Auto-Adjustable Micro-Terrarium

Team #5
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ECE 445 Design Document - Fall 2020
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1. Introduction

1.1 Objective and Background

The Covid-19 pandemic has sparked a nationwide interest in gardening as it is a great way for people to pass time during shelter-in-place while learning about a fascinating new hobby. In some areas in the nation, demand for seeds even increased by upwards of 300%[1]! However, with the increased interest comes the confusion from novice gardeners -- taking care of a plant is not easy work. In order for plants to have the optimal growth rate, many factors need to be considered: the most widely agreed upon factors include temperature, humidity, soil pH, and light[2]. For many of these gardeners, it may be a challenge to maintain optimal conditions for the plants they grow, as their backyards may be lacking the expensive equipment or complex setups available to more experienced gardeners. As a result, they may have trouble germinating and growing the plants they want.

For our project, we want to mitigate these gatekeeping factors as much as possible such that gardening will only require a low level of expertise. Our goal is to create a programmable micro-terrarium to assist the novice gardener in growing and maintaining their plants. With just some user research and input into the device, our project will create the best environment for plants which will keep the terrariums' humidity, temperature, and pH in the desired range. Thus, gardeners can enjoy growing their plants without worrying about micromanagement. There are already a few products similar to an adjustable terrarium online; however, none tackle the difficult problem of maintaining soil pH, they are too large and not rapidly scalable for a wide variety of plants, or they are designed for industrial purposes and experienced botanists. Our project is unique in that the terrarium will be a reasonable scale for an indoor plant and we will also include a feature for soil pH adjustment. We will design and build an adjustable terrarium with these considerations in mind that can self-adjust or use some manual inputs to regulate the environment.

We will use Basil as a test plant since it is a popular plant with a fairly small size. Its optimal pH range is 6.2 to 6.8; its environment's recommended temperature is between 70℉ and 85℉; its optimal light exposure is full sun, or 14 to 18 hours; lastly, its environment's recommended humidity is between 40 and 60%[3].

1.2 Visual Aid

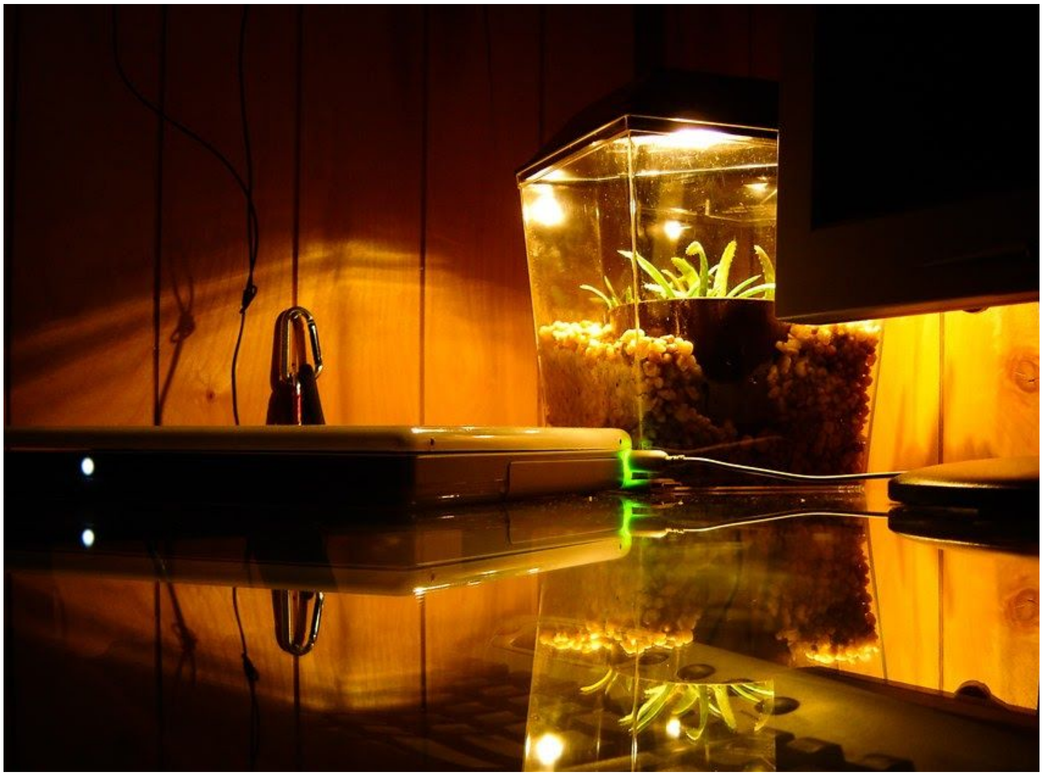

Figure 1: Both novice and experienced gardeners alike are guaranteed to experience a faster growth rate of their plants when utilizing the technology of the Auto-Adjustable Micro-Terrarium.
("Green Thumb" by trekkyandy is licensed with CC BY-SA 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/2.0/)

1.3 High-Level Requirements

- The terrarium has an easy-to-use user interface, understandable and operable by any inexperienced users.
- The terrarium will maintain a near-constant state specified by the user within the container.
- A plant placed within the terrarium has a visibly better growth rate than a plant grown in a natural setting.

2. Design

2.1 Block Diagram

In order for the terrarium to completely control the growing environment for the plant, we will need the device to react and adjust to changes in humidity, temperature, light and pH. To accomplish this task, as you can see in Figure 1, we will divide the logic for our terrarium into four components: the power supply, the control unit, the environment regulator, and the physical display. We will first use the corresponding sensors in the control unit to monitor the settings in the terrarium, which will feed data to a microcontroller chip. Depending on the user input, the microcontroller will then control the outputs to the heating/cooling system, the water and pH chemical valves, and the light source. The microcontroller will also interface with an embedded LCD display/touchscreen interface that will let the user know/control the current settings within the environment.

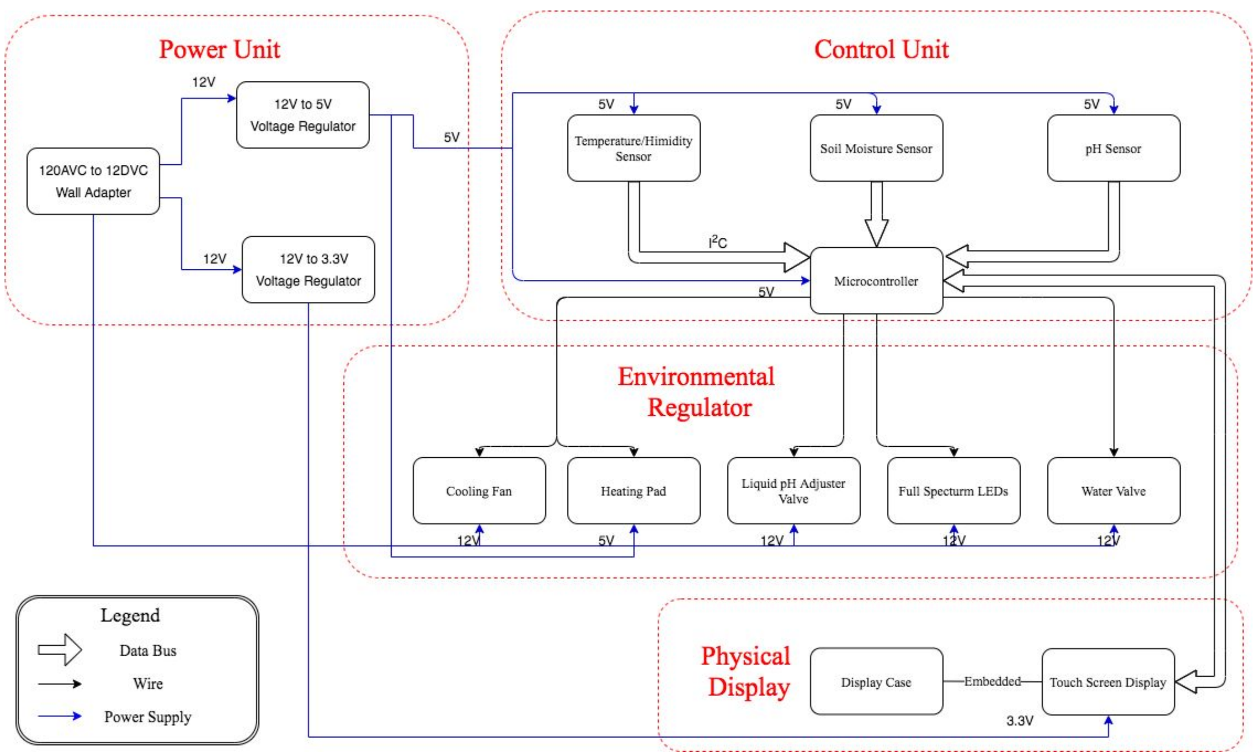

Figure 2: Terrarium Block Diagram

2.2 Physical Design

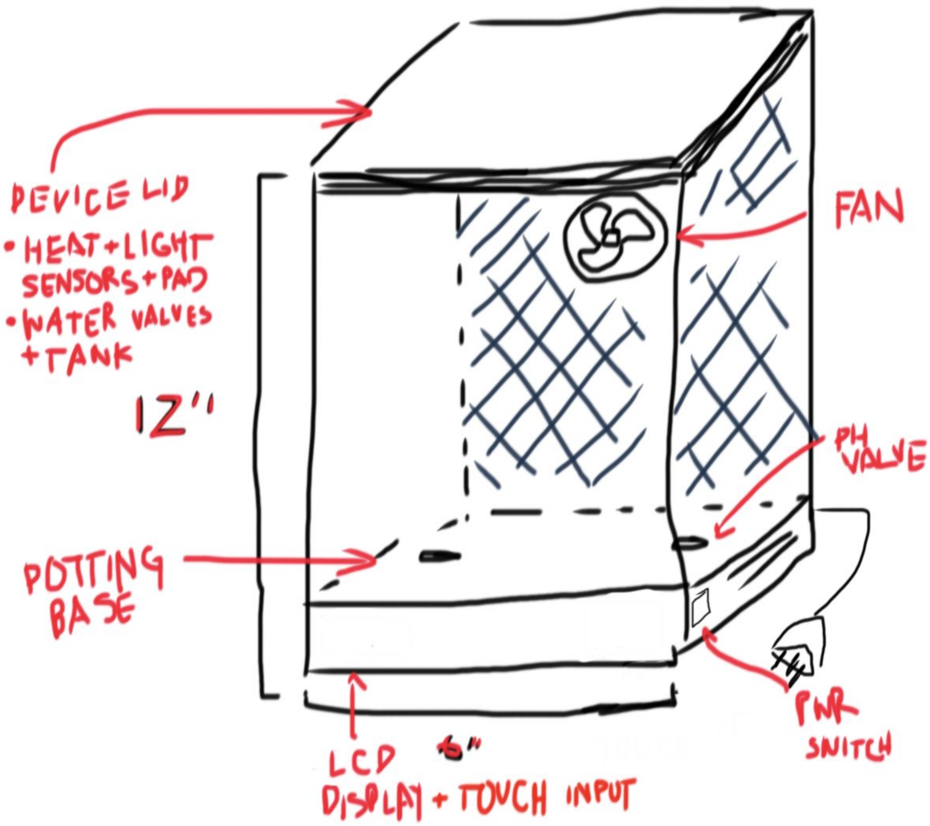

Figure 3: Terrarium Design Sketch (Not drawn to scale)

Our design for the terrarium will be a clear rectangular container with a removable lid and a base component. The lid must be removable to allow the gardener the ease of transplanting the plant to and from the container. The terrarium will be viewable from three sides, with the back panel opaque to hide the circuitry. The top lid component will hold the valves and containers for water, as well as the heat and light sensors and control units. The back panel will house the fan as well as connect the circuitry between the lid and base. The bottom base will house the pH valves, the LCD touchscreen display, the power circuit, and the user button interface.

2.3 Power Unit

The power unit needs to provide energy to make sure that the sensors, microcontrollers, and environment regulators can continuously work. We will have a wall adapter AC-DC supply to generate 12V for the elements of the project. We will use SWI5-12-N-P5 wall adapter and PJ-009AH power barrel connector jack in order to provide 12V to our PCB. Since different parts of the project require different DC voltages, we will have a LM317 voltage regulator and create a circuit in order to step the 12V to 5V ± 5% which supplies the temperature/humidity sensor, soil moisture sensor, ATmega32 microcontroller and Heating Pad. Another voltage LM317 regulator and circuit will output 3.3V ± 5% for the LCD display. These voltage conversion circuits can be seen implemented in Figures 5 and 6 in Section 2.7. Following Equation 1 shown below, both circuits take as input 12V, then step down that voltage to 5V and 3.3V based on the ratio of the resistor values.

$$V_{OUT} = 1.25\text{ V} \times \left(1 + \frac{R2}{R1}\right) \quad \text{Eq. 1}$$

Requirements	Verification
Voltage regulator circuits must be able to step 12V down to 5V and 3.3V ± 5%.	A. Use the oscilloscope to measure the output voltage of the converters. B. Check whether the output voltage is within 5% of 5V and 3.3V for each respective circuit.

2.4 Control Unit

The control unit must analyze the humidity, temperature, lighting, and PH level of the terrarium and communicate with the environment regulators to adjust those factors to the desired level. Therefore, the control unit will include all detection sensors and control mechanisms in order to help the terrarium self-adjust.

2.4.1 Temperature/Humidity Sensor

HDC1010 humidity and temperature sensor[3] can measure temperature between 0 ℃ and 60 ℃. It has a supply voltage of 2.7 V to 5.5 V and the output is digital using I^2C so we will not need to use an ADC to convert to digital. In order to interface with the sensor and read its outputs, we will program an I^2C peripheral within the MCU.

Requirements	Verification
MCU/I^2C peripheral must be able to interface with the sensor and read its temperature and humidity measurements/data.	A. Use a humidity meter and thermometer to read the ambient humanity and temperature of the room. B. Run the I^2C program and read the outputs of the sensor. C. Confirm that the data read by the MCU is within 2% of the ambient measurements in part A.

2.4.2 pH Meter

Most pH sensors are far too expensive to incorporate into the project. However, we found a cheap pH meter on Amazon that can measure pH from 3.5 to 8[7]. Thus, we plan to "reverse engineer" the sensor by first recording its measurement for soils of three different pH values. Then we will take the meter's case off in order to attach a multimeter to the probes of the meter. For each of the three different soils, we will measure the corresponding voltage that is output to the meter's MCU. This will help us understand how the measured voltage varies with changes in pH. Thus, we will be able to attach the probes directly to our own MCU and use the voltage to read the pH value of the soil within our terrarium.

Requirements	Verification
MCU must be able to correctly take pH meter's voltage as input and read pH values from 3.5 to 8.	A. Check pH of soil using litmus paper and pH meter. B. Confirm that pH derived in MCU matches the measured value in part A.

2.4.3 Soil Moisture Sensor

The Soil Moisture Sensor[8] requires 5V supply. The output voltage will range between 0 and 5V, which is proportional to the change in the content of water in the soil.

Requirements	Verification
The soil sensor needs to output values within the range 0-5V to accurately detect soil moisture.	Test sensor range using a dry paper towel and gradually wetting it, the sensor should start by outputting 5V but gradually reduce to 0V.

2.4.4 Microcontroller

The ATmega 32-bit chip will read the sensors' data, communicate with the user, and give commands to the environmental regulators. The operating voltage is from 4.5V to 5.5V[9]. The MCU will be responsible for the control of the entire circuit. It must be able to read data from each sensor, incorporating an I^2C peripheral and voltage-to-pH conversion program in order to do so. In addition, it will employ logic that decides, based on the sensor inputs, which subsystems of the environmental regulator must be turned on; then it will send signals to turn on those subsystems. Lastly, the MCU will interface with the touchscreen display in order to handle any user input and interaction.

Requirements	Verification
Microcontroller must modify appropriate control modules each clock cycle.	Confirm that correct pins output a high voltage when the corresponding subsystem of the environmental regulator must be turned on.

2.5 Environment Regulator

The environment regulators will adjust the environment based on the signal from the microcontroller. For example, if the soil moisture sensor passes a low data to the microcontroller, the water valves will open to water the plant until the sensor gives proper data to the microcontroller. Then, the MCU will send a low signal to close the valve.

2.5.1 Full Spectrum LEDs

Chanzon 1W LEDs are low power, full spectrum grow lights for plants. The input voltage is 12V. There will be a timer incorporated into the MCU in order to control how long the LEDs are on for at a time, as well as how long they remain off. It's important that we chose full spectrum LEDs for a couple of reasons. First, this helps guarantee that the user can grow a plant from anywhere indoors, regardless of natural light availability. Second, full spectrum light accelerates plant growth. As you can see in Figure 4, both blue light and red light are impressive performers when it comes to plant absorption, but each has its pros and cons[10]. Blue light accelerates plant growth to a better extent than red light, but also inhibits photosynthesis. Red light, on the other hand, promotes photosynthesis and ensures your plant will grow with its fullest and brightest colors.

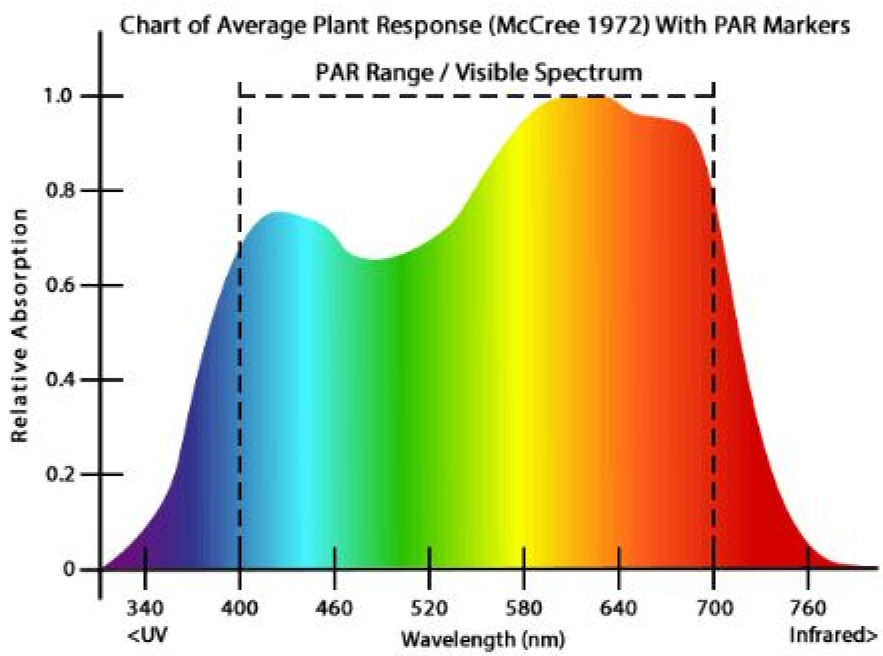

Figure 4: Full spectrum lighting promotes photosynthesis while accelerating plant growth, a crucial selling point of the Auto-Adjustable Micro-Terrarium.

Requirements	Verification
LEDs must stay on for 16 hours straight, then stay off for 8 hours (or whatever lengths of time are needed, as commanded by the MCU).	A. Time how long the LEDs stay on for 16 hours straight. B. Check that the LEDs automatically turn on/off after a given amount of time.

2.5.2 Water/pH Chemical Valving

Three 12V solenoid valves can control the flows of water and two different pH-changing chemicals. In normal conditions, the solenoid blocks the liquid. When a 12V applies to it, the liquid will be able to flow through the solenoid[11] valve and affect the environment. These will be used in regulating the environment. For example, if the moisture measurement of the soil is too small, the MCU will send a signal to open the water valve to dampen the soil. When the sensor reads that the soil moisture level meets requirements, the MCU will turn the signal low in order to block the flow of water to the soil.

Requirements	Verification
Valves must be able to open when sensor data falls out of range and close when the corresponding sensors output data that falls within the recommended ranges.	A. For pH: Insert pH meter. Raise optimal pH of soil 0.2 values over current pH measured. Confirm valve opens. When pH measurement falls within optimal range, confirm that valve closes. B. Repeat Part A. for soil moisture.

2.5.3 Temperature Regulator

Two electrical heat pads will turn on when the microcontroller gives a high signal to raise the temperature. It requires 5V supply. Two cooling fans will turn on when the microcontroller gives a high signal to lower the temperature.

Requirements	Verification
Heating pad/cooling fan will run until the environment is within ± 5% of user-set temperature.	Check sensor's temperature reading when heating pad/cooling fan turns off. Confirm that sensor's reading falls within 5% of optimal range.

2.6 Display Unit

The display unit allows the user to set input for the device. The user can choose the manual to adjust the environment or the terrarium automatically does it. There is an LCD to display the existing conditions to the users. If the user chooses to manually adjust the environment, the LED will notify the user and guide him or her in making the correct adjustment. The display case is under the considerations for conductivity to keep conditions as constant as possible. The display unit meets our high level requirements to set up an easy-to-use user interface.

2.6.1 Touch-Screen Display

NHD-1.8-128160EF-CTXI#-FT display[13] is 2.4”, offering enough room to display all current conditions, then updating the user on the dynamics of the environmental regulation. It has a touch screen, allowing the user to easily interact with the environment. Its supply voltage is 3V.

Requirements	Verification
1. Display must correctly portray all sensor measurements of the environment. 2. Interface must allow the user to input optimal ranges for plant growth and send to MCU.	1. Check what sensor values the MCU is reading, and confirm that they match those displayed. 2. Use the touch screen to input optimal temperature that is much higher than current range. Confirm MCU received input by checking if heating pads turn on.

2.7 Circuit Schematics

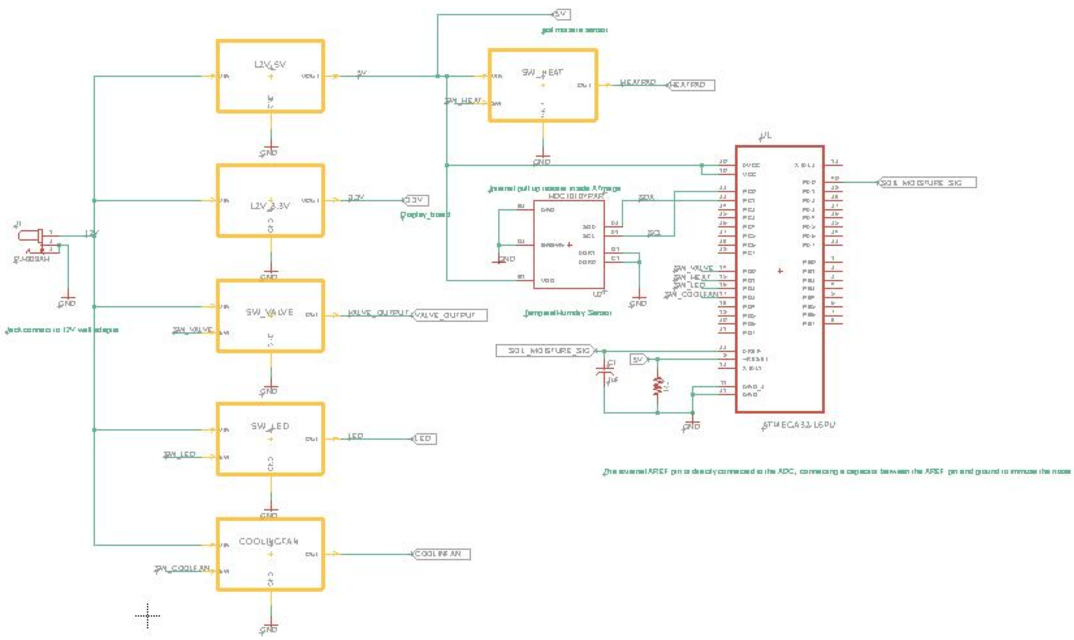

Figure 5: Top-level circuit schematics

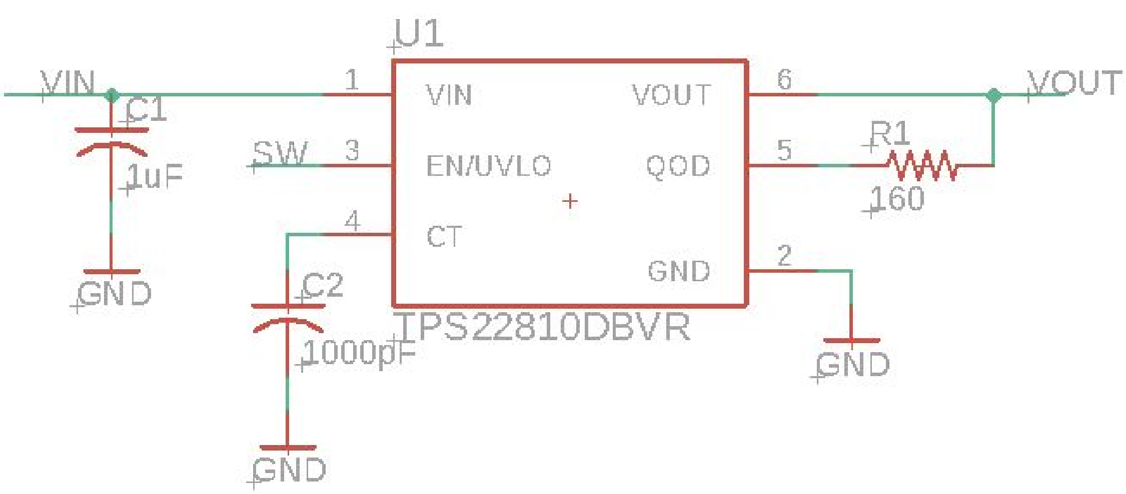

Figure 6: Select switch circuit for environmental regulator subsystems

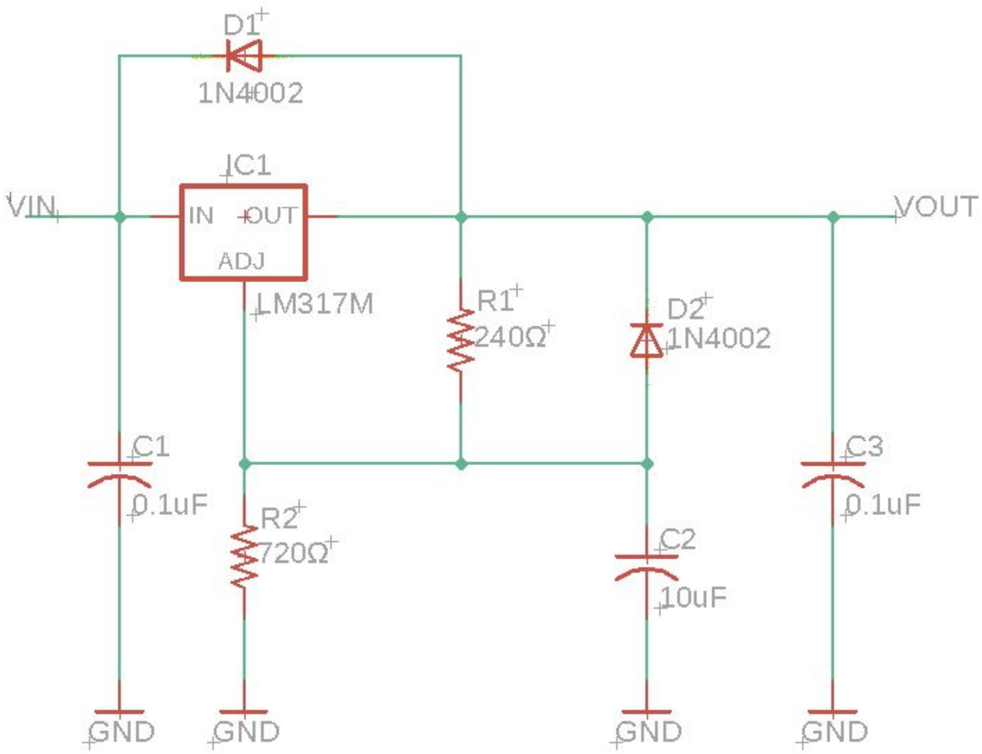

Figure 7: 12V-to-5V Voltage Conversion Circuit

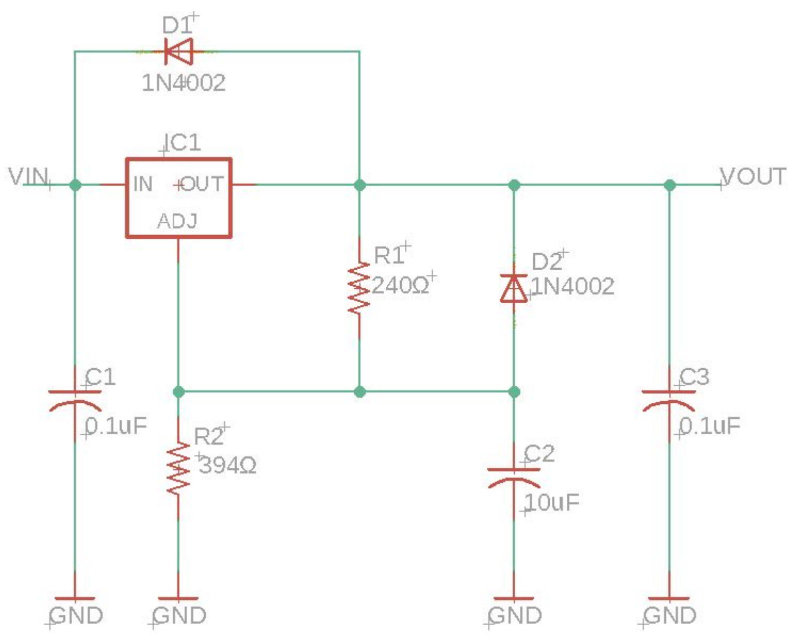

Figure 8: 12V-to-3.3V Voltage Conversion Circuit

2.8 Board Layout

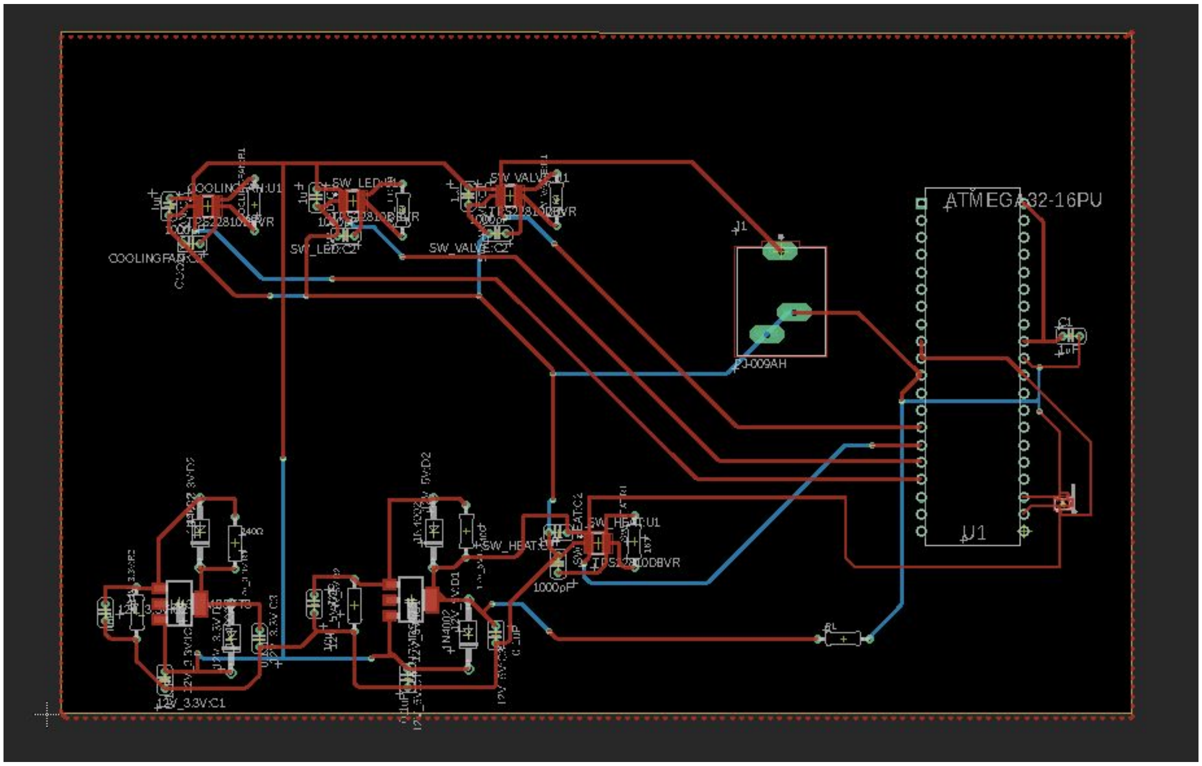

Figure 9: Proposed PCB layout

2.9 Microcontroller Logic

A large portion of the time the terrarium will be in an idle state. We will have the microcontroller detect and adjust settings only when the control sensors detect that any variables fall outside the acceptable range dependent on the input of the user. A multiplexer will be used to control which signals are sent through the I^2C protocol in order to detect and adjust the various settings for the terrarium.

We propose a high level diagram of the tentative logic flow of our project below in Figure 10. While connected to a power source, the microcontroller will constantly stay in a passive state and read in data from the I^2C data bus. When the sensors send a faulty signal, the microcontroller will sequentially loop through all the control modules to check which readings fall outside the set input ranges. In order to adjust the settings within the terrarium, the microcontroller will output high signals to the appropriate components while constantly accepting the corresponding sensor readings until the sensors read the corresponding input value. In order to minimize the amount of times we need to update the environmental regulator module, we need to pick a tolerance range to stop updating the device to be smaller than the acceptable tolerance of the operating range.

Although in our requirements we allow the environment to have conditions within ± 5% of the user input range, we will likely pick a smaller tolerance, possibly ± 1%, to update the device settings within, in order to make sure the microcontroller isn't constantly updating the conditions between the boundary values.

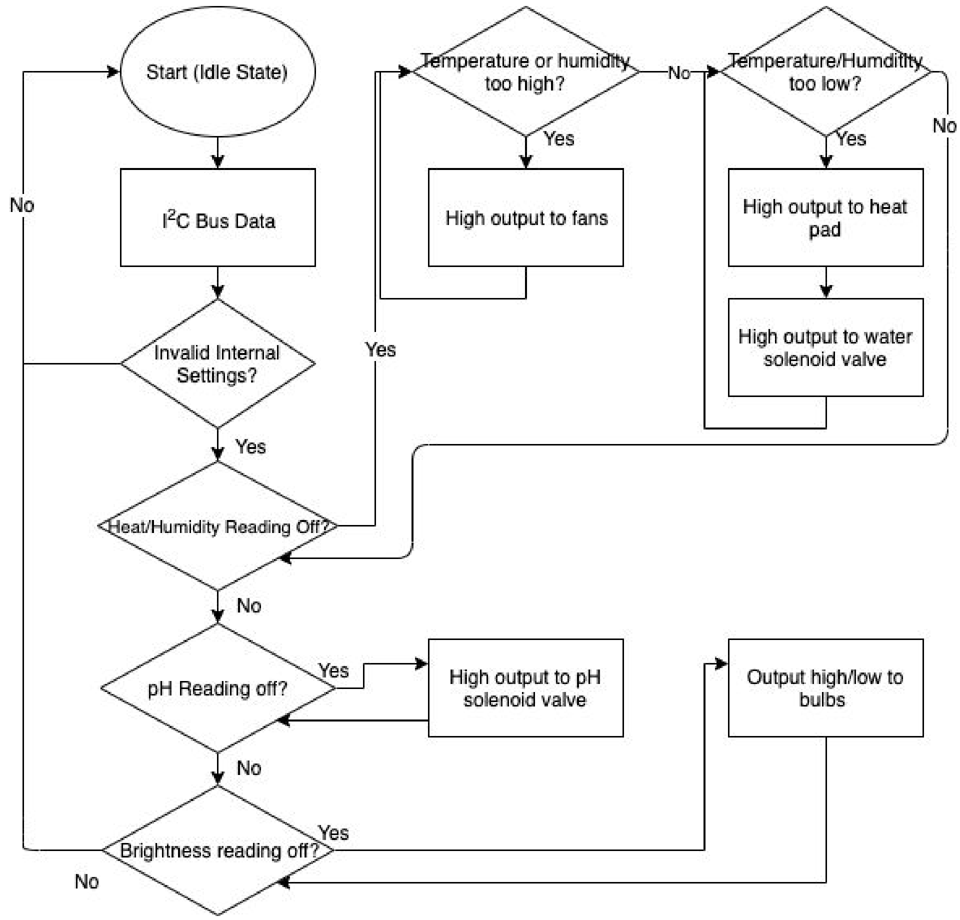

Figure 10: Sequential Microcontroller Logic

2.10 Tolerance Analysis

As mentioned above in our high level requirements, the terrarium must be able to keep the internal environment stable within a range of ± 5% the input values by the user. Thus, an extremely important design consideration we need to make is the material we will use for the terrarium viewing panels. The material must be transparent, and ideally we want to minimize the cost of the material as well as its thermal diffusivity. For the scope of this project we considered four materials: Polycarbonate (PC), Polyethylene (PE), glass, and plexiglass. We summarize the information for the materials we are considering in the table below:

Material	Cost $\$/in^3$	Thermal Conductivity $W/(m*K)$	Density $kg/m3$	Heat Capacity $J/(kg*K)$
Polycarbonate	0.429	0.20	1.21 x 10^3	1.25 x 10^3
Polyethylene	0.271	0.44	0.94 x 10^3	1.90 x 10^3
Glass	0.147	0.80	2.50 x 10^3	0.84 x 10^3
Plexiglass	0.336	0.18	1.18 x 10^3	1.45 x 10^3

Figure 11: Table of Material Information

With the data above, we can calculate the thermal diffusivity of each of the materials, which will measure the rate of dissipation of heat through the panels. We will calculate the rate of dissipation using the formula for thermal diffusivity as follows:

$$\alpha = \frac{k}{\rho c_p} \qquad \text{Eq. 2}$$

Where k is the thermal conductivity, ρ is the material's density, and c_p is the material's heat capacity. Thermal diffusivity α is represented by the units m^2/s which denotes the rate in which heat transfers through a medium. Using Eq. 2 from above, we can calculate the thermal diffusivities for each of the materials. We will get the following values:

Material	PC	PE	Glass	Plexiglass
(m^2/s)	1.322 x 10^{-7}	2.464 x 10^{-7}	3.810 x 10^{-7}	1.052 x 10^{-7}

Figure 12: Table of Thermal Diffusivities

As shown above, high density Polyethylene and glass dissipates heat far too quickly, and will have the tendency to make the terrarium constantly adjust to keep the environment stable. On the other hand, Plexiglass and Polycarbonate have similar diffusivity, but Plexiglass has the superior specs, beating PC in price and diffusivity. This is why we will decide to use Plexiglass panels in our physical design. With that design consideration in mind, we can then calculate the rate at which we need to adjust the device to keep conditions stable. To do that, we will first approximate the heat penetration depth D, given α and time t in seconds as:

$$D = \sqrt{\pi\alpha t}$$ Eq. 3

We then will calculate rate t we need to update the device as a function of D, the thickness of the panels we will be using. We can rewrite Eq. 3 as a function of time as such:

$$t_{dissipation} = \frac{D^2}{\pi\alpha}$$ Eq. 4

Choosing a conservative figure such as $D = 0.002\ m$ which underestimates the actual thickness of the panels we'll be using, we will get dissipation time $t = 12.1\ s$ for the heat to penetrate through the panel. This figure is a lower bound on the time intervals the device needs to update, as we will be likely to choose a larger thickness, as well as the fact that there will be an extra tolerance threshold we are granting the settings within the terrarium. Even so, 12 seconds to update the terrarium is a generous amount of time, as it is far slower than the Atmega32 microcontroller's clock cycle.

2.11 COVID-19 Contingency Plan

With the onset of the COVID epidemic this year, we understand that external factors may impact the level of success and implementation we can reasonably achieve until school ends in-person instruction after Thanksgiving Break. While we plan on completing our design for the PCB and physical display case before then, we cannot say with certainty that we will be able to assemble all the components and demonstrate proof of concept before then. Therefore we plan to have a contingency plan to complete and demonstrate the functionality of our modules individually.

For the display module, the most critical component is the LCD display, as the user will have to rely on its readings in order to confirm the terrarium is operating correctly. We will connect the PCB to the LCD display and demonstrate that it can display the readings off each sensor properly, which will also serve as proof of concept for the control unit. For the control module, we will connect the button interface to the individual components and demonstrate that they will adjust when the user input is read. These components will be attached to the power circuit, and the proof of concept will be inherently shown if the components are able to be turned on.

Should we not be able to meet any physical or time constraints, we will have to consider dropping some features or functionality of the terrarium in order to deliver the best product we are able to. As mentioned above, the pH component of the project is the most likely to not be implemented, as it is already a challenge budgeting and incorporating the sensor into our design. Thus, we will focus on the other three environmental control components. Ultimately not having a pH adjusting component should not affect the functionality of the terrarium significantly, as novice users will still effectively be able to use the device in order to better grow their plants.

Cost and Schedule

3.1 Cost Analysis

As young engineers graduating from ECE at Illinois, we anticipate an hourly wage of around $40 during the research and development of our product. In addition, we plan to have the final prototype completed by the end of 12 weeks of work, with each team member contributing an average of 8 hours of work every week. Thus the total labor cost of the development of the product, including overhead, is:

3 employees x $40/hour x 8 hours/week x 12 weeks x 2.5 (hypothetical overhead) = $28,800

As for the product itself, the total costs of parts for both a single prototype as well as products manufactured in bulk are measured below:

Part (Distributor)	Cost (Prototype)	Cost (Bulk)
Acrylic Display Case (Amazon)	$26.99	$26.99
5V DC Heating Pad (Digikey / COM11288) x 2	$7.90	$7.90
12V DC Cooling Fan (Digikey / HA40101V4-1000U-A99) x 2	$6.28	$3.91
LCD TFT Touch Screen Display (Digikey / NHD-1.8-128160EF-CTXI#-FT)	$15.04	$13.01
12V One-Way Solenoid Valve (Digikey / ROB-10456) x 3	$23.85	$23.85

Chanzon 1W LED Grow-Light (Amazon) x 10	$6.50	$6.50
Humidity / Temperature Sensor (Digikey / HDC1010YPAR)	$3.39	$1.45
ATMEGA32 8-bit MCU (Digikey)	$5.46	$4.53
Soil Moisture Sensor (Amazon)	$5.99	$5.99
Buck converter x 2 (TI/LM317)	$0.80	$0.80
Assorted wires, resistors, transistors, etc (Digikey)	$5.00	$0.50
pH Meter (Amazon)	$8.99	$8.99
Jack connector (digikey/PJ-009AH)	$0.82	$0.40
12V wall adapter (digikey/SW15-12-N-P5)	$6.95	$4.83
Total	$123.96	$109.2

Therefore, the total cost of development for the prototype, incorporating parts, labor, and overhead, is $28,923.96.

3.2 Schedule for Success

Week	Robert	Joyce	Colin
10/4/20	Design multiplexer/counter circuit for sensors	Order parts; plan adjustments to display case with machine shop	Design interface for handshaking between LCD display and MCU
10/11/20	Implement I2C peripheral to read sensor output in MCU	Design environmental regulator subsystems	Implement control unit logic; begin PCB design

10/18/20	Test each sensor and check that results correctly display	Test regulator subsystems with MCU given various sensor readings	Implement program to read results of pH meter and probe
10/25/20	Test Colin's MCU programs on hardware/regulator	Test interactions between changes in environment and new sensors readings	Finalize PCB design and order; design user interface
11/1/20	Implement sensor subsystems into prototype	Implement regulator subsystems into prototype	Debug MCU programs that fail testing
11/8/20	Test user interface, manual inputs	Finalize prototype and test with planted basil	Continue improving user interface
11/15/20	Debug prototype, prepare for Final Demo	Debug prototype, prepare for Final Demo	Begin work on Final Report
11/22/20	Prepare Final Presentation	Work on Final Report	Work on Final Report
11/29/20	Edit Final Report	Practice Final Presentation	Practice Final Presentation

4. Safety and Ethics

There are several safety and ethical considerations we will have to make while we develop our project.

4.1 Safety Considerations

The biggest safety consideration we must take into account is that we are using electronics in a humid environment with plants that must be regularly watered. Thus, we need to ensure we are always practicing safe techniques when introducing water and humidity to the environment, especially during testing and in the early phases. We must limit our exposed electronics and make use of any waterproof casings.

In addition, we must remember that plants can catch fire, especially if the environment is hot and dry with a lot of direct light. Thus, we must practice lab safety and be ready to extinguish any sight of smoke or flames from its onslaught. We must only leave the power source on when we have the ability to supervise, especially during testing and in the early phases of the project when we are still getting comfortable with the environmental regulation. We must also wait to introduce the plant to the environment when we are fully comfortable with the progress of the project and know that it is a safe time to do so.

4.2 Discussion on Ethics

One of our biggest goals for this project is to bring the joy and excitement of gardening to prospective gardeners by demonstrating how new technologies can aid them through the difficulty of maintaining plants. Thus, following the IEEE Code of Ethics #2, we intend to "improve the understanding by individuals and society of the capabilities...of conventional and emerging technologies"[15].

Due to the nature of our project, we are aware that users may use the terrarium to grow dangerous plants. This will contradict #4 and #9 of the IEEE Code of Ethics, which state respectively "to avoid unlawful conduct in professional activities" and " to avoid injuring others, their property, reputation, or employment by false or malicious actions....or physical abuses"[15]. Unfortunately, because there will be no way to control what plants the user decides to grow in the terrarium, we believe that the benefit of the terrarium will outweigh the potential downsides of having a small malicious user base. We believe by disclosing these caveats that we comply with the IEEE Code of Ethics #6, "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations"[15].

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