Functional Lighting and Optimal Watering for Environmental Regulating System

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***Abstract* — This project aims to achieve three self regulating garden environments for different plants. To accomplish this, three cubbies are made for each plant, and the environment of each plant will be monitored by a light, temperature/humidity, and moisture sensor. These sensors process the current data readings from the sensors and are displayed onto a mobile device for the user to read. When the moisture sensor is placed in the pot, it will detect a threshold on how wet the soil is and will trigger a solenoid valve to dispense water into the pot.**

***Index Terms* — Bluetooth, capacitive moisture sensors, environmental automation, LED lighting control, smart garden system, soil temperature, wireless plant monitoring.**

I. Introduction

Indoor plant care offers ecological, psychological, and aesthetic benefits, yet maintaining optimal conditions for diverse plant species remains a challenge. The Functioning Lighting and Optimal Watering for Environmental Regulation System (F.L.O.W.E.R.S.) addresses this issue by automating watering and lighting. Designed by a team of senior engineering students, the system enables users to grow multiple plant species simultaneously while minimizing the maintenance burden. By integrating sensors, wireless communication, and user-defined input, F.L.O.W.E.R.S. represents a cost-effective, scalable solution for personalized plant care.

II. System Design Overview

The F.L.O.W.E.R.S. system supports three distinct plant environments. Each zone is equipped with a wireless moisture and temperature sensor, a solenoid valve for water regulation, and programmable LED lighting. A central ESP32 microcontroller collects data from sensors and drives actuation responses. A mobile app provides an interface for users to assign specific care profiles per plant, including water needs and preferred lighting spectra. Data is exchanged via WiFi to ensure localized and low-power communication. The system was built with energy efficiency in mind, leveraging low-power sensor designs and duty-cycle-controlled lighting.

III. System Hardware Components

This section outlines and explains the key hardware components selected for our project and how it contributes to the overall system functionality. The key features in each item that will be integrated into the overall system will be looked at and further expanded upon. These components play a vital role in the project and its functionality.

A. MCU

The ESP32 serves as the central microcontroller unit (MCU) for the F.L.O.W.E.R.S. system, managing sensor data acquisition, processing, and overall system control. It communicates wirelessly with the Shelly RGBW PM device via Wi-Fi, enabling seamless control of both the LED lighting and irrigation valves without the need for additional wiring. The ESP32 continuously collects data from the moisture sensors, temperature/humidity sensors, and light sensors through the I2C multiplexer, then processes this information to make real-time decisions about environmental regulation. Utilizing its built-in Wi-Fi capabilities, the ESP32 sends commands to the Shelly device to adjust lighting brightness and activate valves based on sensor feedback. The integration of Wi-Fi communication enhances the flexibility and scalability of the system, allowing for remote monitoring and control through connected devices. Moreover, the ESP32's low power consumption [3] and versatile I/O interfaces make it an ideal choice for embedded control in smart gardening applications.

B. Shelly RGBW PM

The Shelly RGBW PM device functions as both the driver for the LED lighting system and the wireless relay for controlling the irrigation valves. It receives commands wirelessly from the MCU, allowing for flexible control without direct wired connections. As a lighting driver, the Shelly RGBW PM regulates the power supplied to the 12V LED light strips, adjusting their brightness based on signals from the light sensor to maintain optimal lighting conditions for the plants. Additionally, the device acts as a relay for the solenoid valves, switching them on or off to regulate water flow based on moisture sensor inputs processed by the MCU. This dual functionality simplifies the system design by consolidating lighting control and valve actuation into a single, remotely controllable unit. Communication between the ESP32 and the Shelly RGBW PM utilizes the Wi-Fi protocol [4], ensuring reliable and low-latency control over the environmental regulation system

C. I2C Multiplexer

The PCA9547D (I2C multiplexer) controls the data reading of the VEML7700 (light sensor) and the SHT45 (temperature/humidity sensor). The purpose of this multiplexer is to address each of the sensors at different times since each type of sensor has the same address as the other. The PCA9547D communicates with one sensor at a time, allowing for the use of sensors with the same addresses. The data from one sensor is read, sent to the PCA9547D, and sent to the ESP32 so that the user is able to read the data. Once the data has been received by the ESP32, the PCA9547D moves onto the next channel that a sensor is on and begins reading the data of that sensor.

D. Water Pump

The Seaflo 42 water pump is a critical component in the F.L.O.W.E.R.S. system, responsible for delivering a consistent water supply to the irrigation valves. Its design includes an adjustable flow feature that enables continuous low-volume water delivery, effectively reducing the need for frequent on/off cycling. This adjustment ensures that the pump maintains constant pressure in the system while minimizing mechanical wear and extending the pump's operational lifespan. By preventing rapid cycling, the Seaflo 42 also contributes to smoother and more reliable water flow, which is essential for precise soil moisture regulation. Controlled by the MCU, the pump activates only when water is relieved through valve actuation, optimizing energy usage and maintaining system efficiency. The pump's compact size and compatibility with the project's water requirements make it an ideal choice for smart gardening applications requiring steady and controlled irrigation.

E. Temperature / Humidity Sensors

The SHT45 is a high-precision digital sensor used in the F.L.O.W.E.R.S. system to monitor ambient temperature and relative humidity within the growing environment. Manufactured by Sensirion, the SHT45 offers exceptional accuracy, with a typical temperature tolerance of ±0.1 °C and humidity accuracy of ±1.0% RH, making it well-suited for applications requiring tight environmental control. The sensor communicates with the ESP32 via the I2C protocol, routed through the PCA9547D multiplexer to avoid address conflicts with other I2C devices. Its compact form factor and low power consumption make it ideal for embedded systems, while its fast response time enables timely environmental adjustments. Data collected from the SHT45 is used to assess current conditions and inform watering and lighting decisions, ensuring that the system maintains optimal growth conditions for the plants. The robust reliability and high sensitivity of the SHT45 contribute to the overall precision and responsiveness of the environmental regulation system.

F. Light Sensors

The VEML7700 is a precision ambient light sensor used in the F.L.O.W.E.R.S. system to monitor real-time light intensity in lux. Its high sensitivity and wide dynamic range make it ideal for detecting subtle changes in indoor lighting conditions relevant to plant growth. The sensor communicates with the ESP32 via the I2C protocol [2] through the PCA9547D multiplexer, allowing it to share the bus with other I2C devices of the same address. The VEML7700 plays a central role in the system's feedback control loop: its lux readings are continuously evaluated by the ESP32, which then adjusts the brightness of the LED grow lights accordingly. This dimming control is sent as a wireless signal to the Shelly RGBW PM driver, ensuring that lighting levels remain within a target range conducive to optimal plant development. By implementing this closed-loop system, the F.L.O.W.E.R.S. project maintains consistent environmental lighting conditions despite external variations, improving the reliability and adaptability of the smart garden. The use of the VEML7700 enables precise, automated lighting regulation with minimal user intervention.

G. Moisture Sensors

The soil moisture sensing subsystem in the F.L.O.W.E.R.S. project is built on a custom-designed PCB that utilizes a 555 timer circuit to function as a capacitive moisture sensor. These sensors operate by measuring changes in capacitance caused by varying levels of soil moisture, with the 555 timer producing a frequency output that corresponds to the dielectric properties of the soil. As the soil dries or becomes saturated, the frequency shifts accordingly, providing a reliable and non-corrosive method of assessing moisture content. The output signals from the moisture sensors are read by the ESP32, which processes the data and determines whether watering is needed. Based on this analysis, the ESP32 sends a wireless command to a dedicated Shelly RGBW PM device that controls the solenoid valves responsible for irrigation. This setup enables a closed-loop feedback control system, where real-time soil moisture conditions directly influence the actuation of watering hardware. By integrating the sensors into a custom PCB, the system maintains a compact and cost-effective design while offering consistent performance in varying environmental conditions.

H. Shelving

The shelving unit used in the F.L.O.W.E.R.S. project serves as both the physical foundation for the plant containers and the mounting platform for critical hardware components. Constructed from durable plywood, the structure measures 54 inches in width, 30 inches in height, and 14 inches in depth, providing ample surface area for plant pots while maintaining a compact footprint suitable for indoor environments. The shelving is designed not only for structural support but also for system integration; key hardware components—including the Seaflo 42 water pump, solenoid valves, main PCB, and both Shelly RGBW PM devices—are securely mounted to the rear face of the structure. This design keeps wiring organized and concealed, reducing clutter and simplifying maintenance. By centralizing all mechanical and electronic subsystems onto a single platform, the shelving unit ensures a streamlined layout that enhances both functionality and accessibility. The use of plywood offers a balance between strength, ease of customization, and cost-effectiveness, making it an ideal choice for a modular and scalable smart gardening solution.

H. Water Solenoid Valves

The water solenoid valves in the F.L.O.W.E.R.S. system are responsible for directing water flow to individual plant containers based on feedback from the soil moisture sensors. These valves operate at 12V and are capable of fully opening within five seconds, meeting the project's engineering specification for actuation speed. Each valve is wirelessly controlled by signals relayed from the ESP32 to the Shelly RGBW PM device, enabling precise and on-demand irrigation in response to soil moisture conditions. When a valve is activated, it relieves pressure in the line, prompting the Seaflo 42 pump to deliver water through the open channel. Once sufficient moisture is detected, the valve is closed, stopping the flow and restoring pressure equilibrium. Mounted on the back panel of the shelving unit, the valves are positioned for easy access and minimal tubing complexity. Their fast response time and compatibility with the system's 12V supply ensure reliable operation and effective integration into the closed-loop watering control system.

IV. Hardware Technical Design

This design incorporated elements of technical design across all elements of the project, but to avoid redundancy, there will be three highlighted areas of specifically technical design, being the regulator design, the main PCB design, and the moisture sensor design.

A. Regulator PCB Technical Design

Below is a figure of the custom designed regulator:

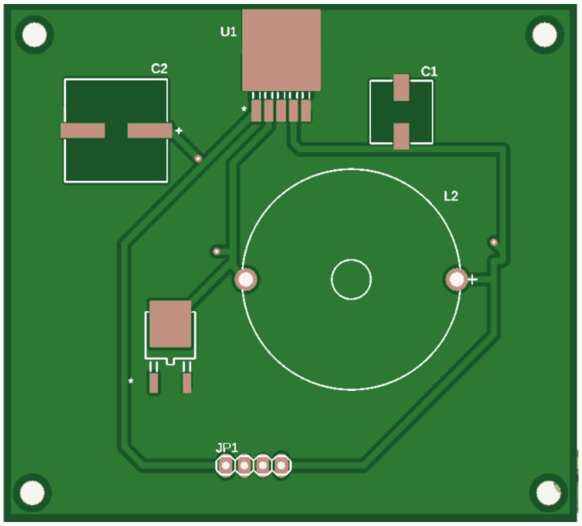

Fig. 1. Regulator PCB Schematic

The project required the powering of multiple 3.3V peripheral devices, including I2C sensors on the main board, as well as external capacitive moisture sensor boards. Considering the critical importance of balancing simplicity and efficient implementation, to meet the reliability and affordability requirements, a switching regulator design was chosen. These boards utilise the LM 2576 surface mount chip, located at U1, to step down the voltage from 7.4V to 3.3V. 0805 pad size components were chosen, and capacitive and inductive loads were chosen to match the datasheet requirements for the LM2576.

B. Moisture Sensor PCB Design

Below is the figure for the custom design moisture sensor:

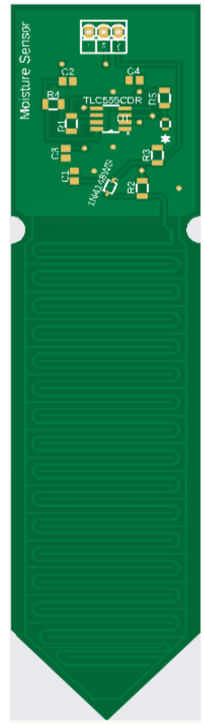

Fig. 2. Custom Moisture Sensor PCB

The custom moisture sensor borrows many elements of the Gikfun capacitive moisture sensor, mostly in regards to component spacing relative to the capacitive traces. As mentioned previously, the fundamental component on the board is the 555 timer, which facilitates the sending of the analog data via timed pulses which ultimately are read by the ESP32 microcontroller as digital values (after on-chip analog to digital conversion). The long strip on the bottom of the moisture sensor contains the long traces which serve to essentially form a capacitive plate between the analog out line and ground, and it was an important design element to consider what length would be required for accurate readings. The remaining components on the board are relatively trivial, in that they serve only to smooth the signal or control the 555 timer.

C. Main PCB Technical Design

Below is the figure of the custom main PCB board:

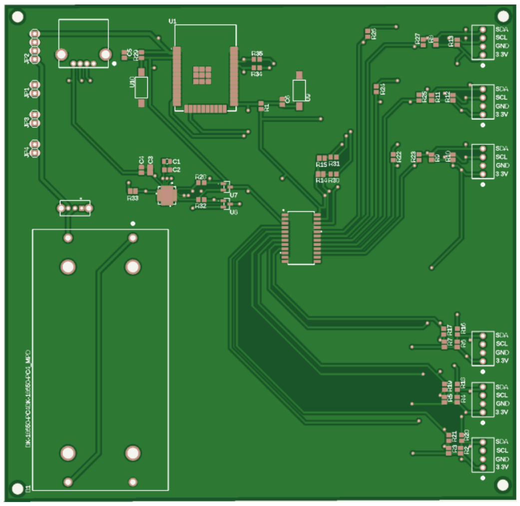

Fig. 3. Main PCB Schematic

The main board required the culmination of the hardware design for the project. It includes the MCU mount, the USB to UART bridge (for programming the ESP32), the I2C Multiplexer, all six I2C sensors (three SHT45 Temp sensors and three VEML7700 Light Sensors), as well as connections for all 4 regulator boards. This design required consulting the datasheet for spec values, as well as careful consideration of component placement, even going as far as to place I2C components as close to the chip as possible to minimize wire noise.

V. System Configuration

Our project can be looked at as two different systems that are working together. This was accomplished by using an ESP32 in order to communicate between the two. This section will cover how this was accomplished and how these systems are communicating. The functionality of our project can be further understood in the diagram below.

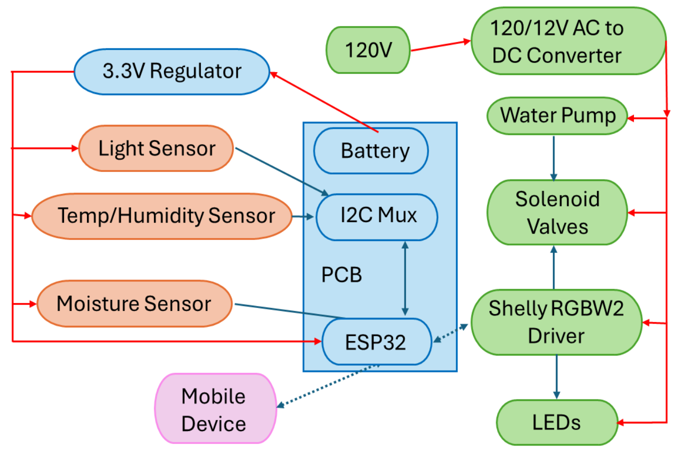

Fig. 4. Functional System Overview Hardware Block Diagram

On the main PCB, two 18650 lithium ion batteries are used to supply 7.4V to four regulators. The regulators are made on daughter boards and connected to the main board via jumper wires; these regulators will supply 3.3V each. One regulator is wired back to the main board and the other three will each be wired to their own moisture sensor. While the main board and each moisture sensor could have been powered by a single regulator, a design feature that we wanted to include was wireless communication via ESP-NOW with the moisture sensors. Doing this would require much more power for each sensor, which was the rationale of each sensor having its own regulator.

Each SHT45 and VEML7700 sensor will be connected via jumper wires to the main board. The sensors are then wired from the jumper connection to the PCA9547D on the main board, with 1k pull-up resistors on the sensor lines. Choosing a 1k pull-up resistor, over larger resistors, allows for more current to flow, which is important for the long lines that the sensors run on. This allows for less noise in communication lines. However, the pull-ups for the PCA9547D are 10k. This was done during the troubleshooting process of our board and we were only able to get readings when using 10k's as a pull up resistor for the PCA9547D.

The SHT45 and VEML7700 sensors are each placed onto their own small platform within each cubby. This allows the sensors to sit up right and record accurate measurements. The sensor boards are screwed into place on their platform to stabilize them, along with the main board which is attached onto the back of the system.

V. Software Design

This section provides a detailed overview on each of the software components and how it is programmed within our project.

A. I2C Multiplexer

For the I2C multiplexer to communicate with the ESP32 GPIO pins 13 and 14 are configured with the multiplexer to allow for communication and the clock is set to 100k Hz. Once the program is able to pull the pins high it prints that the ESP32 was able to initialize communication and scans for the list of possible addresses of the multiplexer. However, this scan is more of a safety feature since the address of the multiplexer is given to us in the datasheet and is hardcoded.

The program will then look to initialize each of the sensors. This is done by going through each channel of the multiplexer and selecting a specific channel for each sensor. The channels that each sensor is supposed to be on are hardcoded, this allows for the program to confirm that the sensor is connected. If not, then the program will output that there is no connection for the sensor on that specific channel. Lines of code will also execute if it is unable to initially communicate with the sensor when confirming the address. The address of the sensor is hardcoded into the program as well, while the address of the sensor is provided by the datasheet of the sensor. The function to initialize the sensor from the multiplexer is fairly similar for both the SHT45 and VEML7700 since all it needs to do is to confirm the address.

Once each of the sensors has been initialized and communication has been confirmed, the program looks to configure the sensors. Libraries for the SHT45 and VEML7700 were used to help configure the sensors. Once the configuration is complete, the details of it are then printed onto the serial monitor. Then the data of each sensor is printed onto the serial monitor and begins to loop continuously. In this loop, if a sensor is unable to be initialized, it will continue to output that there is no communication on that channel. The loop also checks for a new connection on all channels, if the sensor is able to begin communicating once the program has already started the data of that sensor will now be printed. The following figure shows what would be printed in the serial monitor for a VEML7700 light sensor.

```
=== Reading All VEML7700 Sensors ===

Reading VEML7700 on Channel 5:
  Raw ALS: 5159 (0x1427)
  Raw White: 6807 (0x1A97)
  Lux: 297.27
  Light Level: Normal Indoor

Reading VEML7700 on Channel 6:
  Raw ALS: 4930 (0x1342)
  Raw White: 6851 (0x1AC3)
  Lux: 283.91
  Light Level: Normal Indoor

Reading VEML7700 on Channel 7:
  Raw ALS: 4934 (0x1346)
  Raw White: 6928 (0x1B10)
  Lux: 284.14
  Light Level: Normal Indoor
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Fig. 5. VEML7700 Sensor Data Readings in Arduino Serial Monitor

B. The Embedded System Design

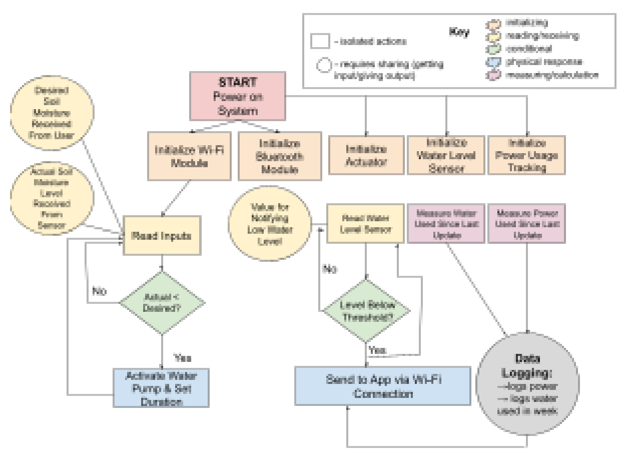


Fig. 6. The Embedded System Flowchart Diagram

C. Mobile App and ESP32 Communication

When powered on, the ESP32 will automatically enter access point mode, waiting for the user to send the WiFi credentials, which will be prompted to the user on the mobile app. Neither the mobile app or ESP32 will move forward with other behavior until this connection is established. If the user enters incorrect credentials, they will be informed on the mobile app that the connection could not be validated and be prompted to re-enter the credentials.

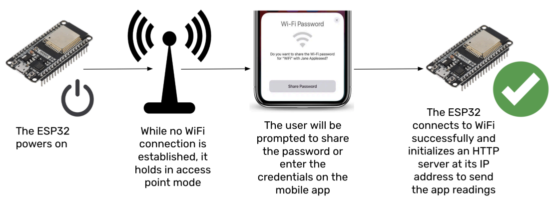


Fig. 7. The WiFi initialization on ESP32 and connecting the system to the mobile app

Once the connection is properly established, the ESP32 will initialize a web server on port 80 using its IP address. Every 5 seconds, this server will update its JSON file with the readings of all soil moisture, light, humidity and temperature sensor readings.

The mobile app will use this server to pull the JSON data and demonstrate for the user the proper environmental statistics pertaining to each environment.

D. App Design

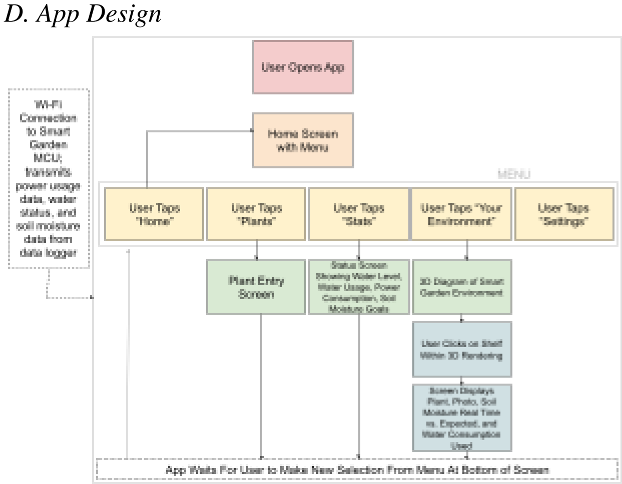
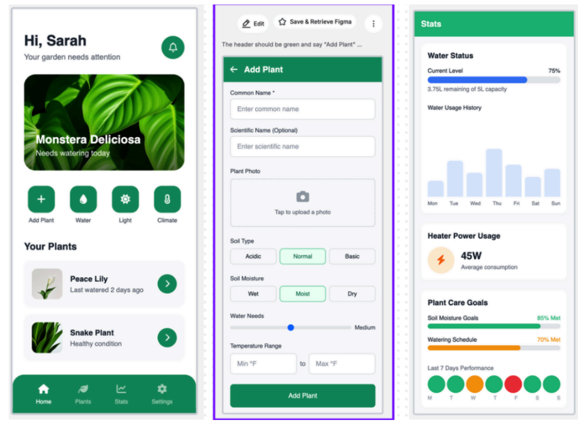


Fig. 8. Software flow chart for the mobile app



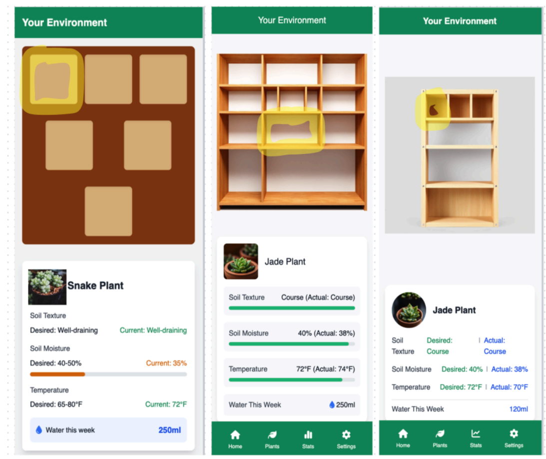


Fig. 9.(top) and Fig.10.(bottom) overview of app development in Figma with UXPilot assistance

The mobile app will automatically load into a home page that gives the user quick access to add a plant, or check watering, lighting, and climate information for each environment. It will also give a sliding update bar with the image of the plant the user has updated for each of the three environments. The menu allows the user to see their library of current and previously added plants; view the statistics of their environment's needs such as power consumption, water usage and status and overall performance; view the environment and how each plant's environmental factors are performing compared to preferred.

The mobile app will also allow the user to change notification settings to which notifications are important enough to result in push notifications (ex.

Low water warning or error with a sensor) and which notifications should only be posted to the notification log within the app without a push alert (ex. watering occurred).

VI. Conclusion

The F.L.O.W.E.R.S. system offers an efficient, low-maintenance solution for indoor plant care by combining smart sensors, wireless communication, and automated control. Its modular design supports multiple plant environments, while custom hardware and software ensure accurate monitoring and responsive watering and lighting. The system is cost-effective, scalable, and energy-efficient making it ideal for personalized, automated gardening.

VII. Acknowledgements

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VIII. The Team

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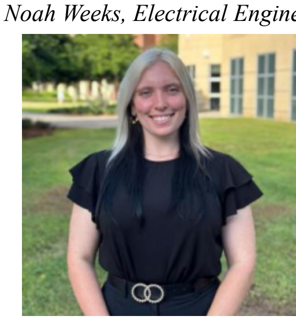

Ashley Hanzelka, Computer Engineer

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[2] Vishay, "VEML7700 Ambient Light Sensor," Datasheet, Vishay Semiconductors, 2023.

[3] Espressif Systems, "ESP32-WROOM-32 Datasheet," 2021.

[4] Shelly Cloud, "Shelly RGBW2 User Guide," 2023.