

Project Proposal: Soil Moisture Controller (Pitched Project)

This project is a pitched project idea by the U.S. Department of Agriculture's research laboratory on campus. It will be performed in partnership with a capstone team of students from the Department of Agricultural and Biological Engineering.

Introduction

Problem

One of the biggest limiting factors for gains in agricultural productivity is the ability to provide sufficient moisture in the soil for the growth of crops. In particular, arid regions face the possibility of the occurrence of droughts that reduces the crop yields in dryland agriculture. To manage this issue, various water management strategies have been developed to ensure that there is sufficient water being applied over these crop lands. These irrigation systems have to provide control over the amount of water that is being applied over these crop lands such that optimal agricultural productivity is achieved while ensuring maximum water use efficiency.

Currently, the measurement of soil moisture content in pots are performed manually with individuals monitoring the moisture level based on weight, or the use of gravimetric sensors.

Upon irrigation, the weight or load of the pot would be at its maximum, and due to evapotranspiration over time, this weight would be lowered. When it eventually crosses a threshold set by the sensor, irrigation of the pots would be triggered again. However, due to the many different components that make up the weight of the pot, it is difficult to measure the exact proportion of increase in plant mass to the change in soil moisture content to obtain an accurate indication of when the irrigation has to be activated. As a result, there is a need for a more precise method to measure and maintain the soil moisture conditions in these pots through the use of soil moisture sensors. These soil moisture sensors would allow for the moisture that exists in the pot to be read so that sufficient irrigation is provided for consistent moisture.

Solution

Our solution consists of a cheaper yet more effective device that provides constant moisture monitoring and water irrigation as needed to different types of soil. When the moisture within the substrate is below the predetermined target level (e.g. 25, 50, 75, or 100 percent), the water valve will be triggered to an extent where the moisture can be maintained at that level. In addition, there is also an interface so users are also allowed to check the current status of each pot, that is whether the substrate moisture is desirable as indicated by LED lights, and control the target level in the pot through a keypad.

We will work alongside the team of ABE students to construct the irrigation system and ensure that our solution could be scaled up for high-throughput of at least 50 plants in the future.

Visual Aid/Physical Design

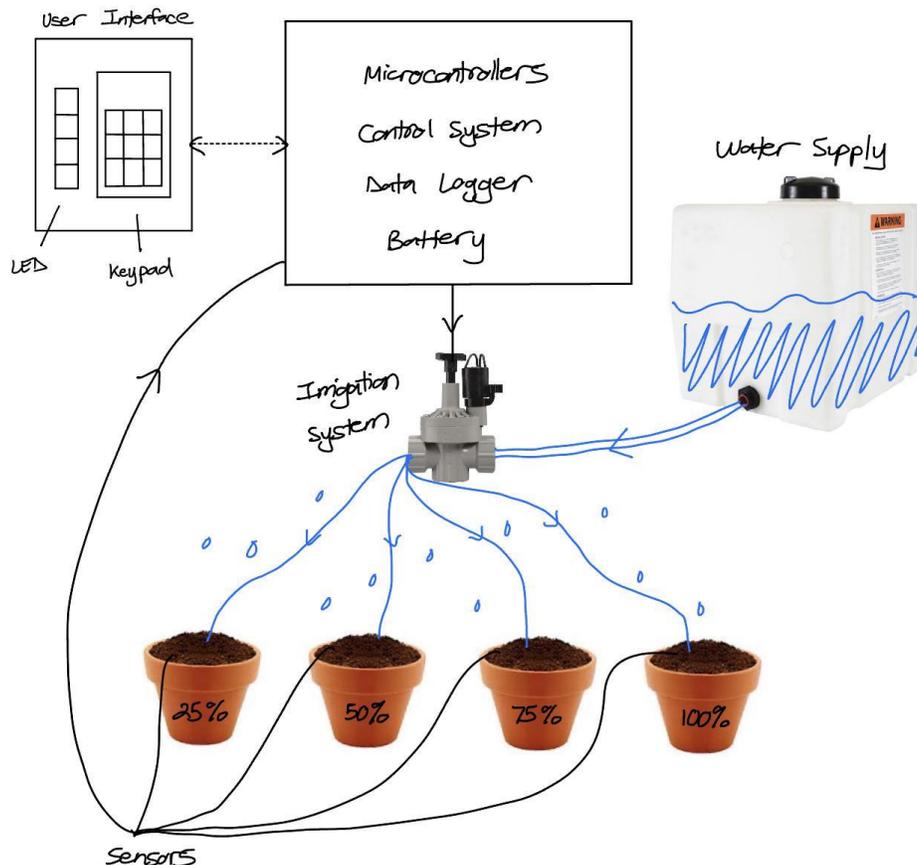


Figure 1: Visual aid of our project

High Level Requirements List

These criteria for success are based upon the requirements articulated by the client (USDA) and jointly developed with the ABE team working together on this project.

- The moisture sensors should be able to detect the current level of moisture in the soil to an accuracy of $\pm 5\%$ for the moisture level data to be logged on an SD card and displayed on an LED bar graph on an hourly basis
- The system should be able to provide irrigation when the moisture level falls beyond a set threshold level as inputted using a keypad by the user and maintain it to an accuracy of $\pm 5\%$

- The system should be scalable to four different pots and the moisture level maintained at 100%, 75%, 50% and 25% in each of the respective pots

Design

Block Diagram (with Summary)

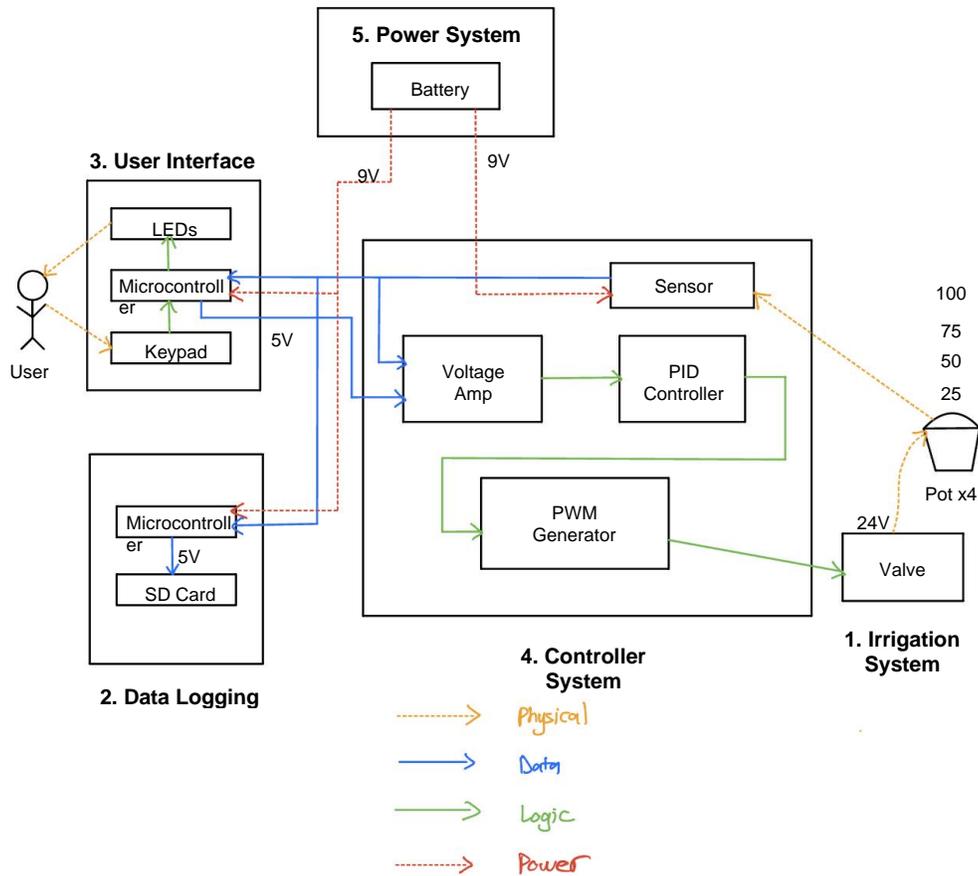


Figure 2: Block Diagram

As shown in *Figure 2*, our project can be broken down into five subsystems: irrigation, data logging, user interface, controller, and power. The irrigation system consists of a valve, pipes, and water supply that will be used to water 4 different pots of soil in order to maintain a specific moisture level in each. We will work with the ABE team to design this. The data logging system will collect and store data such as temperature, weight, etc. every hour, and consists of a microcontroller and SD card. The user interface allows users to type on a keypad to manually control the watering/moisture level monitoring of a pot (if necessary) and LEDs as a display to see the moisture level of each pot. The controller system consists of a sensor, voltage amp, PI controller, and PWM generator. It will take in moisture level and user data as input, and output a signal that tells the water valve how much water should be given to each pot. Finally, the power

subsystem is made up of a 9V battery, but we are open to exploring other options to supply power to our system.

A further breakdown of our block diagram tied to our visual aid can be found below in *Figure 3*.

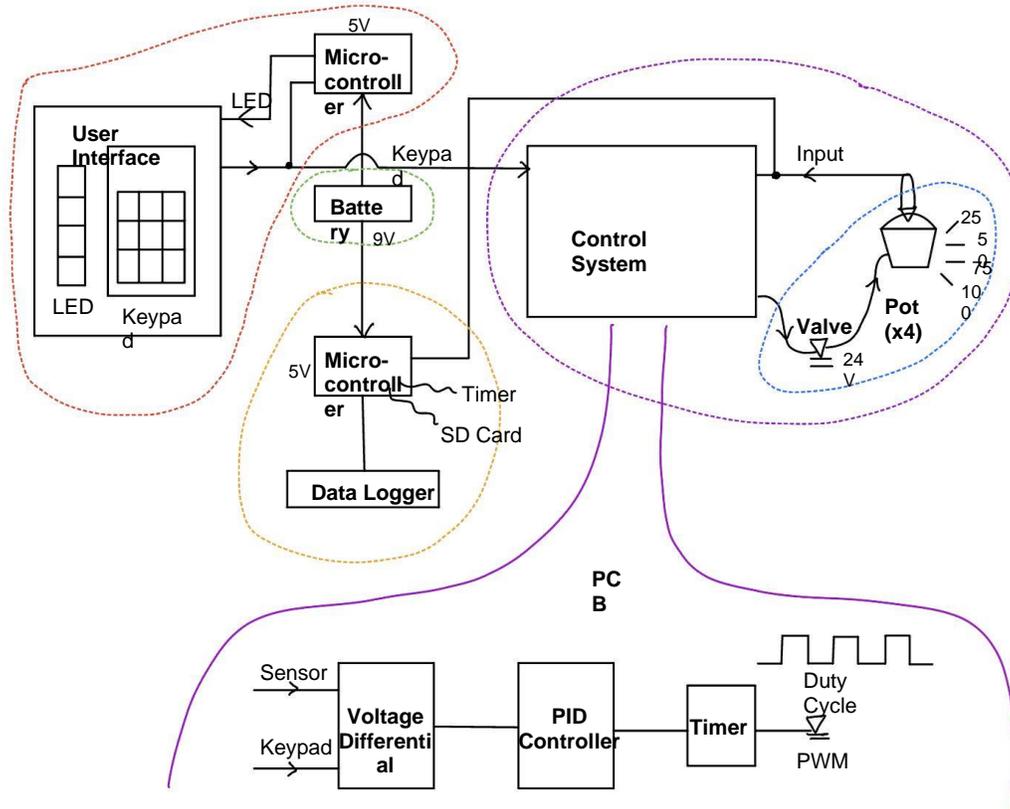


Figure 3: Further breakdown of block diagram and visual aid

Block Descriptions

Subsystem 1: Irrigation Subsystem

Irrigation is the process of artificially applying controlled amounts of water to land or crops. This is done by using valves as well as a system of tubes and pumps to bring in water from pipes, canals, sprinklers, and other man-made water sources, instead of relying on rainfall. For this project, the irrigation subsystem for each soil pot would consist of a valve that would open and close based on the moisture level measured, in order to maintain a desired set of moisture conditions for different soil and soilless substrate mixes. Irrigation is needed in a given pot if it is sensed that the moisture level falls below a certain value (for example, below 75 for fine soil). When this happens, relay switches activated by a microcontroller, such as an Arduino, will operate the irrigation valves

(likely 24V) that correspond to each sensor-controlled pot, and water will flow out until the soil reaches an ideal value again.

Requirement 1: Valves will open/close to dispense a correct amount of water to the appropriate pot based on the signal received from the controller

Requirement 2: The irrigation system should be scalable so that at least 4 pots can be watered in by respective amounts at the same time

Requirement 3: Water will be pumped from a supply tank using a series of tubes until a moisture level between 0 and 100 is reached for a given pot

Materials:

- 3/4" valve:

https://www.amazon.com/Galcon-Irrigation-Reinforced-Greenhouse-Residential/dp/B08MTQB8BX/ref=sr_1_4?crd=3RHJI5FFG6PJE&keywords=24v+irrigation+valve+3%2F4+water&qid=1675117467&srefix=24v+irrigation+valve+3%2F4+water%2Caps%2C113&sr=8-4

https://www.amazon.com/Beduan-Electric-Solenoid-Normally-Colsed/dp/B07YTHKHL4/ref=sr_1_3?crd=2QMUSM9AGT0L8&keywords=24v%2Brrigation%2Bvalve%2B3%2F4&qid=1675117428&srefix=24v%2Brrigation%2Bvalve%2B3%2F4%2Caps%2C100&sr=8-3&th=1

- Tubing

https://www.amazon.com/Tubing-Flexible-Hybrid-Lightweight-10-Foot/dp/B07HF648M5/ref=sr_1_4?keywords=clear+plastic+tubing&qid=1675117678&sr=8-4

- Hose ring

https://www.amazon.com/Selizo-Including-Adjustable-Clamps-Stainless/dp/B07G9TZLRM/ref=sr_1_8?crd=1C737TN4ANA1X&keywords=hose+ring&qid=1675117705&srefix=hose+ring%2Caps%2C114&sr=8-8

Subsystem 2: Data Logging Subsystem

The data acquisition subsystem will consist of a data logger, an instrument that monitors and records changes in conditions over time. Most data loggers can accept two or more types of input, so we would program ours to take inputs such as voltage, current, temperature, etc. The data logger will ultimately communicate the need for irrigation by measuring and recording calculated factors like volumetric water content for each soil, and generating a list of plants that require irrigation. Then, this list of plants will be sent to the microcontroller that carries out the irrigation process for the relevant plants by using a pulsing I/O signal of either 0 or 5V to communicate whether or not irrigation is needed. There are many expensive existing data loggers such as the CR100, but we

would want to buy or build one that is still battery-powered and effective for a cheaper price. One option that nicely interfaces with an Arduino microcontroller would be to create a data logger from scratch using a data-logging shield, coin battery, and SD card.

Requirement 1: Send a pulse I/O of 0 or 5V to signal to the controller whether or not irrigation is needed for each pot

Requirement 2: Record data every 60 minutes (sample rate) for each pot and store on an SD card

Requirement 3: Data logger should be able to read more than 2 inputs such as voltage, current, temperature, etc. at once

Materials:

- Data-logging shield:

https://www.amazon.com/AITRIP-Logger-Logging-Recorder-Arduino/dp/B09PDL7XM7/ref=sr_1_4?crid=13UWJYJNEUANV&keywords=data+logger+arduino&qid=1675121100&sprefix=data+logger+%2Caps%2C112&sr=8-4

https://www.amazon.com/HiLetgo-Logging-Recorder-Logger-Arduino/dp/B00PI6TQWO/ref=sr_1_3?crid=13UWJYJNEUANV&keywords=data+logger+arduino&qid=1675121312&sprefix=data+logger+%2Caps%2C112&sr=8-3

- Coin battery for shield
 - SD card
- www.adafruit.com

Subsystem 3: User Interface Subsystem

The user interface subsystem would consist of two main components. The first component would be a 10-segment LED bar graph that shows the soil moisture level as detected by the sensors in each pot. This would give the user visibility of the soil moisture level in the pot at any point in time instead of having to check on the data log in the SD card.

The second component would be a 4x4 keypad where the user is able to input the desired soil moisture level that the user would like the pot to be maintained at. The compact size of the keypad would be beneficial in a greenhouse setting where the user would not have to rely on inputting this data via a laptop.

An Arduino Uno microcontroller can be used for interfacing between the soil moisture sensors, 10-segment LED bar graph and 4x4 keypad.

Requirement 1: Visualize soil moisture level data collected by the sensors in the pot on the 10-segment LED bar graph

Requirement 2: User must be able to input any percentage value of soil moisture level from 0 to 100 using keypad

Requirement 3: The microcontroller must be able to send and receive data to and from the voltage comparator in the controller subsystem

Materials:

- 10-segment LED bar graph
https://www.digikey.com/en/products/detail/lite-on-inc./LTA-1000G/153278?utm_adgroup=LEDs%20-%20Circuit%20Board%20Indicators%2C%20Arrays%2C%20Light%20Bars%2C%20Bar%20Graphs&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Product_Optoelectronics_NEW&utm_term=&utm_content=LEDs%20-%20Circuit%20Board%20Indicators%2C%20Arrays%2C%20Light%20Bars%2C%20Bar%20Graphs&gclid=Cj0KCQiAofieBhDXARIsAHTTldrpPCV_Ld2bW2hLmQAX61QWZ-tQ2mlopMmiCsqRrKTo4rm2n1DHGv8aApWvEALw_wcB
- 4x4 keypad
<https://www.digikey.com/en/products/detail/parallax-inc/27899/3523678>
- Arduino Uno R3 ATMEGA328P Eval microcontroller
<https://www.digikey.com/en/products/detail/arduino/A000066/1050-1024-ND/2784006>
- Breadboard
<https://www.digikey.com/en/products/detail/dfrobot/FIT0096/1738-1326-ND/7597069>

Subsystem 4: Controller Subsystem

In order to efficiently gain the desired substrate moisture level, we decide to implement a PID controller which takes the feedback input from the moisture sensor, compares the measured value with the desired value, and triggers the water valve if the measured value is below the desired value.

The value from both the moisture sensor and user input will be sent to a differential amplifier that outputs a voltage proportional to the voltage difference. The filtered voltage will then be inputted to the PID controller which consists of potentiometers for tuning the controller, inverting op-amps for amplification, and capacitors for implementing the integrator, and derivative circuits.

Finally, the output of the controller will be amplified and connected to a LM555 Timer chip in order to generate a PWM signal to the water valve so that the amount of water being given is sufficient to each pot.

Materials:

- LM741

https://www.ti.com/lit/ds/symlink/lm741.pdf?ts=1675601882198&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM741

- PID Circuit
https://www.nutsvolts.com/magazine/article/the_pid_controller_part_1
- LM555
<https://www.ti.com/lit/ds/symlink/lm555.pdf>

Requirement 1: The voltages from the moisture sensor and user input must be calibrated to the same scale in order to acquire a reasonable voltage difference.

Requirement 2: The control system must be able to remain stable and reach the target level within five minutes.

Requirement 3: The controller must be able to send the information on the amount of water needed for each pot so that the relative error would be less than 5%.

Subsystem 5: Power System

The power subsystem would consist of 9V batteries that are rechargeable and provide power to the other subsystems like user interface subsystem, data log subsystem and controller subsystems. The power subsystem must be capable of outputting sufficient current such that all devices can be powered consistently.

For the Arduino microcontrollers in the user interface and data log subsystems, the 9V battery can be used together with a snap-in connector and a DC barrel jack. The Arduino microcontrollers accept 7-12 V DC through the power jack and the onboard voltage regulator steps down the voltage to the required 5 and 3.3 V DC. This would allow for the data log and user interface subsystems to be used as portable devices without a need for mains voltage, which is often the situation in a greenhouse.

For the controller subsystem, it is likely that a higher voltage of around 24 V DC is required for the irrigation valves. To step up this voltage, a voltage booster can be used.

Requirement 1: The batteries should be able to provide enough voltage to the whole system and recharge when needed using a battery charger

Requirement 2: The voltage booster should be able to convert the 9V from battery to required 24 V for the irrigation valves with a tolerance of ± 0.1 V

Materials:

- 9V rechargeable battery
<https://www.digikey.com/en/products/detail/energizer-battery-company/NH22NBP/4477695>
- 9V battery charger
https://www.acehardware.com/departments/lighting-and-electrical/batteries/household-battery-chargers/3900800?store=16427&gclid=Cj0KCQiAofieBhDXARIsAHTTldpCjpBw_LcU

[HaEZVtvyXccioBCeHD3nd7LEZQ_yjOh9rdOfBOB-1qYaAukmEALw_wcB&gclid=aw.ds](https://www.digikey.com/en/products/detail/sparkfun-electronics/PRT-09518/5762387)

- Snap in connector for batteries
<https://www.digikey.com/en/products/detail/sparkfun-electronics/PRT-09518/5762387>
- 9V to 24 V voltage converter
<https://www.digikey.com/en/products/detail/xp-power/DTE6024S24/5931178>

Tolerance/Risk Analysis

The most challenging part of the project is to construct a closed-loop control system that satisfies all the subsystem requirements, which are the ability to remain stable within 5% from the desired level. Since the PID controller will be implemented with operational amplifiers (op-amps), resistors, and capacitors, majority of the tuning will be done by adjusting the resistance, capacitance, and ratios between resistance on each side of the amplifier. In order to test the feasibility of the control system itself, a simulation of the closed-loop system in response to a unit step function is run on LTSpice. All op-amps in the simulation are in LM741 model.

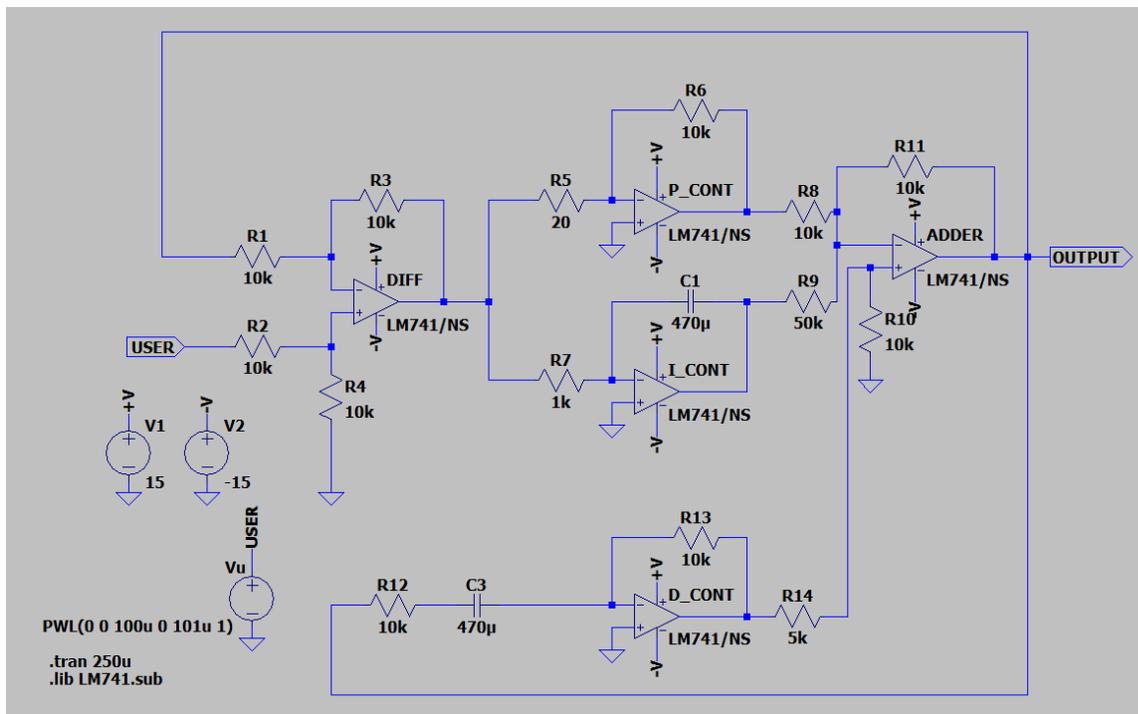


Figure 4: Closed-loop control system circuit for simulation

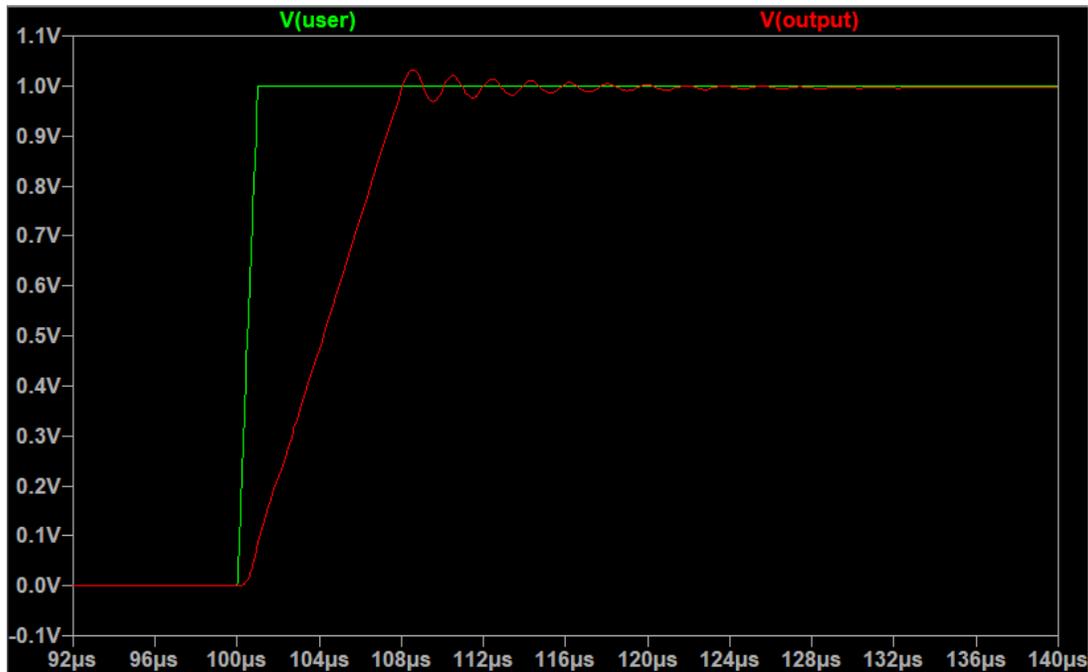


Figure 5: Simulation Result

From the simulation result above, it can be seen that the output can track the unit step from the input, and the output remains stable within the required tolerance over 8 microseconds. Additional tuning would be needed after connecting the system with the moisture sensor and water valve. The methods which will be used to tune the system are as follows:

- If the resistance used in the simulation does not exist, the scaling of the resistances across the op-amp can be done so that the ratio remains constant.
- If the scale of the moisture sensor and user input does not match, the ratio of the resistance in the first op-amp (or voltage differential op-amp) can be adjusted.
- If the offset or range of the control system output does not fit with the valve specifications, additional voltage divider circuit and op-amp can be connected to fix both issues.
- If the steady state of the control system is out of the tolerance limits or the response time is too long, higher proportional gain is needed.
- To fix the instability problem, lower derivative gain is needed. To reduce the oscillation or overshoot of the system, lower proportional and integral gains are needed. The gains can be lowered by increasing the resistance in each part.

Ethics and Safety

One of the main ethical standards that should be followed in this project is keeping our project ideas original and different from other ideas that are already found on the market. There should not be any plagiarism of product designs and other applicable sources found during the research process should be properly cited and credited. (IEEE Code of Ethics II.5). In the context of our

project, other automated soil moisture-based irrigation control technologies that utilize smart watering to tailor irrigation schedules to meet the water needs of the area are present. Careful consideration should be made to keep our project idea distinct from these existing technologies, in terms of the methods we use to achieve the implementation of such a system. Additionally, the IEEE Code of Ethics I.5 states that the claims and estimates based on available data should be honest and realistic. As our project would be dealing with making soil moisture data available for the user to make decisions on irrigation schedules, our team pledges to ensure the solution is sufficiently tested such that the data shown by the sensor system is accurate and precise. This includes a comparison of the water moisture level detected by the sensor across multiple occasions such that the measurements made by the sensor are repeatable.

Specific safety concerns in our project should also be addressed. Upon review of the laboratory safety regulations as set by the Division of Research Safety in the Office of the Vice Chancellor for Research and Innovation, our team pledges to follow these regulations strictly in the lab sessions that we engage in during the semester. Our team would always work in a team of at least two people, report any broken equipment immediately, clean up after each lab session, and avoid bringing any food into the lab (ECE 445 p.3). One of the potential safety risks that might be encountered during the project would be the possibility of short circuits when the electronic components are wired to a power source resulting in damage to all the combustible crop around the soil moisture controller. Accidental skin contact with the circuit with moisture would also increase the risk of dangerous electric shocks through our body. Special attention would be paid to ensure that electrical systems are kept entirely separate from any external irrigation systems that release water over croplands.

Citations and References

1. Ortiz, Diego, et al. "A Cost-Effective and Customizable Automated Irrigation System for Precise High-Throughput Phenotyping in Drought Stress Studies." *PLOS ONE*, vol. 13, no. 6, 2018, <https://doi.org/10.1371/journal.pone.0198546>.
2. ECE 445 Lab. Lab : ECE 445 - Senior Design Laboratory. Retrieved February 2, 2023, from <https://courses.engr.illinois.edu/ece445/lab/index.asp>
3. IEEE code of Ethics. IEEE. (n.d.). Retrieved January 24, 2023, from [//www.ieee.org/about/corporate/governance/p7-8.html](http://www.ieee.org/about/corporate/governance/p7-8.html).
4. Liao, R., Zhang, S., Zhang, X., Wang, M., Wu, H., & Zhangzhong, L. (2021). Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept. *Agricultural Water Management*, 245, 106632.