HomeGrow

Low-Cost Automated System for Growing Produce at Home

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1 Introduction

1.1 Problem

During the pandemic, growing plants have been both a way to sustain people's positive moods and also elevate their mental well-being. Many people desire to consume fresh and organic produce, but lack the means to get it. Many college students do not have cars to travel to the stores and organic food is usually priced above their budget. A great alternative is to grow organic food at home, this also includes an added benefit of relieving stress-induced depression. This however presents issues as many working-class people do not necessarily have the time, knowledge, or means to keep their plants thriving all the time.

Making fresh food resources expensive only increases the already existing food gap for those with lower incomes and their ability to eat healthy and sustain themselves.

1.2 Solution

Our solution is to create a vertical-farming-based automated system that provides the best growing conditions for a variety of different plans. We plan to design it with LED grow lights and watering schedules to match the needs of the designated plants.

We can place our setup anywhere, without the constraint of locations near windows for the natural light, or to optimize space. There is a built-in lighting system that allows for this flexibility. The lighting and watering is controlled by a microcontroller which contains the details of the needs of several different plants, with a focus on produce.

1.3 Visual Aid

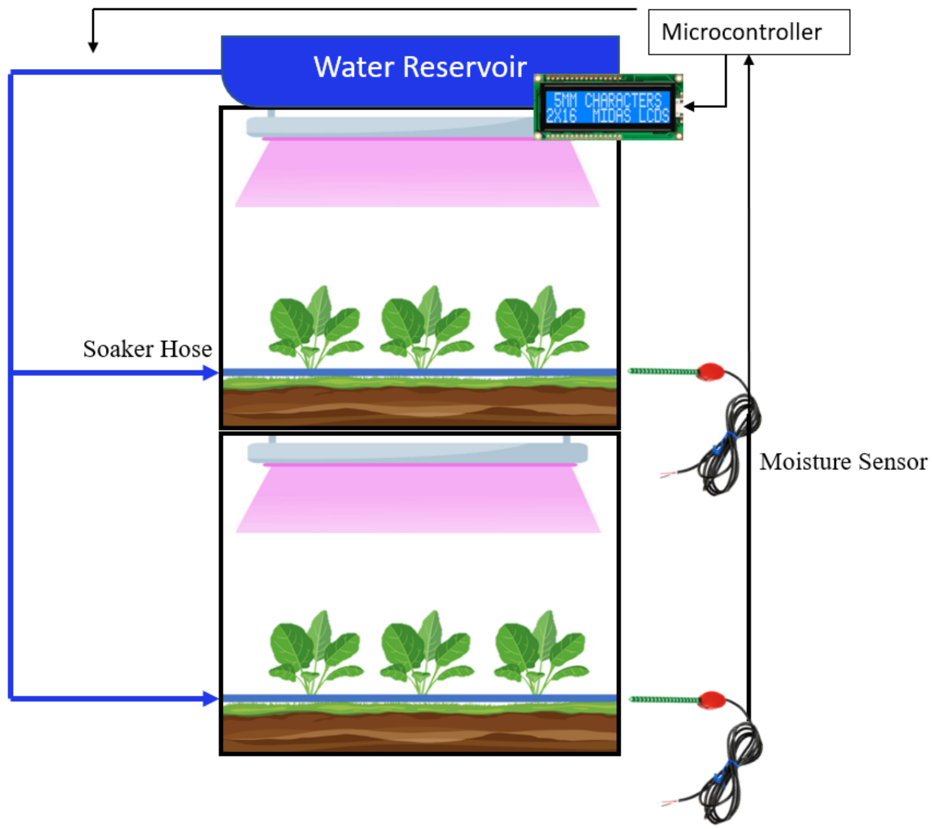

Figure 1: Mock up of the design featuring two plant beds that get watered from the same reservoir. Each plant bed has a moisture sensor to tell the microcontroller the saturation level of the soil.

1.4 High-Level Requirements List

- LCD Display will display the time of day and number of hours until the next watering cycle
- Solenoid water valves will release water at a steady flow rate for 10 minutes every 24 hour period, except when the moisture sensor detects moisture levels above 60% saturation [1]
- LED grow lights will turn on when instructed by the microcontroller and will be on for 12 hours and shut off for 12 hours

2 Design

2.1 Block Diagram

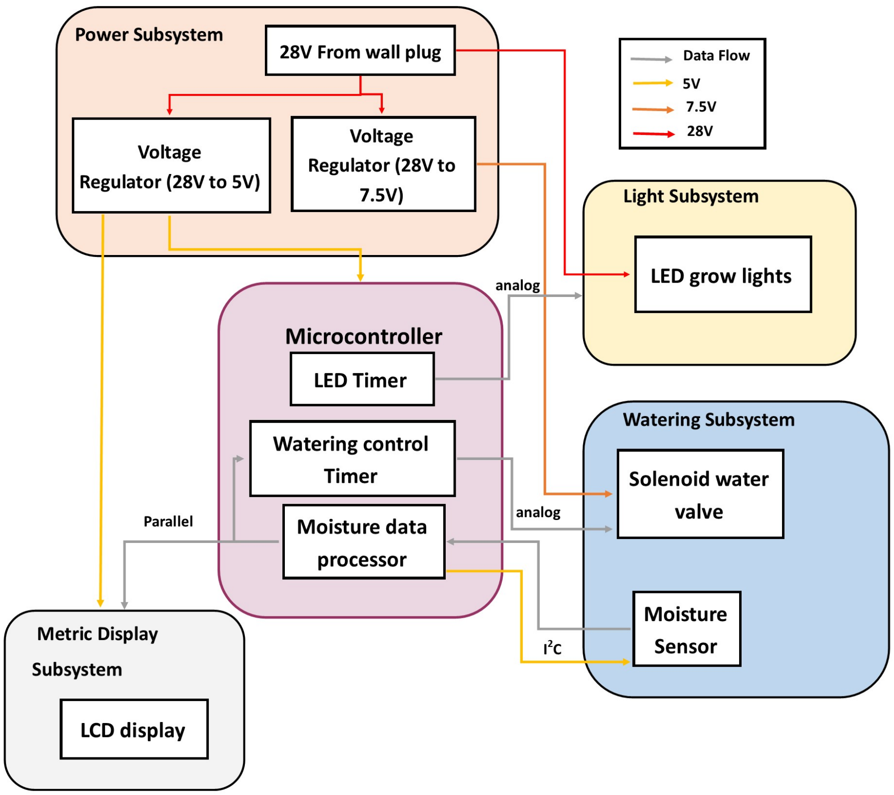

Figure 2: Block diagram to show data and power flow between each subsystem

2.2 Physical Design

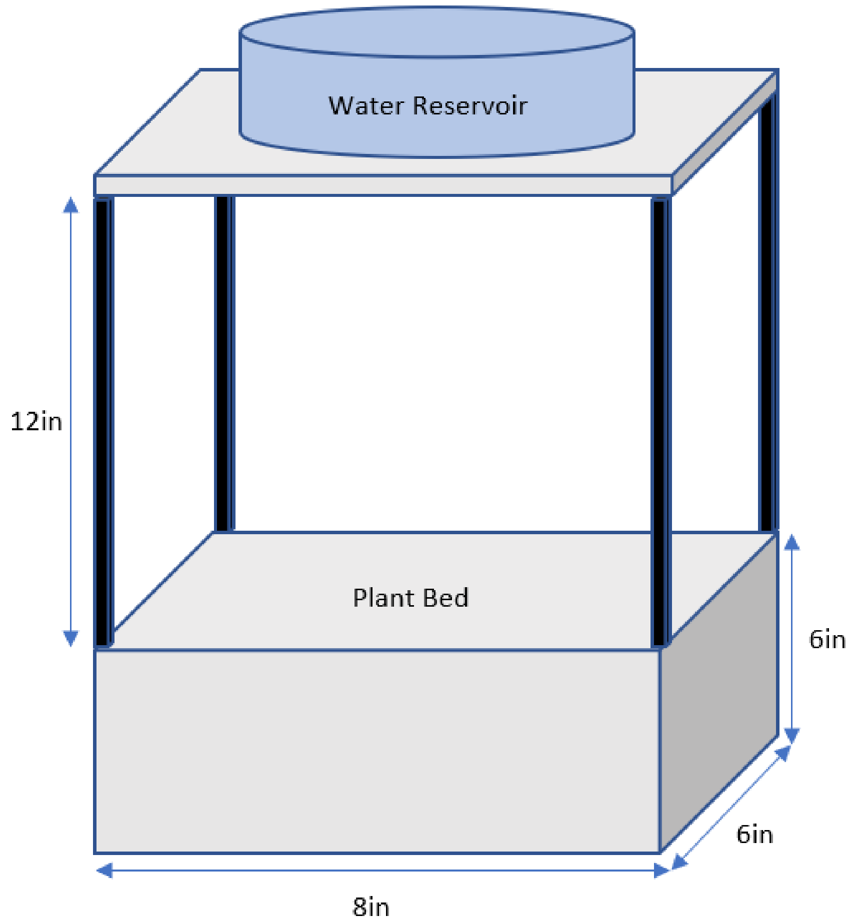

Figure 3: Physical Diagram

Our physical Diagram shown above demonstrates a single tier of our proposed two tier system. Here water flows down from the reservoir down to the plant bed via tubes. The moisture sensor in this design will be placed at half the level of the soil, 3”, to have a better idea of the saturation through the soil. The plant bed has designed with a small footprint to be more accessible to those with limited space.

2.3 Schematic Designs

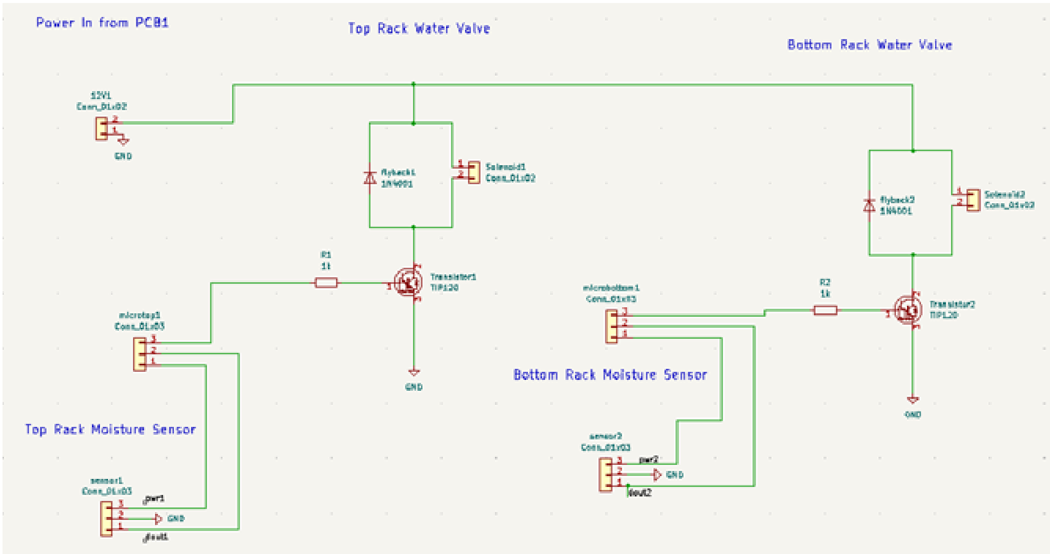

Figure 4: schematic of the watering subsystem

The solenoid water valve will get power from the voltage regulator, the current will run through the solenoid when the transistor receives high input from the microcontroller. The solenoid is connected in parallel with a fly-back diode in order to dissipate the current safely. The moisture sensor is powered by the microcontroller and sends the data back to the microcontroller. Both the transistor and the diode are the components suggested on the datasheet of the water valve

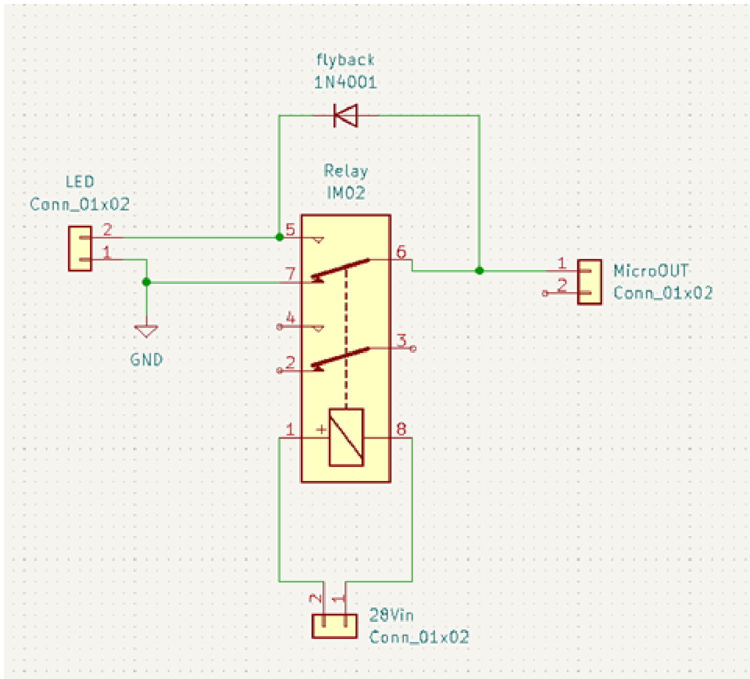

Figure 5: Schematic of the light subsystem

The LEDs are powered by the 28V input from the voltage regulator. The IM02 relay is what allows the microcontroller to switch the LEDs on and off by sending voltage to the relay. The IM02 is rated for 220VDC and 2A which is well over the requirements for our system which are 28VDC and 1.25Amps.

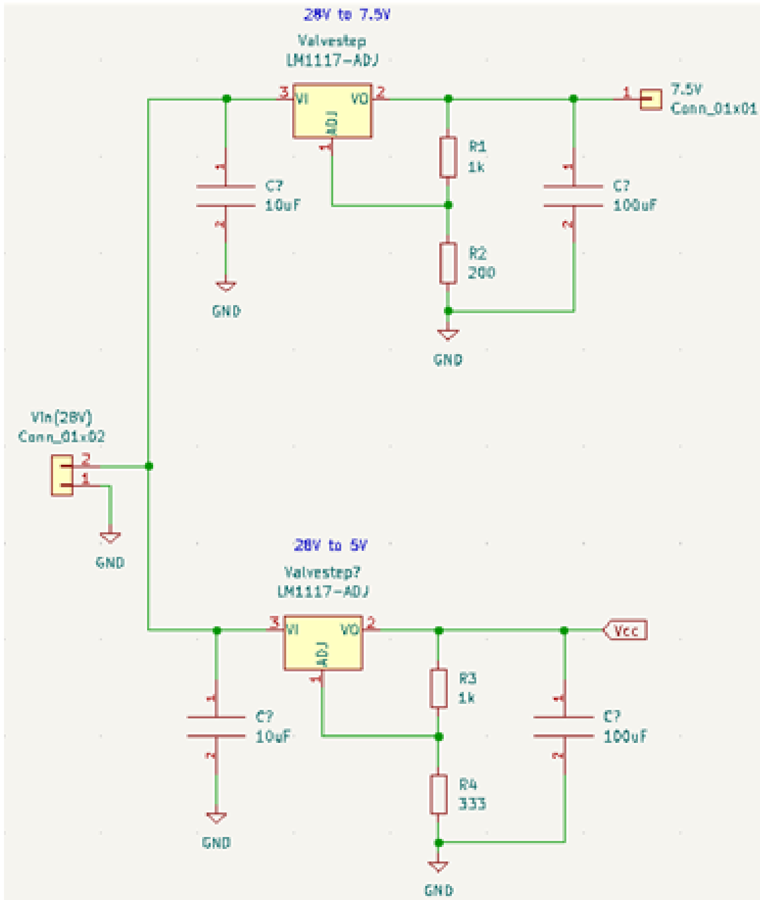

Figure 6: Rough draft of the schematic of the voltage regulators

2.4 Subsystem Overview

2.4.1 Watering

For the watering system, we chose to have a water reservoir on the top that will flow down with the help of gravity to each plant bed. From the water reservoir there is a tube or PVC pipe to bring the water down to the soil. Laying on top of the soil in each plant bed there is another tube or PVC pipe with small holes around it to let the water out into the soil. To connect these two segments of pipe is a solenoid water valve. This valve is normally closed when there is no voltage going to the solenoid and opens when there is voltage running to it. This solenoid is connected to our microcontroller where we can control the duration of plant watering. We will have the valve open for 10 continuous minutes every 24 hours.

One of the most common problems with indoor gardening is over watering. To avoid this from happening we will put moisture sensors in the soil in each plant bed. These sensors is connected to the microcontroller subsystem to tell the system how moist the soil is and if it needs to skip a watering cycle. We would program the microcontroller subsystem so that it will water for 10 minutes a day at same time every day unless the moisture level, detected by the moisture sensor is sufficient, then it will skip that water cycle and water the next day. Underneath the plant racks, there is a draining storage area for extra water to run off and be stored (to prevent inconveniencing the user with spotty water runoff).

Watering Subsystem Requirements and Verification Table	
Requirements	Verification
1. Water Valve opens when 6 Volts is applied	1A. Apply 6V of direct power for 20 seconds and check that valve opens fully and stays open upon application of voltage 1B. Apply 1V of power and check that valve stays closed.
2. Moisture sensor gathers data of the moisture level of the soil when powered on (+-2% VWC)	2A. Supply the sensor with 5V and check the output signal using an oscilloscope 2B. Over saturate soil with water and check that moisture sensor is measuring greater than 60% moisture level

2.4.2 Lighting

Light is an essential part of plant growth because it is needed for photosynthesis to take place. Mimicking sunlight as close as possible is a key component of our project keeping plants alive. We have selected to use LED's as our light source because it is the easiest way to manipulate wavelengths of light. In our research, we found that the 400-500 nm spectrum, or blue light, is helpful in increasing the quality of the plant. This wavelength promotes stomatal opening which is what allows CO2 to enter the leaves. The red light spectrum of 600-700 nm is also essential for the health of the plants. Red light encourages photosynthesis because it gets absorbed by the chlorophyll pigments. Because of this, it promotes stem and leaf growth. However, if you only give it a red light, then it would be overstretched without having the strong roots it needs. Therefore, we have decided to use a balance of both red and blue LED strips to encourage healthy plant growth[2] The LED lights are controlled by the microcontroller. Inside the microcontroller there is a timer that turns them on for 12 hours and off for another 12 hours.

The duration of light administered is monitored and maintained by programmable lights that are timer-controlled by the microcontroller subsystem. Depending on the growing needs of the plants, the lights would turn on and off accordingly.

Lighting Subsystem Requirements and Verification Table	
Requirements	Verification
1. Each row of lights turns on when supplied with 5 Volts	1A.Supply 5 Volts with the power supply to the light system and check to see that the row of lights is fully illuminated
2.The light system adheres to the designated cycle (12 hours on, 12 hours off in 24 span)	2A. Monitor the light system to ensure the proper lighting duration and cycle

2.4.3 Metric Display

Without some sort of display, the user is rendered blind as to what is going on with their home grow system. An LCD screen is implemented into our system to allow the user to have some information about the plants. The display will provide information on the watering schedule and alert the user when it is watered and when there is a delay in the program. Information from the microcontroller subsystem is sent to the LCD display subsystem to tell the user updates on its watering schedule. The LCD display is a valuable tool to keep the user in touch with the system. Displaying the remaining time until the next water cycle prevents the user from tampering with the system just before the system is set to water.

Metric Display Requirements and Verification Table	
Requirements	Verification
1.The display correctly displays the remaining time until the next watering cycle	1A.Through the course of a 24 hour period, monitor the LCD Display and ensure that the it decrements accordingly to the watering schedule

2.4.4 Power

In the interest of usability of the device, it is powered by a standard wall outlet. This power subsystem provides power to the light subsystem and water subsystem to properly administer light and water. It also powers the microcontroller subsystem to keep track of the system operations. Standard power output from wall outlet is 120 V in the United States. We will have an adapter that takes the 120V of AC power and covert it into 28V of DC Power. This is used to power the grow lights. An LM1117 voltage regulator is used to step-down the voltage to 5V which is needed to power both the microcontroller and the LCD Display. There is an additional voltage regulator that will step down the initial 28 Volts to a voltage between 6 and 12 which is needed to open the solenoid water valve. Using an adjustable LM1117, we can make the output 7.5 volts by choosing common resistors, which is enough power to activate the solenoid.

Power Subsystem Requirements and Verification Table	
Requirements	Verification
Voltage steps down to 5 volts +/- 5%	Use a multi-meter to probe the input and the output of step-down circuit
Voltage steps down to 7.5 volts +/- 5%	Use a multi-meter to probe the input and the output of step-down circuit

2.4.5 Microcontroller

The microcontroller is the central processing element of the project and tells the other subsystems what to do. It receives and interprets data from all input systems and sensors. The microcontroller receives power from the power subsystem and it sends out the voltage to the other three subsystems when necessary. There is code that will send out voltage for 12 hours for the lights to be on, then wait 12 hours and repeat. Similarly, the microcontroller will send current to open the water valves, keep it open for a set amount of time before stopping the current and closing the valve. This will occur at set times unless the signals from the moisture sensor tells it not to. The moisture sensor sends data to the microcontroller to tell it how much moisture is in the soil. The microcontroller will turn on the moisture sensor when it needs to read the data, and turn it off at other times as to not have electricity and water for long periods of time. The microcontroller will send data to the LCD screen to give the user information about the watering schedule.

Microcontroller Requirements and Verification Table	
Requirements	Verification
1. The control system must correctly determine based upon the moisture senor input, whether or not to open the watering valve at the scheduled watering time	1A. At a scheduled watering time, create two separate scenarios wherein the moisture detected from the moisture sensor is above the maximum saturation level (60%) and one where it is below the minimum saturation level. 1B. In the case where it is saturated greater than 60%, the microcontroller should not supply voltage to open the valve. 1C. In the case where saturation is less than 40%, the microcontroller should allow the valve to open
2.The microcontroller should turn on and off the LEDs at the correct schedule (12hr on 12hr off)	2A. Monitor the LED system for a 48 hour period and ensure the cycle is followed

2.5 Tolerance Analysis

2.5.1 Watering System

One of the most common problems when it comes to indoor gardening is improper watering, people tend to either over or under water their plants. In order to avoid this in our design, we researched what the proper saturation level is for growing plants [1]. We found that all vegetables need a soil moisture between 41 and 80 percent. Looking at the moisture sensor, it has two probes which act as a variable resistor - more water in the soil means better conductivity and results in a lower resistance, and vice versa.

One of the biggest parameters for quantifying the soil water content is VWC (volumetric water content). VWC is the ratio of the volume of water to the unit volume of soil. Field capacity (FC) is the threshold at which water in larger pores has been drained away by gravitational force - an irrigation depth causing the soil water content to go above field capacity is undesirable due to water percolating to layers deeper than the roots can reach. The TAW is the total available water to plants (estimated as difference in SWC between FC and permanent writing point). Above FC, water is available to plants only for a short while before being lost to drainage. The MAD (management allowable depletion) is the portion of the total available water that can be depleted before plants experience water stress and growth stunting. [3]

The value of MAD is a function of stress tolerance, growth stage, and water usage of said crop - sensitive crops like lettuce have a MAD of 0.3, and less sensitive crops like potatoes have a MAD of 0.65.

For sensors that report VWC, we use the following equations:

1: $IrrigationTriggerPoints = FC - (MADxTAW)$

2: $TAW = FC - PWP$

Example Plant Levels		
Plant Type	MAD	Max Root Depth (ft.)
Carrots	0.35	1.5-3.3
Lettuce	0.3	1.0-1.6
Sweet Peppers	0.3	1.0-1.6

* Above MAD values are for water use of 0.2 inch/day

2.5.2 Voltage Regulator

We will be using a LM1117 in our design to regulate the voltage and step-down the voltage when needed. To adjust the output voltage, you adjust the resistors in the circuit. We are going to need two regulators. One to step down from 28V to 5V for the microcontroller and one the step-down from 28V to a value between 6V and 12V for the solenoid. Taking the equation from the schematic shown below in Figure 7, we can find the resistor values needed for these regulators .

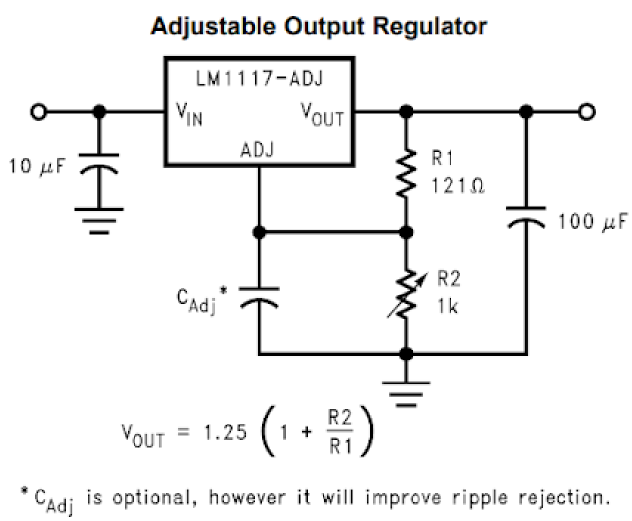

Figure 7: Schematic of voltage regulator[4]

$Vout = 1.25(1 + R1/R2)$
if we set R1 to 1kohms and R2 to 333Ohms, we get:
$Vout = 1.25(1 + 1000ohm/333ohm) = 5.0037Volts$
These are the desires resistors for the microcontroller regulator
If we keep the same R1 of 1k ohm, and change the R2 vavlue to 200 ohm, we get:
$Vout = 1.25(1 + 1000ohm/200ohm) = 7.5Volts$
This gets an output of 7.5 volts which is within range to open the solenoid water valve

3 Cost & Schedule

3.1 Cost Analysis

Labor Cost: The average salary of a person with a BSEE from Illinois is 79,000. Given there are approximately 2080 working hours in a year, the average hourly rate is about $38/hr.

Student labor hours: $10weeks * 8hr/week * \$38 * 2.5 * 3people = \$22,800$
Machine shop labor hours: $\$50/hour * 5hours = \$250$

Parts Breakdown			
Part	Price	Quantity	Final Cost
Microcontroller(ATMEGA325)	$5.18	1	$5.18
LED grow light	$9.31	2	$18.62
Relay(IM04)	$4.41	1	$4.41
Plastic Water Solenoid Valve	$6.95	2	$13.90
Moisture Sensor	$6.95	2	$13.9
Clear Plastic Water Reservoir	$5	1	$5
Planter box	$10	2	$20
PVC tubes and Framing	NA	NA	$15
LCD Display	$18.50	1	$18.50

3.2 Schedule

Project Schedule		
Goal date	Task	Who is taking lead
2/24/22	Design Document	Team
2/27/22	Finalize parts list	Stephanie
2/28/22-3/2/22	Design Review	Team
2/29/22	PCB Board basic mock-up	Stephanie
3/2/22	order parts	Sanjana
3/5/22	discuss design and dimensions of watering system	Ciara
3/8/22	PCB Audit	Stephanie
3/9/22	Design voltage regulator circuit	Sanjana
3/10/22	Write light control code	Ciara
3/11/22	turn materials into machine shop(depends when parts arrive)	Team
3/24/22	Test soil sensor on current plants and arduino module	Stephanie
3/25/22	Test LCD Display	Sanjana
3/30/22	write watering system code	Stephanie & Ciara
4/4/22	program microcontroller and test that it can run simultaneously	Team
4/8/22	Assemble prototype	Team
4/11/22	begin running tests on prototype and record videos	Team
4/18/22	Mock Demo	Team
4/25/22	Final Demo	Team
5/4/22	Final Paper	Team

4 Discussion of Ethics & Safety

4.1 Ethics

The IEEE Code of Ethics [5] Section 1.2 discusses the importance of ethical conduct ”to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems”. This is relevant to our project as we are creating an intelligent watering system with the purpose of aiding people obtain higher quality and healthier foods.

Finally working in a group, it is important to pay mind to the IEEE Code of Ethics Section 2.2, where we commit ”to treat all persons fairly and with respect, and to not engage in discrimination...”. These values will help to promote a healthy and conducive work environment.

4.2 Safety

Section 1.1 of the IEEE code of Ethics [5] Section 1.1 indicates that it is important ”to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment”. This is relevant and important to our project as we are creating a system that incorporates water and electricity for proper function. In order to eliminate any issues of this sort the design is created such that the water and electrical components will be kept on different sides of the product.The design also includes a pipe watering method instead of an overhead watering so that the lights and the water would avoid contact with each other. However, the water release valve needs to be connected to power. In this case, we will keep the wires and water double-insulated to ensure the safety of the user. In addition, the solenoid valve is designed for water usage, and should not pose any issues either. When applicable, we are also adhering to IEEE Standards like 833-2005[6], on the Recommended Practice for the Protection of Electric Equipment from Water.

5 Citations

[1] "AcuRite Blog - Soil Moisture Guide for Flowers, Plants and Vegetables," www.acurite.com. https://www.acurite.com/blog/soil-moisture-guide-for-plants-and-vegetables.html

[2] "Grow Light Spectrum Explained: Ideal LED Spectrum for Plants," BIOS Lighting, Apr. 29, 2020. https://bioslighting.com/grow-light-spectrum-led-plants/grow-lighting/

[3] S. Datta, S. Taghvaeian, and J. Stivers, "Understanding soil water content and thresholds for irrigation management - Oklahoma State University," Understanding Soil Water Content and Thresholds for Irrigation Management — Oklahoma State University, 01-Aug-2018. [Online]. Available: https://extension.okstate.edu/fact-sheets/understanding-soil-water-content-and-thresholds-for-irrigation-management.html. [Accessed: 24-Feb-2022].

[4]Texas Instruments, "LM1117 800-mA, Low-Dropout Linear Regulator, LM1117 datasheet, Nov. 1997 [Revised June 2020].

[5] "IEEE code of ethics," IEEE, Jun-2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: 22-Mar-2022]

[6]"Recommended Practice for the Protection of Electric Equipment in Nuclear Power Generating Stations from Water Hazards," in IEEE Std 833-2005 (Revision of IEEE Std 833-1988) , vol., no., pp.1-20, 19 May 2006, doi: 10.1109/IEEESTD.2006.216286.