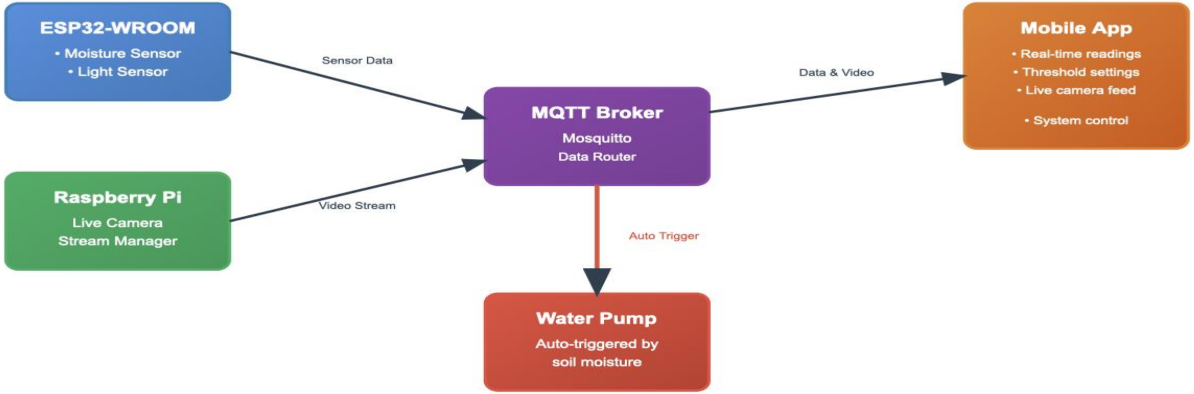
- Developed a smart plant care system combining hardware + software
- Mobile app integrated with MQTT services (Mosquitto.org)
- Hardware includes live camera, light (lux) sensor, soil moisture
- sensor, and a water pump
- Controlled by ESP32-WROOM, tested successfully on a breadboard
- System is autonomous but can also be controlled from the app

Why a Mobile App?

- **Preferred by users** → people expect mobile phone integration for convenience
- **Accessible anywhere** → monitor and control plants remotely, not limited to local access
- **Better than a website** → faster, optimized for touch, works offline or with low connectivity
- **Better than onboard UI** → avoids clunky buttons/screens, reduces hardware complexity
- **Just better**: improves engagement, provides feedback, and encourages plant care consistency

System Architecture

- ESP32-WROOM collects data from moisture & light sensors
- Raspberry Pi manages the live camera stream
- Data and video are sent to the mobile app through MQTT (Mosquitto broker)
- App shows real time readings, thresholds, and live camera feed
- Pump is triggered automatically based on soil moisture levels



Hardware Setup

- ESP32-WROOM: chosen for Wi-Fi, sensor integration, and pump control
- Sensors:
- Lux sensor → measures light exposure
- Capacitive moisture sensor → detects dry/wet soil
- Pump: powered from Arduino’s 5V rail during testing, controlled by ESP32
- Raspberry Pi camera: used for live video feed integrated into the app
- Full prototype assembled and tested on a breadboard

Why ESP32-WROOM(Comparison)

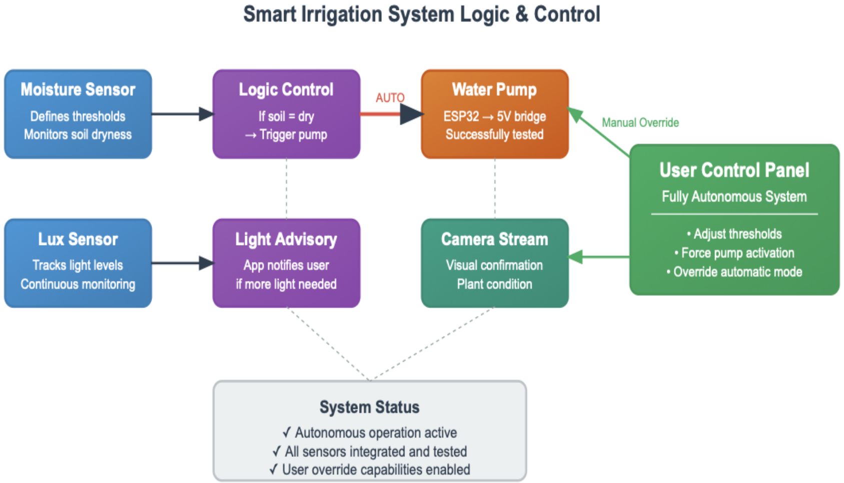
- ESP32 Wroom vs. ESP8266: more GPIO, dual core, supports Bluetooth, better for multiple sensors
- ESP32 Wroom vs. Arduino Uno/Nano: built in Wi-Fi, higher speed, more memory
- ESP32 Wroom vs. Raspberry Pi Zero: much lower power consumption, real time sensor control
- Cost effective and well supported in IoT community

Mobile App & MQTT

- Mobile app is the main interface for users
- Provides real time dashboard: soil moisture, light levels, live camera feed
- Uses MQTT with Mosquitto.org for fast, lightweight communication
- MQTT chosen over HTTP → lower latency, event driven updates
- Supports both automatic operation and manual control from the phone

Sensor Integration & Autonomy

- Moisture sensor defines thresholds → triggers pump only when soil is dry
- Lux sensor tracks light → app advises user if plant needs more exposure
- Pump control tested successfully with ESP32 bridge to 5V rail
- Camera stream integrated to confirm plant condition visually
- Fully autonomous system, but user can adjust thresholds or force actions



Development (IDE Choice)

Arduino IDE (for ESP32-WROOM programming):

- Chosen for its simplicity, large community, and fast prototyping
- Allowed us to quickly test sensors, pump control, and breadboard setups
- Wide library support made integration easier

Android Studio (for mobile app development):

- Chosen for building a native Android app with full customization
- Provided tools to integrate MQTT communication and live camera feed
- Flexible UI design to keep the app beginner-friendly and intuitive

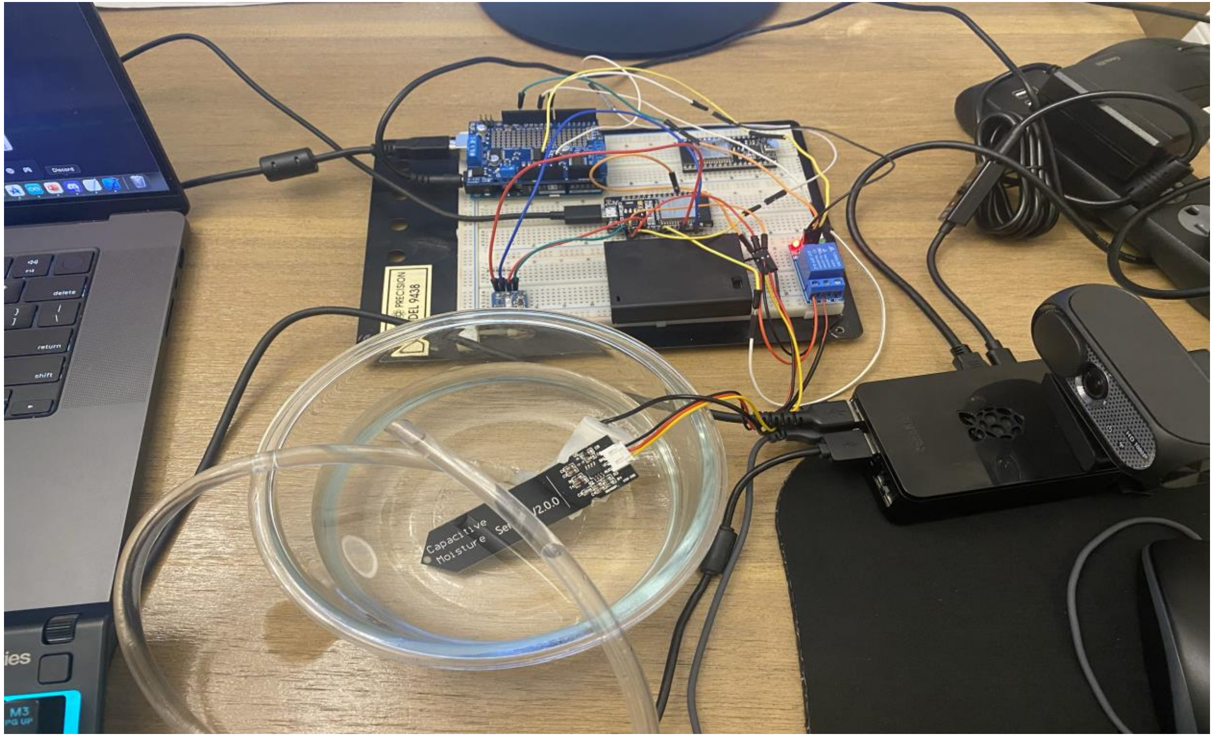
Comparison:

- PlatformIO (VS Code): more advanced features, but slower for quick testing
- ESP-IDF: professional and powerful, but too complex for our timeline
- Other mobile app builders (e.g., MIT App Inventor) were too limited for MQTT + camera

Breadboard Testing

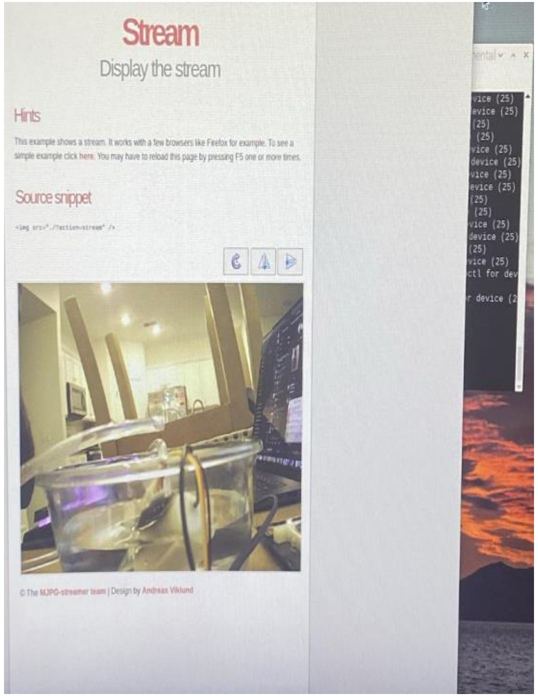
- Prototype assembled on breadboard for validation
- Sensors responded correctly:
- Moisture values clearly separated dry vs. wet soil
- Lux sensor responded to bright/dark conditions
- Pump turned on/off reliably through app commands and thresholds
- Camera integrated successfully into app interface
- Confirmed full end to end functionality of system design

BreadBoard Testing Cont.

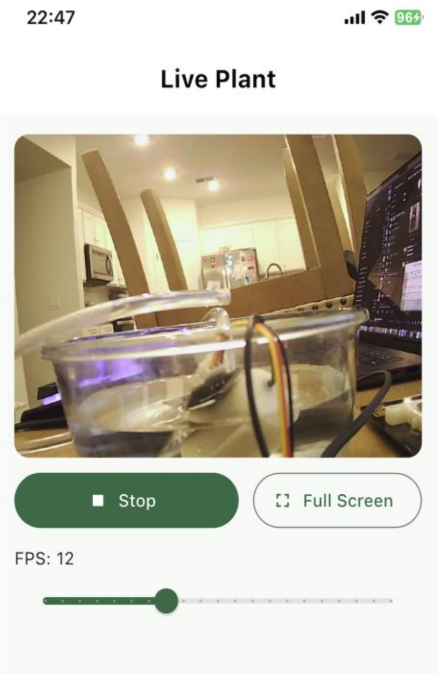


Camera Livestream Testing

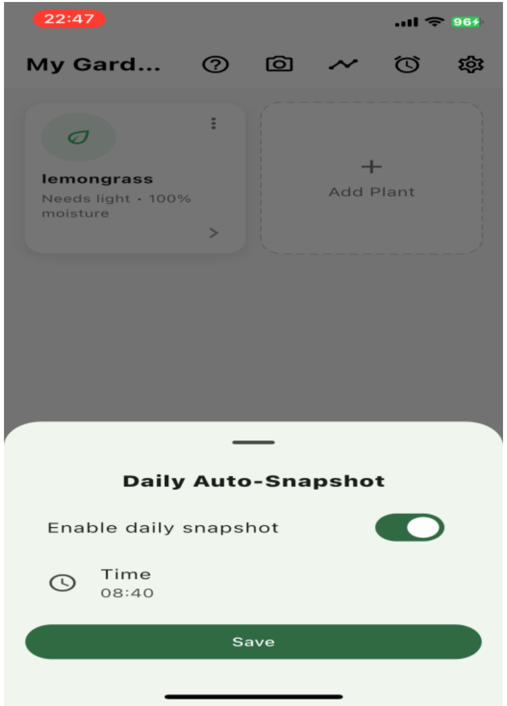
Livestream on Raspberry-pi



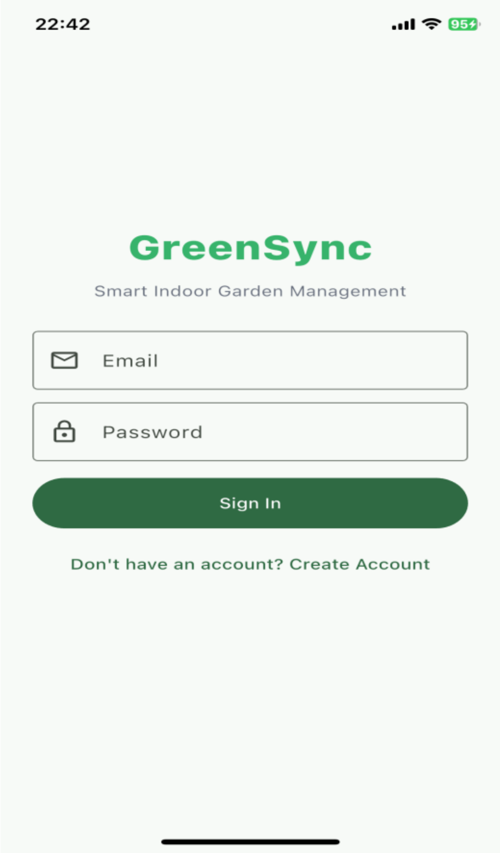
Livestream on our Mobile Application

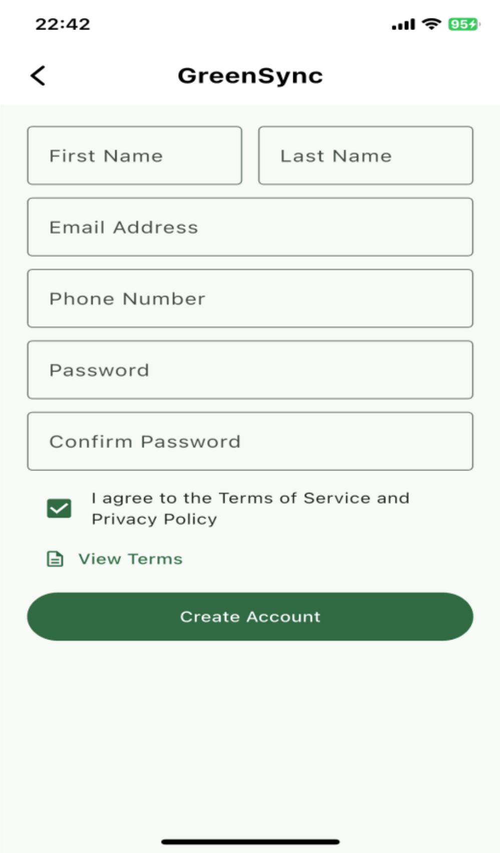


Daily snapshot

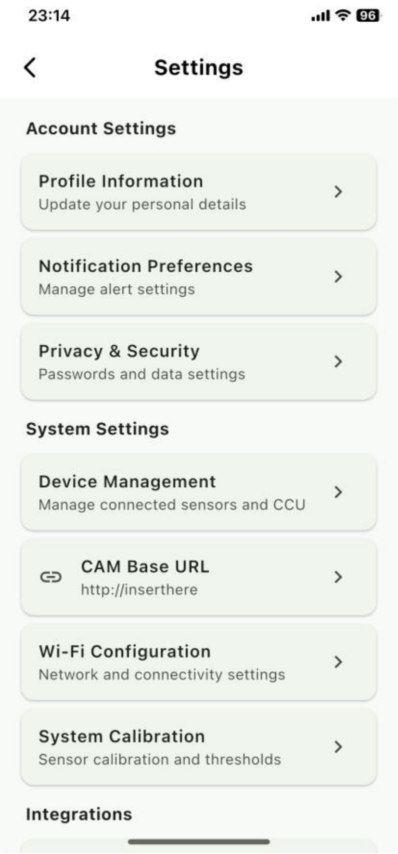


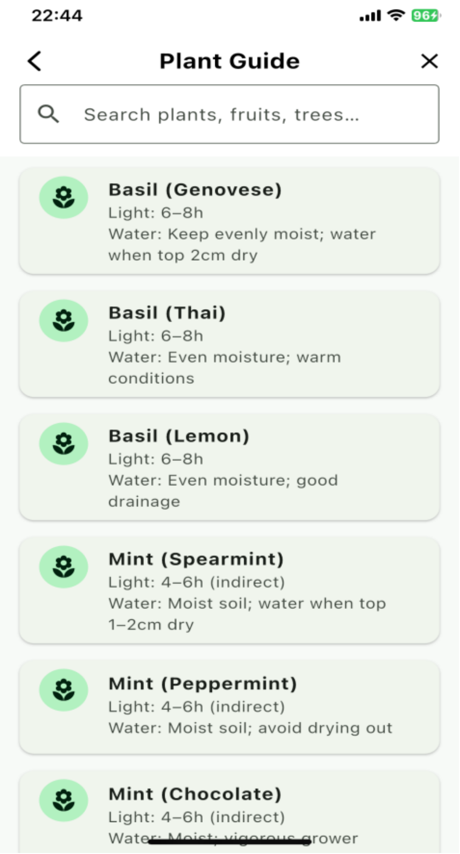
Official Mobile application

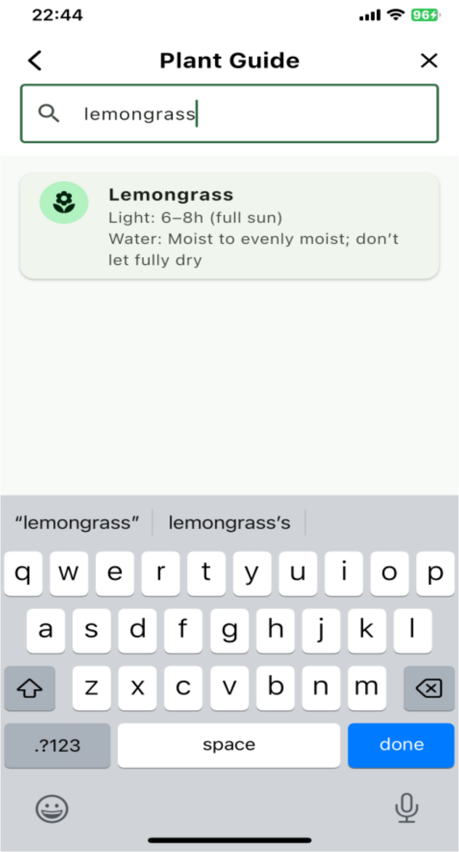




Official Mobile application Cont.







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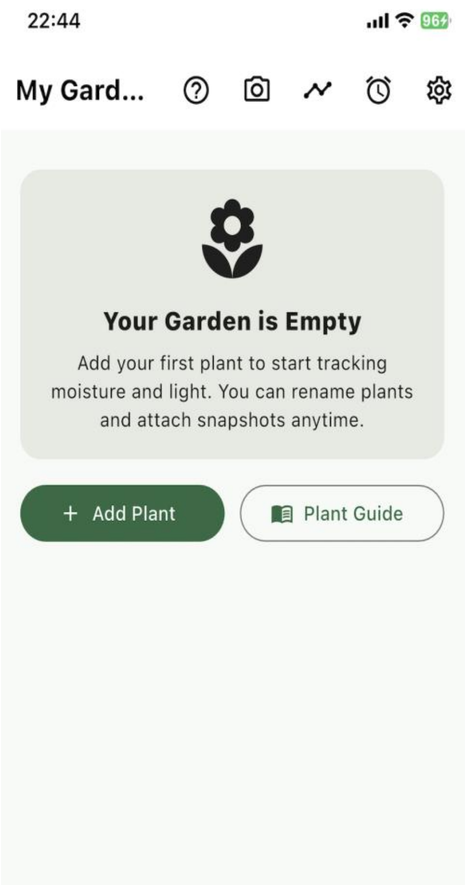

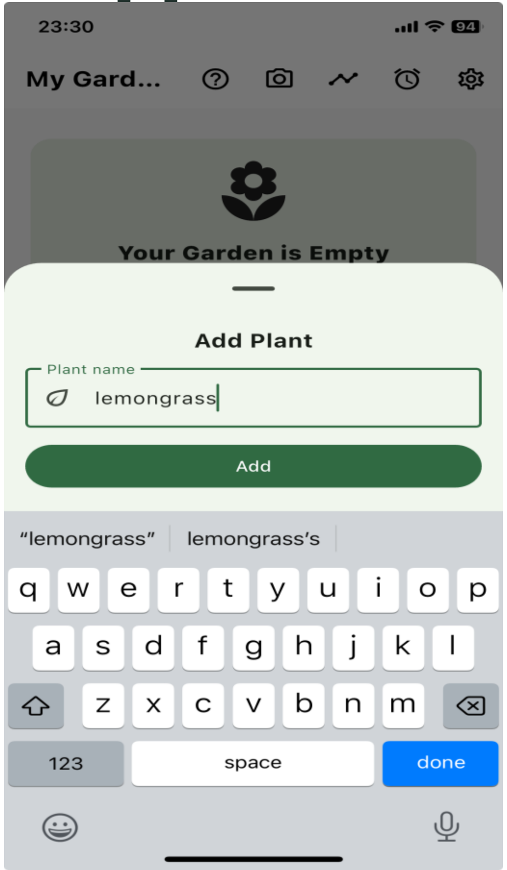

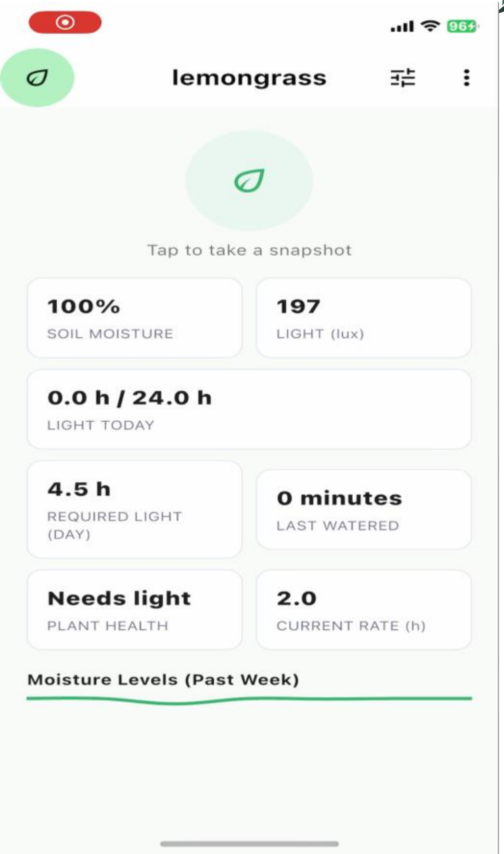

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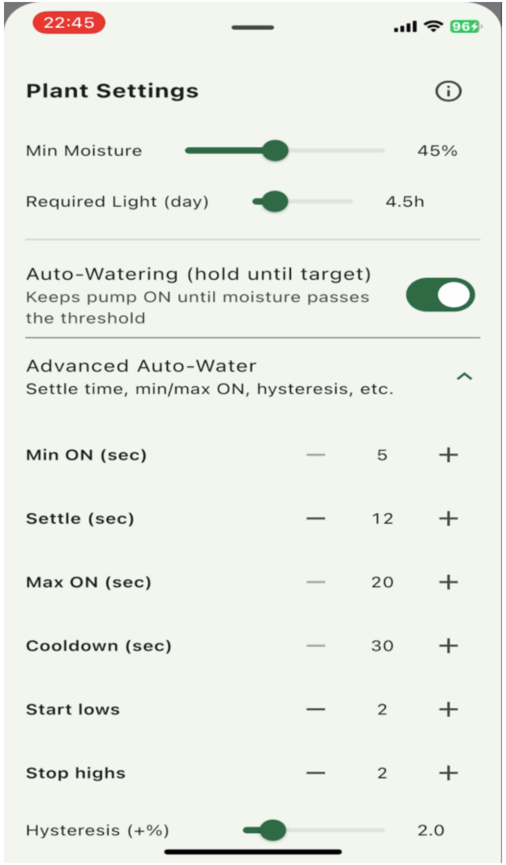

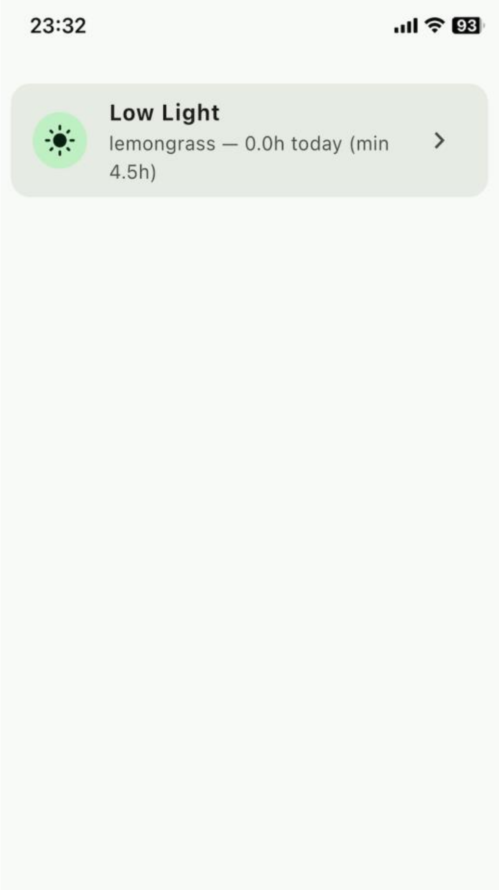

Future Work & Roadmap

- Add automatic grow light controlled by lux sensor
- Transition from breadboard to custom PCB for stability
- Improve security with TLS(so that no one can send fake data) for MQTT communication
- Add data logging for plant growth trends (watering history, light exposure)
- Camera improvements: time lapse, AI health detection
- Full beginner’s guide inside app: more plant care tips

Name	Primary Role	Secondary Roles
Roman Luknicki	Lead, Live-Streaming Camera	Power Supply PCB Design
Rohit Goeptar	Mobile Application Interface	Firmware Development System Integration, & Testing
Victor M. Arteaga-Cuenca	Firmware Development	Mobile Application Interface, Environmental Sensing Subsystem
Thomas Parker	PCB Design	Enclosure

Bill of Materials

CATEGORY	COMPONENT	DESCRIPTION	COST (USD)
PCB Design	PCB Designs & Parts	Custom circuit board designs and electronic components	$200.00
Main Controller	Raspberry Pi 4b	Primary computing unit for farm control system	$120.00
LED Lighting	PicoFarm LED	Sponsored grow light system for plant cultivation	Sponsored
Water Pump	Submersible Water Pump	Automated watering system pump for irrigation	$6.97
Microcontroller	ESP32	WiFi-enabled microcontroller for sensor management	$10.00
Camera	USB Webcam	Visual monitoring and plant growth documentation	$30.00
Moisture Sensor	Moisture Sensor	Soil moisture detection for automated watering	$12.00
Light Sensor	Light Sensor	Ambient light level monitoring and LED control	$11.00
Test Camera	ESP32-CAM	Secondary camera module for testing and backup imaging	$6.00
Enclosure	Enclosure	Protective housing for electronic components	$30.00

Progress & End Game

CATEGORY	TASK	NOTES	PROGRESS
Research	Research & Development	Research never ends - continuous improvement	95%
PCB & Parts	PCB Design & Parts Sourcing	Circuit board design and component procurement	100%
Prototyping	Hardware Prototyping	Building and assembling physical prototypes	90%
Testing	System Testing & Validation	Testing functionality and performance validation	75%
Mobile App	Mobile Application Development	iOS/Android app for system control and monitoring	90%
Overall	Project Completion	Total project progress across all components	70%

CATEGORY	NEXT STEP	DESCRIPTION	PRIORITY
Verification	1. PCB Verification and Integration	Validate PCB functionality and integrate all components	HIGH
Configuration	2. LED Grow Light Configuration	Set up and configure LED lighting system parameters	HIGH
Construction	3. Build Enclosure	Construct protective housing for all system components	MEDIUM
Testing	4. Final Testing	Comprehensive system testing and performance validation	CRITICAL

Thank You :D