5-2019

# Automated Greenhouse Watering System for Schenectady ARC

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ECE 499 Electrical Engineering Capstone

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March 21, 2019

## Report Summary

The Schenectady ARC Maple Ridge Center is a local chapter of the NYSARC, Inc. located in the Albany region. It is a non-profit organization dedicated to supporting individuals with developmental disabilities and their families throughout the New York State and contains a greenhouse which helps the individuals to develop useful skills in greenhouse management and maintenance. Their current watering system for the seed bed is cumbersome, unintuitive, and time-consuming to use; therefore, the goal of this project is to construct an automatic irrigation controller and water delivery system that will be affordable, easy to maintain, and simple to operate even for those with disabilities.

The system is largely made up of four parts: the controller, the user interface, the soil moisture detection unit, and the water delivery unit. The controller coordinates the behavior of the other three parts of the system. The user interface interacts with the user to present information about the soil moisture conditions and to allow the user to specify the settings of the system in a manner that is intuitive and usable by those with disabilities with little supervision. The soil moisture detection unit is responsible for acquiring calibrated soil moisture values in real time, so the controller can determine when to water and the water delivery unit delivers water to the seedlings in a safe and controlled way in response to either user input or the soil moisture conditions.

Currently, calibration experiments have been done to acquire data pertaining to the relationship between the analog values provided by the microcontroller moisture sensors and a water pressure value provided by a tensiometer. A linear relationship has been determined and coded into the controller for conversion of values to display to the user. The controller, currently an Arduino Redboard, operates in two modes, an automatic mode that compares the current soil moisture values to a threshold set by the user to determine when to water and a manual mode that waters when the user continuously presses a button. The Netafim misting system is currently being tested in the greenhouse with one already set up for control

via a manual switch. However, issues with the mister have been encountered and are currently being resolved with experts at Griffin Greenhouse. Soon after the issues are resolved, I would like to work on assembling the entire misting system to respond to manual control so the Schenectady ARC can at least water their seedlings manually during the germination period of the year.

Overall, the system is more economic that other irrigation controls currently on the market and is customized to incorporate the behaviors required by the Schenectady ARC. It provides a system for watering the seed bed that is simple to use and learn, even for those with disabilities, and functions in various modes for times when no one at the ARC can manage the greenhouse. While there is still a lot to do for the project such as integrating it with the heating system for the seedlings and conducting more calibration tests, much has been accomplished to meet the design requirements and create a functioning system. Throughout the design process, I worked closely with those at the Schenectady ARC to determine the design of the system and learned a lot about the iterative process of design. I will also continue to work on this project in the next term to achieve the future goals mentioned.

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## 1. Introduction

The Schenectady ARC Maple Ridge Center is a local chapter of the NYSARC, Inc. located in the Albany region. It is a non-profit organization dedicated to supporting individuals with developmental disabilities and their families throughout the New York State [1]. An integral part of the center is their greenhouse which not only partially funds the ARC through selling the grown plants but also helps the individuals to develop useful skills in greenhouse management and maintenance. Individuals at the Maple Ridge Center are responsible for operating the water system to irrigate the plot daily and ensure the proper amount of water is distributed to the plants. This task enables them to be independent, develop their participation in the community, and participate in an engaging and rewarding activity.

**Figure 1.** Current ARC Greenhouse controller setup

**Figure 2.** ARC Greenhouse hose with exchangeable wand

However, the current watering system for the seedling bed in the ARC greenhouse requires manual operation and is cumbersome, time-consuming, and unintuitive (Figure 1). It simply consists of a hose with two Y-connected nozzles, one that is routed to the overhead watering sprinklers (which currently do not work) and one that is routed to an exchangeable wand (Figure 2) which must be manually carried and operated to water the seedling bed. This process can take as long as two hours every time and is complicated by the fact that there are individuals who cannot hold the wand on their own or require direct supervision. In addition, the moisture conditions of the seedlings in the greenhouse currently require manual monitoring with a hand-held sensor that offers no objective measurement of how much water the seedlings have – simply a green or red digital reading indicating satisfactory soil moisture content. To address these concerns, an improved and upgraded watering system is required.

This paper describes a system to implement an automatic irrigation controller and water delivery system that will be affordable, easy to maintain, and simple to operate. We have been collaborating with Donna Vincent, the director of the Schenectady ARC, during the design process to identify desired system specifications. We are concerned with developing a system that can automatically provide gentle, regular watering to a seedling bed and is, most importantly, operable by those with developmental disabilities with little supervision and difficulty. The following section in this report will discuss more background information regarding the treatment and needs of those with developmental disabilities as well as the current setup of the greenhouse watering system, alternative systems currently on the market, previous work. This will be followed by a description of the design requirements and alternatives. Finally, the preliminary and final prototype design will be presented along with a performance evaluation, cost evaluation, overview of the production timeline, and discussion of future work.

## 2. Background

### *2.1 Treatment of Individuals with Developmental Disabilities*

Throughout history, those with developmental disabilities have mostly been either outright ignored or shunned from society. Prior to the 17th and 18th centuries, there was a complete lack of understanding of and services for people with disabilities [2]. They were thought of sinful or immoral and were subject to physical abuse and chains in hospitals until social reformers like Philip Pinel and Dorothea Dix advocated for better services for people with disabilities. Dix describes their condition,

> "More than nine-thousand idiots, epileptics, and insane in these United States, destitute of appropriate care and protection. Bound with galling chains, bowed beneath fetters and heavy iron balls, attached to drag-chains, lacerated with ropes, scourged with rods, and terrified beneath storms of profane execrations and cruel blows; now subject to jibes, and scorn, and torturing tricks, now abandoned to the most loathsome necessities or subject to the vilest and most outrageous violations."

Their advocacy helped pave the way for public institutes and training schools that attempted to educated people with disabilities to enable them to return to the community and lead productive lives. However, the institutes quickly became asylums that employed a dehumanizing process. They no longer encouraged interaction with the community, were in rural areas away from the view of most people and used the people with disabilities as free labor – training them in only skills that would make them productive workers in the institute. During this period, a common misinformation became popular – that people with disabilities were feebleminded, dangerous, and "other" (Figure 3).

It was not until the 1950s after the end of World War II that attention was refocused on changing the treatment and outlook of society on those with developmental disability. For the first time, the United

Nations declared the Rights of Disabled Persons which outlined the basic rights for disabled persons including the right to respect for their human dignity much like others. There was an increased focus on

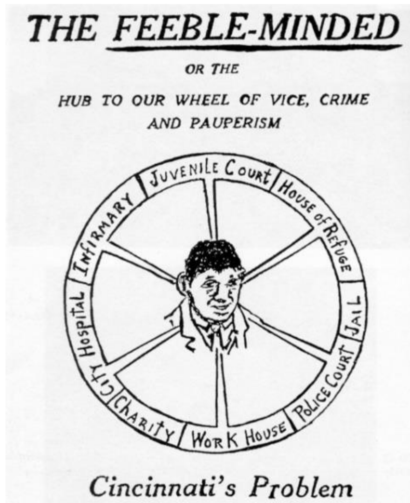


**Figure 3.** Flyer advocating the idea that feeble-minded persons were the cause of society's evils

providing not only improved quality of services people living in institutions but also in developing community residential alternatives for people leaving institutions or those wanting to remain in the community. People began to recognize that everyone can be supported to live in the community.

*2.2 Schenectady ARC – Providing Opportunity to Individuals with Disabilities*

Since 1952, the ARC has strived to provide people with developmental disabilities with the resources, services, and supports that enable to advocate and participate within their communities [3]. They have created a network of human service agencies ensuring that people with disabilities have the strongest civil rights advocates promoting and protecting their needs at all levels. They believe that with the appropriate resources and support, people with intellectual and developmental disabilities can make their own decisions about their lives and have the civil and constitutional rights to actively participate in all aspects of society. One way in which the ARC accomplishes this mission is by allowing people with disabilities to develop skills and hobbies that allow them to develop a sense of independence and participate actively in the community. At the Schenectady ARC, individuals with disabilities actively

participate in maintaining the ARC greenhouse and learn the skills necessary to manage a greenhouse. In addition, all the produce and plants that is grown in the greenhouse ultimately goes into funding the Schenectady ARC to provide more activities and opportunities.

*2.3 Seedling Environmental Necessities*

The ARC greenhouse currently contains a seedling bench that does not currently have the correct equipment to properly allow individuals with disabilities to operate the system. Unlike the rest of the greenhouse, the seedling bench requires more careful monitoring of moisture content as well as more gentle water delivery method. To water young seedlings, it is recommended to use a fine sprinkler and avoid powerful jets of water as it could damage delicate plants [4]. It is also very important to water seedlings regularly to keep the beds moist at all times.

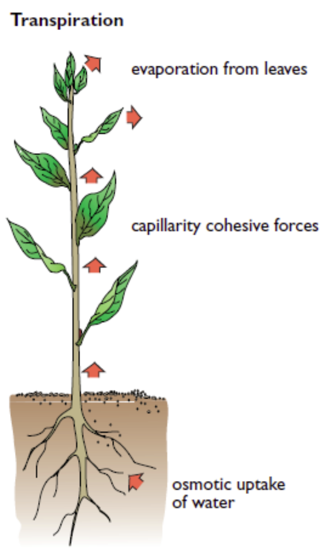


**Figure 4.** Transpiration process in plants

In addition, seedlings benefit greatly from growing in a humid environment [5]. Water moves up through a seedling via a process called transpiration in which sun hits the leaves of the seedling, water evaporates, cooling the leaves and pulling more water to the leaves from the stem, and ultimately pulling the water

to the roots from the ground (Figure 4). Growing in a humid atmosphere prevents water from evaporating from the leaves faster than it can be absorbed through the roots.

The current setup in the ARC greenhouse requires a handheld method of watering and constant manual monitoring of the moisture content of the seedlings to ensure proper growth. Ideally, an automatic system, one that can be used by individuals with developmental or intellectual disabilities, would enable greater participation in the greenhouse management system and streamline the process for ensuring proper growth of the seedlings.

*2.4 Irrigation Controllers in the Market*

Automatic greenhouse watering systems do exist on the market that would fulfill the watering and moisture sensing requirements of the seedlings. However, they are for the most part, expensive, unintuitive to operate, and difficult to repair/replace. No irrigation controllers currently in the market are designed for people with developmental or intellectual disabilities. The operation process is complicated even for people without disabilities to understand and would require extensive reading of the manual. This is without even mentioning the time it would take to learn how to operate the machine as well as the time required for supervisors to teach the individuals how to operate it. Economically speaking, an irrigation controller without any form of water delivery system is at least $200 (the most basic) and can be up to $1000 [6]. For example, the weathermatic bundle SL1612-SLW5 from the Sprinkler Warehouse (Figure 5) is priced at $756 which is expensive, especially when taking into account that a water delivery system is not included.


**Figure 5.** Weathermatic bundle SL1612-SLW5

Furthermore, most irrigation controllers on the market have different functions than the ARC desires. The SL1612-SLW5 irrigation controller, for example, includes a wireless weather station that is unnecessary but does not include any way of monitoring soil moisture. Therefore, it would not be ideal to modify or buy irrigation controllers currently in the market. Instead I am focusing on designing our own irrigation controller with a moisture monitoring system and water delivery system specifically tailored to the needs of the Schenectady ARC with components that are easily available and off-the-shelf for easy replacement in the event of damage or degradation.

*2.5 Previous Work*

Previously, Qianyue from Union College worked on developing the automatic watering system for the ARC [7]. She was able to build a basic prototype that was able to sense soil moisture and operate a solenoid attached to a drip tube (Figure 6). However, she encountered problems with calibrating the moisture sensors and getting them to read a wide range of values for different amounts of soil moisture. She did some preliminary data gathering in which she compared the moisture reading values from the moisture sensors to a value from a highly sensitive and accurate tensiometer. However, she was not able to further modify or test the prototype and most of her work (e.g. the code and circuit setup) is no longer assembled.

Therefore, I reassembled her work and then further improve on her prototype through communication with the Schenectady ARC and an iterative design process.

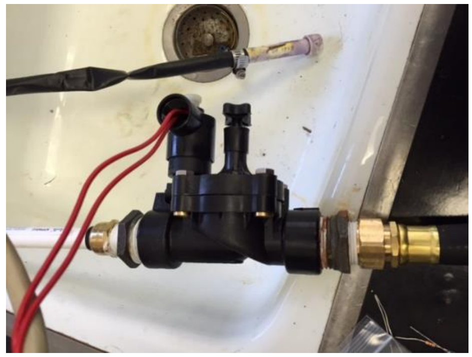

**Figure 6.** Solenoid and drip tube setup for water delivery (Qianyue's prototype)

Kyle Stengel from Union College also worked on a related project dealing with constructing a heating system for the same seedlings in the Schenectady greenhouse [8]. Incorporated in his design is a controller that runs a Linux operating system to interact with the user with a touchscreen GUI. However, the controller currently only boots a Python program that allows the user to control the settings for the heating pads. Because the heating and watering system both operate on the same seedling table, I will incorporate the two systems together into one cohesive unit managed by a single controller after ensuring the modularly defining the design specification and testing the functionality of the water delivery system.

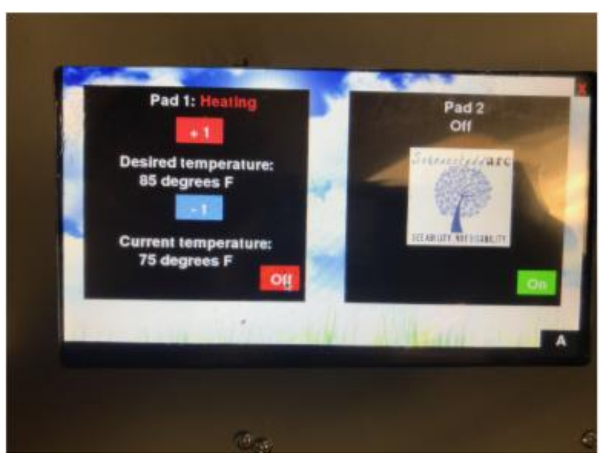


**Figure 7.** Touchscreen GUI for heating pad system (Kyle's prototype)

## 3. Design Requirements

As the greenhouse watering system is customized to the unique needs of the Schenectady ARC, I have communicated regularly with Donna, the director of the Schenectady ARC, to discuss the specifications she is requesting. As the system is being installed into the greenhouse, some requirements of the design may be changed, or new specifications may be added given that the design must work with the layout already in place and around the other components in the greenhouse.

### *3.1 Accessibility of Interface*

Perhaps the most integral portion of this project is the necessity of the system controller to be accessible and operable for people with developmental and intellectual disabilities. Therefore, it should be intuitive and simple to operate, i.e. learning how to operate the system should be relatively self-explanatory and not require the need to read an extensive manual. The interface should not require any physical knobs or dials to control the operation of the system as they are intuitively difficult to understand as compared to touchscreens or buttons. Simple operations such as the pushing of a button or a touchscreen selection of a setting should be offered to control functionality of the other units of the system. More complex manipulations can be offered but should not be required to operate it. In addition, the interface should not require the user to understand the underlying functionality of the system.

### *3.2 Water Delivery*

Seedlings are sensitive to damage in the early stages of growth and require different specific and constant soil and air moisture conditions depending on the type of seedling. Therefore, the water delivery system must be able to gently mist the water evenly over each quadrant area and the entire area of the table. It must consider the amount of water each type of seedling requires (which can be specified by the user) without over or under-watering or wasting water. Upon discussion with Donna, the Schenectady ARC sets up a variety of seedlings on the bed including vegetables such as potatoes and peppers and flowers such

as marigolds, tulips, and chrysanthemums. Specific quantitative water amounts for these types of seedlings should be options available for selection. In addition, the watering system must eventually be integrated into the Schenectady ARC greenhouse, so water must be able to be routed from the existing plumbing line to the system setup without affecting the existing water delivery system for the rest of the greenhouse. This most likely necessitates some form of pressure regulation and filter to prevent damage to the water delivery system as well. Per Donna's request, at least some form of simple water delivery should be available by the end of March as the Schenectady ARC begins to plant seedlings at that time to start the growing season.

*3.3 Moisture Sensing*

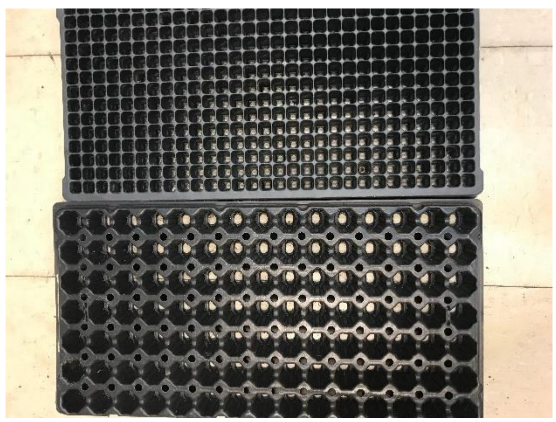

**Figure 8.** Seedlings trays

The system must be able to obtain stable soil moisture values that are calibrated to some industry standard of measuring soil moisture content. The information should be obtained constantly at regular intervals and updated accordingly so the system can process the data and control watering in response to conditions in real-time. In addition, the presence of the moisture sensors in the seed beds should not harm or inhibit the growth of the seedlings which may be problematic due to the size of the seedling trays (Figure 8). If deemed necessary by Donna, the system should also be able to relate the soil moisture content to the moisture content in the air since seedlings are quite sensitive to both conditions.

*3.4 Area of Operation and Uniformity*

The system must be able to sense moisture level and provide watering uniformly to an 8' by 11' seedling bench (Figure 9). Because the area is quite large, it will be divided into four quadrants as per Donna's request and the water delivery across each quadrant should be uniform, i.e. each seedling in the quadrant should be getting approximately the same amount of water – one should not be drowned in water while another one is perfectly moist. Similarly, the moisture readings for the quadrant should be indicative of the moisture level for each of the seedlings in the quadrant. Between the actual moisture level for each seedling and the moisture reading for the quadrant, there should not be a difference greater than 10%.

**Figure 9.** 8' by 11' seedling bench

*3.5 Automation*

Because there is often no staff to work the greenhouse on the weekends, the system should be able to operate without any manual operation or human intervention aside from the initial setup of the settings. Based on the required moisture levels in the seedlings, the system should automatically compare it to a set minimum threshold upon which when the reading has gone below, should trigger the water delivery to deliver water until the moisture content has returned to above the threshold value. This automatically regulates the watering of the seedlings based on regular moisture readings. It should also offer the option to run the watering system automatically based on a specified time schedule as most of the automatic function is utilized on the weekend when no one is available to control the system. In the event of an error

during operation in automatic mode, the system should be able to communicate an error message wirelessly to the directors of the greenhouse, informing of the nature of the malfunction.

*3.6 Economics / Cost and Maintenance*

Because the Schenectady ARC is a non-profit organization, it does not have the means to spend a lot of money on the development of the system. Therefore, it is necessary that the development of the system can be completely covered by the funding provided from the Union College Student Research Grant Fund and the CREATE (Cultivating Resources for Employment with Assistive Technology) grant from NYSID (New York State Industries for the Disabled). The CREATE grant provides up to $1000 for each project [9]. Therefore, the system should not cost no more than that and more ideally, no more than $800 due to restrictions in obtaining funds near the limit. In addition, the system, once integrated into the Schenectady ARC greenhouse, should be economic to maintain meaning the parts should not require replacing regularly. This is of concern because the greenhouse is constantly exposed to UV light which degrades materials such as PVC. Any parts that do need replacing or repair should be readily available and cheap due to the non-profit nature of the ARC. Any repair should be performable by the managers of the Schenectady ARC.

*3.7 Safety*

The system must necessarily function in the presence of water and water is a natural conductor of electricity. Therefore, it is of paramount importance that the system, especially the controller, should be fully enclosed such that none of the wiring or electrical components are accessible to the users since there could be high voltages and currents powering the system which would be harmful upon contact with the users. In addition, the design of the system should not exceed the bounds of the table by an exorbitant amount to avoid interfering with the activity in the rest of the greenhouse and to avoid any potential hazards for individuals that are working around the system.

**4. Top Level Design**

Based on the project requirements, the project can be divided into four major subunits: the water delivery, moisture sensing, user interface, and a system controller (Figure 10).

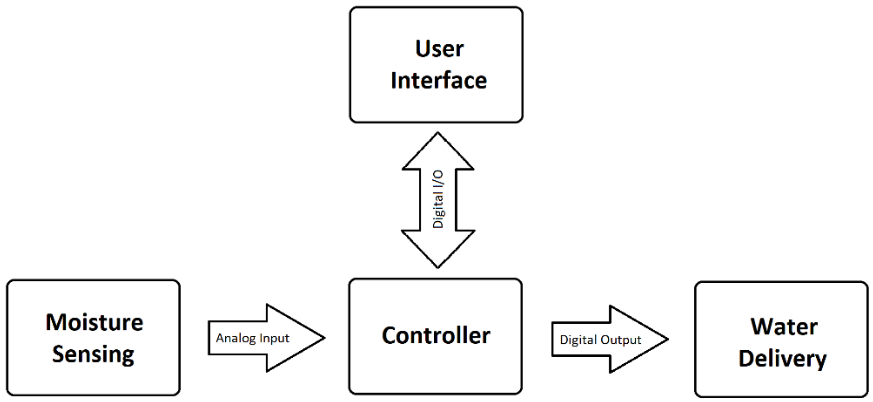


**Figure 10.** Top level schematic for system

The controller is responsible for coordinating the other subunits of the system into a cohesive automated system. The moisture sensing unit senses the moisture conditions of the soil and sends the information as an analog voltage signal to the controller at regular time intervals. The controller can then convert the analog voltage value into a calibrated soil moisture content value and output it digitally to the user interface subunit. The user interface is also responsible for managing general user input for both automated and manual control and outputting information about the state of the overall system such as malfunction error messages. For manual control, the user input directly controls when to send digital output to the water delivery system to trigger the start and stop of watering. For automated control, it takes in numerical inputs from the user specifying the desired threshold moisture content values upon which to start and stop watering. It sends that information as a digital input to the controller, so the controller can compare the soil moisture content value to the user specified value to decide whether a digital signal should be output to the water delivery system to water the plants. In the future, the controller and user interface will be interfaced with the heating system controller developed by Kyle.

## 5. Design Alternatives

### *5.1 Water Delivery*

The market currently provides three main alternatives to water delivery: drip tubes, overhead misters, and mat irrigation [6]. Drip tubing is accomplished with a tube system that laid on the soil near the root of the plants. It is used to deliver water directly to the roots of the plants and is a precise and efficient method of water delivery that conserves water. However, drip tubing does not provide moisture to the surrounding atmosphere which is paramount to the growth of the seedlings. Mat irrigation encounters the same problem. With mat irrigation, the plants are grown on top of a mat that remains perpetually moist which allows the seedlings to receive constant moisture. However, it also has no means of providing water into the air. In addition, it would be more difficult to control and change the moisture level in response to the current moisture conditions using this method. Overhead misters resolve the problem of providing atmospheric moisture and are also easy to control in response to soil moisture conditions with solenoid valves. In addition, they are an economic option that costs no more than $10 per unit and easy to maintain and switch out during the testing and upon installation.


**Figure 11.** Netafim overhead mister

Previously, Qianyue had ordered parts from Griffin Greenhouse and had developed a working relationship with them. That along with their existing relationship with providing greenhouse products to the ARC and their wide selection of items in their catalog, I decided to obtain parts for the water delivery system from them. I chose to use Netafim misters (Figure 11) from the Griffin Greenhouse catalog as they are designed

to provide uniform watering for single benches where they are arranged on an overhead frame in a grid-like fashion with 3 feet between each adjacent mister [10]. Based on that information, I can design an initial setup relatively simply for the 8’ by 11’ seedling bench and then revise the layout to obtain the optimal performance. In addition, Griffin Greenhouse also provides leak prevention devices, pressure regulators, filters, and polyethylene tubing that have been specifically designed for the misters which would enable a simple installation of the system into the existing plumbing line in the ARC greenhouse. The design is clean and easily adjustable if further modifications upon installation are necessary and the hanging structure of the water delivery system ensures that the components are out of the way of the rest of the greenhouse activity.

*5.2 Moisture Sensing*

The three alternatives considered for moisture sensing were a tensiometer, a microcontroller capacitive moisture sensor, and a microcontroller resistive moisture sensor.

**Figure 12.** Spectrum Technologies irrigation tensiometer

**Figure 13.** Sparkfun resistive moisture sensors


**Figure 14.** Worldchips capacitive moisture sensors

The tensiometer is an industry standard of obtaining soil moisture readings. The department had a Spectrum Technologies 6-inch irrigation tensiometer (Figure 12) left from Qianyue's work available as a method of moisture sensing. The tensiometer measures soil moisture tension in kPa extremely accurately which is directly related to the soil moisture content [11]. However, the tensiometer is large with a 3-inch-long tip, one inch in diameter, that must be inserted into the soil carefully to ensure that there are no air pockets between the ceramic tip and the soil. The size of the grids in the seedling tray are only an inch on each side so the tensiometer could not be inserted into them directly. In addition, the device is over $500 in price, meaning that installing multiple over the area of the seedling bed would not be economic. Using the tensiometer also requires utilizing Specware 9, the compatible software, to record values but the interface is complex and difficult to incorporate into a controller.

Therefore, microcontroller moisture sensors are preferred for their small size (both one inch wide), ease of compatibility to any microcontroller, and cheap cost despite having to compromise accuracy of the moisture reading. The values can be calibrated using the tensiometer to achieve better accuracy. Between the Sparkfun resistive sensor (Figure 13) and Worldchips capacitive sensor (Figure 14), the resistive sensor had two smaller probes which is more conducive to fitting in the small seedling trays. However, the major deciding factor is their ability to provide a variability in moisture readings between different soil moisture conditions and stable readings when the moisture content of the soil does not change. Both were considered as potential options for the initial design until further calibration tests could be performed.

*5.3 User Interface*

Because the user interface must necessarily be intuitive and simple to operate, alternatives included implementing a touch screen for both user input and displaying the current system settings or implementing a simple 4 x 4 Arduino keypad for user input (Figure 15) and a 16 x 2 LCD for the display (Figure 16). Touchscreens are arguably more intuitive for user input and display than an LCD and keypad combination but are difficult to implement as they require developing an intuitive and easy to understand GUI and puts restrictions on to the type of controller the system requires to more computation intensive controllers. An LCD and keypad combination implementation is simple, easy to implement and test, and more cost effective. Due to the minimal input nature, it is much easier to consider and deal with any side effects from unexpected user inputs. Most importantly, given that the interface will eventually be merged with the GUI from Kyle's system, the simple inputs/outputs of the LCD and keyboard are easier to interface with the main controller in the heating system.


**Figure 15.** 4 x 4 Arduino Keypad


**Figure 16.** 16 x 2 LCD Screen

*5.4 Automation / System Controller*

The controllers considered were the Raspberry Pi and the Arduino RedBoard. The Raspberry Pi is capable of intensive computation which would be beneficial particularly for utilizing a touch screen for the user interface [12]. However, most of its utility such as ethernet and microSD support are not necessary for the functionality of the system and its computation ability is mostly wasted if the system does not use a touchscreen. The Arduino RedBoard is a simpler microcontroller and that can provide the basic computation functionalities that the system requires. In addition, I have had more experience in programming it and it was readily available. The Arduino RedBoard has 20 I/O pins, 6 of which are analog, which is adequate for constructing the independent prototype. Therefore, the Arduino RedBoard was used for the design. In the future, upon greenhouse installation, it may be swapped out for a microcontroller with more I/O ports if needed or incorporated into Kyle's controller entirely.

**6. Preliminary Proposed Prototype Design**

The preliminary proposed prototype design is depicted with the schematic in Figure 17 and all specific parts utilized in the design are listed in Table 1. The system utilizes a RedBoard Arduino as the controller that coordinates between the moisture sensing, the user interface, and the water delivery unit.

**Table 1.** Components utilized in the prototype design

| **Item** | **Subunit** |
|---|---|
| Arduino RedBoard | Controller |
| WR1220 Solenoid – 110 VAC | Water Delivery |
| Crydom D2425 Solid State Relay | |
| Netafim Mister System | |
| Worldchips Capacitive Soil Moisture Sensor | Moisture Sensing |
| Sparkfun Resistive Soil Moisture Sensor | |
| Arduino 4 x 4 Keypad | User Interface |
| 16 x 2 Serial Enabled LCD | |
| Push Button and Switch | |

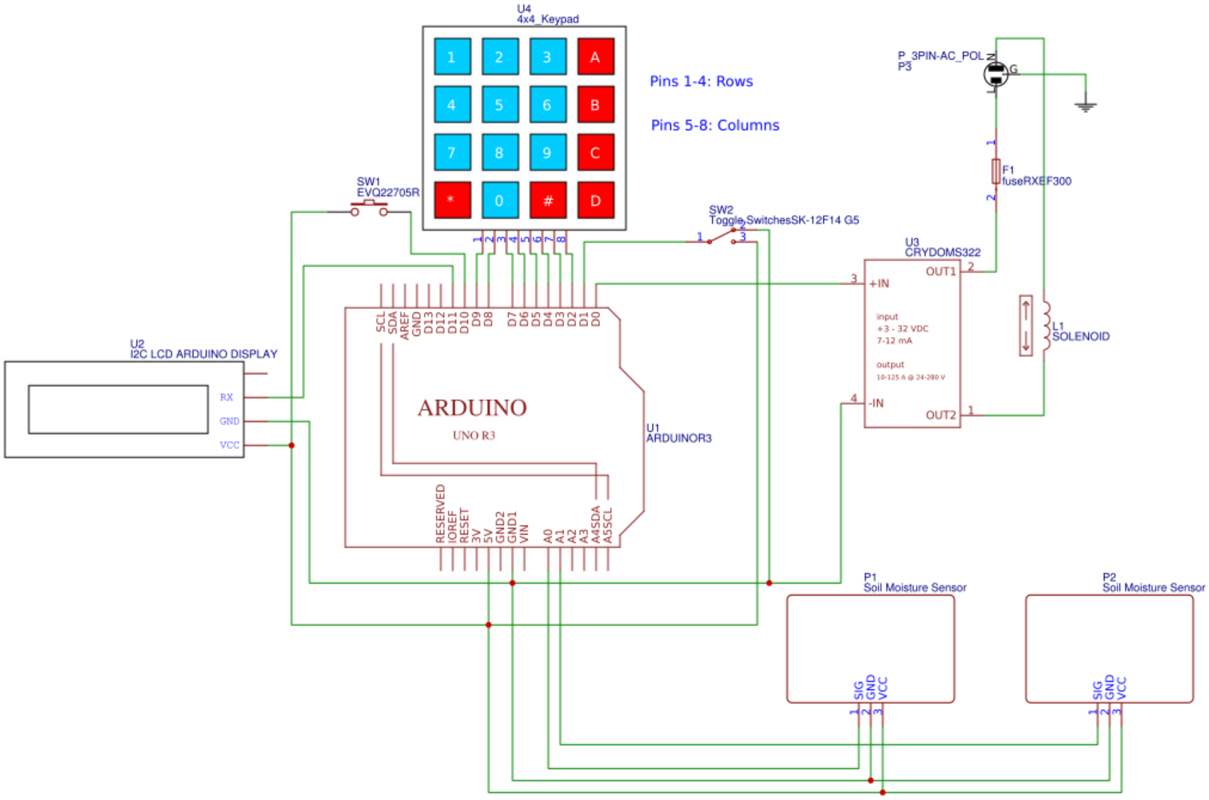


**Figure 17.** Schematic of Prototype

*6.1 Moisture Sensing Unit*

A Worldchips capacitive moisture sensor and Sparkfun resistive moisture sensor make up the moisture sensing unit in this design. They are connected at A0 and A1 respectively and each provide an analog voltage input between 0-5 volts that varies depending on the moisture content of the soil they are inserted into. The controller converts the analog voltage input value to a value between 0-1023.

*6.2 User Interface Unit*

The user interface consists of a 4x4 keyboard, pushbutton, and switch for user input and a 16x2 LCD screen for user output. The LCD is connected to the microcontroller via a serial output – Pin D11. The analog moisture values that are received from the moisture sensors are displayed in real time on the LCD screen (Figure 18) for the user to see.

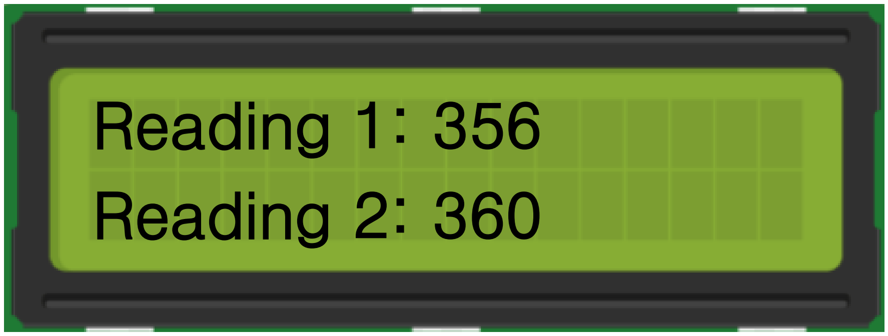


**Figure 18.** LCD display of analog moisture readings

The 4x4 keyboard is connected to digital pins D2-D9 to specify the rows and columns of the keypad. This allows the user to setup automatic watering of the plants by inputting a threshold value. The controller compares the sensed moisture value to the threshold value set by the user at regular intervals to determine whether to signal the water delivery unit to begin or stop delivering water. Under the condition that the user wants to manually signal the water delivery unit to begin delivering water, a pushbutton is connected to digital pin D10. The switch (Pin D1) controls whether the system is in automatic or manual mode.

*6.3 Water Delivery Unit*

The water delivery unit consist of a 110 VAC solenoid that is incorporated in the larger Netafim sprinkler system to control when to begin and stop delivering water. A digital HIGH signal is sent by the controller when either the user manually requests it or when the moisture of the soil is inadequate compared to the set threshold value. A Crydom solid state relay (Pin D0) is required to trigger the opening of the solenoid valve as the RedBoard microcontroller can only send a 5V DC signal. While I considered alternatives such as a mechanical relay, the Crydom solid state relay was more durable and had been proved to be reliable in Qianyue's prototype, making it the optimal choice. The SSR accepts 3-32 VDC at 7-12 mA and functions with outputs of 24-280 VAC at 10-125 A [13]. Therefore, the solid state relay acts as switch that completes the output circuit with the solenoid and a wall plug (power source) upon a HIGH signal from the RedBoard. When the circuit is completed, the solenoid is powered and opens, allowing water to flow to the misters

that are used for water delivery. A fuse is also incorporated into the circuit design to ensure safety of the users using the system.

### *6.4 RedBoard Microcontroller Code*

Calculations and the management of inputs and outputs in the system as described above are conducted in the following manner by the controller.

```
Initialization:

    1.  Import SparkFun Serial LCD and Keypad Library
    2.  Attach serial enabled LCD's RX line to digital pin 11
    3.  Setup keypad instance
    4.  Setup variable for threshold
    5.  Setup default operation mode (manual)
    6.  Setup variables to hold moisture readings and their string forms
        for display on LCD

Setup:

    1.  Set up serial port for 9600 baud
    2.  LCD screen asks user to threshold input
    3.  Take in threshold value

Main Loop:

    1.  While operation is manual:
            a.  Move cursor to beginning of first line
            b.  Clear LCD display by sending space
            c.  Read in analog voltage values and convert them to values
                within the range 0-1023 corresponding to 0-5 V
            d.  Generate strings to be printed to LCD screen
            e.  Print values to LCD screen
            f.  If button is pressed, send HIGH signal to solenoid
    2.  While operation is automatic:
            a.  Move cursor to beginning of first line
            b.  Clear LCD display by spending spaces
            c.  Read in analog voltage values and convert them to values
                within the range 0-1023 corresponding to 0-5 V
            d.  Generate strings to be printed to LCD screen
            e.  Print values to LCD screen
            f.  If the value is greater than the threshold, send a HIGH
                signal to the solenoid
            g.  Else if the value is less than or equal to the threshold,
                send a LOW signal to the solenoid
```

**Figure 19.** Pseudocode for RedBoard controller

**7. Moisture Sensing Testing**

Although the microcontroller moisture sensors are a smaller and cheaper alternative to the industry standard of a tensiometer, they are unable to give meaningful values. They simply send an analog value between 0-5 V to the microcontroller which gets depicted as a value between 0-1023. There is no meaning to a single value aside from being a comparative measure. Therefore, we must calibrate the values to a standard scale indicating a certain amount of soil moisture.

*7.1 Tensiometer Function*

The tensiometer has been used as a standard in the industry for a long time as exhaustive tests by soil scientists demonstrate that they provide the most accurate and sensitive method of measuring soil moisture in the range in which most crops are grown [11]. In fact, they are often used as reference instruments to check the accuracy of other methods of acquiring soil moisture information. They give highly accurate measurements of soil moisture by determining the soil moisture tension.

A tensiometer consists of a ceramic tip that contains pores that allows water to move freely in or out of the tube. As the soil dries out, water is sucked out of the tensiometer through the tip, creating a partial vacuum inside which is read as a pressure value on the attached pressure gauge. When the soil is sufficiently saturated, water flows back into the tensiometer, relieving the inner pressure and lowering the gauge reading. Gauges are normally calibrated in kilopascals and offer a range from 0-100 kPa although they only operate successfully up to 75 kPa [14]. The typical meaning of tensiometer readings are given in Table 2 below although the ranges may vary depending on the soil type and depth of the tensiometer.

For a standard 30cm deep tensiometer, it is typically recommended to commence watering at 30-40 kPa and to give 1mm of water ($1L/m^2$) per kPa. However, given that our tensiometer is not embedded that deeply in the soil and that we are concerned with watering seedlings and not full-grown crops, these

measures will be modified to what is appropriate for seedlings upon completion and testing of the prototype.

**Table 2.** Meaning on ranges of tensiometer readings

| Reading | Meaning |
|---|---|
| 0-5 kPa | Saturated soil. Plants will suffer from ma lack of oxygen in the root zone. |
| 10 kPa | Field capacity. After one or two days of draining saturated soil, free water has drained away leaving a good balance between water and air-filled pores in the soil. |
| 10-25 kPa | Ideal soil, water, and aerations conditions. |
| 25-80 kPa | As moisture is removed from the soil, the thickness of the water film surrounding soil particles becomes thinner and is held on with greater tension. Decreased availability of soil water to the plant results in evaporative forces drawing moisture from plant cells quicker than the soil can provide it. |
| 80-100 kPa | Excessive quantities of air enter the tensiometer. The water column in the tube will be broken and the water lost. The tensiometer will then show a zero reading despite the soil being dry. It must be removed, cleaned, and reinstalled. |

*7.2 Testing Setup*


**Figure 20.** Watchdog 1000 Series data logger for tensiometer

The tensiometer was soaked in water for 2 days before being filled with distilled water (mixed with a drop of green dye for visualization of the water level). Any excess air in the tube and the ceramic tube was removed a hand vacuum pump that was applied twice to the opening of the tensiometer. Upon placement of the cap on the tensiometer, the tip was removed from the water and placed into soil, completely

covering the ceramic tip. It remained there for a day before testing in order to allow it to reach the proper gauge reading. Readings were read off a WatchDog data logger that was attached to the tensiometer's gauge transducer as it offered a more detailed reading than the gauge (Figure 20). These readings could also be reviewed in the Specware 9 software upon connection of the data logger to the computer.

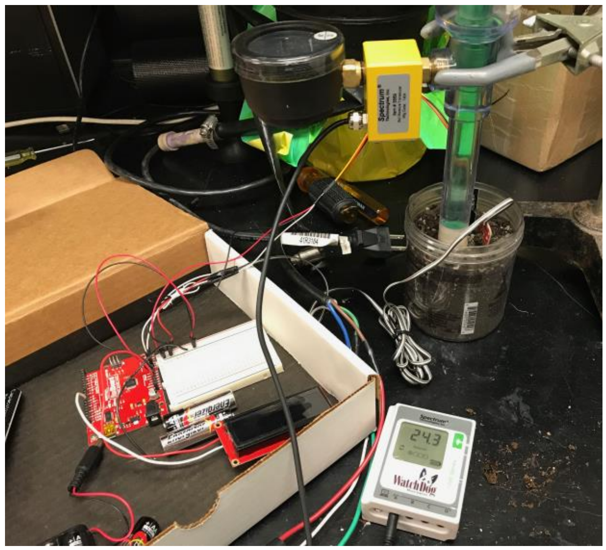

**Figure 21.** Calibration testing setup

The two microcontroller moisture sensors were placed adjacent to it and connected to the Arduino RedBoard which ran a simple program for reading the voltage values and converting them to a value between 0-1023 that was then displayed on an LCD screen (Figure 21). Water was given in 3-minute intervals via a spray bottle to mimic the water delivery of sprinklers. Measurements were taken at the end of each interval before the next spray to allow the sensors and the tensiometer to stabilize.

*7.3 Testing Results*

The readings from the tensiometer and the two microcontroller moisture sensors were plotted against one another to examine any correlation between the values. Results are plotted in Figure 22.

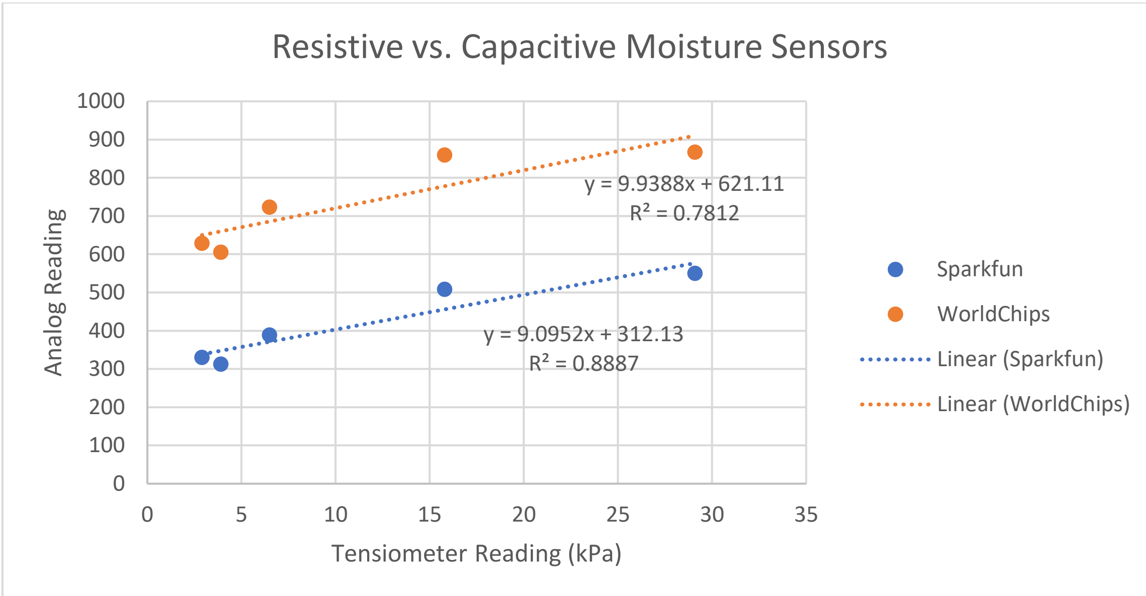


**Figure 22.** Correlation of analog readings to tensiometer gauge reading

A good linear correlation was identified between the microcontroller sensors and the tensiometer which indicates that a simple mathematical calculation can be done to convert between the two values. Both the SparkFun and WorldChips sensors had good variability in values between saturated and dry soil with a range of about 300. The WorldChips sensor had a correlation equation of Y = 9.9388X + 621.11 and the SparkFun sensor had a correlation equation of Y = 9.0952X + 312.13. However, the $R^2$ value for the SparkFun sensor was 0.7812 which was significantly worse than the $R^2$ value for the Worldchips sensor of 0.8887. This indicates that it is less reliable at giving correlated results with the tensiometer. In fact, during testing, the SparkFun sensor tended to be hypersensitive to conditions other than soil moisture such as the movement of the connecting wire. In addition, it took longer to stabilize the moisture value than the WorldChips sensor. While the correlation coefficient of the WorldChips sensor is not particularly impressive either, it is considerably better than the SparkFun sensor and was most stable during the testing. Therefore, it was decided to proceed instead with the WorldChips capacitive sensor for further testing and the final design.

### *7.4 Schenectady ARC Measurements*

The two microcontroller moisture sensors and connected microcontroller testing setup was also brought to the greenhouse. Donna gave us two different pots, one that she considered as dry soil and one that she considered to be optimally moist. Readings were obtained to gain a measure of the soil conditions required for seedlings as compared to the standard industry measurements for crops. For the dry soil, the Sparkfun resistive moisture sensor obtained a value of 514 while the Worldchips capacitive moisture sensor obtained a value of 575. For the wet soil, the resistive sensor obtained a value of 260 while the capacitive sensor obtained a value of 250.

### *7.5 Performance Evaluation*

While a clear correlation was obtained, the correlation coefficient is weak which may be due to the lack of data obtained during the testing. Obtaining more data will hopefully confirm the linear correlation more strongly and generate a fit that is a better indication of the conversion equation. In addition, it was noted that the values obtained at the Schenectady ARC does not match with the values obtained during the calibration experiment. This is most likely due to the difference in soil types which greatly affects the readings. Future testing should be done in soils with similar or the same texture. Overall, we were able to calibrate the moisture sensors to offer a standard measure of soil moisture. In addition, the moisture sensors are able to read this value in real time to the microcontroller.

## 8. Controller Design

### *8.1 Final Implementation*

Minor changes were made to the initial system design in the moisture sensing unit based on the testing results. The SparkFun resistive moisture sensor was replaced instead with another WorldChips capacitive sensor and calculations were added to the controller to enable conversion between analog values and water pressure values. The LCD screen should only display the converted water pressure values. The

controller code can be viewed in its entirety in the appendix in Figure A1. The implementation of the final design can be seen in Figure 23.

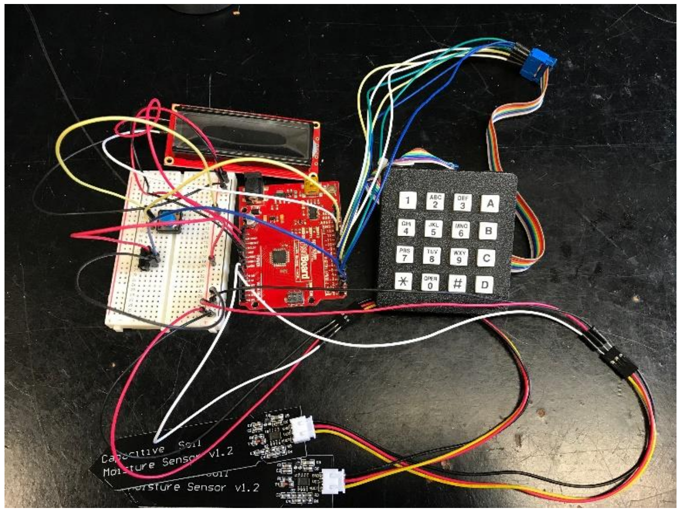


**Figure 23.** Implementation of system controller

*8.2 Performance Evaluation*

As desired, the design incorporates a simple and intuitive user interface that is usable by those with developmental disabilities with relatively little supervision. The system requires a simple user manual specifying the steps needed to configure the settings but otherwise is self-explanatory, avoiding the large learning curve necessary for irrigation controllers currently on the market. It also updates the user on the soil moisture status of the seedlings in real time. For manual control, it properly intakes input from the user to determine when the activate the watering system (opening the solenoid). Similarly, for automatic control, it can properly compare the moisture value to the desired threshold value and activate the watering system when the value goes below the threshold. While a threshold value can only be specified at startup, that will be remedied in the future upon incorporation with the heating system touchscreen. In addition, the system is currently simply prototyped onto a breadboard. Upon incorporation with the heating system and installation, the circuitry will be moved onto mounted perfboard that is contained inside of a waterproof casing for safety.

## 9. Water Delivery System Setup

*9.1 Sprinkler System Design*

In order to enable the sprinklers to hang down and deliver water, a support structure either hanging from the ceiling or grounded to the floor was necessary. Due to the raised dome structure of the greenhouse and the presence of hanging pots, a support structure rising from the floor was more ideal as it would not interfere with the other operations of the greenhouse and would not require a sturdy ceiling structure. The frame was built to follow the borders of the table closely as to not be a safety hazard to those working in the greenhouse (Figure 24). The base was 8’ by 8’ and excluded the 3’ of the table directly next to the wall of the greenhouse as the dome was not tall enough there to raise the structure high enough. The structure needed to be 7’ feet tall (4’ taller than the table) to allow the sprinklers to hang 3’ feet down and still have a foot above the seedlings to allow the mister to have proper coverage.

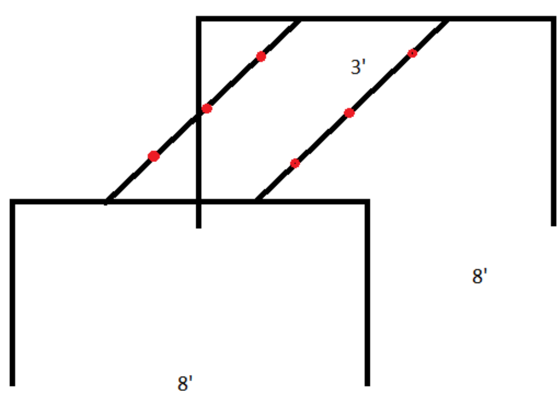


**Figure 24.** Support frame and sprinkler layout

Upon recommendation of an employee of Griffin Greenhouse, Bud, who had previous experience with the Netafim system, the sprinklers would run down the length of the table in two columns with three sprinklers on each column (denoted as red dots). The sprinklers have a radius of 1.5’ and therefore would provide adequate coverage with about 3’ spacing between each sprinkler.

*9.2 Support Frame Setup*

**Figure 25.** Clean, elegant MakerPipe connectors

The support frame was installed into the Schenectady ARC greenhouse first in order to guide the watering system. It was built using ¾" electrical metal conduit connected with MakerPipe connectors (Figure 25). Electrical metal conduits were chosen over normal PVC piping as the greenhouse is constantly exposed to UV light which degrades the piping, eventually causing it to sag. MakerPipe connectors elegantly connect the conduits together and can be easily adjusted with a wrench in the future in case adjustments need to be made.

*9.3 Netafim Sprinkler System Setup*

**Figure 26.** Solenoid and sprinkler system control unit

**Figure 27.** Mister hanging above seedling bed

The tubing and circuitry to operate a single mister is set up in the Schenectady ARC greenhouse. The solenoid and filter/pressure regulator control unit are attached under the table as to avoid them hanging or extruding from the table (Figure 26). The mister hangs from the left column 1.5’ into the table over the seedling bed (Figure 27). The polyethene tubing is zip-tied to the support structure and runs along it and under the table to the solenoid. The solenoid has electrical wires that also run underneath the table to the manual control unit.

**Figure 28.** Manual control box with four switches

A metal box containing four switches is the controller for the system to enable users to manually switch the sprinklers on and off (Figure 28). A hole was drilled into the back of the container to allow wiring to pass through. Otherwise, the casing is well protected against water, protecting the electrical connections inside from short-circuiting. Currently, only the first switch is being used to control the misting but four are available for possibly enabling individual control of different quadrants in the future.

*9.4 Performance Evaluation*

The conduit structure provides adequate support for the water delivery system to run along. Since electrical metal conduit does not degrade under UV light, it is economic in that it does not have to be replaced every few years which could get expensive. Unfortunately, it is unable to cover the last 3' of the table due to the shape of the greenhouse meaning the mister system will not be able to provide water for the outermost foot of the table. This was discussed with Donna who agreed to the plan as the last foot is not often not even used for seedlings.

The water delivery system is in place and controllable with the switch but the mister is not able to properly mist but rather expels a direct stream of water. I have been in contact with an employee at Griffin Greenhouse to determine whether the issue lies in the sprinkler itself or some other portion of the system. Initially, I received information that an exchange of pressure regulators was necessary and that with the new pressure regulator, it would be necessary for all six misters to be attached to a single line to avoid too much pressure being applied to one mister. Therefore, it would not be possible to split the table into quadrants as I initially wanted unless modifications are made to the design. However, upon discussion with Bud, he said that the pressure regulator was indeed correct and should properly operate a single mister. He will continue to aid us in debugging out system. Upon fixing the mister issue, the other 5 misters will be added, and the system tested again.

## 10. Production Schedule

*10.1 Fall Term*

- Visit the Schenectady ARC to discuss the desired functionality of the system with Donna. Visualize the layout of the greenhouse and seedling table (Week 1-2)
- Obtained microcontroller, moisture sensors, and LCD screen (Week 3)
  - Implemented moisture reading system for calibration testing (Week 3)
  - Visited the ARC greenhouse to acquire moisture readings (Week 4)
- Ordered tensiometer software (Week 5)
- Constructed the preliminary design for the circuitry of the system (Week 6)
  - Constructed circuitry to control solenoids upon microcontroller output (Week 7)
- Setup calibration testing system (Week 8)
- Completed and submitted SRG grant (Week 8)
- Completed and submitted CREATE grant (Week 10)
- ECE 498 Paper (Week 9-10)

*10.2 Winter Term*

- Visited the greenhouse to acquire table measurements for support structure setup (Week 1)
- Obtained SRG grant (Week 2)
- Visited Griffin Greenhouse to plan parts for Netafim sprinkler system (Week 3)
- Obtained CREATE grant (Week 4)
- Obtained Netafim sprinkler system parts (Week 5-7)
- Constructed sprinkler system support structure (Week 6)
- Conducted calibrations testing (Week 7)
- ECE 499 Presentation / Demonstration (Week 8-9)
- Attached Netafim sprinkler system to support structure for manual operation (Week 10)
- ECE 499 Final Paper (Week 9-10)

*10.3 Reflection*

The original production schedule also included constructing the prototype and testing out the ability of the system to evenly distribute water and sense moisture over different quadrants in the Union College

greenhouse. However, due to the lateness in obtaining funding and difficulties in obtaining the Netafim sprinkler parts, this portion of testing was unfortunately pushed for future work. Due to Donna's request to have at least a functioning water delivery system by the end March, we focused more attention on finishing that portion of the system first and having it be functional for the Schenectady ARC.

While it was good to set tight deadlines to encourage a fast and on-time project, the timeline was ambitious and left very little for error. It did not account for any difficulties encountered along the way such as finding appropriate times to visit the ARC that worked for all parties involved or obtaining all the necessary equipment to manage the tensiometer as some parts had been damaged or misplaced entirely. As the construction process was mostly linear, it also meant there was some time simply spent on waiting for funding or parts to arrive. Finally, as we continued to communicate with Donna, more specifications and requests were made that changed the direction in which we approached the project, causing it to differ from the original plan.

**11. Cost Analysis**

Table 3 below details the overall cost for all needed components to construct the prototype. The cost of the entire design came out to be $507.80 total. This is completely covered by the CREATE grant of $522.26. Any extra costs including the Spectrum 9 software required for the tensiometer and insurance parts including more MakerPipe connectors and metal conduit were covered by the SRG grant of $261.55. These parts will either most likely be donated to the school or used to create a smaller prototype to test further improvements upon installation of the system. Components that were already available such as the SparkFun resistive sensors and the tensiometer were not included into the cost calculation.

**Table 3.** Detailed cost of individual parts

| QTY | Item | Vendor | Total Price |
|---|---|---|---|
| 1 | Arduino RedBoard | SparkFun | $19.95 |
| 2 | Capacitor Soil Moisture Sensor | WorldChips | $2.54 |
| 1 | ¾” Disc Filter 120 Mesh | Griffin Greenhouse | $32.00 |
| 1 | ¾” 35 PSI Medium Flow Pressure Regulator | Griffin Greenhouse | $21.00 |
| 1 | 16 mm 100’ Polyethelene Tubing | Griffin Greenhouse | $26.07 |
| 6 | 36” Hanging Sprinkler Assembly | Griffin Greenhouse | $13.50 |
| 1 | 4/7 mm Punch | Griffin Greenhouse | $18.59 |
| 6 | Sprinkler LPD | Griffin Greenhouse | $11.64 |
| 6 | Green Mist JR Nozzle | Griffin Greenhouse | $8.52 |
| 4 | 1” 24V Solenoid Valves | Griffin Greenhouse | $147.00 |
| 1 | 100 Nylon Cable Ties | Griffin Greenhouse | $10.72 |
| 1 | T135 KwikCut Cutter | Griffin Greenhouse | $17.52 |
| - | ¾” Steel Metal Conduit | Home Depot | $60.00 |
| - | MakerPipe Connectors | MakerPipe | $33.00 |
| - | Adaptors | Lowes | $40.00 |
| 1 | D2425 Solid State Relay | Crydom | $45.75 |

The cost of the system is much more economic compared to most irrigation controllers that are on the market currently. While marketed irrigation controllers can typically cost around $700-800 in of themselves, that is, not even including the water delivery component, our system costs about $200 less,

encompasses an automated water delivery unit, and is designed precisely to the needs of the individuals at the Schenectady ARC.

## 12. User Manual

### *12.1 Start Up*

Upon startup, the LCD screen will display a message asking for a 2-digit value that corresponds to the threshold moisture pressure value. The value can be inputted one digit at a time using the keypad. Once the value has been entered, the system will automatically begin operating in whatever mode has been specified by the switch. The two possible modes are automatic and manual.

### *12.2 Operation*

If the switch has been set to allow the system to operate in manual, the pushbutton needs to be pushed down and held to enable watering. When it is not pressed, the misters will not turn on regardless of moistures sensing readings. If the switch has been set to allow the system to operate in automatic mode, pushing the pushbutton will have no effect. The on/off state of the water delivery system will solely rely on the comparison of the moisture reading values to the entered threshold. The misters will automatically turn on upon the moisture reading dipping below the set threshold and turn off upon ascending it. Current moisture levels are displayed on the LCD screen in real-time.

### *12.3 Maintenance / Repair*

Due to the constant exposure of the system to UV light and water, the zip-ties, tubing, and moisture sensors should be checked every year for degradation or damage. Upon signs of degradation or damage, the components should be replaced by the replacement components provided to the Schenectady ARC. All electricity and water flow should be turned off at the time of the replacement. The zip-ties are trivial to replace while the tubing could be replaced in sections using the tubing cutter provided. The soil

moisture sensors can be replaced by removing the waterproofing at the top of the sensor, unplugging the electrical wiring from the connector, and attaching a new one.

The filter of the Netafim water delivery system should be cleaned periodically by opening the cap and emptying the contents. In the event that a component of the Netafim water delivery system malfunctions, e.g. the mister, filter, or pressure regulator, Griffin Greenhouse should be contacted for advice or a replacement part. Given a leak in the system, the circuitry may short circuit and need to be dried and restarted before resuming proper operation.

## 13. Discussion

### *13.1 Conclusion*

The purpose of this project was to provide the Schenectady ARC greenhouse with a new automated watering system that was customized to their needs and was intuitive such that people with disabilities could use it with little supervision. After two terms, the controller is able to coordinate the behavior of the system according to the user input. It meets the design specifications of being intuitive and simple to use and is also conducive to future incorporation into the heating system. The moisture sensing units have been calibrated to a standard measurement of water pressure which the controller uses to convert the analog values from the moisture sensors. With some further testing, this correlation could be strengthened, and more accurate values achieved. Finally, although the water delivery system is not able to properly deliver misting, the issue is currently being worked on via communication with Griffin Greenhouse. Control of the solenoids has been made possible with manual switches for the time being in the Schenectady ARC so once the misting issue is resolved, they can use the system on manual mode.

### *13.2 Lessons Learned*

This project taught me a lot about the design process especially in terms of working with a customer who has a specific set of design requests. Although Union teaches a lot about engineering principles and the

design process, I have never had the experience of continuously working with a customer to design a functioning system as large as this. It threw hurdles in the design process that I had not previously experienced such as having to consider new design specifications midway through planning/building the prototype or having to make compromises on parts of the project to meet the deadlines of another part. In addition, as this project involved a lot of trial and error as neither I nor Professor Hedrick had experience with setting up a watering system, I learned that I should account for the time it takes to test the system and work out issues. Working with Donna was a rewarding experience that taught me a lot about iterative design. She and many others, namely Professor Hedrick and Bud from Griffin Greenhouse, were great mentors that helped me accomplish as much as I did in this project

### *13.3 Future Work*

A lot of work still remains to be done especially on the water delivery system and the moisture sensing unit. In the next term, my first priority is to resolve the mister issue and install the fully functioning manual water delivery system into the Schenectady ARC greenhouse. Then, I would like to acquire more data to achieve a better correlation between the tensiometer and the WorldChips capacitive moisture sensor and also incorporate a mini water delivery system into the prototype to ensure automatic and manual control function properly in the presence of water. Finally, the prototype can be integrated into the heating control system and additional features added such as more moisture sensors, a GUI for user interaction, proper mounting and water-proofing of circuitry, and error reporting via WiFi. With more feedback from the individuals at the Schenectady ARC, I would also like to build a miniature prototype in the Union College greenhouse for further testing and improvement of the system and as a guideline if the system can be expanded to places other than the Schenectady ARC.

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## Appendix

```
// SparkFun Serial LCD and Keypad library
#include <SoftwareSerial.h>
#include <Keypad.h>

// Attach the serial enabled LCD's RX line to digital pin 11
// Arduino SS_RX = pin 10 (unused), Arduino SS_TX = pin 11
SoftwareSerial LCD(10, 11);

// rows and columns in keypad
const byte numRows = 4;
const byte numCols = 4;
// defines key pressed according to row and column
char keymap[numRows][numCols] = {
{‘1’, ‘2’, ‘3’, ‘A’},
{‘4’, ‘5’, ‘6’, ‘B’},
{‘7’, ‘8’, ‘9’, ‘C’};
{‘*’, ‘0’, ‘#’, ‘D’}
};
byte rowPins[numRows] = {‘9’, ‘8’, ‘7’, ‘6’};
byte colPins[numCols] = {‘5’, ‘4’, ‘3’, ‘2’};
//instantiates instance of Keypad
Keypad myKeypad = Keypad(makeKeymap(keymap), rowPins, colPins,
    numRows, numCols);

int var1, var2;
char var1string[4], var2string[4];
int thresholdmin;
bool auto = false;
int buttonPin = 10;
int switchPin = 1;
int waterPin = 0;

void setup()
{
  pinMode(buttonPin, INPUT);
  pinMode(switchPin, INPUT);
  pinMode(waterPin, OUTPUT);
  LCD.begin(9600); // set up serial port for 9600 baud
  Serial.begin(9600);
  delay(500); // wait for display to boot up
  LCD.write(254);
  LCD.write(128);
  LCD.write(“Input Threshold );

  char threshold1 = myKeypad.getKey();
  while (threshold1 == NO_KEY) {
    threshold1 = myKeypad.getKey();
  }
  switch(threshold1) {
  case ‘1’:
    thresholdmin += 10;
    break;
  case ‘2’:
```

```
  thresholdmin += 20;
  break;
case ‘3’:
  thresholdmin += 30;
  break;
case ‘4’:
  thresholdmin += 40;
  break;
case ‘5’:
  thresholdmin += 50;
  break;
case ‘6’:
  thresholdmin += 60;
  break;
case ‘7’:
  thresholdmin += 70;
  break;
case ‘8’:
  thresholdmin += 80;
  break;
case ‘9’:
  thresholdmin += 90;
  break;
default:
  thresholdmin += 0;
}

char threshold2 = myKeypad.getKey();
while (threshold2 == NO_KEY) {
  threshold2 = myKeypad.getKey();
}
switch(threshold2) {
case ‘1’:
  thresholdmin += 1;
  break;
case ‘2’:
  thresholdmin += 2;
  break;
case ‘3’:
  thresholdmin += 3;
  break;
case ‘4’:
  thresholdmin += 4;
  break;
case ‘5’:
  thresholdmin += 5;
  break;
case ‘6’:
  thresholdmin += 6;
  break;
case ‘7’:
  thresholdmin += 7;
  break;
case ‘8’:
  thresholdmin += 8;
  break;
case ‘9’:
```

```
    thresholdmin += 9;
    break;
  default:
    thresholdmin += 0;
  }

}

void loop()
{
  while (auto == false) {
    // move cursor to beginning of first line
    LCD.write(254);
    LCD.write(128);

    // clear display by sending spaces
    LCD.write("Reading 1:      ");
    LCD.write("Reading 2:      ");

    // read in analog voltage values (0-1023 corresponding to 0-5V)
    var1 = analogRead(0);  // Sparkfun moisture sensor
    var2 = analogRead(1);  // Worldchips moisture sensor
    // convert value to pressure reading
    var1 = (int)((var1 - 621.11) / 9.9388)
    var2 = (int)((var2 – 621.11) / 9.9388)
    sprintf(var1string, "%d", var1);
    sprintf(var2string, "%d", var2);

    // print to LCD
    LCD.write(254);
    LCD.write(139);
    LCD.write(var1string);
    LCD.write(254);
    LCD.write(203);
    LCD.write(var2string);

    if (digitalRead(buttonPin) == HIGH) {
      digitalWrite(waterPin, HIGH);
    }
    else {
      digitalWrite(waterPin, LOW);
    }

    if (digitalRead(switchPin) == HIGH) {
      auto = true;
    }
  }

  while (auto == true) {
    // move cursor to beginning of first line
    LCD.write(254);
    LCD.write(128);

    // clear display by sending spaces
    LCD.write("Reading 1:      ");
    LCD.write("Reading 2:      ");
```

```
    // read in analog voltage values (0-1023 corresponding to 0-5V)
    var1 = analogRead(0);  // Sparkfun moisture sensor
    var2 = analogRead(1);  // Worldchips moisture sensor
    // convert value to pressure reading
    var1 = (int)((var1 - 621.11) / 9.9388)
    var2 = (int)((var2 – 621.11) / 9.9388)
    sprintf(var1string, "%d", var1);
    sprintf(var2string, "%d", var2);

    // print to LCD
    LCD.write(254);
    LCD.write(139);
    LCD.write(var1string);
    LCD.write(254);
    LCD.write(203);
    LCD.write(var2string);

    if (var1 < thresholdmin) {
      digitalWrite(waterPin, HIGH);
  }
  else {
    digitalWrite(waterPin, LOW);
  }

    if (digitalRead(switchPin) == LOW) {
     auto = false;
    }
  }
}
```

**Figure A1.** Complete RedBoard controller code