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Soil Moisture Sensing Robot: A Novel Agricultural Device

Original Article

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Abstract: With less farming space and water available globally, it is important to optimize the growth of crops. Agricultural production, including the quality and quantity of produce, is highly dependent on soil moisture. If soil moisture is not accurately measured, inappropriate watering of crops could lead to crop failure, and wasted space, seeds, and money. Current methods to check moisture include inaccurate qualitative observations, inconvenient hand-held sensors, and unaffordable wireless systems. To construct a cost efficient, accessible, and convenient device to maximize crop production for all farmers, a robot equipped with an Arduino-powered soil moisture sensor was prototyped. This radio-controlled robot can be driven to various locations, where a 3D printed arm inserts the moisture sensor into soil. The readings collected were logged through the program TeraTerm and imported into a color-coded spreadsheet, where users can easily view soil moisture levels. The robot measured moisture levels of 3 soil samples (under-watered, normal, and over-watered) to test for all aspects of the engineering goals; all goals were successfully met. This robot is also cost efficient, making it readily accessible to farmers, agriculturists, gardeners, etc.

Keywords: Soil Moisture • Arduino • IDE • Wireless Network • Servo Motor • PETG Filament • Spreadsheet • TeraTerm

1. Introduction

In modern times, agriculture sustains growing populations. With less and less farming space available, it is important to optimize the growth of crops in available farmland. In order to grow the most crops with limited resources, farmers must make sure plants are appropriately watered. Growth of crops, including the quality and the amount of produce, depends highly on soil moisture. Soil moisture can even affect fertilizer efficiency [1]. Now, more than ever, it is important to frequently check soil moisture throughout the year since global warming and climate change cause changes in weather patterns. Research has shown that continuous rainfall for over a

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week can ruin agricultural sites, as can persistent heat waves which have increased in frequency [2]. To avoid further damage to crops, an accurate understanding of current soil moisture levels is necessary.

Even well managed irrigation systems waste up to 50% of water [3]. A lack of water for plants results in loss of money due to reduced crop yields, as well as a decrease in the quality and size of the crops [1]. Overwatering, on the other hand, results in even greater consequences for crops and farmers. Overwatering wastes water as well as money needed for the irrigation systems. Extra moisture also leads to erosion, runoff, unwanted weed growth, and leaching of nutrients which upsets crops [1]. Although many people don't realize its importance, different levels of soil moisture are required at different points in a crop's growth. In order for germination to occur, soil moisture must be maintained at a certain level for at least six days before the seeds die [4]. Typical properties in Australia waste up to 625 ML of water worth approximately $31,000 due overwatering [5]. Valuable seeds, and space can also be wasted if soil moisture is not accurately measured, as germination will not occur. With the world population increasing rapidly, farmers need to meet demands for crop production amid decreasing farmland availability. Monitoring soil moisture not only allows optimization of limited agricultural space, but also prevents water wastage.

Many farmers check soil moisture manually by forming balls of dug up soil, and check for properties like texture and ability to mold [1]. However, this method only estimates qualities based on observations, and is therefore not very accurate. Existing soil moisture sensors in the market are handheld, and need to be manually moved or used in large numbers. Wireless Network Systems (WNS), also used to improve farming, are often expensive, not portable, and inefficient for poor farmers [6]. Most handheld sensors do not record data and are unable to track trends. Soil moisture sensors that are stationary (nodes-not handheld) often require wireless network systems to communicate to each other and a laptop. These often become too expensive for farmers, and are difficult to maintain for farmers without access to wireless communication technology.

The purpose of this study was to create a radio controlled robot, equipped with an Arduino- powered soil sensor, to benefit all farmers. The device eliminates the need to dig up dirt, estimate soil moisture, or read multiple small sensors. This robot can travel and take soil moisture readings from multiple locations by inserting a sensor into the ground using a robotic arm. The collected data is returned to the driver in a spreadsheet, where the color of the cells indicates whether the area is under or over watered. Furthermore, for those who cannot afford or gain access to WNSs and other methods of soil moisture monitoring, this sensor equipped robot is a cheaper, convenient, and more accessible tool for maximizing crop production. Different crops and soils require different levels of moisture, which can also be affected by weather; with current and accurate readings taken from soil, this device enables users to test the status of their plants in real-time. By tailoring irrigation plans for specific areas, farmers, botanists, and agriculturalists will be able to improve agricultural practices, productivity, and conserve water.

2. Methods

2.1. Engineering Goals

The engineering goals are as follows: First, to use an Arduino-powered soil sensor on a small (14 in by 14 in frame) radio-controlled robot that will be manually driven, and on command test a chosen location's soil moisture by inserting the sensor into the ground with a robotic arm. Second, to engineer the robot to travel far and take readings from multiple locations quickly, when compared to the time it takes to take soil moisture readings with handheld sensors. Third, to make this robot cost effective and significant to farmers, botanists, and agriculturalists. Fourth, to return soil moisture data to the user, and to create an autonomous color-coded spreadsheet that logs and saves the data collected to convey whether the area tested by the robot is under or over watered, which other agricultural robots don't do according to background research.

2.2. Electrical/Mechanical Components for Mechanism Description:

The components of the simple arm mechanism that lowers the soil moisture sensor into the ground are: Adafruit STEMMA Soil Sensor (12C Capacitive Moisture Sensor), TowerPro SG-5010-5010 Standard Servo Motor, 200 mm JST PH 4-Pin to Male Header 12C STEMMA Cable, Polyethylene Terephthalate Glycol (PETG) 3D Printer Filament, and an Arduino Uno Microcontroller Board. Figure 1 illustrates the components of this mechanism.

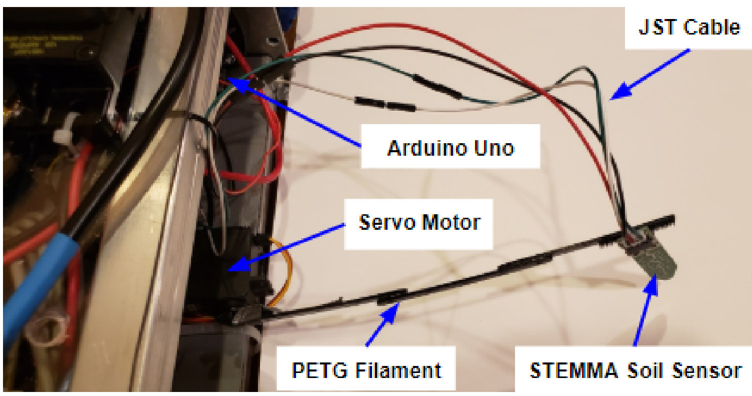

Figure 1. **3D-printed sensor arm mechanism.**

2.3. Electrical Components for Drive Base Description:

The electrical components of the drive base include: AndyMark Cheap and Dirty Radio Receiver, 8 Ganged ATC Fuse Block, 30 Amp Snap Action Breakers, 12V Battery, Victor SPX Speed Controllers, 12/24 VDC to 5VDC Power Converter, and a 120 Amp Breaker. Figure 2 depicts the electrical components of the robot drive base. The 12 volt battery (not depicted below; see Figures 7-9) powers the drive base of this robot. The Arduino boards and the soil moisture mechanism are powered separately with AA batteries. For the electronics of the drive base, the 12V battery is connected to the circuit directly to the fuse box and amp breaker, which functions as the off/on switch for the robot. The speed controllers, being transmitted power from the power converter, are connected to the fuse box and to the motors of the drive base, transferring the flow of power to run the device. The radio receiver functions solely to maintain the connection between the robot and a hand-held controller used to maneuver the device (not pictured). The hand-held robot controller can be found in Appendix A.

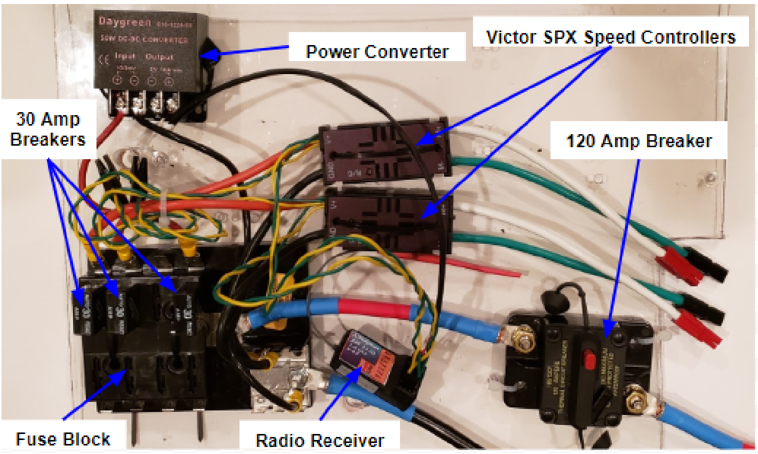

Figure 2. **Electrical components for the robot drive base.**

2.4. Mechanical Components for Drive Base Description:

The mechanical components of the drivebase include: 6" HiGrip Wheels, 6" DuraOmni Wheels, Toughbox Micro Gearboxes, CIM Motors, AndyMark Pillow Blocks, and AndyMark Peanut Extrusion. Figure 3 illustrates the mechanical components of the robot drive base.

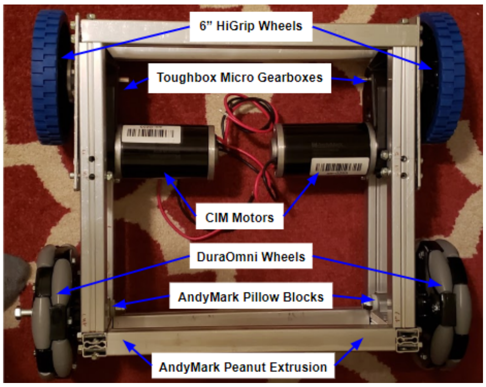

Figure 3. **Constructed mechanical aspects of the robot drive base.**

2.5. Code Description:

The source code for both the servo motor and the soil moisture sensor are written in the Arduino Integrated Development Environment. The code is a combination of C and C++ functions. The servo motor source code utilizes the Adafruit Servo Library and the soil moisture code utilizes the Adafruit Seesaw Library. The program logs and saves soil moisture sensor output data as a .csv (comma-separated value file) using Tera Term (a terminal emulator program). The source code for the servo motor can be found in Appendix B. The source code for the soil moisture sensor can be found in Appendix C.

2.6. Spreadsheet Description:

The color-coded spreadsheet program that color codes and presents the data collected by the soil moisture sensor is based in Google Sheets. The data from the soil moisture sensor is logged using Tera Term, which is a terminal emulator program that produces a log of real-time soil moisture values from the sensor and saves them as a .csv (comma-separated value) file. This .csv file is then uploaded into Google Sheets. The Google Sheets spreadsheet is programmed with conditional formatting, conditional format rules, and mathematical inequalities to automatically change cell color based on the soil moisture values imported from Tera Term. If a soil moisture value is in between 200 and 300, the soil moisture is dry and that spreadsheet cell turns red. If a soil moisture value is in between 300 and 1000, the soil moisture is in the moderate range and that spreadsheet cell turns green. If a soil moisture value is in between 1000 and 2000, the soil moisture is in the overwatered range and that spreadsheet cell turns blue. These values are a universal range that most crops fall under, backed by field research of the company manufacturing the sensor. The ranges can easily be adjusted in the conditional formatting for specific crops. Figure 4 depicts these color ranges and the conditional formatting rules in Google Spreadsheets that determine the spreadsheet cell color changes.

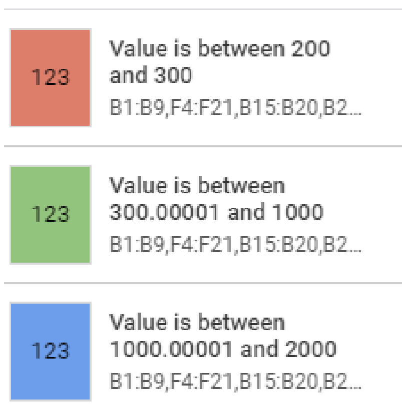

Figure 4. **Conditional formatting rules used for data cells in Google Sheets.**

2.7. Protocol:

Step 1	Step 2	Step 3	Step 4
Construct Drive Base	**Assemble Soil Sensor Mechanism**	**Programming Components**	**Analyzing Data**
A. Assemble AndyMark Peanut Chassis. B. Lay out Andymark Cheap and Dirty electronics for two motors. C. Connect AndyMark Cheap and Dirty electronics for two motors to the drivebase motors of the Peanut Chassis and connect to Victor speed controllers and onboard radio control system. D. Connect electronics to battery. E. Ensure that the onboard radio control system connects to driver radio system.	A. Connect Adafruit STEMMA Soil Sensor - to an Arduino Uno Board with JST PH 4-Pin to Male Header Cable - 12C STEMMA Cable - 200mm. B. Connect Standard servo - TowerPro SG-5010 - 5010 to Arduino Uno C. Mount Standard Servo Arm and Horn Set - 25 Spline to Servo Motor. D. Mount Adafruit STEMMA Soil Sensor to Servo Arm. E. Mount the Servo assembly onto robot drive base.	A. In the Arduino IDE, program the commands for the Servo Motor. B. Write the code for the Adafruit STEMMA Soil sensor to input data. C. Write the code for the Adafruit STEMMA Soil sensor to output data. D. In the Arduino IDE, program the Adafruit STEMMA Soil Sensor to collect and save data onto laptop using Tera Term. E. Use conditional formatting to program color-coded spreadsheet cells in Google Sheets.	A. Run the program and collect data with the soil sensor on the robot. B. Open spreadsheet to view the data in color-coded cells. C. Once raw data is saved in the spreadsheet, analyze data using charts and graphs as visual aids.

Figure 5. **Steps taken to complete the experiment.**

Table 1. **Blank table used to collect soil moisture readings and average soil moisture reading per each soil sample during testing.**

Soil Moisture		Dry Soil Average:
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		Moderate Soil Average:
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		Wet Soil Average:
Soil Moisture		
Soil Moisture		
Soil Moisture		
Soil Moisture		

2.7.1. Preparing Soil:

Predetermined soil samples are used to test the accuracy of the robot and soil sensor. One and a half cups of soil placed in 3 identical aluminum trays are used. The first tray contains dry, sand-like soil ("under-watered" soil), the second contains normal soil (control), and the third tray contains "over-watered" soil. Miracle-Gro All Purpose Garden Soil is used for all three samples. Figure 6 illustrates the three different trays of soil with different moisture levels. 1/2 cup of water is added to the soil to make the "overwatered" sample. Once the set-up of the soil is finished, the robot is driven to each sample and the arm equipped with the sensor was programmed to lower into the trays. The soil moisture sensor collects the moisture levels of each tray, and the data recorded is sent through the program TeraTerm into Google Spreadsheets. The readings are organized based on moisture, which is color coded in the spreadsheet. Table 1 illustrates the table used to collect readings from each tray before entering the data. These predetermined soil samples allow for testing the accuracy of the soil moisture sensor. During the testing of the soil moisture sensor, the sensor was placed in a sample containing 100% water (0% soil) and the sensor returned the value 2000, which demonstrates its accuracy because according to the programming of the sensor, the value 2000 represents 100% water. In addition, when the sensor was placed in a sample containing extremely dry soil, the sensor returned a value in the 200s, which was also expected based on the ranges of the soil sensor mentioned in the Spreadsheet Description and Figure 4. This demonstrates the accuracy of the soil moisture sensor.

Figure 6. **Dry, normal, and wet soil samples used to test the robot.**

2.7.2. Terrain Testing:

The robot was also driven on various surfaces, to test for its ability to drive in different environments. The robot was driven on the following surfaces: hardwood floor, carpeted floor, cement sidewalk, grass lawn, dirt, and a forested trail in a local state park. The device was able to function normally on all the listed surfaces, regardless of the mud and tree roots in the forested trail, demonstrating that it is able to drive in these environments. Further improvements to the prototype can ensure function on uneven terrain as well.

3. Results

Table 2 shows the moisture values and an average moisture value per soil sample collected by the robot collected during testing. Figures 7-9 depict the robot in its entirety. The electrical components for the 3-D printed arm, servo motor, and Arduino powered soil moisture sensor can be seen in the lower level of the robot in Figure 7, a front view of the completed device. A top view of the robot, including the electrical panel for the drive base, is shown in Figure 8. Figure 9 depicts the experimental setup used to test the completed device with the three soil samples based on moisture levels. The robot is driven to each tray, the arm with the soil moisture sensor is lowered into the soil, and readings are sent to the spreadsheet database.

Table 2. **Color-coded soil moisture data and averages per each soil sample collected by the robot during testing. Note that the values of the sensor are capacitive, ranging from 0-2000, the minimum value being completely dry and the maximum value complete moisture. There are no units to these values.**

Soil Moisture	245	Under-watered Soil Average:
Soil Moisture	248	246
Soil Moisture	247	
Soil Moisture	249	
Soil Moisture	241	
Soil Moisture	808	Moderate Soil Average:
Soil Moisture	814	814.25
Soil Moisture	815	
Soil Moisture	811	
Soil Moisture	820	
Soil Moisture	819	
Soil Moisture	807	
Soil Moisture	820	
Soil Moisture	1103	Over-watered Soil Average:
Soil Moisture	1117	1111.2
Soil Moisture	1108	
Soil Moisture	1112	
Soil Moisture	1116	

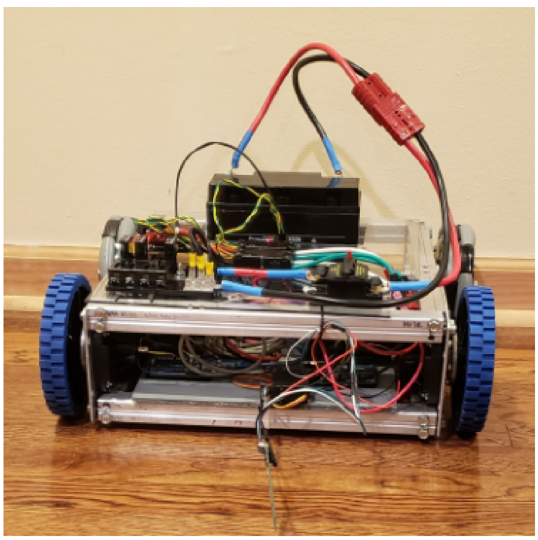

Figure 7. **Front view of the completed robot.**

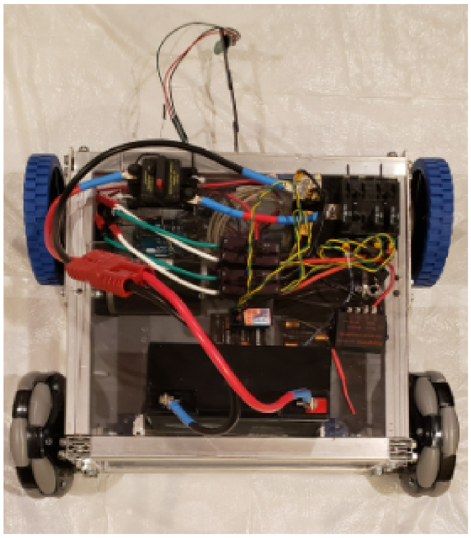

Figure 8. **Top view of the completed robot.**

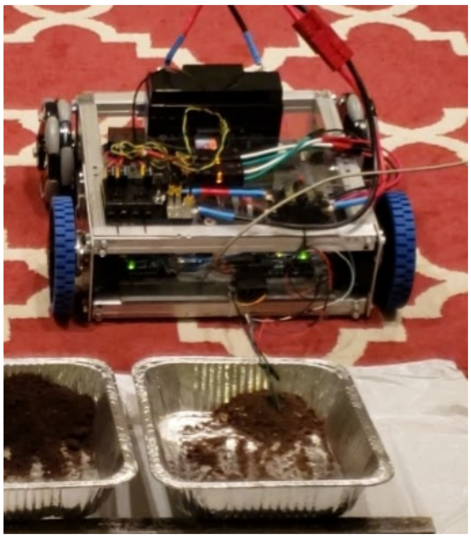

Figure 9. **Completed robot taking soil moisture readings during testing.**

After thoroughly testing the robot and accompanying spreadsheet program, both are determined to be effective. The robot is built completely and successfully drives to different locations of plants. The robot's servo motor accurately lowers the soil sensor mechanism into the soil, submerging the sensor each time. The soil moisture sensor takes readings of the soil moisture and successfully logs the data. The data is then automatically stored in a spreadsheet with color-coded data cells to clearly represent the levels of moisture of the plants (red cells represent dry soil/under-watered plants, green cells represent moist soil/perfectly watered plants, and blue cells represent wet soil/over-watered plants).

4. Discussion

4.1. Durability

This robot was designed with durability in mind. One set of wheels (the blue wheels) of the robot are high-grip wheels that allow the robot to have ample traction on multiple surfaces [7]. This is crucial to the design because it allows the robot to operate outdoors on different terrains. The other set of wheels (the grey and black wheels) of the robot are omni-directional wheels that allow for easy turning of the robot, making it easier to steer and make micro-adjustments in small amounts of time [8]. This enables easy positioning of the robot adjacent to plants, ensuring the device can maneuver swiftly to avoid crushing plants when taking soil readings. The device moves fast from location to location, as it is small and relatively lightweight. It currently takes about 25 seconds for the sensor to insert, collect, log data, and come back up from the soil; this time can be shortened in the code as well if desired. This time is less than what it would take to locate, read, log, and manually enter data into a spreadsheet with individual sensors. The battery used in this experiment is an AGM battery, which compared to conventional flooded batteries, withstands colder temperatures, has a longer life span, and charges up to 5 times faster [9]. The arm of the mechanism that lowers the soil moisture to the ground is 3D printed with PETG (Polyethylene Terephthalate Glycol) filament. This filament is a glycol modified, impact-resistant copolyester filament for extra durability [10]. Although the mechanism is a moving part that can be subjected to impacts and jostling, the extremely durable filament extends the life of the mechanism and reduces the amount of repairs needed. In addition, the Adafruit STEMMA soil moisture sensor in this device is better than other low-cost sensors on the market; the Adafruit sensor has no exposed metal, only one probe, doesn't introduce DC current to plants, and doesn't require constant calibration of the programming code [11]. This robot is also radio-controlled, which eliminates concerns about the connection between a laptop, the robot, and a controller. By designing the robot with a radio-controlled driving system, the range between the robot and the controller is larger than if the robot was connected to the controller via Ethernet cable or a WiFi connection method [12].

4.2. Usability

In addition to a durable robot, a comprehensive, user-friendly spreadsheet program for farmers, botanists, and agriculturalists accompanies the robot. Using the program Tera Term, the spreadsheet automatically logs and saves the soil moisture readings from the robot as a .csv file. Tera Term is a free, open-source software implemented, terminal emulator program that emulates different types of computer terminals, including the serial port connection used in this project [13]. This file is then imported to Google Sheets, where the data cells are automatically color-coded for users to easily see the moisture levels of their plants' soil. The cells are arranged in three color categories based on the recommended soil moisture intervals that can be set for different crops: red for under-watered, green for perfectly watered, and blue for over-watered. Rather than trying to understand the raw data values of the soil moisture sensor readings, viewing the data quantitatively and in color categories enables users to read the moisture levels of their plants in a quick and easy manner. This program also runs and saves data without a WiFi connection and the color-coded Google Sheet is able to be viewed offline, making it easy for users to use in any location, regardless of WiFi connection. Based on the irrigation needs of each crop, the user can code the spreadsheet to color the cells according to different parameters. Specific feedback provides tailored care.

4.3. Cost-Benefit Analysis

Table 3. **Cost analysis of the robot.**

Item	Name	Quantity	Cost per 1	Item Total Cost
Arduino Uno Board	Arduino Uno Rev3	2	$22.00	$44.00
Jumper Wires	ELEGOO Solderless Flexible Breadboard Jumper Wires 4 Different Lengths Male to Male	6	$0.09	$0.54
Peanut Chassis	AndyMark Peanut Chassis Materials	1	$439.00	$439.00
Robot Electronics	AndyMark Cheap & Dirty Electronics for Two Motors	1	$340.00	$340.00
Soil Sensor	Adafruit STEMMA Soil Sensor - 12C Capacitive Moisture Sensor	1	$7.50	$7.50
JST Female Cable	JST PH 4-Pin to Female Socket Cable - 12C STEMMA Cable - 200mm	1	$1.50	$1.50
Servo Motor	Standard servo - TowerPro SG-5010-5010	1	$12.00	$12.00
Plywood	1/4" thickness 1.95' x 1.95' sanded pine plywood	1	$4.85	$4.85
Lexan	0.2" thickness 12" by 12" clear lexan sheet--CHECK BRAND	1	$13.43	$13.43
Arduino Battery Packs	Corpcorate Computer 6 AA Battery Holder With 2.1 mm x 5.5 mm Connector 9V Output	2	$3.49	6.98
Total Cost	**$869.80**			

Not only is this robot durable and easy to use, it is also cost efficient. The total cost of the robot is $869.80, which is significantly less expensive compared to other smart agricultural robots. The FarmBot Genesis MAX v1.5, a backyard garden agricultural robot costs consumers $5,995.00 USD [14]. This is very costly for those looking to maximize crop production in personal gardens and other small-scale settings. Another robot on the market is the SuperDroid Robots Prebuilt 4WD IG52 - SB Custom Length Assembled Robot with 13 inch Tires [15]. This robot costs consumers $1,935.00. Although the SuperDroid robot uses similar drivetrain concepts to the prototype in this study, such as the same drive base design and radio controlled driving, it is much more expensive. The SuperDroid robot is essentially only a drive base and does not contain any sensors or other agricultural mechanisms. In order to use the SuperDroid robot, agriculturalists would have to design mechanisms for the agricultural purposes they would like to utilize the robot for, which would further add to the cost [15].

Overall, when compared to other agricultural robots on the market, this robot is more cost efficient than other robot options for agricultural purposes, such as robots sold by the aforementioned agtech company FarmBot.

The robot is still cost efficient when compared to individual nodes or handheld sensors in the long term. Handheld or stationary sensors, which are small, must be bought in bulk in order to cover significant areas. Therefore, the costs add up, and each sensor must be maintained. This robot eliminates the need for farms to rely on individual nodes or handheld sensors for soil moisture readings, making it more cost efficient than the aforementioned methods of collecting soil moisture data.

5. Conclusion

All engineering goals for this project were met. An Arduino- powered soil sensor, successfully placed on a small (14 in by 14 in) radio-controlled robot, can be manually driven. The sensor tests a chosen location's soil moisture on command by inserting the sensor into the ground with an arm-like robotic mechanism. The design of this device allows the robot to travel and take readings from multiple locations at the discretion of the driver. This robot is also cost effective, and a more accessible device for all farmers, botanists, and agriculturalists who cannot afford larger-scale options. A cross verification test also validates that soil moisture sensor readings are accurate based on predetermined dry, normal, and wet soil samples (the results of this test are depicted in Table 2, which also serves as an example of how data is presented in the color-coded spreadsheet). Soil moisture data is successfully returned to the driver in a color coded spreadsheet, which displays the state of each location's soil moisture as under-watered, moderately watered, or over-watered. The automatic color-coded spreadsheet not only stores the data collected, but can be utilized to produce analytical charts/graphs. The automatic color-coding of the soil moisture data in the offline setting of Google Sheets is novel because other agricultural robots have not transmitted or displayed data in this way before.This device is a valuable tool for farmers when used alone, or even coupled with other technologies.

Although this prototype has a lot of potential to improve agriculture and irrigation, there are a few limitations. Owners of the device must have access to a computer. The computer is necessary to view data from the soil moisture sensor and to display the color coded spreadsheet. In addition, the robot cannot currently operate outdoors during precipitation. The electronics are mounted on top of the robot, meaning that there is no protection against water, snow, or ice. The battery life of the robot is another limiting factor; the battery must be charged in order for the robot to operate, limiting the amount of time the robot can be utilized during one use.

Even though limitations exist, this device is still a prototype. To further improve the prototype, the robot design can be made compatible with a battery with a longer life. Creating a protective housing over the electronics would reduce chances of damage to the robot. A weatherproof housing covering made of polycarbonate particularly, or any other lightweight material, would accomplish this. This housing could also house the laptop or other device needed to view the soil moisture data. In terms of mechanical design, increasing the radius of the wheels will make the robot more adaptable to rougher terrain. The robot itself can also be made autonomous. Doing this will eliminate the need to manually drive the robot. To make the device autonomous (operate without being manually controlled by a driver), more expensive and complex electronics, and more advanced programming will be required, increasing the cost. However, this may be an option for farmers who can afford a more advanced robot. Adding a GPS tracking system to the robot is also a possibility. The addition of a camera to allow for the robot operator to view the robot's path of travel would also be a useful addition to this robot in the future, along with modified electronics and programming to allow for the addition of the camera. One such camera that could be used is the fish-eye lens camera that was utilized by the WormBot, an earthworm-like robot that maneuvers through narrow spaces and uneven rubble [16]. cellular app can be created to map out paths of the robot prior to testing in the field, as well as record the path taken during testing. Through a data aspect, improving the outputs of the data is another possibility for the future. Data collected in the spreadsheet can be analyzed by an advanced algorithm that automatically controls sprinkler systems and the duration of irrigation. By taking action based on the sensor readings, farmers can save water, crop yields, and time due to less personal involvement.

This robot has the ability to significantly improve agriculture. Water wastage can be drastically decreased, and the accuracy of crops or soil predictions can improve greatly. It is possible to design cost efficient, simple to use, and portable devices for farmers to use in large farms. As long as the user has access to a laptop, it is easy to understand the data, even if the user has no technical background. Furthermore, this research conveys that there is no need for expensive networks or multiple sensors scattered throughout a field. Individual sensors may become faulty over time due to usage and weather conditions. However, using a robot such as the device in this engineering project, only one soil sensor is needed at a time, and can easily be replaced with one of the same kind if it should break or malfunction over time. Most importantly, this prototype provides accurate readings for farmers who may currently depend on only rudimentary qualitative observations, such as feeling soil moisture with their fingers. This device is affordable and easily usable for poorer farmers or those with less land. With its many implications, this device can be used in numerous agricultural settings. Greenhouses, small farms, and large farms can all take advantage of this robot. Due to decreased farmland, efforts to reduce carbon emissions, and a higher demand for food, even small plots of land must be maximized. Because of its small and compact design, this robot can also be used in backyard or rooftop gardens, as well. Based on data from New Mexico State University, the size of rows between common crops in the United States are larger than this robot, enabling this robot to easily maneuver in between rows of crops [17]. This data can be found in Appendix D. Advances in agtech (agricultural technology) have become essential, due to decreasing water and increasing populations. This device, with further improvement, has the potential to maximize agricultural production when it is needed the most.

6. Acknowledgements

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Conflict of Interest

Authors of this article declare that they have no conflict of interest.

Human Studies/Informed Consent

No human studies were carried out by the authors for this article.

Animal Studies

No animal studies were carried out by the authors for this article.

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Appendices

APPENDIX A: ROBOT CONTROLLER

Figure 10. **Hand-held radio transmitter robot controller.**

APPENDIX B: SERVO MOTOR SOURCE CODE

```
#include <Servo.h>

Servo myservo;

int pos = 0;

void setup() {
  myservo.attach(9);
}

void loop() {

  for (pos = 130; pos >= 45; pos -=1) {
    // in steps of 1 degree
    myservo.write(pos);
    delay(600);  //speed
  }
  delay(5000);

  for (pos = 45; pos <= 130; pos += 1) {
    myservo.write(pos);
    delay(600);        //speed
  }
  delay(10000);
}
```

Figure 11. **Source code that controls the servo motor of the robot's arm mechanism.**

APPENDIX C: SOIL MOISTURE SENSOR SOURCE CODE

```
#include "Adafruit_seesaw.h"


Adafruit_seesaw ss;

void setup() {
  Serial.begin(115200);

  Serial.println("Soil Sensor Readings ");

  if (!ss.begin(0x36)) {
    Serial.println("ERROR sensor not found");
    while (1);
  } else {
    Serial.print("version: ");
    Serial.println(ss.getVersion(), HEX);
  }
  while (!Serial) {

  }

}

void loop() {
  float tempC = ss.getTemp();
  uint16_t capread = ss.touchRead(0);

  //Serial.print("Temperature: "); Serial.print(tempC); Serial.println("*C");
  Serial.print("Capacitive "); Serial.print(","); Serial.println(capread);
  delay(10000);



}
```

Figure 12. **Source code that controls the soil moisture sensor's input and output of data.**

APPENDIX D: NEW MEXICO STATE UNIVERSITY CROP ROW DATA

Table 4. **New Mexico State University data on the distance between rows of crops for common crops in the United States.**

Vegetable	Inches Between Rows
Artichoke, Globe	48-60
Artichoke, Jerusalem	24-36
Asparagus	36-48
Beans, Broad	36-48
Beans, Dry	18-24
Beans, Lima	18-24
Beans, Snap or Green	18-24
Broccoli	24-36
Brussels Sprouts	24-36
Cabbage	24-36
Cardoon	36-48
Cauliflower	24-36
Celeriac	24-30
Celery	24-30
Chard	18-24
Chayote	60
Chicory	24-36
Chinese Cabbage	18-30
Collards	18-24
Cress	18-24
Cucumber	18-72
Eggplant	24-36
Endive	18-24
Horseradish	18-24
Kale	18-24
Kohlrabi	18-24
Muskmelon	60-96
Okra	24-36
Parsnip	18-24
Pea, Shelling	18-24
Pepper	24-36
Potato, Irish	24-36
Sweet Potato	36-48
Pumpkin	60-120
Rhubarb	36-48
Rutabaga	18-24
Salsify	18-24
Sorrel	18-24
Soybean	24-30
Spinach, New Zealand	24-36
Squash, Summer	18-48
Squash, Winter	60-120
Tomato	24-48
Watermelon	60-120