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Introduction

Problem to be Solved

Plants are often not watered efficiently, which wastes water and can harm the plant. Too little moisture can result in plant death, while too much causes root disease and wasted water. Proper irrigation, on the other hand, can maximize water efficiency and provide conditions for optimal plant growth. Precise control over the plant's growing conditions leads not only to a healthier plant, but also better water management.

The experimenter will build a watering system that will water a plant automatically based on soil moisture content and solar radiation to optimize plant growth and conserve water. The experimenter will use 2 separate plants with different soil types, one highly porous and one less porous, in order to demonstrate the difference between the soil types' ability to retain water. The experimenter will then try to determine if there is a relationship between soil moisture content, solar radiation, and the total amount of water used to water the plant.

Origin of the Idea

The experimenter wanted to conduct an experiment that had both engineering aspects as well as research aspects. The experimenter wanted to do something involving conserving natural resources like water and helping improve irrigation techniques because that is a very important issue in today's society. The experiment wanted to conduct a project with a lot of future applications.

Summary of Research

Soil moisture

- The ability for soil to retain moisture heavily depends on the soil type.
- Soil with larger particles retain less moisture, while soil with smaller particles, such as clay, retain a lot of moisture.
- However, soil types with smaller particles are harder to extract water from, and if extracting water from the soil requires too much energy from plants, the plant will die.
- The ideal soil for most growing conditions is a loamy soil with a variety of particle sizes and enough structure which can hold a lot of water that is easy for plants to withdraw.
- Placing numerous soil moisture sensors at different depths produces the best and most accurate results.
- The soil moisture sensor should be placed 2-3 inches deep in a spot that receives an average amount of water.

Terms

- Saturation: the condition where all soil pores/voids are filled with water. Saturated soil is heavy, contains little air, and can be thought of as mud.
- Field Capacity: water is easily available to plants, and the soil solution contains ample oxygen. Optimal growing conditions for most plants occur at Field Capacity or slightly drier than Field Capacity.
- Management Allowable Depletion (MAD): the lowest moisture level which can be sustained by plants without unfavorable effects on plants.

Arduino board

- One of the advantages of an Arduino board is being able to upload self-written code on the board itself.

Evapotranspiration

- Evapotranspiration is all the water that is lost through evaporation and transpiration combined in plants.
- More than 99.9% of the water used by an irrigated plant is drawn through the roots and transpires through the leaves.
- By using weather variables such as solar radiation, temperature, humidity, and wind, water loss due to evapotranspiration can be predicted.

Multi variable regression

- Multi variable linear regression equations can be written in the form
  $y=a + bx + b_1x_1 + b_2 x_2 +.... + b_3 x_3 + e$

where *y* is the dependent variable, *a* is the y intercept, and $b_p x_p$ is an independent variable, and e is an error or residual

- A multi variable linear regression equation with 2 independent variables requires a 3D graph.

VARIABLES

Independent Variables:

Average amount of brightness each day

Average soil moisture level each day

Dependent Variable:

Total water used to water the plant in a 24-hour period

ENGINEERING GOAL/HYPOTHESES

Engineering Goal:

The goal is to build an automatic and intelligent watering system that waters plants efficiently based on the soil's moisture level and solar radiation.

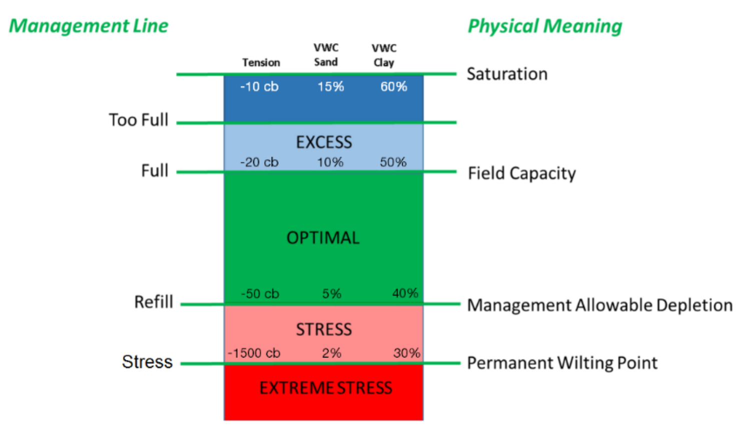
Hypotheses:

The higher the average soil moisture level is for 24 hours (on a percent scale), the less water will be used to water the plant

The higher the average brightness is for 24 hours, the more water will be needed to water the plant.

BACKGROUND INFORMATION

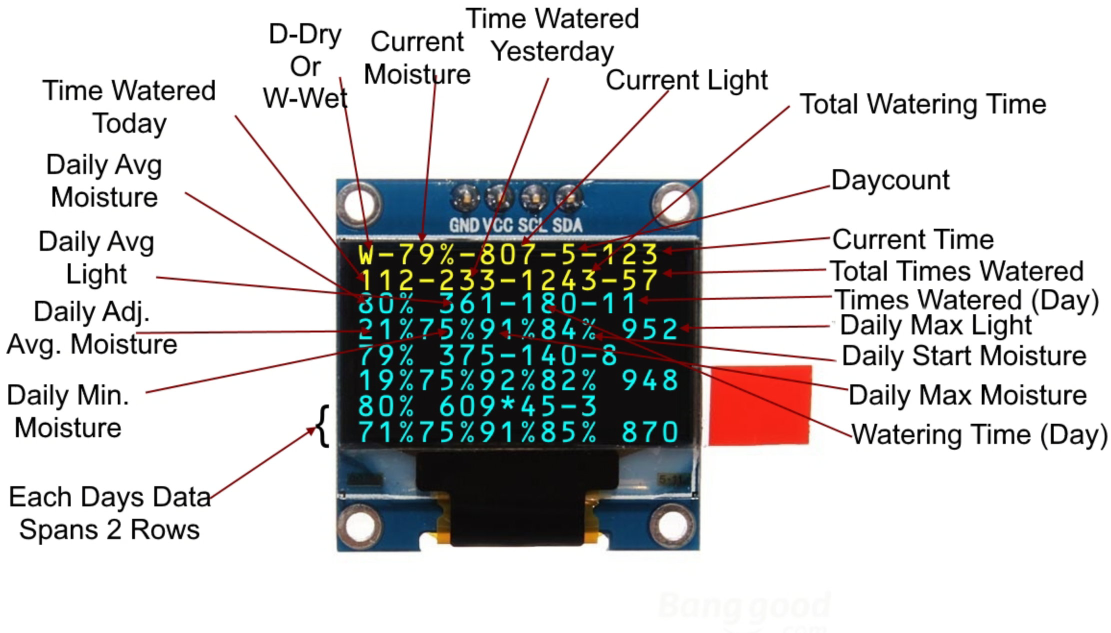
- The optimal soil moisture content is about 70-90%
- Managing root zone soil moisture is critical to optimum crop growth.
- The ability for soil to retain moisture heavily depends on the soil type.
- With precise managing of soil moisture content, plants have optimal growth conditions and water is conserved.
- Clay loam or medium loam is the best type of soil for optimal plant growth.
- The experimenter will be using 2 different soil types, one highly porous and one less porous in order to demonstrate the difference between the ability to retain water.



Research Plan

Data Analysis

The experimenter will gather data from an OLED on the breadboard. The experimenter will insert the data (amount of water used each day, average soil moisture each day, average solar radiation every day) into Microsoft Excel and find a regression line. The experimenter will then make a 3-D graph displaying this information. The experimenter will also get an equation by using the Data Analysis Tool pack in Microsoft Excel.



Design Criteria

- Has to be as small as possible.
- Has to be waterproof because external conditions such as rain could damage it.
- Has to be portable for easy movement to and from the plant.
- Has to be able to water automatically without any human involvement.
- Has to be able to sense conditions such as soil moisture content and solar radiation.
- Has to all be connected with a circuit.
- Has to be have a display within the circuit in order to take data.

MATERIALS

1. Jumper wires as needed
2. Breadboard
3. Plant
4. 1 Photoresistor
5. 1 Arduino Uno/Nano board
6. 1 Soil Moisture sensor assembly
7. Alligator clip wires as needed
8. 1 bucket with water
9. 1 Computer/laptop
10. 1 USB cable
11. 1 OLED screen
12. 2 Resistors – 220Ω and 1kΩ each
13. 1 LED
14. 1 5V watering pump
15. 1 USB power adaptor
16. 1 Wire stripper
17. 2 Transistors
18. ¼ Inch Watering Hose
19. 18 AWG Electrical wire

Procedure

1. Assembling the breadboard (as shown in figure 1
    a. The Arduino Nano (Rev3), a miniaturized version of the Arduino Uno, is attached directly on the board.
    b. The photoresistor is connected as an input analog sensor to the A0 pin on the Arduino.
    c. The soil moisture sensor is made of a comparator, that sits on the board and a probe which goes directly in the soil.
    d. The comparator is connected as an input analog sensor to the A1 pin on the Arduino.
    e. A constant current to the soil moisture probe would lead to quick corrosion of the probe; therefore, the power to the comparator and the probe is regulated using a transistor that is attached to the comparator and controlled by the digital output pin D10 on the Arduino.
    f. The output pin D9 on the Arduino is used to drive a pump to water the plant and to control an LED indicator, which tells if the water pump is on.
    g. Because the maximum current output from any Arduino pin is limited to 40 mA, and the water pump needs a current of 100-150 mA, a transistor is used to increase the current.
    h. An OLED display is connected to the Arduino as shown, in order to provide status indications and data for research purposes.
    i. Power the Arduino by connecting a USB power adaptor to an electrical outlet.
2. External connections from the breadboard.
    a. Connect the load and the neutral wires from the water pump to the appropriate wires on the breadboard using 18 AWG extension wires and alligator clips.
    b. Connect a ¼ inch water hose from the water pump to the plant.
    c. Place the water pump in a bucket of water.
    d. Connect the soil moisture probe to the wires from the comparator using 18 AWG extension wires and alligator clips.
3. Programming the Arduino Nano
    a. Install the Arduino IDE package.
    b. Create an Arduino project based on the program logic as explained in pages ___. The actual code is attached on pages___
    c. Compile and upload the code to the board using the onboard USB interface.
4. Data Collection and Analysis
    a. The OLED will display relevant data points at 5-minute intervals in a 24-hour daily cycle.
    b. Log the data points in Microsoft Excel every 24 hours.

PROGRAM LOGIC

The top section defines the variables and the constants. These can be set as certain values.

An Arduino sketch has 2 major components. The first component is the setup() routine which initializes the variables and hardware components. The second component is the loop() routine where the core programming logic is implemented. The loop() routine runs indefinitely in an endless loop until the board is powered off.

In the setup() routine, the photoresistor, the soil moisture sensor and the OLED display are initialized.

Core logic for the loop () section as implemented sequentially

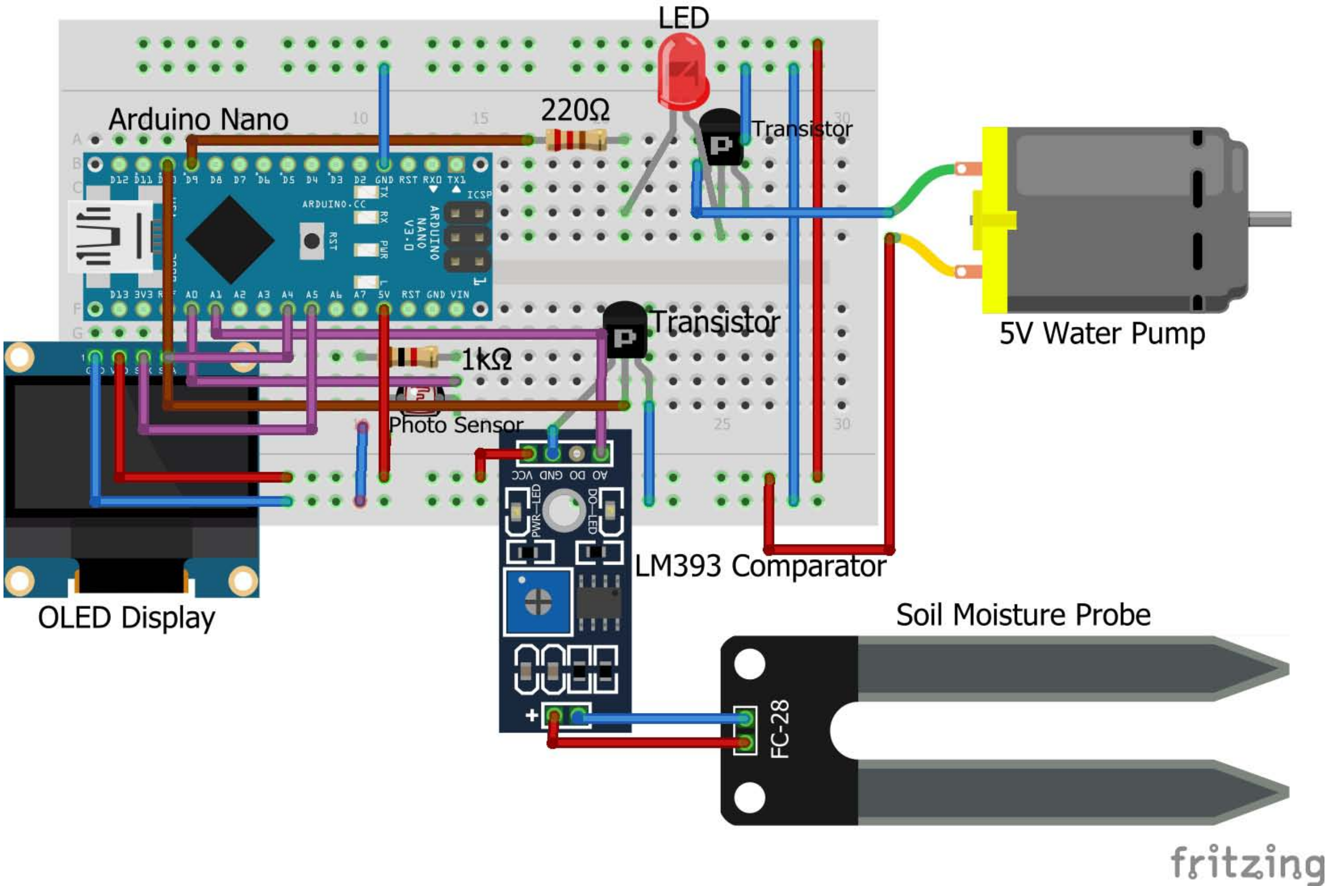
- Reset the display
- Power on the soil moisture sensor
- Take the moisture reading
- Power down the soil sensor to prevent corrosion
- Take the photoresistor reading
- Call function calculateAverages() to store data in a 3x10 array, each row representing 10 data points per day, used for data analysis
- If the moisture is greater than the threshold (75%), the water pump will not water
- If the moisture is critically low (<50%), the water pump will start irrespective of the light conditions.
- If the moisture is between 50% and 75%, watering will only begin if there are shade conditions (light reading <900)
- Once in the watering routine
    - Water for 5 seconds
    - Wait for 5 seconds so water is absorbed
    - Power on moisture sensor
    - Take moisture reading
    - Power off moisture sensor
    - Take photosensor reading
    - If (moisture has increased to greater than 90%) AND (the plant is in shade conditions)
      OR if (moisture has increased to greater than 75% AND (the plant is in sunny conditions),
      STOP watering
    - Else, continue watering
- Call function storeArray() to store the data in the array
- Write the appropriate output to the OLED display

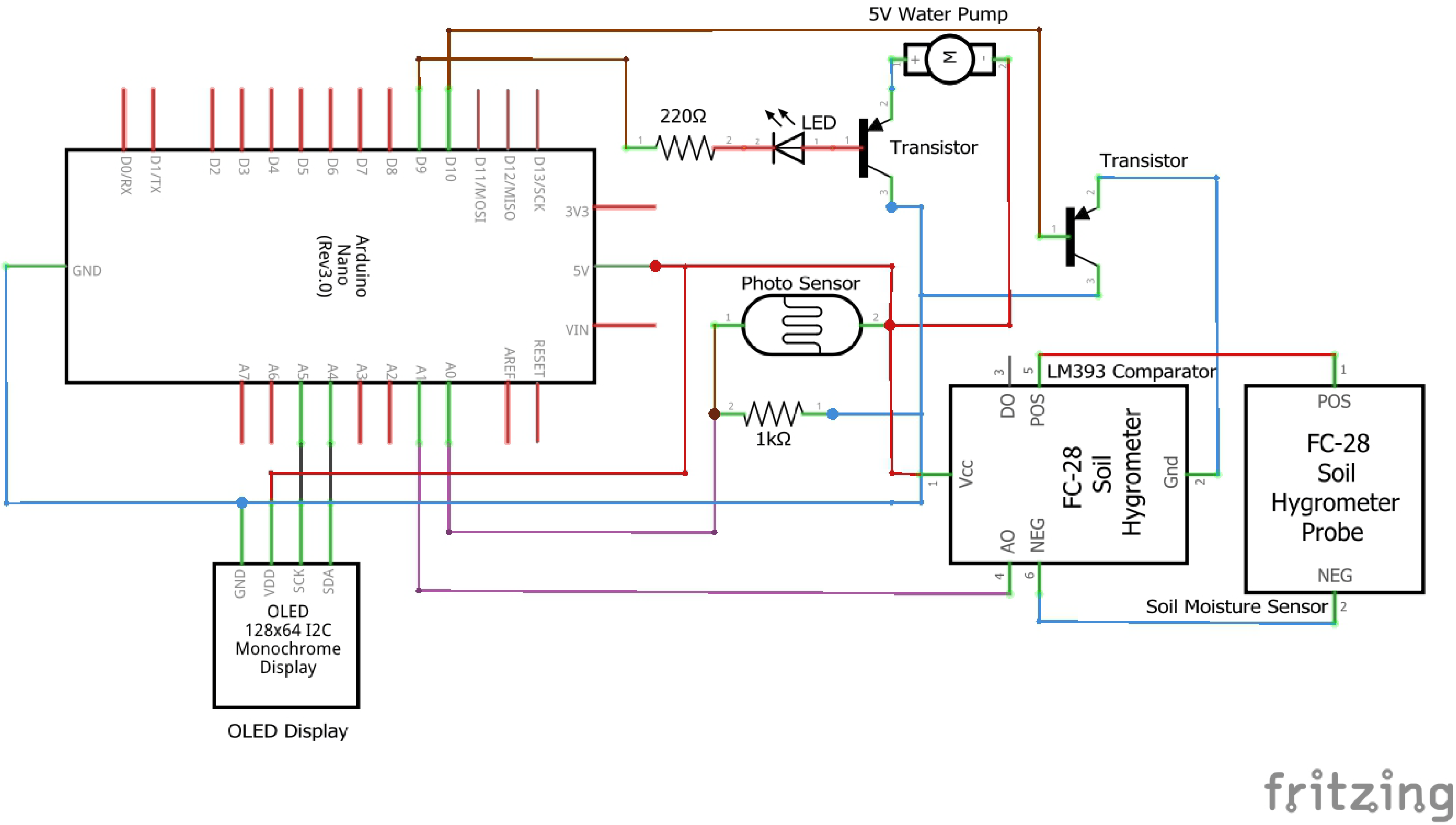
- Every call to calculateAverages() checks to see if 24 hours have elapsed and a day rollover has occurred.
- If a day rollover has occurred, the appropriate values are stored in the array and the appropriate variables are reinitialized
- Return to main loop () and repeat
- There are some helper functions (writeMsg() msg(), and pad()) to help formatting output and low-level OLED writing

CODE

CODE

CODE


LED
Arduino Nano
220Ω
Transistor
5V Water Pump
Transistor
1kΩ
Photo Sensor
OLED Display
LM393 Comparator
Soil Moisture Probe
FC-28
fritzing


5V Water Pump
220Ω
LED
Transistor
Transistor
D0/RX
D1/TX
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11/MOSI
D12/MISO
D13/SCK
3V3
5V
VIN
GND
Arduino
Nano
(Rev3.0)
A7
A6
A5
A4
A3
A2
A1
A0
AREF
RESET
Photo Sensor
1kΩ
LM393 Comparator
DO
POS
Vcc
FC-28
Soil
Hygrometer
Gnd
AO
NEG
POS
FC-28
Soil
Hygrometer
Probe
NEG
Soil Moisture Sensor
GND
VDD
SCK
SDA
OLED
128x64 I2C
Monochrome
Display
OLED Display
fritzing

Results

DATA TABLES AND GRAPHS

PHOTOS

Photo 1. 2 plants set up with the watering system. Taken by the experimenter on 10/30/17.

Photo 2. Original breadboard part of the watering system. Taken by the experimenter on 10/23/17.

Photo 3. Miniaturized breadboard of watering system. Taken by the experimenter on 10/23/17.

Conclusion

Conclusion

More sensors, such as temperature sensors, wind sensors, and air humidity sensors, could be added to increase accuracy and effectiveness. One could then test these variables and see which ones result in more/less water being used to water the plant. Many more intelligent watering systems could be made for large-scale plants and crops, which would help increase crop yields as the crops would be growing very well because of the improved conditions for plant growth.

ERROR ANALYSIS

The sensors might not have been calibrated correctly or as accurately as they could have been. The soil moisture sensor could have been inconsistent or inaccurate.

Bibliography

ANNOTATED BIBLIOGRAPHY

1. B. (n.d.). What is an Arduino? Retrieved August 25, 2017, from https://learn.sparkfun.com/tutorials/what-is-an-arduino

This source tells what an Arduino board is. An Arduino Board is a programmable circuit board which is useful when building a circuit and programming a certain component to do something. This was useful because the source told the most common board, an Arduino Uno, and its specific functions so the experimenter would know if the board would apply to the project, and the board does. Sparkfun seems pretty reliable because the source is widely used and professional. Learning about an Arduino would not really require a super reliable source, because the only thing needed would only be common facts. The experimenter is using an Arduino Uno board in the experiment and this source gave the basics of how to use the board

2. Dukes, M.D., Shedd, M., & Cardenas-Lailhacar, B. (2015, February 11). Smart Irrigation Controllers: How do Soil Moisture Sensor (SMS) Controllers Work? Retrieved August 25, 2017, from https://edis.ifas.ufl.edu/ae437

The experimenter used only a part of this website, the part about how a soil moisture sensor should be placed inside the soil. The experimenter learned that the soil moisture sensor should go near the roots and should not touch air. This will help because the experimenter now knows where to put the soil moisture sensor now and that ensures that the results will be reliable and that they won't be different and invalid because the sensor was put in the soil incorrectly. This source is reliable because the website came from the University of Florida and was written by a team of 3 who are probably experts in this field.

3. Evapotranspiration - The Water Cycle. (n.d.). Retrieved August 26, 2017 from water.usgs.gov/edu/watercycleevapotranspiration.html

This website tells what evapotranspiration is. The experimenter only mostly used the first half of the website because the first half summarized evapotranspiration. This helped the experimenter know some ways that water could be used up by plants. The experimenter also learned a new term that is related to the project. This source is reliable because the website is a government site.

4. Department of Physics and Astronomy. (n.d.). Retrieved August 26, 2017, from https://www.physastro.iastate.edu/

The experimenter used this website to learn about what projects could be related to physics and astronomy. However, the experimenter learned that a project relating to physics and astronomy was not really possible because nothing could be tested. This website is reliable because the source is a major university website.

5. Davis, M. (n.d.). How I built a motorized sun tracker for my solar panels. Retrieved August 27, 2017, from http://ww.mdpub.com/suntracker

The experimenter used this website to learn about other possible projects, which in this case was a rotating solar panel. The experimenter realized that this project which had an enormous amount of detail, would take too long. The author of this website focused on building items and the author posted photos and explanations with a lot of detail, so it can be concluded that this website is credible.

6. Jones, R. (2017, June 15). Build a Soil Moisture Sensor with the ADICUP Evaluation Board from Analog Devices. Retrieved August 27, 2017, from https://www.allaboutcircuits.com/projects/build-soil-moisture-sensor-adicup-evaluation-board-analog-devices/

This source is a similar experiment but much simpler. The experimenter will be doing something much more advanced than this but this source helped the experimenter figure out what exactly the experimenter would be doing in the project, such as coding. The experimenter learned that the soil moisture sensor has a scale which is inversely related to the amount of water the plant needs. This website seems reliable because the site has the author's name and the website that focuses on science. This source was very useful because the site showed the experimenter the foundation of the experiment and what the project would require.

7. Wiki. (2017, June 20). Retrieved August 27, 2017, from https://wiki.analog.com/resources/eval/user-guides/eval-adicup360/reference-designs/demo-cn0398

This source included specific lines of code for the experiment previously mentioned above. This helped the experimenter realize that a project similar to this would require coding skills. The website also said that the relationship between the soil moisture level measured by a soil moisture sensor and the scale was inversely related. This greatly helped the experimenter because the project the experimenter was doing used a soil moisture sensor. The source helped the experimenter understand how to interpret the readings that the soil moisture sensor gave.

8. Rogers, K., & Kadiner, R.J. (n.d.). Bacteria. In *Encyclopedia Britannica*

This source helped the experimenter learn more about bacteria in general because at that time, the experimenter was still considering using bacteria for a project. This source is reliable because Encyclopedia Britannica is one of the most well-known encyclopedias and is very reputable.

9. How do I measure bacterial growth in agar dishes (either by cell mass or by cell count)? (n.d.). Retrieved September 7, 2017, from https://biology.stackexchange.com/questions/10570/how-do-I-measure-bacterial-growth-in-agar-dishes-either-by-cell-mass-or-by-cell-count

This source mentioned that one way to measure bacteria was with a spectrophotometer, and the source also gave a definition and instructions for it. This helped the experimenter because at that time the experimenter was considering doing an experiment with bacteria and doing an experiment with bacteria would require having a way to measure the bacteria.

10. W. (2017, May 11). How to Measure Bacterial Growth. Retrieved September 7, 2017, from https://wikihow.com/Measure-Bacterial-Growth

This source mentioned that there were 3 ways to measure bacteria. One of the listed methods was using a spectrophotometer but the website did mention that is was very costly. This helped the experimenter because the experimenter was still looking into doing an experiment with bacteria. The experimenter realized that because there were no very precise methods to measure bacteria, an experiment with bacteria would be difficult to measure and therefore would probably not have the best results.

11. Regression with Two Independent Variables. (n.d.). Retrieved September 08, 2017, from https://faculty.cas.usf.edu/mbrannick/regression/Reg2IV.html

This source had information on how an equation with multiple independent variable would be constructed. The source provided a visual and the source had a lot of valuable information. This helped the experimenter because the experimenter knew that the project would have 2 independent variables and therefore would require a multi variable equation. The source also stated that an equation with 2 independent variables would require a 3D graph and this made the experimenter realize that the experimenter's project would need a 3D graph.