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Recording Humidity, Temperature, and Moisture in a Hydroponic Greenhouse

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Abstract

George Mason University's hydroponic greenhouse and the Patriot Green Fund requested an irrigation data logging system to track how weather conditions affect the frequency at which plants need to be watered. A prototype system was created and tested in the greenhouse. The initial prototype was found to have significant issues and was brought back to the lab for modification. Upon testing in the lab, it was found that the sensors had multiple issues; further testing is required to find solutions. This project has wide implications in the field of sustainability, as it could be used in medium- and small-scale hydroponics operations across the world.

Author's Note

When our team was offered the opportunity to work with the President's Park Hydroponic Greenhouse to develop a more efficient and sustainable irrigation system, we knew we had to take it. Our internship at George Mason University allowed us to work with multiple departments, and the greenhouse (along with the accompanying Patriot Green Fund) happened to be one of them. Realizing that little data had been collected on weather conditions in the greenhouse, we decided to tackle this gap in knowledge. We believe that the data we helped collect could help the greenhouse water crops exactly how much they need to be watered, ultimately increasing yield and using water and other resources more efficiently. This would also create opportunities for students and faculty to further study how conditions change in the greenhouse due to different seasons and weather conditions.

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Introduction

The goal of this study was to create a data collection (and/or automatic irrigation) system for George Mason University's hydroponic greenhouse. Initially, the desired goal was to create a fully automated watering system that would account for several factors including humidity, temperature, and sunlight levels, but it was quickly decided that this would not be feasible in the amount of time given. Instead, the project switched focus to helping the greenhouse collect data on humidity and moisture levels both in the greenhouse as a whole and in the hydroponic trays where food is grown.

The hydroponic greenhouse at GMU uses a timer-based irrigation system at present. This system works, but it has several flaws and requires frequent maintenance. As the seasons and weather change, so do the temperature and humidity in the greenhouse, causing water to evaporate at differing rates; this can result in over- or under-watering of crops, creating problems such as wilting and root rot. The greenhouse staff's primary goal was to find a way to record data on weather conditions and their correlation with moisture levels in the hydroponic trays where plants are grown.

Hydroponic systems are incredibly beneficial to the environment as a greener way to grow food. They use far less water than traditional, soil-based agriculture, take up less space, and allow many crops to be grown locally where that would not be feasible otherwise. The high degree of control afforded by hydroponic systems (over pH, nutrient content, water levels, etc.) can also produce an increased crop yield.

This is not to say that hydroponics doesn't have its own set of problems; first of all, hydroponic systems are expensive to construct. There are simply more components and more complex technology involved than there would be in a traditional garden. Issues such as power outages and waterborne disease can quickly harm plants, and a high degree of monitoring is required to ensure that these and other problems (such as pests) do not affect crops. An institution like GMU, with plenty of resources and time to dedicate to sustainability seems an ideal place to streamline hydroponics and solve some of these problems. This would allow the rest of the world to more readily implement hydroponics, allowing for more efficient use of space and resources.

Humidity and temperature sensors were tested in the greenhouse and reported that temperature rises, and humidity falls significantly during the day. Then, a prototype of an integrated data collection system was built and tested in the greenhouse; however, data collection stalled in the middle of the night and the system had to be brought back to the lab. Finally, the project moved to fine-tuning this system and re-testing in the lab. It was found that the moisture sensors used in the prototype were malfunctioning in the lab (showing multiple fluctuations in moisture where there should be none) and corroding when placed in the greenhouse's hydroponic trays. While our team did not have the opportunity to find solutions to these problems or test alternate sensors, we would propose this as a starting point for future investigators.

This paper is organized into several sections; first, a brief review of literature surrounding the project is provided. Second, the methods and experimental process are described. Third, results are relayed, and implications of those results both for this project and for future work in the field are discussed. Finally, this paper concludes with suggestions for improvement on this project and an overview of the project's effect on the hydroponic greenhouse and their future operations.

Literature Review

The project began by reviewing several papers on hydroponics and microgreen growth (as our project mainly collected data from trays growing microgreens). In this review, we found that there has been much research on automating hydroponic systems in greenhouses, primarily focused on controlling the flow of nutrient solutions (Dhal et al., 2022) or on monitoring temperature and humidity (Yanshori et al., 2022). Additionally, attempts have been made to solve the problem of environmental factors inhibiting plant growth by controlling those environmental factors; that is, by proposing a fully light-controlled greenhouse (Bhargava et al., 2022). This would not be feasible in GMU's greenhouse, both due to cost and the greenhouse's goal of being fully sustainable.

Other papers have shown that increased temperature during light periods can be beneficial to plant growth and crop yield (Kumazaki, 2022). This means it is likely that increased temperature in the greenhouse in and of itself does not present a problem for plant growth; it is more likely to be beneficial than detrimental. Therefore, a viable solution should not involve an attempt to change the temperature in the greenhouse.

Sensor-based irrigation systems have been implemented in hydroponic greenhouses before (Tatas et al., 2022). Tatas et al. created an irrigation system in which data transmitted about ambient conditions in the greenhouse informs the amount of water pumped through the system. Additionally, Arduino microcontrollers have been used to control the flow of nutrient solution in hydroponic systems (Sihombing et al., 2018). This provides precedent for the work done in this project.

Materials

In this project, an Arduino microcontroller (essentially a small, easily-programmable computer) was used to read sensor values. Moisture sensors were used to measure water content in the hydroponic trays, although the initial model began corroding and a different model was used in the final product. An SD card was used to record data, and components were connected by a circuit board. Additionally, the Smart Hygrometer from Sensor Blue and an android phone were used to collect preliminary data. Finally, burlap fabric was used to test the sensors in the lab and secure them in the greenhouse.

Methods

First, initial data on temperature and humidity was collected from the greenhouse to provide a control dataset from which to calibrate sensors. To collect this data, Sensor Blue's Smart Hygrometer was used. These sensors stream information to an android smartphone, from which data can be exported. One sensor was placed adjacent to the microgreen trays, and another was placed approximately 300 feet away in a different section of the greenhouse. The sensors were left to collect data for 48 hours and recorded the entire time without issue. After the data was exported, it was analyzed in excel, Matlab, and Codap. A detailed report of this analysis is given in the results section of this paper.

Next, a prototype data collection system (referred to in this paper as Prototype 1) was tested in the greenhouse. Data collected by 2 moisture sensors in the hydroponic trays was transmitted via wiring to an SD card for collection and analysis. The prototype was primarily powered by electricity in the greenhouse, although the timepiece was battery powered.

Additionally, the hygrometers were again placed in the greenhouse so that data from the 2 systems could be compared. Prototype 1's moisture sensors were both placed in the hydroponic tray under the burlap the plants are grown on. One of the hygrometers was placed adjacent to the tray, and the other was placed a few feet above the tray. All sensors were left to record data for approximately 21 hours. Approximately 9 hours of data (discussed in the results section) were collected from Prototype 1 in this trial; however, it stopped recording around midnight and did not resume. It is possible that it stopped recording due to power being cut off to the outlet it was plugged into, but it remains unsure why it did not resume recording once the outlet was turned back on. The hygrometers again recorded the entire time without issue. Additionally, it was found that Prototype 1's moisture sensors had begun to corrode, potentially due to the pH of the nutrient solution in the hydroponic trays.

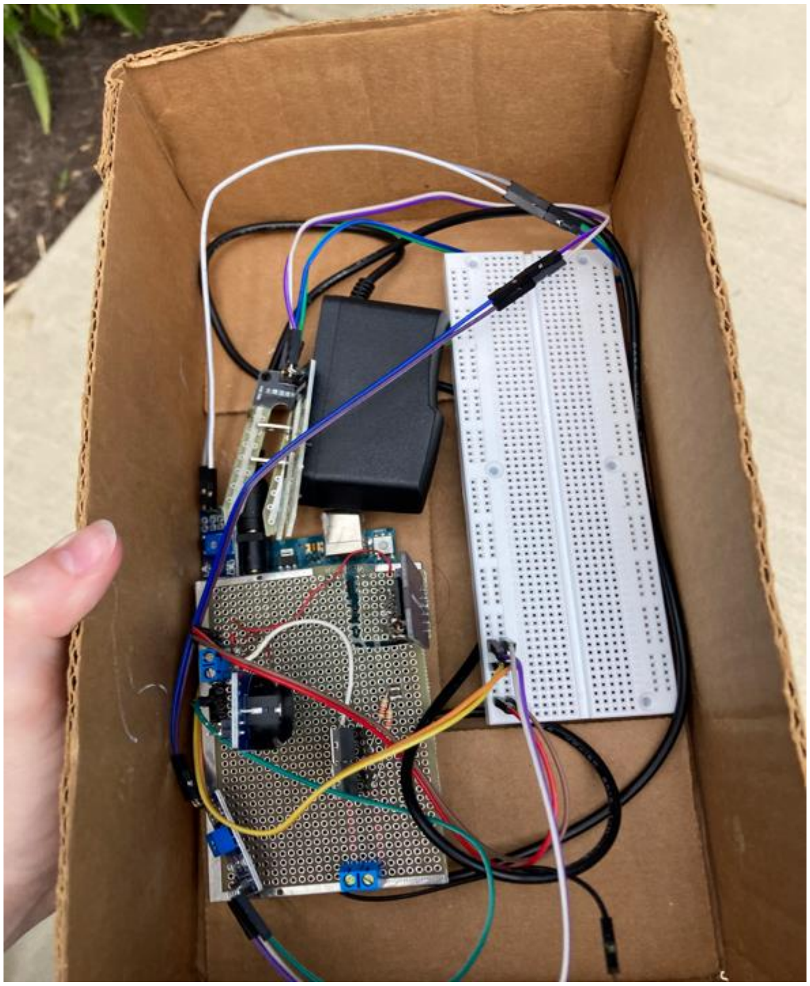

Figure 1. Prototype 1. An image of our first prototype en route to the greenhouse. The Arduino microcontroller (white) is connected to a motherboard that integrates information from the SD card, timepiece, and sensors (connected to the blue & purple wires).

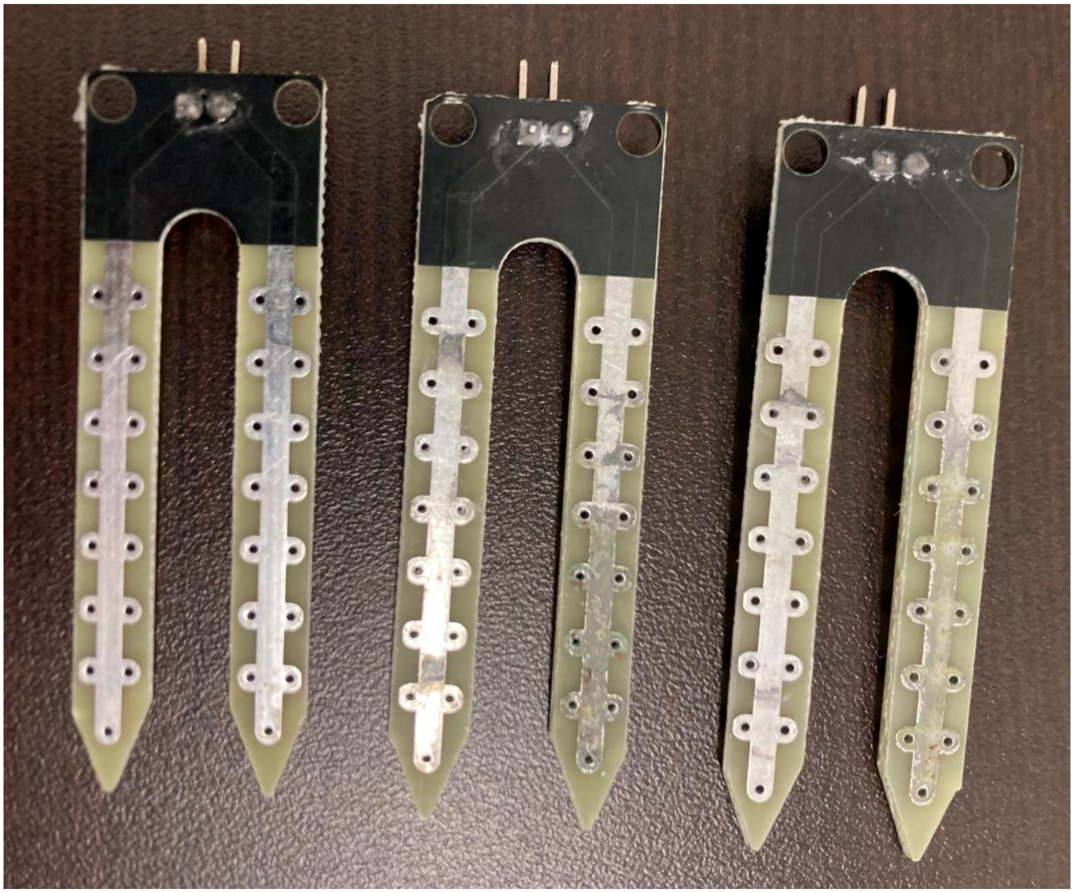

Figure 2. Moisture sensor corrosion. The sensor on the left is unused, whereas the two on the right were used and show visible corrosion.

However, the sensors were re-tested in the lab (both in tap water and in the greenhouse's nutrient-enriched water). The sensor was placed on wet burlap and allowed to dry and did not corrode or have any issue recording data. Further testing is required to determine why the sensors worked in the lab but not at the greenhouse.

Data was analyzed in Matlab and Codap; plots were created to show the trends in temperature (Figure 3) and humidity (Figure 4) from our initial data, then a 3d plot was created to compare and contrast the 2 sets of data (Figure 5). Finally, a chart showing the discrepancies in data collection from moisture sensors in the lab was created to show the problems with these sensors (Figure 6).

Results

In analyzing the data from the control condition, it was found that temperature rises in the greenhouse during the day (particularly from the hours of 10:00 AM to 4:00 PM), and that humidity falls dramatically during those same hours, as shown in Figures 3, 4, and 5. The average temperature in the greenhouse was found to be approximately 76.2 degrees Fahrenheit (with a standard deviation of 5.54), and the average humidity was found to be approximately 77.4% (with a standard deviation of 10.76). According to this data, humidity and temperature in the greenhouse are inversely related, but humidity varies more widely. This is reflected in the maximum and minimum values of each data set, with the maximum and minimum values for temperature being 91.06 degrees Fahrenheit and 69.13 degrees Fahrenheit respectively, and the maximum and minimum values for humidity being 90.4% and 50.3% respectively.

In analyzing the data from the first experimental trial, the smart hygrometers reported similar data to the control trial, albeit with lower variability of both temperature and humidity (temperature had a maximum value of 87.2 degrees Fahrenheit, and a minimum value of 74.4 degrees Fahrenheit, while humidity had a maximum value of 83.3% and a minimum value of 65.9%). This may be because data collection was stopped before the hottest hours of the day (2PM-4PM) or because of variations in weather. The data from the prototype, although it collected data for approximately 9 hours, was largely inconclusive; statistical analysis found little to no pattern.

When tested in the lab, the moisture sensors collected data properly for the duration of the trial; this data (Figure 6), unlike that collected in the greenhouse, did have a pattern. However, the data did not perform exactly as expected; despite the sensor only being wetted once and then allowed to dry, data shows several fluctuations in moisture level (graph shown below). Further testing is required to see why this is the case and if there is any way to make the sensors work properly.

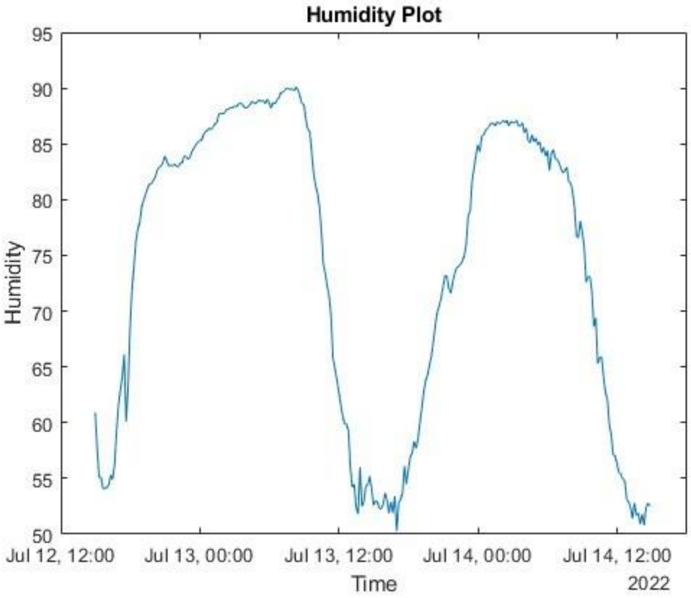

Figure 3. Humidity plot. Plot of humidity vs. time of day; humidity increases at night and decreases during the day.

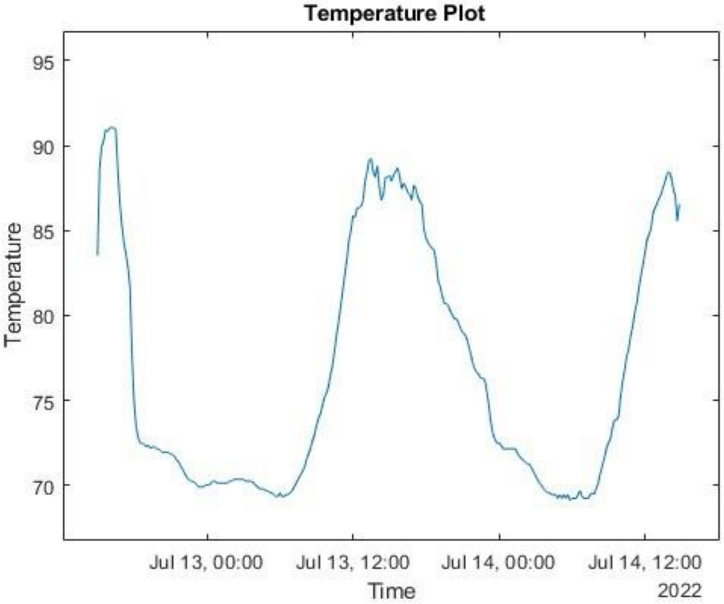

Figure 4. Temperature plot. Plot of temperature vs. time of day; temperature decreases at night and increases during the day.

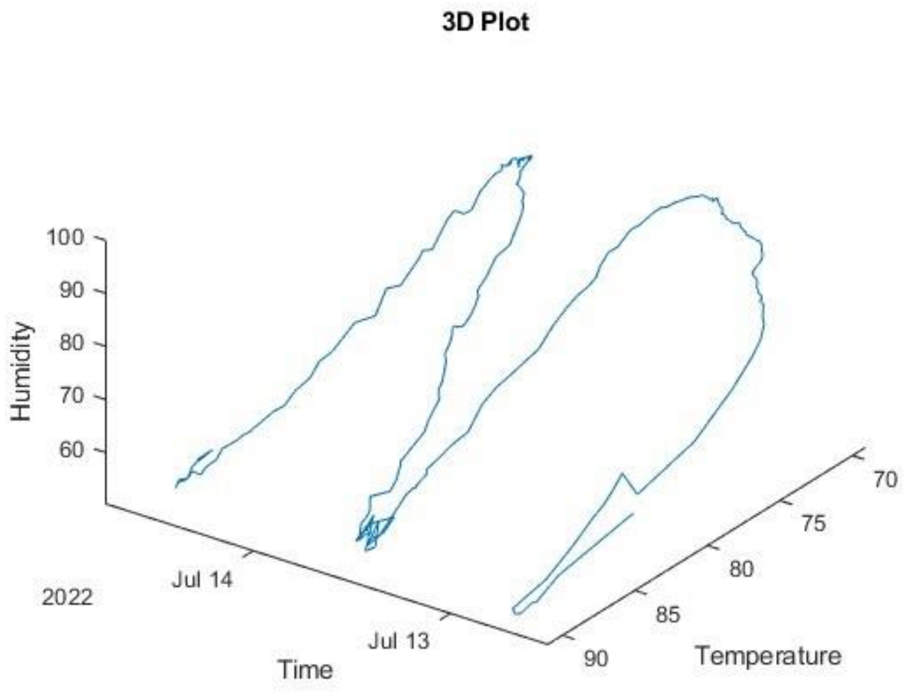

Figure 5. A 3D plot of humidity, temperature, and time of day. Shows the inverse relationship of humidity and temperature throughout the day.

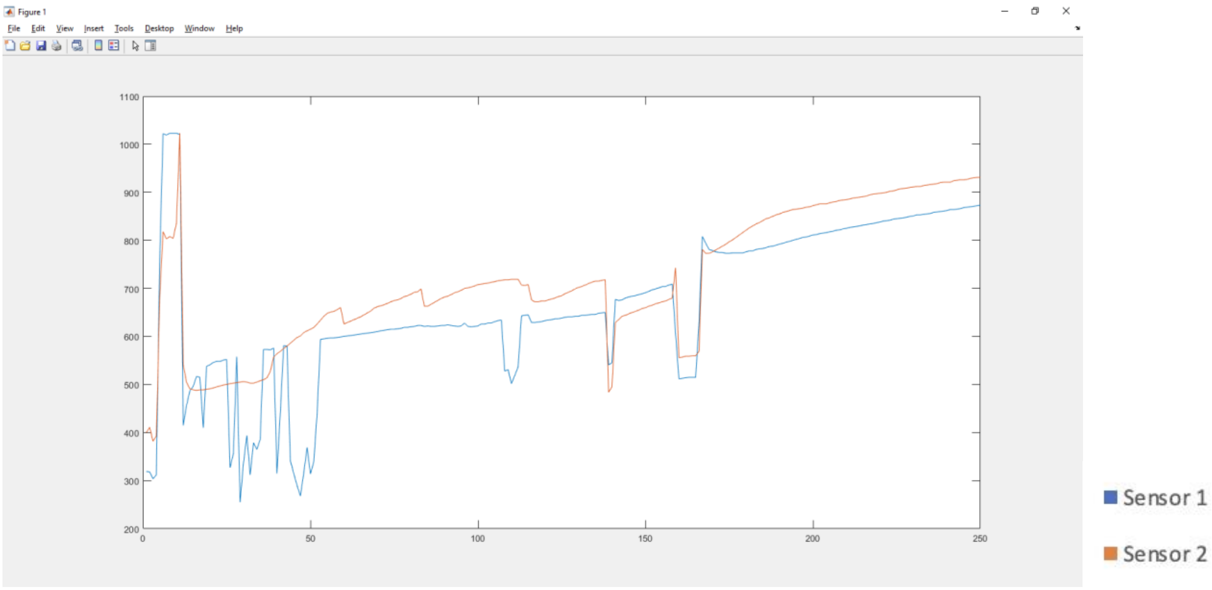

Figure 6. Line graph of data collected from moisture sensors in the lab. High values indicate increasingly dry conditions, while low values indicate wet conditions; despite only being moistened once, the sensors report several fluctuations in moisture.

Discussion

From the data discussed above, we make the preliminary conclusion that temperature and light levels strongly affect humidity and moisture in the greenhouse. Temperature is clearly shown to be inversely proportional to humidity, and the temperature of the greenhouse is largely a function of the temperature outdoors and the sunlight coming into the greenhouse. Since humidity is affected so strongly, moisture levels in the hydroponic trays are almost certainly affected as well, as the humidity should be inversely proportional to the rate of evaporation.

Prototype 1 had several problems, all of which can be explained. First, the prototype unexpectedly shut off around midnight; a potential reason for this is that some of the greenhouse outlets are on timers. Still, it is unclear why the prototype would not resume recording once power was turned back on in the morning. Second, only one of the 2 sensors recorded data at all; this may be due to improper sensor placement. Third, the data that was recorded shows no clear pattern or trend. This is most likely because the sensors began corroding overnight, likely due to the pH and other chemical properties of the nutrient solution. It is also likely that the moisture sensors' demonstrated tendency to display random fluctuations contributed to this.

We concluded that the best solution to the problems with sensors was simply to obtain and test a different sensor; the ones used seem to be incompatible with the nutrient solution GMU's greenhouse uses. These sensors were not chosen for any specific reason; they were simply what the lab had on hand. To fix the sensor positioning problem, a sensor thin enough to be woven into burlap could be used or a clip could be devised to secure the sensors.

Conclusion

In this project, an automatic irrigation system for GMU's hydroponic greenhouse was devised, tested, and revised. This work is important to the field of sustainability due to the environmental benefits of hydroponics; it proposes a partial solution to the problem of hydroponic crops needing constant monitoring to stay healthy. Initial data was collected on weather conditions in the greenhouse, and then a prototype was tested both in lab and in the greenhouse. In both conditions, the moisture sensors used were found to have multiple problems in collecting data consistently and accurately. However, several trends in humidity and temperature were observed, which hopefully will be useful to the GMU greenhouse. Additionally, Prototype 1 provides an excellent framework for improvement with alternate sensors.

This project has many potential implications in the field of hydroponics; other students or faculty could improve upon this design to provide the greenhouse with more accurate and detailed monitoring, or even control of irrigation based on the data gathered by this system. This design could also be altered for use in other small- to medium-scale hydroponics operations, allowing producers around the country and around the world to collect data on weather, moisture levels, and how the two interact. There are countless potential applications for this design, and we hope that our work will be useful to future contributors.

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