Technical Document: A Study of Arduino Used to Measure and Collect Moisture Levels of Crops

Members; Brian Holland, RJ Bailey, Justin Au

Course: EGR 122 01PR

Instructor: Dr. K. Brinkley

Client: J. Sargeant Reynolds Department of Horticulture

Group Code of Ethics

Creating a structure outlining a code of ethics ensures the group will stay focused on the task at hand without unnecessary drama or conflicts. It will also prevent confusion and an imbalance when it comes to work being distributed. Ultimately, having a code of ethics is the key to boosting efficiency toward the completion of the client's product.

Group Rules:

- ❖ Every participant should work on tasks respective to their role. If a member notices another not doing their work productively or at all, one warning should be given before addressing the issue more seriously at a group meeting.
- ❖ Inappropriate language, racial slurs, or other offensive languages will not be tolerated. The offender will be asked to stop, and, if they continue, such actions will be reported to the professor, Dr. Brinkley.
- ❖ If a member wishes to edit and revise work, they should ask for permission before proceeding. If they are unable to get a response promptly, the member can edit the work in question on a separate document. Failure to abide by this rule should be followed by a group meeting to address the issue.

Any other non-ethical actions not mentioned above will also not be tolerated. Consequences will start with a warning, a group meeting, and finally involvement with Professor Brinkley.

Group Structure

All members have their own designated roles, forms of communication, and editing process to help with the completion of the Department of Horticulture's requested product.

Leading roles

- Brian Holland holds the central role of Sr. programmer. This involves the design of the circuitry and the development of output devices (such as the LCD, LED, and buzzer) for the moisture sensor product. He is also responsible for creating a method to store and use data for moisture levels based on the client's needs.
- RJ Bailey is the Sr. designer of the project. He is responsible for creating a suitable housing unit as well as the sketches for it and making sure it fits the client's needs. He is involved in the physical wiring and practicality of the structure. RJ is also the primary member when it comes to submitting work and ensuring group deadlines are met.
- Justin Au is the Sr. researcher, helping to indicate to other members how to best utilize resources to satisfy the client's needs.

If, for any reason, a member is absent from their duty or requires assistance, others must decide who would be responsible under such circumstances.

Communication strategy

- Formal communication involving important information regarding the project (may include meeting dates, group deadlines, future absences, etc.) must be sent via each member's respective email.
    - Brian - bjh25383@email.vccs.edu
    - R.J. - rjb24732@email.vccs.edu or robertjamesbailey88@gmail.com
    - Justin - ja81988@email.vccs.edu or potatosdestiny@gmail.com
- Less pressing information may be sent via Canvas direct messaging and/or text message group chats. Important information can also be sent with Canvas or text messaging, but as a follow-up to email. Each member's phone number is listed below.
    - R.J. - (804)-839-2768
    - Justin - (804)-869-8118
    - Brian - (804)-499-9306

Messages which ask for a response should be followed up within a 24-hours.

Editing process

- All members must be responsible for reviewing their work. Afterward, others should take the time to review and offer feedback when necessary. When required, responsibility for the submission of such work will be listed in ascending order below.
    - Highest priority: RJ Bailey
    - Medium priority: Justin Au
    - Low priority: Brian Holland

Background Information

Design problem: Develop a practical moisture sensor that meets the client's needs. It is essential that the design is practical, portable, and safe to use in outreach programs.

Filament

As the product will be exposed to the elements such as heat, UV rays, water, etc., a suitable filament must withstand outdoor use.

ASA (Acrylic Styrene Acrylonitrile) is a reliable 3D print material as it contains resistance to UV rays (UV rays induce discoloration and stability of filament), chemicals, and water (MatterHackers, 2023). ASA is not as hygroscopic as PETG and PLA, so this filament will not swell as significantly as them (Chapman, 2022). It is also anti-static—it prevents the buildup of static charge, which is crucial as the housing unit would be near electronic components (ASA Quick Start Guide, n.d.). Another benefit to ASA is its ability to resist warping under extreme temperatures. This trait would be helpful for intricate parts of the moisture sensor housing as it would not lose its rigidity. ASA is also relatively affordable, and food safe (for specific brands) but more challenging to print than PLA.

PETG (Polyethylene Terephthalate Glycol) filament is another option for outdoor purposes. Namely, it contains resistance to chemicals, sudden impacts, water, and warping under high temperatures (as it has high flexibility). PETG is also food safe—a benefit as the audience focuses on students in elementary/middle schools (PETG Filament, 2022). This filament is also affordable but prone to scratches, ineffective to paint/coat, and prone to swelling in water (Sanladerer, 2023; Chapman, 2022).

PLA (polylactic acid) is a commonly used filament for indoor use. The material has poor heat resistance—50° C (122° F) and above is where PLA loses its strength (PLA vs ABS vs Nylon, n.d.). And though PLA is relatively stiff and strong, its durability cannot continue to take strenuous loads over time. This filament also is hygroscopic—it will absorb water and potentially swell if left wet over time (PLA does not degrade in water, though) (Chapman, 2022). However, a few upsides are that PLA is UV resistant, chemical resistant, generally food safe, much more cost-effective and easier to print than PETG and ASA (PLA vs ABS vs Nylon, n.d.), and it is also easy to coat, unlike PETG.

Ideally, ASA is the best filament to use out of the three options as it is anti-static, durable, impact-resistant, water resistant, not very hygroscopic, heat resistant, UV resistant, and so on (MatterHackers, 2023; ASA Quick Start Guide, n.d). If PETG or PLA should be used, other techniques should be incorporated to increase viability for outdoor usage. Methods include applying a waterproofing coating, vapor smoothing, and annealing (which makes it more temperature resistant, but sacrifices dimension accuracy) to increase the properties of the filament being waterproof or temperature resistant (Chapman, 2022).

Sensor

The type of moisture sensor is another factor to look into. The two sensors available (for cost reasons) involve a resistive sensor and a capacitive moisture sensor.

> A resistive moisture sensor consists of two exposed and separated electrodes. The probes conduct electricity based on the conductivity of the surrounding area. For example, when the measuring end is in pure water, the voltage drop increases since pure water is a nonconductor of electricity (the water acts like a resistor). In addition to water, fertilizer is measured as well. Different types of fertilizers consist of varying ion concentrations (Adla, et al., 2020). When these ions dissociate in water, they become conductors of electricity and affect the voltage output from the resistive moisture sensor. Since the client will use “various types of fertilizers,” it is necessary to recalibrate for accurate readings. Also considering the nature of a resistive moisture sensor, the exposed probes would lead to possible oxidation when left untreated in water.

> A capacitive moisture sensor is made similar to a capacitor—it consists of a dielectric and two electrodes—one end is positive and the other negative. Capacitance measures how much charge a material can store when fed a set amount of voltage (Hrisko, 2020). Using water as the dielectric, the amount of water content on the sensor will affect the dielectric and cause changes to the capacitance with the help of a 555 timer chip (CircuitSchools, 2022). Other components in the sensor create an ADC output which can then be converted to a voltage.

Since the resistive sensor may oxidize too quickly depending on the amount of DC flow, a capacitive sensor is ideal as it does not pose this drawback.

Client Survey

The survey was instigated to identify client needs and understand other potentially-impacting feedback that may affect the product design. The client was asked questions regarding portability, display signals, crop/fertilizer type, and an open-ended answer for anything they wished to add.

Results

Table 1 displays questions in the survey that were thought of as significant–it helped make design choices on particular aspects of the product. Questions surveyed but not included in Table 1 had no impact on the design.

Question #	Questions	Responses
1	Should this sensor be stationary or portable?	Portable.
2	How long will the sensor be recording data?	Less than 12 hours.
3	How would you like to be alerted of unacceptable levels of moisture? (Select all that apply)	LED, Liquid crystal display (LCD), Active buzzer.
4	What crops are being grown?	Peppers, tomatoes, squash, watermelon, and strawberries.
5	Do you have anything else you want to share?	This will be used for an outreach program.

Table 1. Q&A of the client survey.

Question one, addressing portability, changes the structure of the design. As the client wants the moisture sensor to be portable, the structure of the housing unit should be lightweight, easy to carry around, and quick to stabilize into the ground for every use. Because of its portable nature, it would also be ideal to compact the design to be relatively small for storage purposes. A source of power would be best if the product is battery-powered as it would support a compact design.

Question three asks for types of output systems to be used to signal unacceptable levels of moisture depending on the crop being nurtured. As the client wants an LCD display, a buzzer, and LEDs to signal non-ideal moisture levels, design features must be made to accommodate these output systems.

Question two is regarding the length of time the sensor would be conducting measurements, and question four helps indicate which crops are being grown. Both questions help in determining whether to use a resistive or capacitive moisture sensor. The former has two exposed electrodes while the latter does not. The main difference between the two is the probes and their exposure to the environment, which would affect the oxidation rate under certain circumstances. As the client would be settling the moisture sensor in the ground for more than six hours, and the fertilizer content (determined by the type of crops grown) can be on the slightly acidic side (being 5/5.5 pH minimum) (Jagdish, 2022), this would affect which sensor to use.

The last question asks the client to give feedback if needed to ensure that the surveyors did not miss any other important information that may impact the design of the product. As the client has responded that the product will be used for an outreach program, this questions the audience using the sensor. As the audience's age group is variable, the design must be intuitive and safe for those of all ages, especially younger people.

Proposed Product

Design Rationale

Design problem: Develop a practical moisture sensor that meets the client's needs. It is essential that the design is practical, portable, and safe to use in outreach programs.

Sketches 1.1-1.3 focus on the drawings of the first design, sketches 2.1-2.8 include the second version, and sketches 3.1-3.4 center on the current designs. The first design's flaws consist of an exposed battery pack, potential breaking points, an unnecessarily easy way to open the device for younger audiences, and the absence of other key features which would enhance user experience.

A general idea that would tackle these problems is to seal the battery pack, shown in the front view of Sketch 1.1, inside the housing unit, replace it with lithium batteries, and add a charging port so the battery does not need to be accessed or replaced. To address the potential breakage point of the stakes shown in the front view of Sketches 1.1 and 1.3, a solution includes separating the sensor from the housing unit so that the stakes meant to hold the sensor do not succumb to the housing unit's weight over long periods. The hinge system, although easy to access (shown on the side view of Sketch 1.1), is impractical as it would allow kids to potentially ruin the circuitry or other components. Also, keeping the base water-tight would be challenging as the clip to secure the housing unit closed can act as another potential breakage point. In replace of the hinge system, the components in the housing unit will only be accessible via a screw-in lid. A key feature absent in the original design is the lack of data logging. As the client may use the device for 6-12 hour periods, a memory chip to log data is crucial to collect data intuitively. Another key feature is a handle to accommodate the design's portable nature, making transportation more practical. Finally, design one's sketches did not display the inside of the housing which would cause confusion when securing components to the base of the unit.

Design three introduces a new cutout in sketch 3.2 to accommodate for a recording switch. Design three is now wider in comparison to sketch 2 by 19 mm, considering a slightly larger battery pack.

Refer to Appendix C to look at all the versions of the printed product.

Design 3: Description

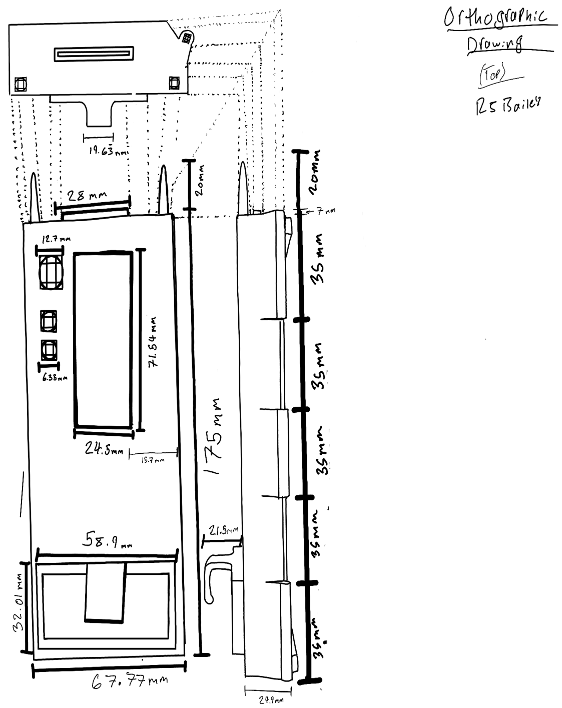
The base of the design, meant to hold most of the components, is shaped similarly to a rectangular prism with dimensions of 89 x 210 x 80 millimeters excluding the handle and 127 x 210 x 80 millimeters with the handle. The handle itself is located on the left side of the main base. It spans 30mm wide, 210 mm long, and 10 mm thick, and is shaped similarly to a trapezoid (sketch 3.1).

The front view of the main base includes vents for air circulation along with, on the opposite side, a 4 mm radii circle cutout for feeding wires to a detached sensor unit, composed of two parts. The first part of the sensor housing is a casing that the moisture sensor slides into, measuring 25 x 15 x 35 millimeters (sketch 3.3). This casing ensures the moisture sensor will be reading at the correct depth in the ground. The second part of the sensor housing unit includes four stakes, located in each corner, with a radius of 2.5 mm (sketch 3.4). The second part, excluding the stakes, totals 50 x 40 x 10 millimeters. Both sensor housing components will be press fit together from the cutout in Sketch 2.6.

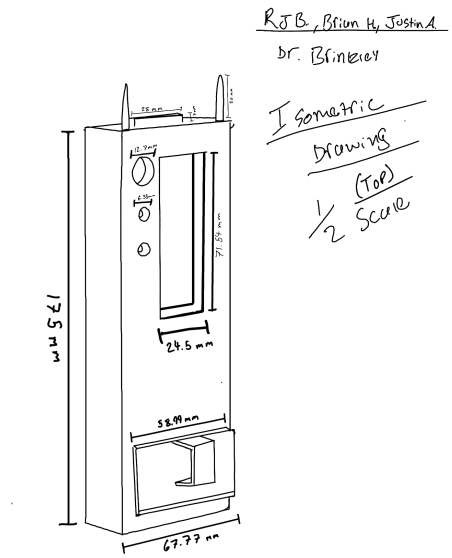
The lid of the main base considers the output and input systems (sketch 3.2). Output systems include the LCD, LED, and buzzer; input systems include a toggleable refresh rate button and two switches. The LCD is located towards the bottom-middle of the top plate. An active buzzer is located above the LCD, which will audibly alert the user on unideal moisture levels. Above the buzzer consists of two LEDs–the first signals the recording state while the second other signals “bad” or “moist” moisture levels (the latter button works in tandem with the buzzer). Two switches also exist which control the data logging and the mode the sensor should measure in. Finally, at the very top, there is an on/off switch that controls the power to the microcontroller.

The two plates are held together by four screws placed in each corner ensuring a waterproof seal. The top plate is designed to have a slope that allows water to flow off and not pool on the plate (sketch 3.2). The back and bottom sides of the main base hold no features (sketch 3.1).

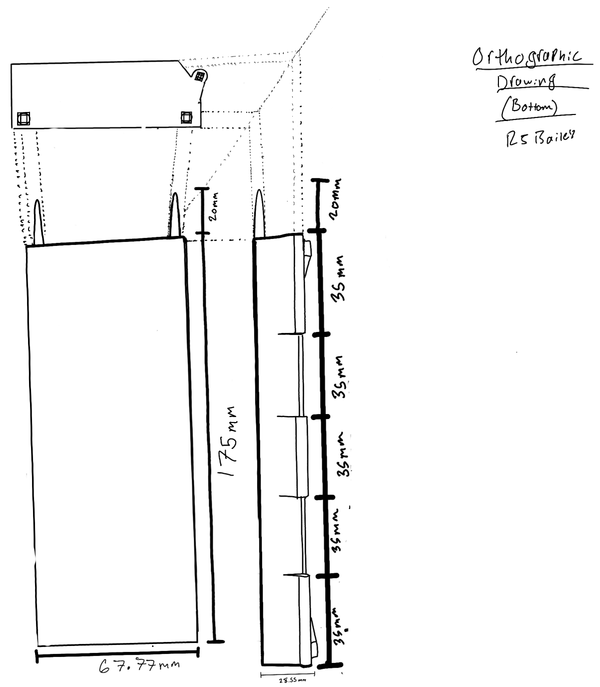
Design 1: Isometric & Orthographic Sketches



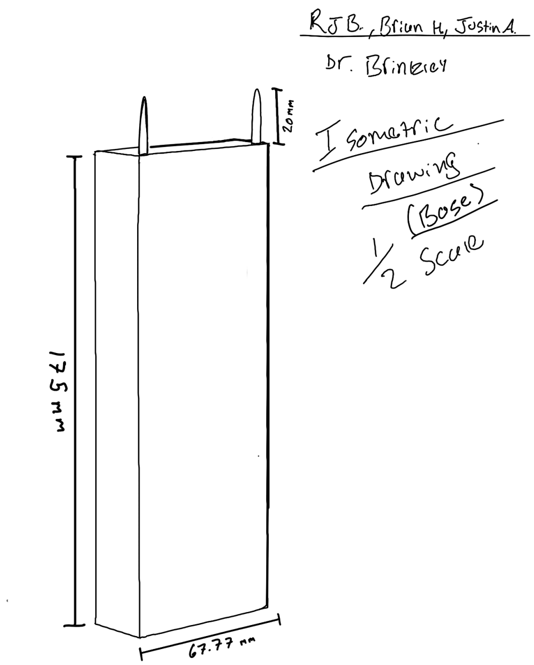
Sketch 1.1. Previous sketch of the front part of the case housing top.



Sketch 1.2. Previous isometric view of the front part of the case housing top.

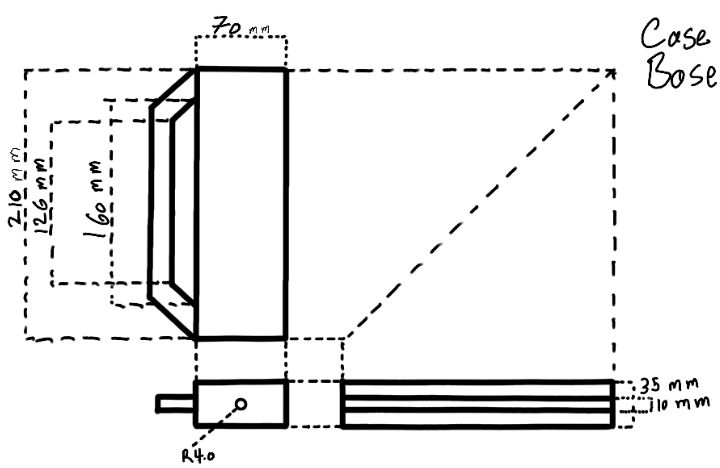


Sketch 1.3. Previous orthographic drawing of the back part of the case housing base.

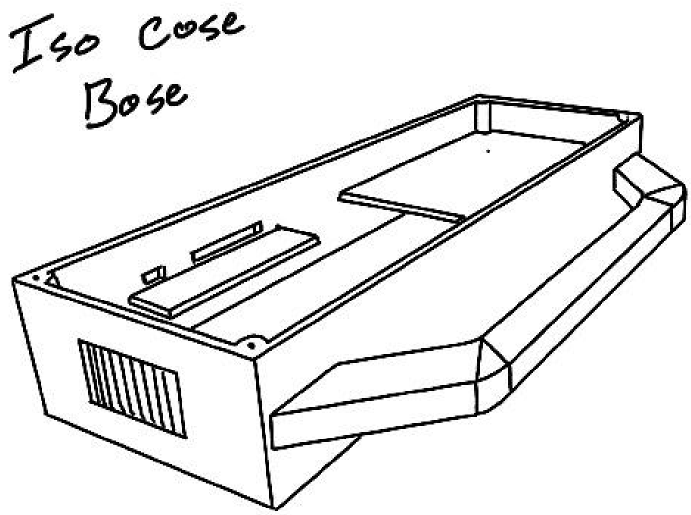


Sketch 1.4. Previous isometric view of the back part of the case housing base.

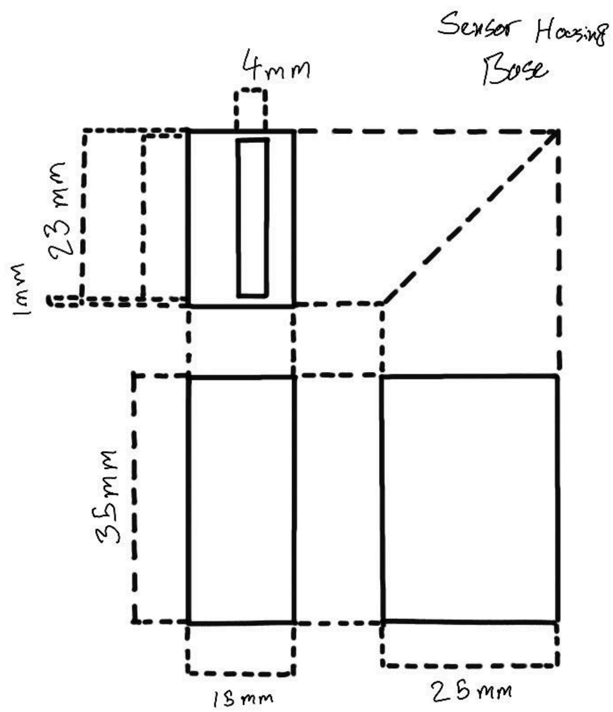
Design 2: Isometric and Orthographic Drawings



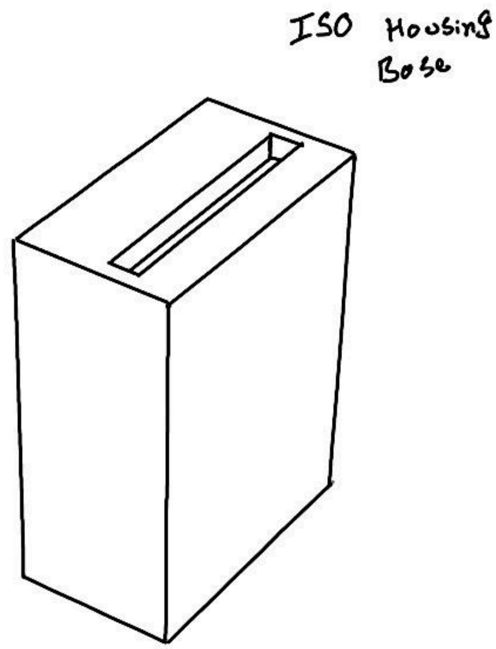
Sketch 2.1. Orthographic sketch of the housing unit for wiring, ventilation, screw holes, battery pack, charger port, and handle. Called "part one."



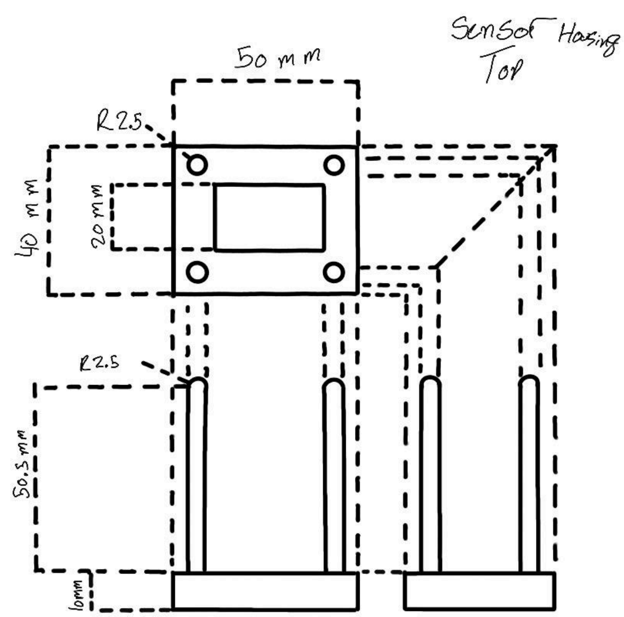
Sketch 2.2. The isometric view of the housing unit/part one.



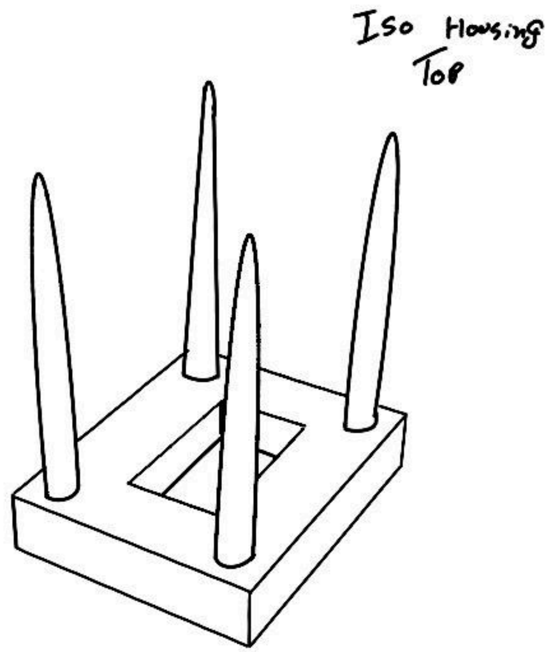
Sketch 2.3. Orthographic drawing of moisture sensor housing unit. Also called "part two," it is detached from the base.



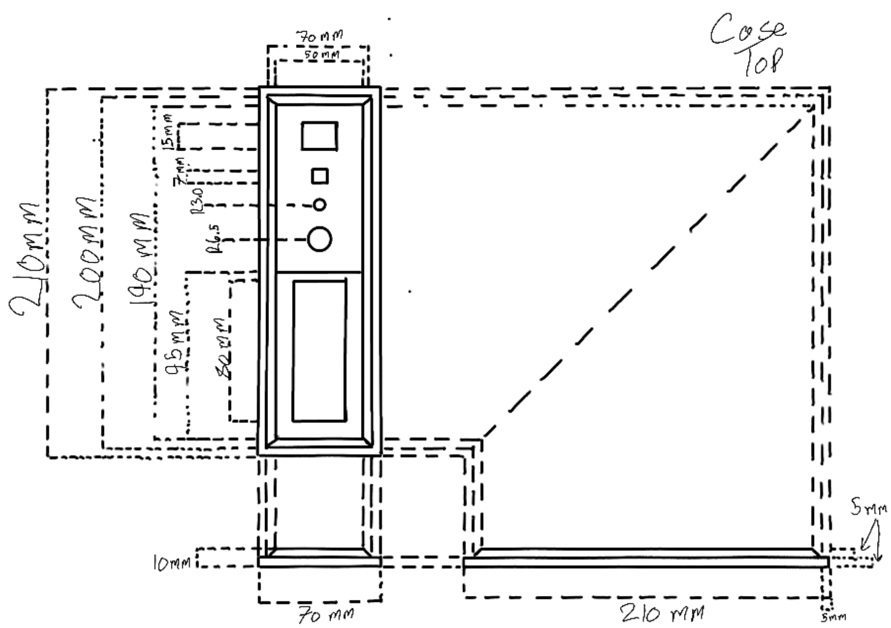
Sketch 2.4. The isometric sketch of the moisture sensor housing unit/part two.



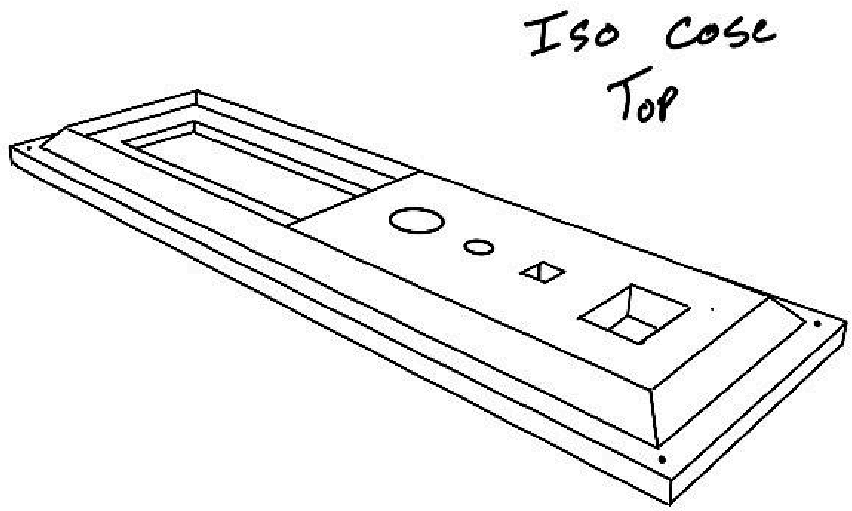
Sketch 2.5. Orthographic sketch of the supports surrounding the moisture sensor. Called "part three."



Sketch 2.6. Isometric view of the supports for the moisture sensor.

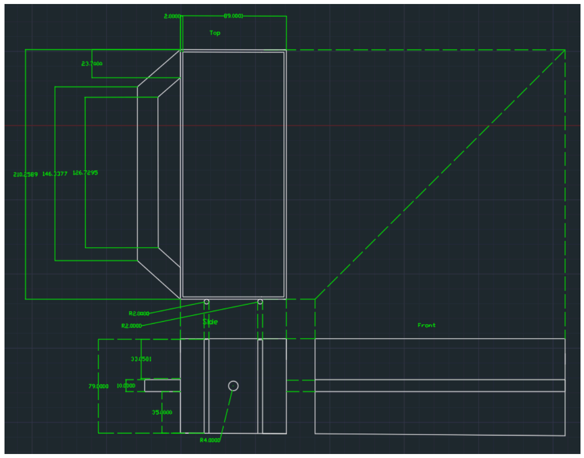


Sketch 2.7. Orthographic sketch of the lid for part one. The lid holds the LCD, LED, buzzer, toggleable refresh rate button, and the on/off switch. Also contains four holes in each corner for screws to secure to part one. Called “part four.”

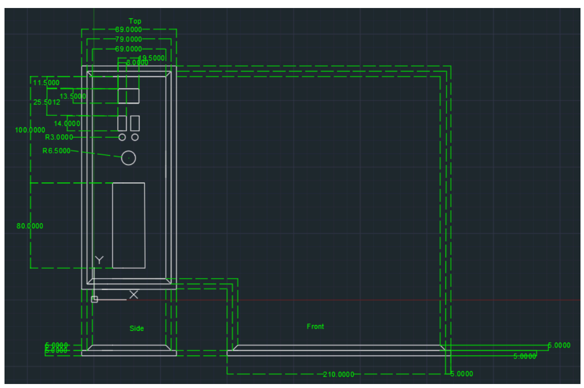


Sketch 2.8. Isometric view of the lid for part one.

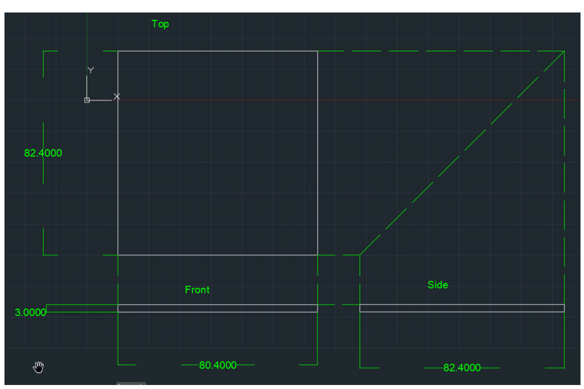
Design 3: Autocad Drawings



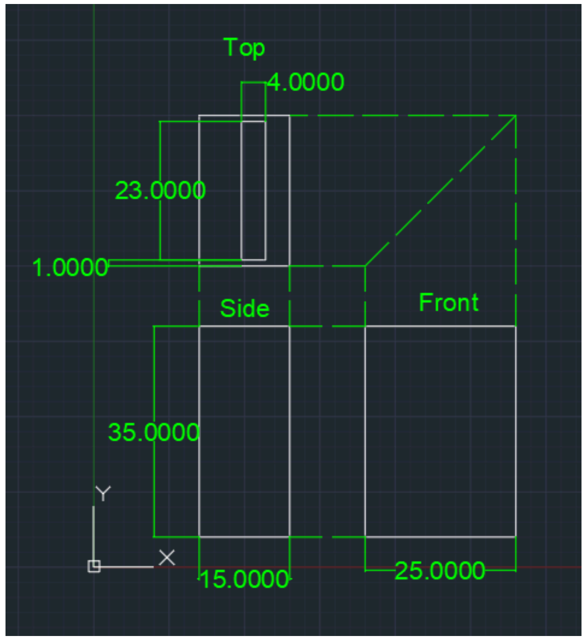
Sketch 3.1. Orthographic AutoCad drawing of the updated version of the microcontroller housing base.



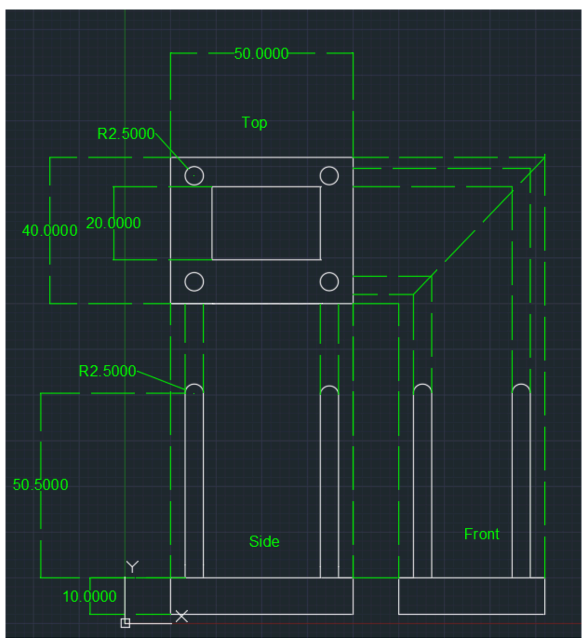
Sketch 3.2. Orthographic AutoCad drawing of the updated version of the microcontroller housing top.



Sketch 3.3. Orthographic AutoCad drawings of the removable Shelf.



Sketch 3.3. Orthographic AutoCad drawing of the sensor housing base.



Sketch 3.4. Orthographic AutoCad drawing of sensor housing top.

Testing Protocol

Two unknowns stood out and were deemed necessary to inform our client. This includes the sensor's accuracy in its own soil type and timing—how long it takes for the sensor to adjust to its calibrated value. In the experimentation process for finding these unknowns, calculations will be done using mainly using gravimetric water content rather than percent moisture as the saturation point of each tested soil will not be needed.

Gravimetric water content (GWC) tells us the mass of water inside a substance of a specific mass. In this case, GWC is the mass of water over the mass of fertilizer and soil. Since the capacitive moisture sensor can be related to GWC, Equation 1.1 can find GWC as the mass of water, dry fertilizer, and dry soil can be found via experimentation.

$$GWC = \frac{0.997\,\frac{g}{mL} * V_w}{m_f * m_s}$$

Equation 1.1. Gravimetric water content using masses of water, fertilizer, and soil. V_w = volume of water in grams, m_f = mass of fertilizer in grams, m_s = mass of soil in grams.

Assuming the client will use a fertilizer solution, the experiment will not consider this because a water-based fertilizer will have a negligible effect on GWC. Equation 1.2 refers to the calculation of GWC, assuming the fertilizer is solution-based.

$$GWC = \frac{0.997\,\frac{g}{mL} * V_w}{m_s}$$

Equation 1.2. GWC using the volume of water and soil. V_w = volume of water in grams and m_s = mass of soil in grams.

General Procedure:
Before testing the unknowns, calibration of the sensor must be done to translate the sensor's output ADC values to GWC. Calibration must be done for each soil type.

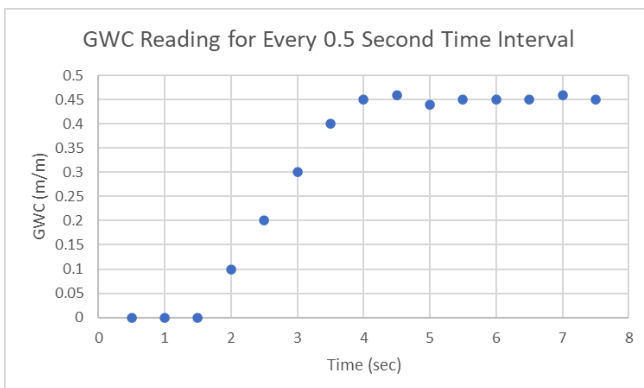
To calibrate, GWC (as a percentage) will be treated as the independent variable and the sensor ADC values will be the dependent variable. By gathering GWC values across different water amounts using Equation 1.2, creating a line of best fit will display the conversion factor needed for the Arduino to go from its ADC measurement to GWC.

Once calibration is completed for each soil type, the accuracy of the sensor will be found by having three known GWC values (at 15, 30, and 45 mL of water respectively) for each of the soils. By comparing the GWC sensor reading to the calculated GWC values, an average percent error for each soil type can be found using Equation 1.3.

$$\%\ error\ GWC = \frac{GWC_c - GWC_e}{GWC_c} * 100$$

Equation 1.3. Percent error calculation. GWC_c is the calculated value and GWC_e is the experimented value from the sensor.

The final procedure is to calculate the time it takes for the sensor to adjust to its calibrated value. By having pots of soil filled to 15, 30, 45 mL, sequentially, the sensor (at the option where it reads in 0.5-second intervals) should be placed in the soil once at dryness. The adjusting time for the sensor can then be found by looking at the first point where the sensor reaches its consistent value and subtracting it from the point right before its consistent dry state is changed. Graph 1.1 shows an example of how the calculation will be done.



Graph 1.1. Graph for calculating adjustment time for the sensor. Adjustment time = 3.5 sec - 1.5 sec = 2 sec. This is an example graph and is not part of the actual experiment.

Materials:

Materials needed for the calibration procedure involve around 2x6 ft^2 of space (around one classroom desk), a tarp to cover the workspace, a 100 mL burette, one 500 mL beaker (for water), two containers to hold 1 L worth of soil, two 300 mL beakers, an analytical/digital balance, potting soil (the experiment will use natural & organic seed starting mix by Jiffy and one other soil), and a glass stirring rod.

Calibration experiment:

1. Prepare the workspace by placing a tarp to cover it.
2. Grab two containers and fill each of them with their own soil to 1 L.
3. Let the soil dry at room temperature for 1-2 days.
4. Record the masses of the two 300 mL beakers.

5. Pour each soil so that they fill their 300 mL beakers to 300 mL
6. Weigh the beakers with soil to then find the mass of each dry soil.
7. Prepare the 100 mL buret by filling it with water to the 100 mL line. Refill when needed.
8. Insert the sensor into the cup at the designated line. Record the ADC value and the total volume of water in the soil.
9. Pour 10 mL into the cup (using a buret). Stir so water is uniformly distributed throughout the soil.
10. Repeat steps 8 and 9 until a total of 50 mL has been dispensed or the soil is saturated (no water is seeping from the bottom of the glass).
11. Create a scatterplot of % GWC vs. the sensor's ADC values and create a line of best fit.
12. Use the line of best fit to find at what ADC value the calibrated sensor would read at 0% GWC and 50% (or when the soil hit its saturation point). These values can then be used to map the equation the calibrated sensor will use. Make sure to input the values into the SD card as integers (refer to the user manual to know how to do this step).

Accuracy experiment - checking calibration accuracy for its respective soil type:

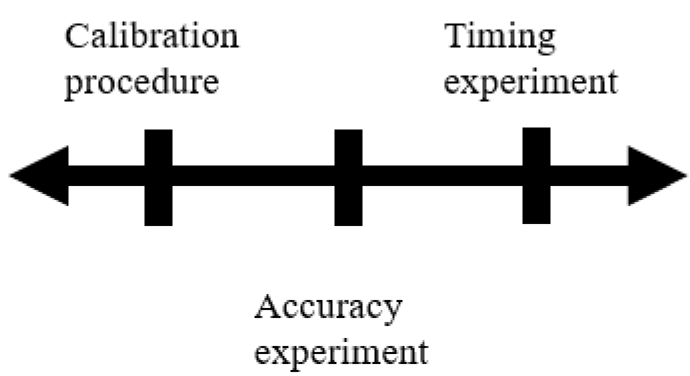
1. Prepare the workspace by using a clean tarp.
2. Record the two 300 mL beakers' masses. Do not do this step if you already know these values from the calibration procedure, but make sure they are clean and dry.
3. Pour the Jiffy potting soil and soil B into the beakers separately to 300 mL, assuming the soils are already dry.
4. Add 15 mL of water to both cups using a buret. Stir so water is uniformly distributed throughout the soil. Each soil type should have its own calibrated equations. Using the respective calibrated sensor, measure its GWC reading in both cups and then record the water added and the GWC reading.
5. Repeat step 4 two more times.
6. Find the percent error for each GWC sensor reading (via Equation 1.3) and average together the ones with the same type of soil. These averaged percent error readings reveal the accuracy of each calibrated sensor.

Timing experiment - calculating the time for the sensor to adjust to its calibrated value:

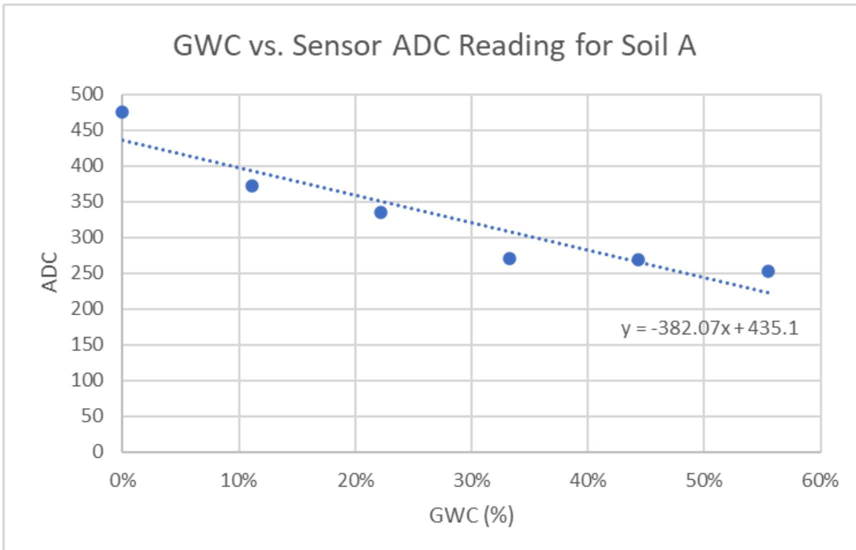
1. Prepare the workspace by using a clean tarp.
2. Record one 300 mL beaker. Do not do this step if you are using the containers from the calibration, but make sure they are clean and dry.
3. Pour the Jiffy potting soil into the beaker to 300 mL, assuming the soils are already dry.
4. Adjust the sensor to GWC and toggle its refresh rate to 0.5 seconds.
5. Add 15 mL of water to the beaker using a buret. Stir so water is uniformly distributed throughout the soil. Ensure you are using the correct calibrated sensor. Turn the recording state of the device on and wait until the sensor is steadily recording its dry state. Place the sensor in the soil to its designated line and wait until the sensor's consistent moisture value is reached. Stop recording and gather your data using the SD chip.
6. Repeat step 7 two more times.
7. Use the recorded values to create three graphs of time (sec) vs. % GWC. Subtract the time when the sensor hits its consistent value when in the soil by the last time the sensor was in its dry state. Average all three values to find the adjustment time for the sensor.

Through the experiment steps and calculations shown above, the client would be aware of the accuracy of the sensor for its calibrated soil type and know the average adjustment time it takes for the sensor to read non-changing moisture levels.

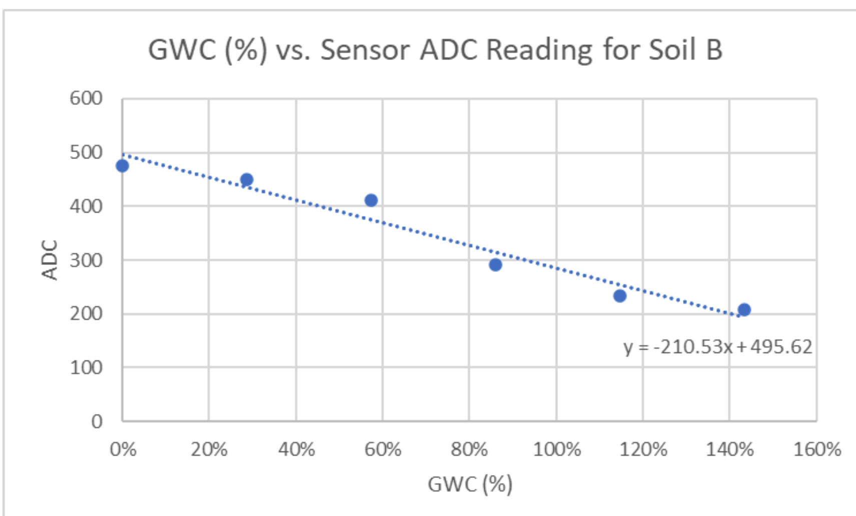
The testing timeline below indicates the order in which the experiments should be done (from left to right).



Results:
Graphs 1.2 and 1.3 display the calibration equations for both of the soils mentioned previously. The sensor uses the GWC values to map the minimum and maximum ADC values. For the soil A sensor, 0% GWC is correlated with 475 ADC, and 55% GWC is correlated with 253 ADC. For the soil B sensor, 0% GWC is correlated with 475 ADC, and 143% GWC is correlated with 207 ADC.

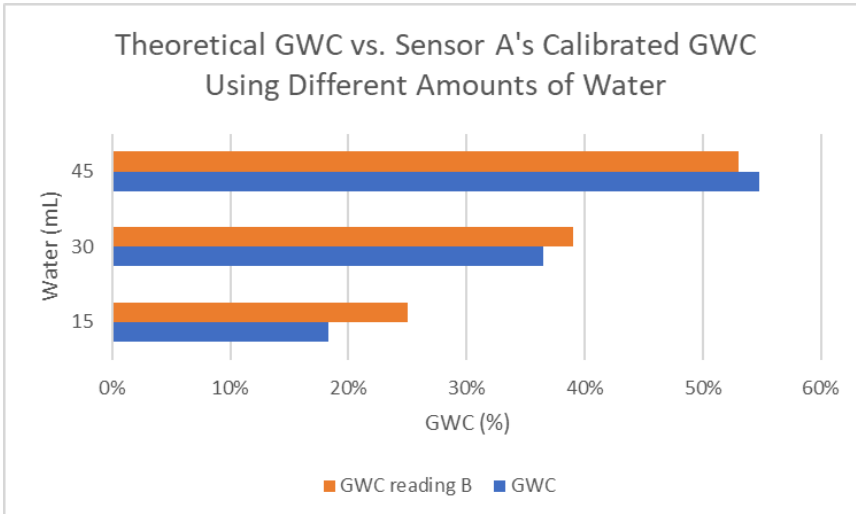


Graph 1.2. Calibration line for Jiffy Potting Soil.

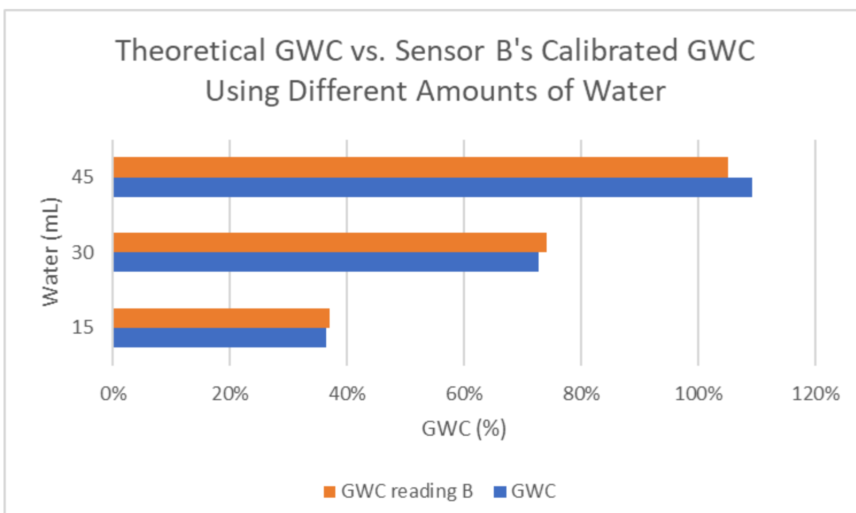


Graph 1.3. Calibration line for soil B.

Graphs 1.4 and 1.5 visually show the offset each sensor's calibrations have on the theoretical GWC value. The average percent error of calibration A and calibration B is 15.56% and 2.39%, respectively.

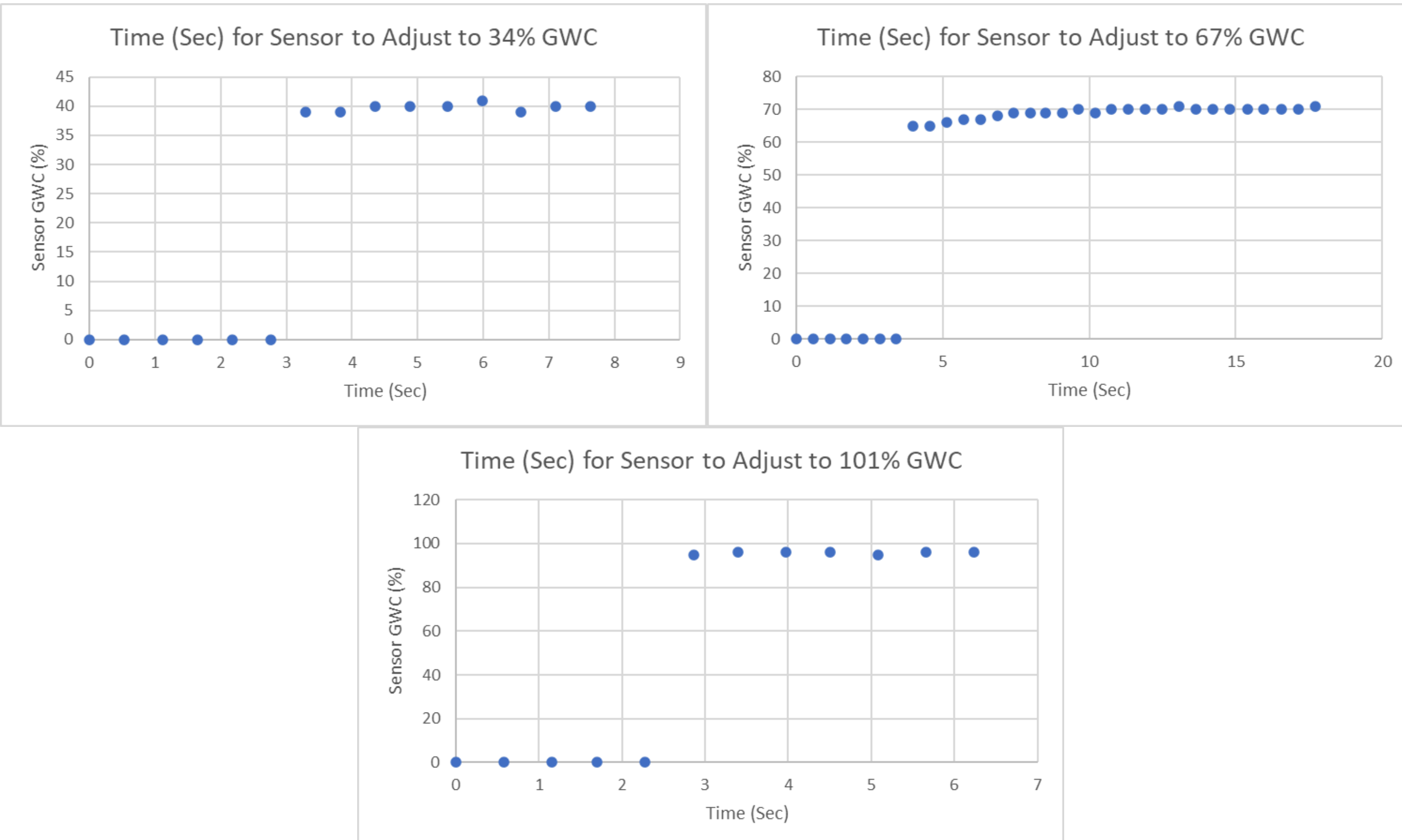


Graph 1.4. GWC calibration comparison of sensor A to the theoretical value using different levels of water.



Graph 1.5. GWC calibration comparison of sensor B to the theoretical value using different levels of water.

Finally, graphs 1.6, 1.7, and 1.8 display the data for the timing experiment using 15, 30, and 45 mL of water or, in this case, 34%, 67%, and 101% GWC, respectively. By averaging the adjustment time for the three graphs, it will take 0.56 seconds for the sensor to adjust to the appropriate value.



Graphs 1.6, 1.7, and 1.8. Adjustment time for calibrated sensor A at different moisture levels.

Prototype

To have a better understanding of the features of the current design without suffering significant costs, a prototype will be made via recyclable materials.

Materials:
Materials needed for the prototype include cardboard, hot glue & hot glue gun, exacto knife, a black sharpie, and eight toothpicks.

Process:
Cut a 70 x 210 mm rectangle (piece one) using an exacto knife. Also, cut another rectangle with dimensions of 50 x 200 mm (piece two). Cut out a 25 x 15 mm rectangle from piece two that's 15 mm from the top of the box (and in the center), using sketch 2.7. Then, 15 mm below the previous cutout, create another rectangular hole that's 7 x 7 mm. Again, 15 mm below the previous cutout, create a circular hole having a radius of 3 mm. 15 mm below this new hole, cut a circular hole with a radius of 6.5 mm. Center piece two with piece one and use a sharpie to outline the cutouts for piece one. Use an exacto knife to cut the holes. Then, hot glue the edges of piece two that is touching piece one. Let the glue sit until dry.

To make the part meant to house all the wiring components, start by cutting several rectangles: 70 x 210 mm, two 70 x 35 mm, and two 210 x 35 mm. Hot glue these parts together so they act as the outer shell of Sketch 2.1. Once dry, at the bottom of the part (referencing the top view of Sketch 2.1), cut out a hole that's a radius of 4 mm in the center of the cardboard. Cut out 4 slots opposite to the recent hole in a 10 x 40 mm rectangle area (in the middle of the wall). To create the hangle for the base, cut three handles as shown in the top view of Sketch 2.1. Hot glue these handles together and on the opposite side of the side view, referencing Sketch 2.1.

Use 4 toothpicks in the corners of the base (top view of Sketch 2.7) and attach the lid to the toothpicks so they are connected.

To make the sensor housing unit as seen in sketches 2.5 and 2.6 or part #1, start by cutting two rectangles that are 50 x 40 mm using an exacto knife. After cutting these rectangles, take one of the two rectangles and cut a rectangle in the middle of the original rectangle that is 20 x 30 mm. After this hole is created glue the two cardboard cutouts together with hot glue. Once glued together, grab four toothpicks and poke them into the rectangles in all four corners 2 mm off each side.

Once these steps are done it is time to create the cover as seen in sketches 2.3 and 2.4 or part #2. To create this housing part, using an exacto knife, cut two rectangles 25 x 35 mm. After cutting these pieces, using an exacto knife cut a third piece 25 x 55 mm. After all the pieces are cut out, glue all parts together with the longest piece being in the middle using hot glue. With the longest cutout being in the center of the two smaller parts it will simulate what the actual sensor will look like.

Once both parts have been assembled, insert part #2 into the square cutout in part #1's center. This will create the final mockup of how the sensor housing and how the wiring housing will look. The steps above should look similar to the figures below

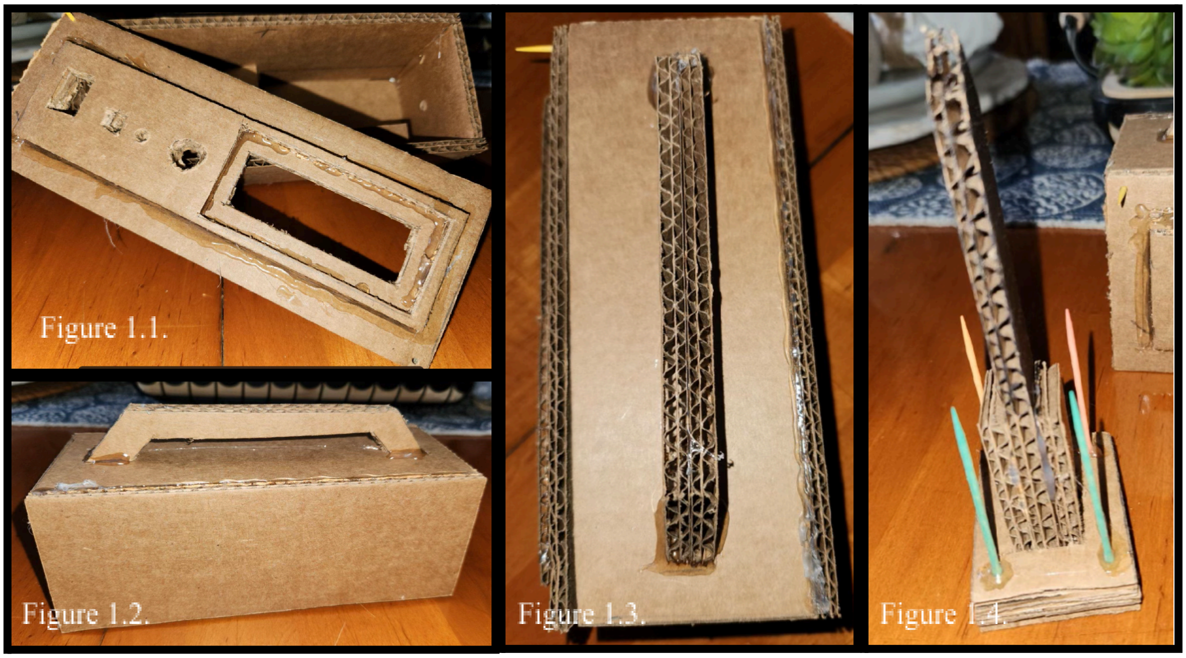


Figure 1.1. The top perspective of the housing unit lid.
Figure 1.2. The top perspective of Sketch 2.1.
Figure 1.3. The side perspective of Sketch 2.1.
Figure 1.4. An isometric view of Sketch 2.4 and 2.6.

Design Functionality

The design has several features that include an adjustable refresh rate, data logging, and two modes–one mode finds % moisture and the other mode finds gravimetric water content. Refer to Appendix A for the design schematic.

A toggleable button can adjust the refresh rate of the button and allows for five options: 0.5, 1, 5, 60, and 300 seconds. The sensor displays its updated data on the LCD screen and serial monitor whenever enough time has elapsed or when the button is clicked again. The LCD screen also displays the rate at which the sensor displays data. It is ideal to lessen the refresh rate if the user will use the device over long periods as this will help with power consumption, especially when logging data.

The micro SD card allows for data logging whenever the recording switch is flipped. Note, the switch automatically defaults to off whenever the device turns back on. If the SD card is not inserted into the adapter or it is broken in some way, the device will display such errors on the LCD screen and stop the program. The LCD screen will also display in the top-right corner if the device is recording or not. An SD card is needed for the program to function when starting it up, and the logged data can be accessed using the micro SD card (in the Excel file called "DATALOG"). The recording switch is also programmed in a way that it cannot log different measuring modes under the same recording. For example, the device will keep reading in % moisture if it was initially in that state before the recording switch was flipped on.

The device also contains another switch which has two options: a % moisture reading and a calibration mode. The former does not need any calibration but can lead to a more accurate reading. The latter, however, must be calibrated and will provide more acceptable readings. Refer to Appendix B for the specifics of each mode.

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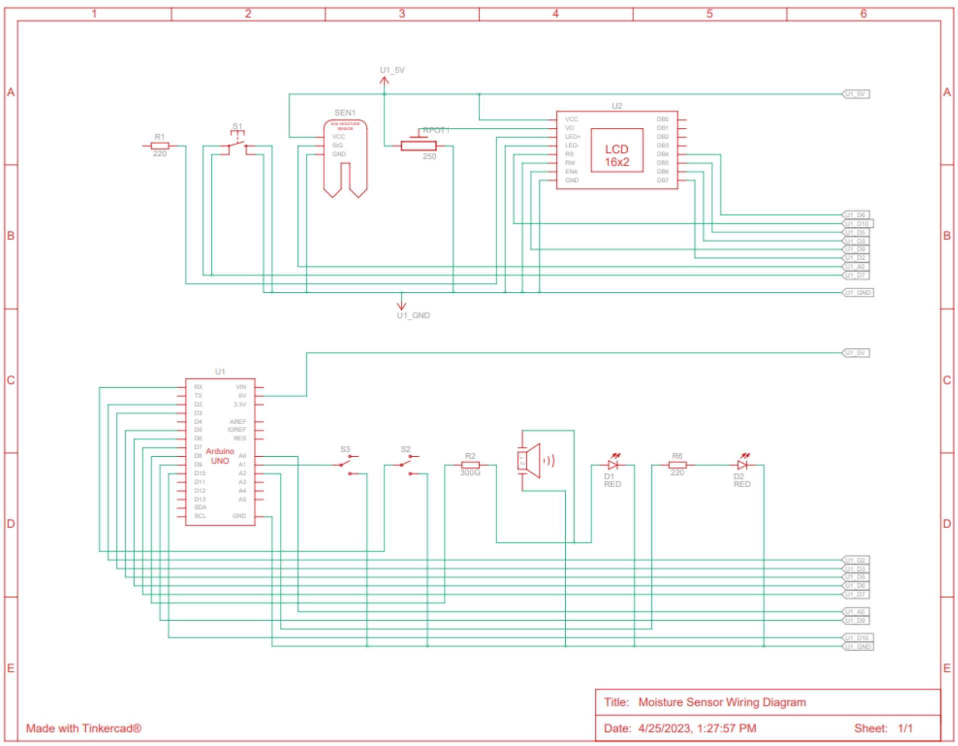
Appendix A

Schematic

Schematic 1 displays most of the wiring and components that make up the design and functionality. Although the schematic does not include the micro SD adapter, it would be connected to VCC, GND, and digital pins 4, 11, 12, and 13. It also does not include the wiring for the lithium batteries as a power source.



Schematic 1. Wiring diagram for the sensor prototype. This does not include the micro SD adapter.

Appendix B

Calibration Option

The first mode, % moisture, is constrained from 0% to 100%--it cannot become negative or a value over 100%. When the % moisture is below 40%, the LCD screen displays the value and the word “DRY” next to the value. When the % moisture is between 41% and 80%, the LCD screen will display “GOOD.” It will then display “MOIST” when over 80%. Whenever the % moisture is “DRY” or “MOIST,” a red LED and buzzer work in tandem and activate to let the user know visually and audibly that the soil moisture is not ideal.

The second mode is the calibration mode. This includes options to either read the sensor’s ADC value or GWC value (if a formula is implemented). To switch between the two options, Image 1 shows all the text/Excel files inside the memory card. The text file named “cal_E” can be changed to either a value of 0 or 1. A value of 0 makes the sensor read the ADC value when the mode switch is flipped to the right. A value of 1 allows for the sensor to read in GWC. To change the calibration formula, four text files require inputs for the formula to work: “min_ADC,” “max_ADC,” “min_GWC,” and “max_GWC.” These values can be obtained after finding the calibration equation, using the calibration procedure in the testing protocol section.

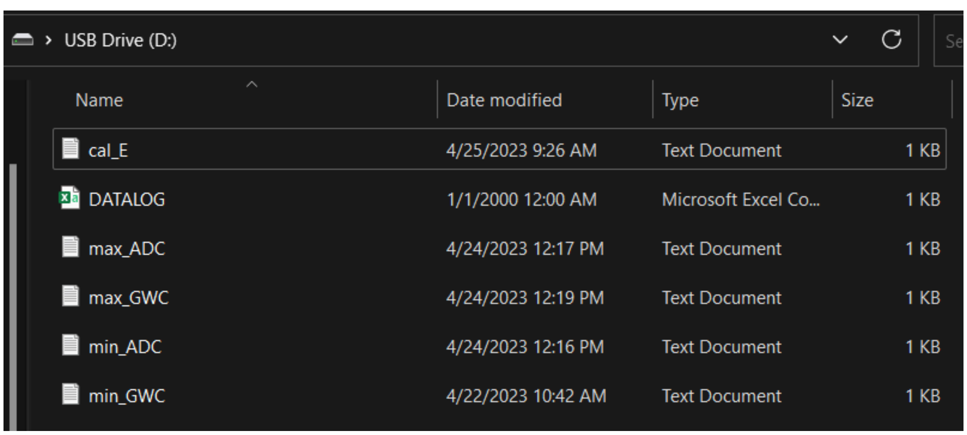


Image 1. Micro SD card files. Cal_E is the calibration enable text file which changes allow the sensor to read in ADC or GWC. The min/max ADC and min/max GWC text files are the inputs needed to calibrate the sensor’s GWC formula.

Appendix C

Design Timeline

Image 2 displays all the versions the design has gone through. The leftmost product is Design 1, and the rightmost product is Design 3, the current and final version.

Image 2. All versions of the housing sensor base are from left to right.