HYDROMETRY: CE 738A

Project 2

A REPORT ON SOIL MOISTURE MEASUREMENT BY RESISTIVE MOISTURE SENSOR IN A PLANT

2022-2023

DEPARTMENT OF CIVIL ENGINEERING

HYDRAULIC AND WATER RESOURCES ENGINEERING

SUBMITTED TO :

Dr. Shivam Tripathi

SUBMITTED BY:

Sahil Agrawal (22103052)

Ranjan Kumar (22103049)

TABLE OF CONTENTS

1. INTRODUCTION
2. LIST OF COMPONENTS
3. CIRCUIT DIAGRAM
4. SEQUENCE OF PROCESS INVOLVED
5. CALIBRATION OF SENSORS
6. UNCERTAINTY ANALYSIS
7. INFERENCES/OBSERVATIONS
8. LIMITATIONS
9. REFERENCE

INTRODUCTION

Soil volumetric water content (Volumetric Water Content) is a vital parameter to understand several ecohydrological and environmental processes. Its cost-effective measurement has potentially drive various technological tools to promote data-driven sustainable agriculture through supplemental irrigation solutions, the lack of which has contributed to severe agricultural distress, particularly for smallholder farmers and various research areas.

The gravimetric method is the most accurate method of VWC measurement, is destructive, laborious, and does not provide results in real-time. This has led to the development of nondestructive, indirect methods for the measurement of VWC. Examples include neutron probe, time domain reflectometry (TDR), time domain transmission (TDT), electrical capacitance, impedance, resistive sensors, electromagnetic sensor (theta probe and hydra probe) , tensiometers and GNSS based soil moisture sensors.

The sensor used in the project is resistive soil moisture sensor and a Dht22 sensor to measure the temperature and humidity of the surrounding.

Multiple studies have investigated the effect of ambient and soil temperature on VWC measurements. So, in this project we didn’t find soil temperature but have tried to observe the effects of atmospheric temperature around it.

LIST OF COMPONENTS

- ## ARDUINO

ARDUINO UNO is a circuit board with a microcontroller based on ATMEGA328P U. The board has 14 digital I/O pins (six capable of PWM output),6 analog I/O pins, and is programmable with the Arduino IDE, via type B USB cable, DC Current per I/O Pin: 20 mA, DC Current for 3.3V Pin: 50 mA,
Flash Memory: 32 KB of which 0.5 KB is used by the bootloader,
SRAM: 2 KB
EEPROM: 1 KB
Clock Speed: 16 MHz

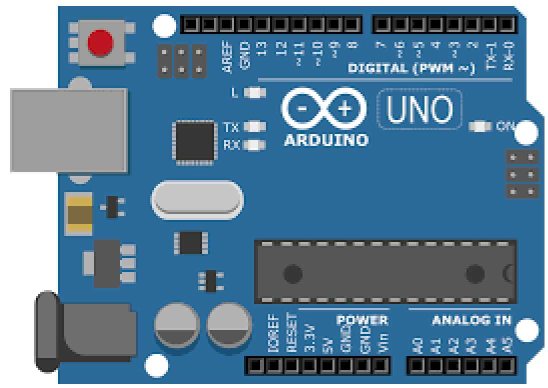


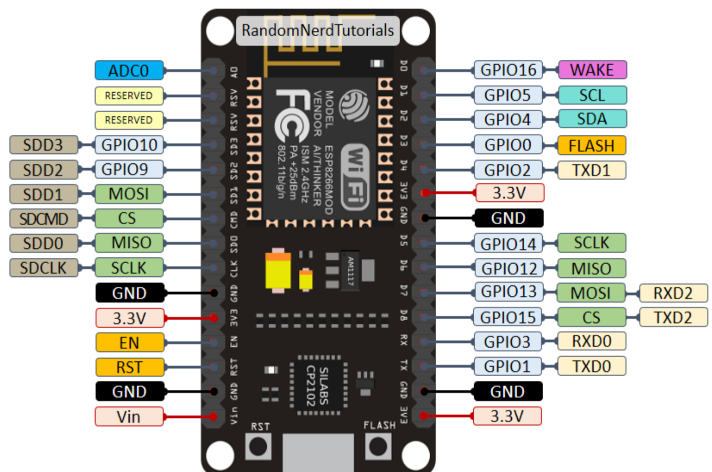
Figure I ARDUINO UNO BOARD

- ## ESP8266 (WIFI MODULE)

The ESP8266 WiFi Module is a self-contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your WiFi network. Support UART / GPIO data communication interface.

Flash size: 4Mbyte

Lowest cost WI-FI



- ## RESISTIVE SOIL MOISTURE SENSOR

A resistive soil moisture sensor works by using the relationship between electrical resistance and water content to gauge the moisture levels of the soil. It has two exposed probes that are inserted directly into the soil sample to record water content.

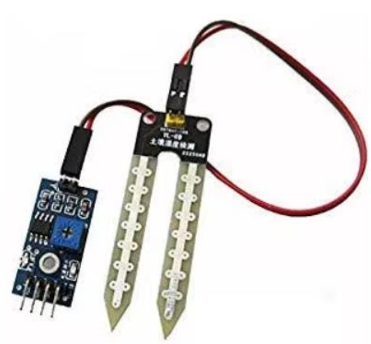


Figure IIII RESISTIVE SM

- ## SD CARD MODULE

The module (MicroSD Card Adapter) is a Micro SD card reader module and the SPI interface via the file system driver, microcontroller system to complete the Micro SD card read and write files.

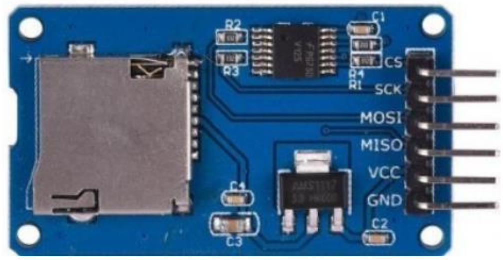


Figure IV SD CARD MODULE

- ## DS1307 RTC I2C Module

The DS1307 can keep track of seconds, minutes, hours, days, dates, months, and years. It can work in either a 12-hour or 24-hour format and has an AM/PM indicator. For months with fewer than 31 days, it automatically adjusts the date at the end of the month, including leap year corrections (valid up to 2100).

It handles all timekeeping functions and communicates with the microcontroller over I2C.

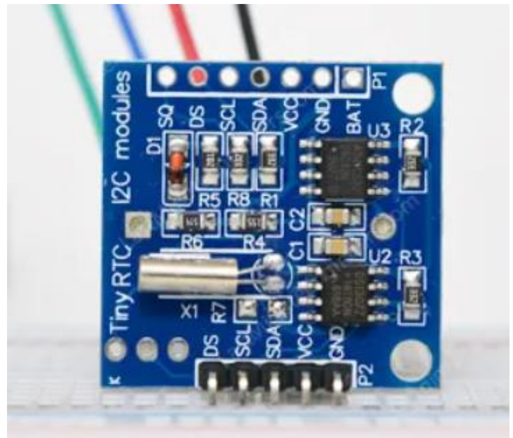


Figure V DS1307 RTC MODULE

- ## BOOST CONVERTER

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load).

Figure IVI BOOST CONVERTER

- ## DHT22

The DHT22 Digital Temperature and Humidity Sensor Module IT is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin.


Figure VII DHT22

- BTP4056 (CHARGING CIRCUIT)

  The TP4056 is a low-cost Lithium Ion battery charger controller IC. It supports a constant current – constant voltage charging mechanism for s single cell Li-Ion Battery.

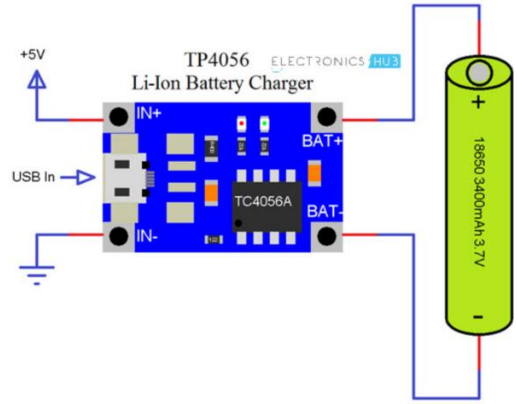


Figure VIII TP4056 AND BATTERY

- BATTERY

  Battery used is Orange ICR 18650 2500mAh 25C Lithium-Ion. It is a single cell, compact, and powerful battery cell with 2000 mAh capacity. It is very convenient to install in your project to fulfill the 3.7 Volt requirement with high capacity. The battery terminals can use in any compatible battery adapter/holder or it can be permanently soldered to your applications power source wires.

- PCB BOARD

  A printed circuit board (PCB) is the board base for physically supporting and wiring the surface-mounted and socketed components in most electronics.

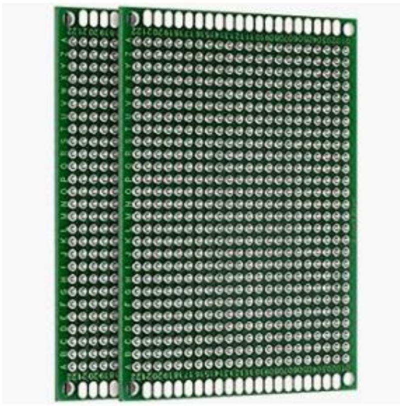


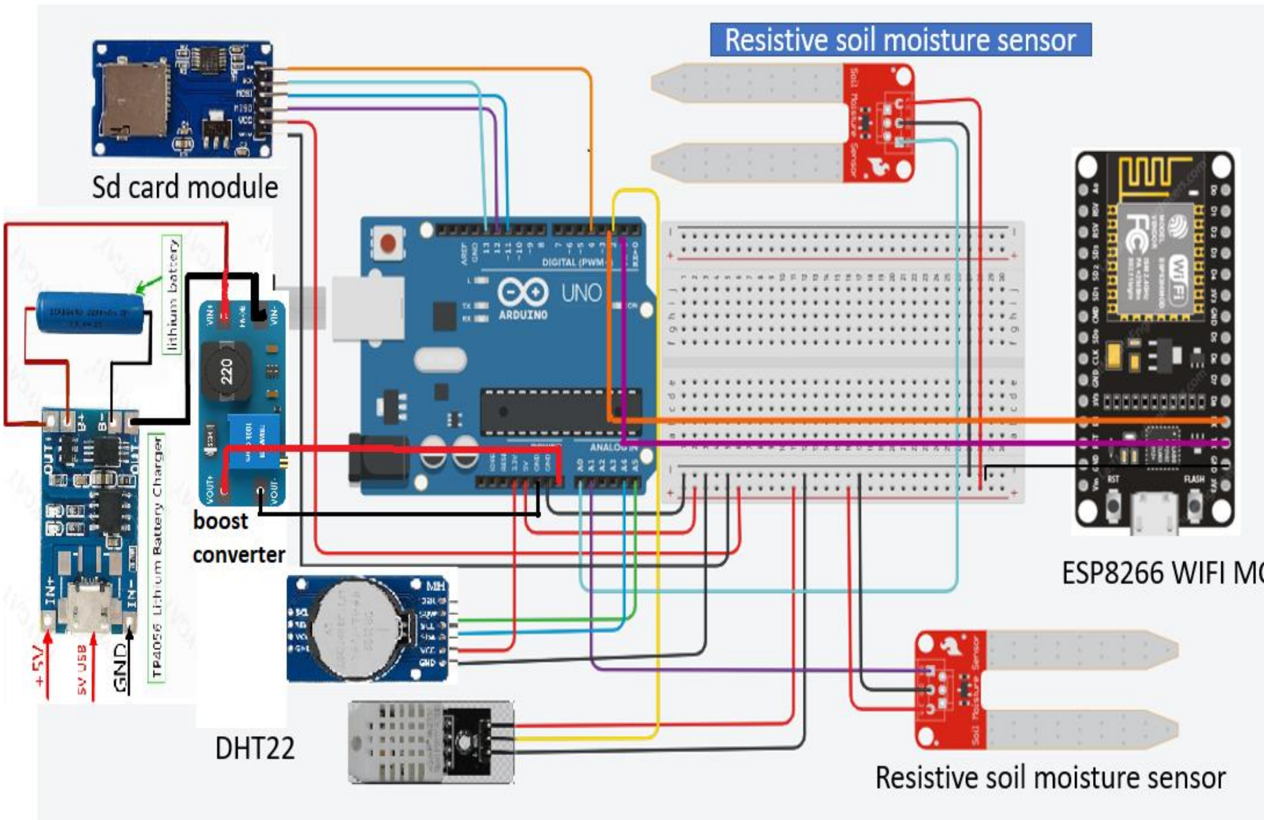
Figure VIX PCB BOARD

- JUMPER WIRE

  A jump wire is an electrical wire, or group of them in a cable, with a connector or pin at each end, which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering.

Figure X JUMPER WIRE

CIRCUIT DIAGRAM



SD CARD MODULE		RTC DS1307		Resistive soil moist.		Dht22	PIN
	PIN		PIN		PIN	VCC	5V
CS	4	SCL	A5	GND	0V	DATA	2
SCK	13	SDA	A4	Data 1	A0	GND	0
MOSI	11	VCC	3.3V	Data 2	A1		
MOSO	12	GND	0V	VCC	5V	ESP8266	
VCC	5V					RX-TX	TX-RX
GND	0V					VIN	3..3V

SEQUENCE OF PROCESS INVOLVED

1. Find the bulk density of the soil.
2. Prepare soil for calibration.
3. After calibration, we get the equation of bilinear relation of the measurand and the desired output.
4. Then perform the uncertainty analysis.
5. Now setup the electric circuit for the use of soil moisture sensor.
6. Electric circuit making includes:
   - Temporary circuit of the calibration purpose,
   - Making a permanent circuit board by soldering the pins and making a frame for the different sensor used.
   - Assemble all the sensor in the box.
7. Write the code of the process we want to do, process includes:
   - Initialization of SD card
   - Setting the time in RTC ,
   - Setup the soil moisture uncertainty analysis,
   - And storing of data in SD card,
   - Sending data to eps8266 through UART communication.
   - Further sending data to the server provided
   - Then extracting data from the server through a python code and saving it in Postgres a database management system.
   - Codes used are separately submitted.
8. Now just put the soil moisture sensor into the soil,
9. Dht22 as an extra component for measuring the surrounding temperature .
10. Now the data is all saved.

CALIBRATION OF SENSORS

Calibration establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties.
For calculating the moisture content of soil from the resistive soil moisture sensor, the sensor needs to be calibrated.
2 soil moisture sensors are used to record readings for the known moisture content so that we can get different readings for different water content.

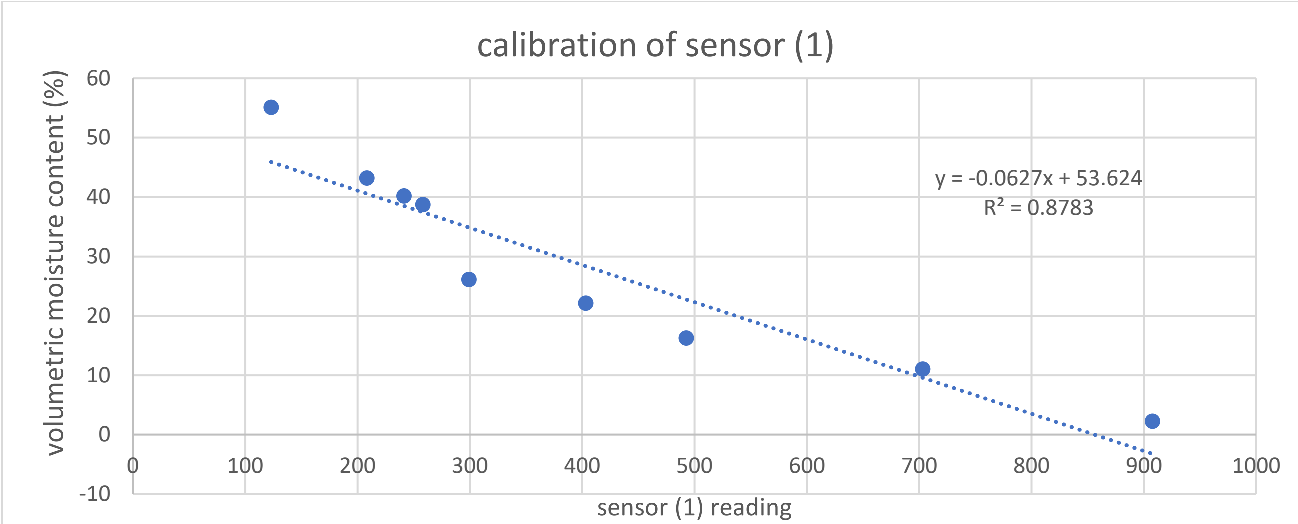
PROCEDURE:

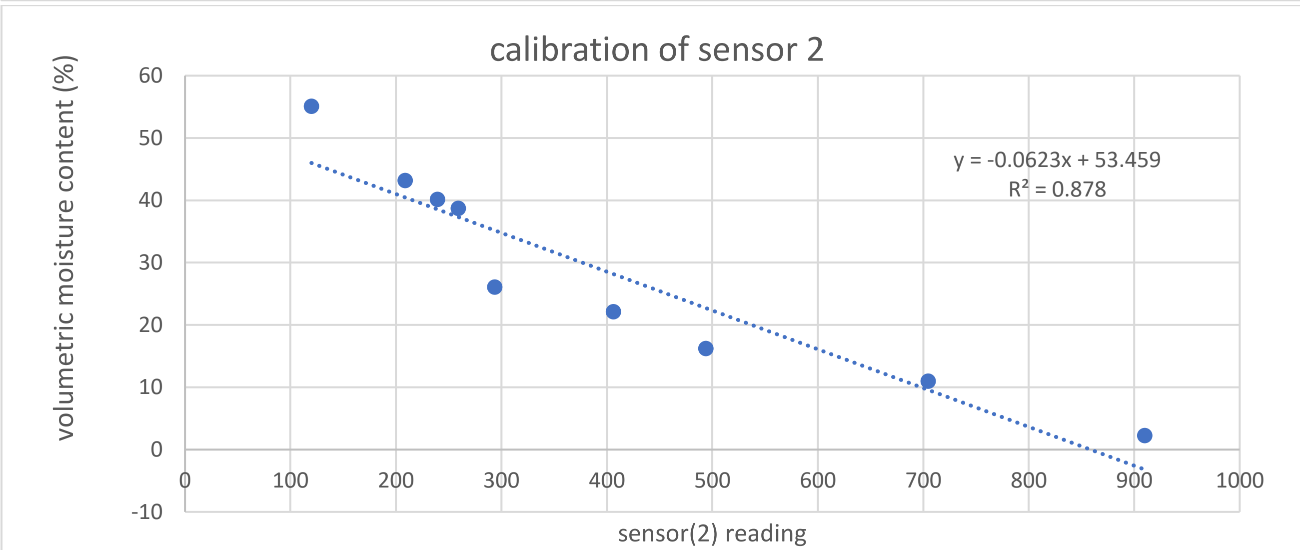
- Firstly, the soil is taken from the site with the sampler of known volume and it is over dried at 105◦C and bulk density of soil sample is calculated.
- Soil is now left open for air drying,
- Now after air drying, prepare the soil sample with various different water content in increasing order
- Now, use the resistive soil moisture sensor and note the readings from serial monitor and take a small amount of sample for oven drying to know its moisture content which will be gravimetric moisture content and then find volumetric content and then find the regression curve for the known values.

Code used for calibration is separately submitted.
Volumetric moisture content = bulk density x gravimetric moisture content

CALIBRATION OF RESISTIVE SOIL MOISTURE SENSOR

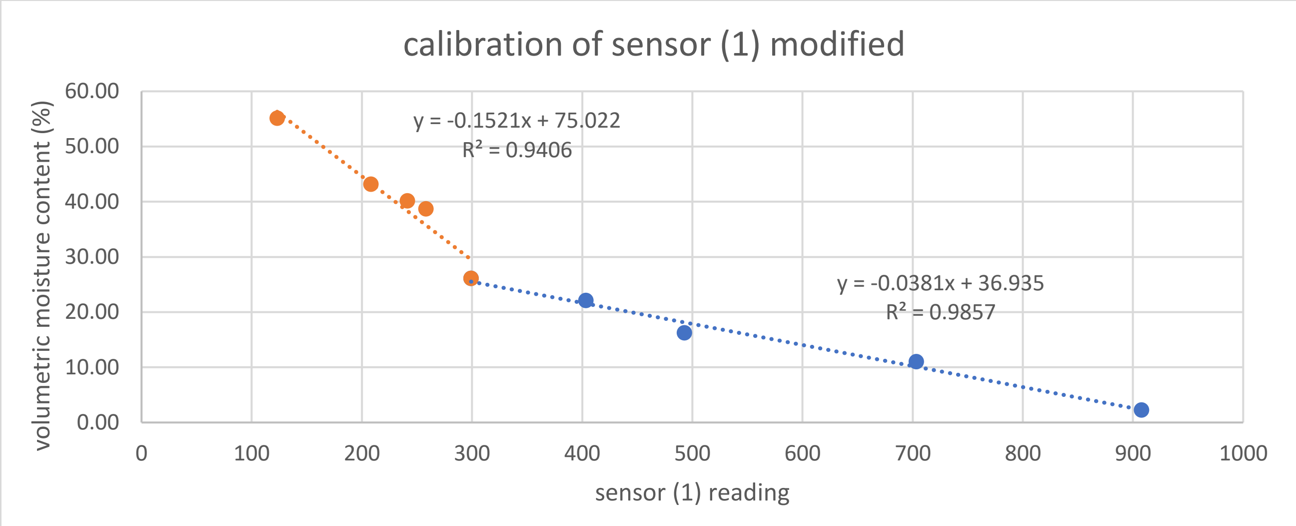
	VOLUMETRIC MC (%)	SENSOR READING (1)	SENSOR READING (2)
SAMPLE 1	2.24	907.80	910.00
SAMPLE 2	10.98	703.30	704.50
SAMPLE 3	16.23	492.70	493.90
SAMPLE 4	22.09	403.20	406.30
SAMPLE 5	26.08	299.10	293.70
SAMPLE 6	38.70	258.30	259.20
SAMPLE 7	40.16	241.40	239.50
SAMPLE 8	43.17	208.30	208.70
SAMPLE 9	55.09	123.10	119.90

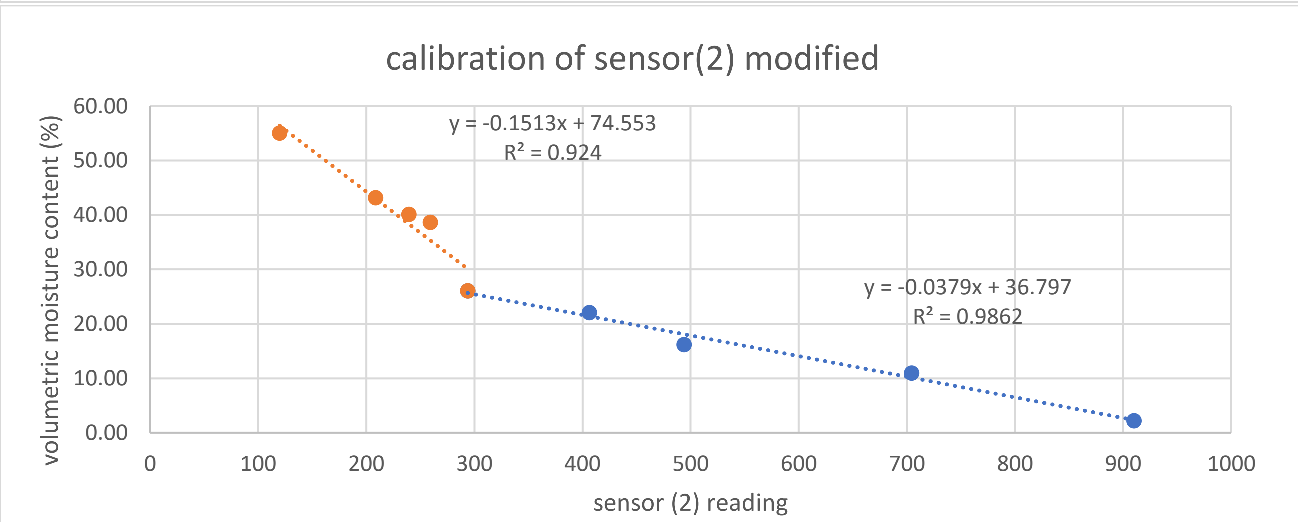




Calibration for all 9-sample after regression analysis gave $R^2 = 0.8783$ and 0.878 for both the sensor,
therefore if we try other calibration model
which is done for separated sample, for sample (1-5) and sample(5-9),we have

	VOLUMETRIC MC (%)	SENSOR READING (1)	SENSOR READING (2)	
SAMPLE 1	2.24	907.8	910	
SAMPLE 2	10.98	703.3	704.5	
SAMPLE 3	16.23	492.7	493.9	calibration 1
SAMPLE 4	22.09	403.2	406.3	
SAMPLE 5	26.08	299.1	293.7	
SAMPLE 5	26.08	299.1	293.7	
SAMPLE 6	38.70	258.3	259.2	
SAMPLE 7	40.16	241.4	239.5	calibration 2
SAMPLE 8	43.17	208.3	208.7	
SAMPLE 9	55.09	123.1	119.9	





The modified calibration gives better results for regression analysis and both sensors show very same results , so we have assumed the same calibration for both with higher R^2 value.

for sensor reading < 299	for sensor reading>299
y = -0.1521x + 75.022	y = -0.0381x + 36.935
$R^2 = 0.9406$	$R^2 = 0.9857$

y represents volumetric moisture content in %

x represents sensor reading

UNCERTAINTY ANALYSIS

Calculation of uncertainty in the measurement of soil moisture present in the soil(VMC), we have 2 sample for bulk density sample.
We have,
Input values
Dry Weight (W), Total volume (V)
Output value
Bulk density (BD)

Measurement model
Bulk density (BD) = W/V
Uncertainty in the input values

WEIGHT : Type A evaluation (of uncertainty): method of evaluation of uncertainty by means of statistical analysis of series of observations.
Measurand is dry weight

weights (gram)	wet soil +ring	dry soil + ring	dry soil	bulk density
sample 1	646	610	418.5	1.674
sample 2	438	399	207.5	0.83

bulk density	1.252	g/cm^3
uncertainty in bulk density U_{BD}	0.422	

GRAVIMETRIC SM : Type A evaluation (of uncertainty): method of evaluation of uncertainty by the statistical analysis of series of observations.
Multiplied by bulk density and we get volumetric water content.
VMC = BD*GMC
$U_{vmc} = GMC * U_{bd}$

WEIGHTS	volumetric(MC) (%)	uncertainty in volumetric content (U_V)
SAMPLE 1	2.236	0.75
SAMPLE 2	10.982	3.70
SAMPLE 3	16.230	5.47
SAMPLE 4	22.094	7.45
SAMPLE 5	26.083	8.79
SAMPLE 6	38.698	13.04
SAMPLE 7	40.158	13.54
SAMPLE 8	43.172	14.55
SAMPLE 9	55.088	18.57

SENSOR READINGS: Sensor reading for calibration used are average of 10 values.

Uncertainty is caused by repeatability
No. of observation = 10

Standard deviation (σ) = $\sqrt{\frac{\sum_1^n (\text{xi}-\bar{\text{x}})^2}{n-1}}$

Uncertainty in duration (U_t) = $\frac{\sigma}{\sqrt{n}}$

Sr. No.	Average reading of sensor 1	Uncertainty in sensor reading 1	Average reading of sensor 2	Uncertainty in reading 2
SAMPLE 1	907.8	0.63	910	0.76
SAMPLE 2	703.3	0.88	704.5	0.45
SAMPLE 3	492.7	0.78	493.9	0.80
SAMPLE 4	403.2	1.45	406.3	0.67
SAMPLE 5	299.1	1.73	293.7	0.87
SAMPLE 6	258.3	0.56	259.2	0.57
SAMPLE 7	241.4	1.23	239.5	1.95
SAMPLE 8	208.3	0.97	208.7	0.21
SAMPLE 9	123.1	0.50	119.9	0.80

In calibration we got a bilinear relation between the volumetric moisture content and the sensor reading.
Which will be our measurement model.

for sensor reading < 299	for sensor reading>299
$y = -0.1521x + 75.022$	$y = -0.0381x + 36.935$
$R^2 = 0.9406$	$R^2 = 0.9857$

By uncertainty analysis in the excel
We get
for sensor reading < 299

	Coefficients	*Standard Error*
Intercept	36.93	1.59
X Variable 1	-0.038	0.0026

for sensor reading>299

	Coefficients	*Standard Error*
Intercept	75.022	5.154
X Variable 1	-0.152	0.022

To calculate the uncertainty in volumetric moisture content,
We know quadrature method,
For $y = fn(x_i)$, where $x_i = x_1, x_2, x_3 \ldots\ldots x_n$
$Y = mx + c$
Where m,x and c all have uncertainty

for sensor reading <299	
m1 (slope)	-0.0381
Um1 (uncertainty in slope)	0.0026
i1 (intercept)	36.9346
Ui1 (un. In intercept)	1.5954

for sensor reading>299	
m2	-0.152
Um2	0.022
i2	75.022
Ui2	5.154

By quadrature method,

$$(U_{v1})^2 = \frac{\partial y}{\partial x\mathrm{m}1}^2 (U_{m1})^2 + \frac{\partial y}{\partial x1}^2 (U_{x1})^2 + \frac{\partial y}{\partial x\mathrm{c}1}^2 (U_{c1})^2$$

$$(U_{v2})^2 = \frac{\partial y}{\partial x\mathrm{m}2}^2 (U_{m2})^2 + \frac{\partial y}{\partial x2}^2 (U_{x2})^2 + \frac{\partial y}{\partial x\mathrm{c}2}^2 (U_{c2})^2$$

we have all variable except the sensor reading average and its uncertainty which is calculated in the code itself while performing the soil moisture test the resistive soil moisture sensor takes average of 50 reading at a time and uncertainty associated with those reading is calculated (U_x) same for both sensors.

And according to the sensor reading average (greater than or lesser than 299) The uncertainty is calculated. And then used in the final formula of volumetric content and the uncertainty in it.

```
if (x1 < 299 and x2 < 299) {
   v1 = m1 * x1 + i1;      (vmc_1)
   v2 = m1 * x2 + i1;      (vmc_1)
by quadrature method we have:
   Uvmc1 = sqrt((m1 * Ux1) * (m1 * Ux1) + (x1 * Um1) * (x1 * Um1) + (Ui1) * (Ui1));
   Uvmc2 = sqrt((m1 * Ux2) * (m1 * Ux2) + (x2 * Um1) * (x2 * Um1) + (Ui1) * (Ui1));
}
else if (x1 > 299 and x2 > 299) {
   v1 = m2 * x1 + i2;
   v2 = m2 * x2 + i2;
   Uvmc1 = sqrt((m2 * Ux1) * (m2 * Ux1) + (x1 * Um2) * (x1 * Um2) + (Ui2) * (Ui2));
   Uvmc2 = sqrt((m2 * Ux2) * (m2 * Ux2) + (x2 * Um2) * (x2 * Um2) + (Ui2) * (Ui2));
}
```

```
else if (x1 > 299 and x2 < 299) {
   v1 = m2 * x1 + i2;
   v2 = m1 * x2 + i1;
   Uvmc1 = sqrt((m2 * Ux1) * (m2 * Ux1) + (x1 * Um2) * (x1 * Um2) + (Ui2) * (Ui2));
   Uvmc2 = sqrt((m1 * Ux2) * (m1 * Ux2) + (x2 * Um1) * (x2 * Um1) + (Ui1) * (Ui1));
}
else if (x1<299 and x2>299) {
   v1 = m1 * x1 + i1;
   v2 = m2 * x2 + i2;
   Uvmc1 = sqrt((m1 * Ux1) * (m1 * Ux1) + (x1 * Um1) * (x1 * Um1) + (Ui1) * (Ui1));
   Uvmc2 = sqrt((m2 * Ux2) * (m2 * Ux2) + (x2 * Um2) * (x2 * Um2) + (Ui2) * (Ui2));
}
```

For every case

$$VMC_{mean} = \frac{M_1 + M_2}{2}$$ (VMC_{mean} = mean of volumetric moisture content)

We have calculated the standard uncertainty in both sensors vmcs.
Therefore combined uncertainty of vmc (U_{vmc}) can be calculated by quadrature method:

$$(U_{vmc})^2 = \left(\frac{\partial V}{\partial M1}\right)^2 (U_{vmc1})^2 + \left(\frac{\partial V}{\partial M2}\right)^2 (U_{vmc2})^2$$

$$\frac{\partial V}{\partial M1} = \frac{\partial V}{\partial M2} = \frac{1}{2}$$

$$U_{VMC} = \frac{\sqrt{Uvmc1^2 + Uvmc2^2}}{2}$$

Expanded uncertainty (U) ,

$U = k^* Uc_c$ (k = coverage factor)

K= 2 for 95% confidence interval assuming gaussian distribution

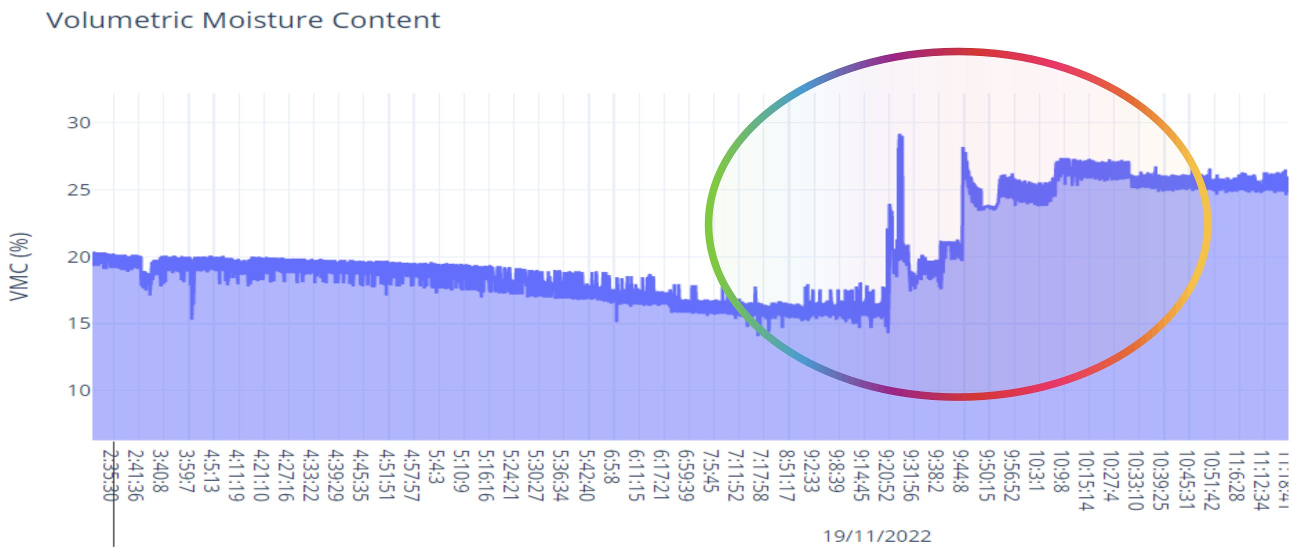
$U = 2^* U_{VMC}$

Hence,

Volumetric moisture content (VMC) = $VMC_{mean} \pm U$ %

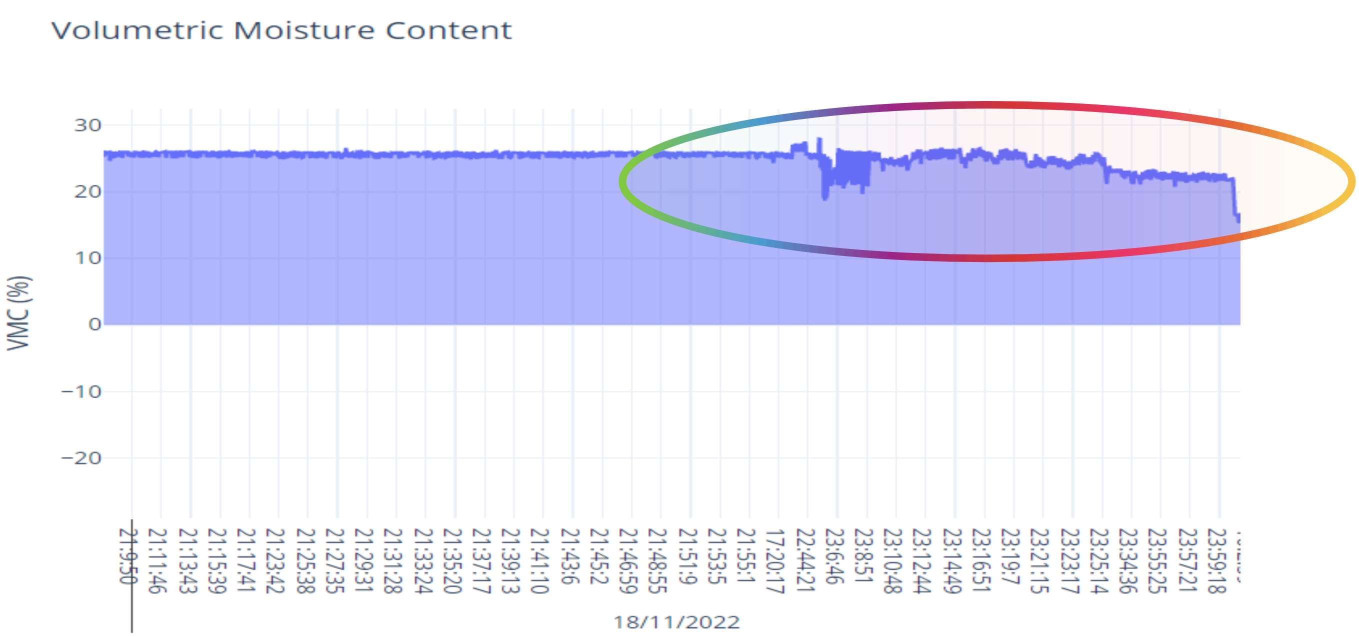
INFERENCES/OBSERVATIONS

- Moisture sensor shows late response to change in moisture content in plant pot. Watering time = 19/11/2022 , 08:56 am..

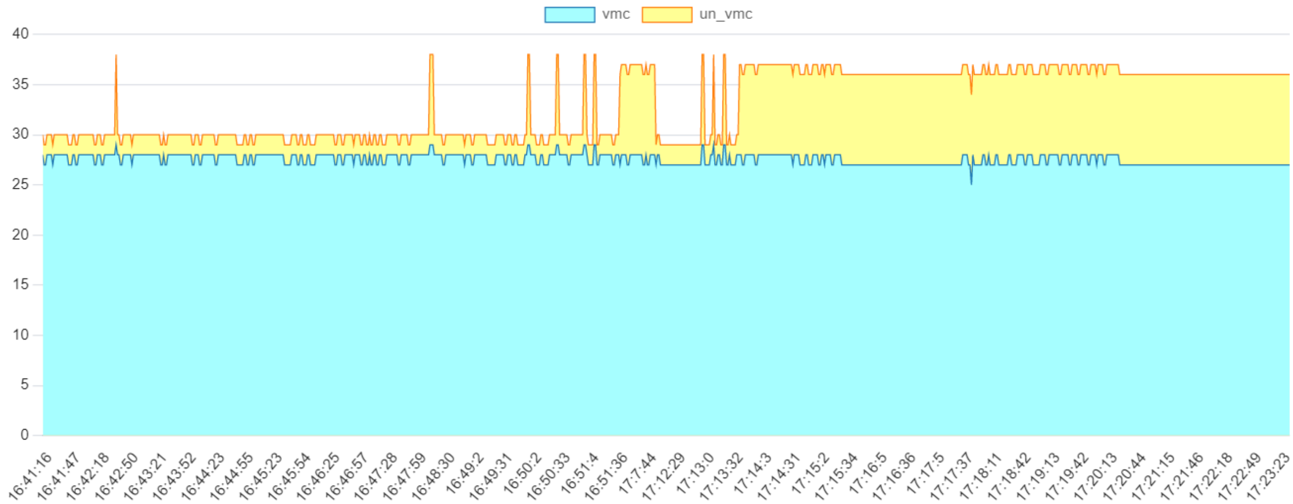


The graph reached a constant increased VMC in around 90 minutes.

- Change in temperature caused change in moisture content value and fluctuations in sensor readings.
  Plant pot was kept inside room at roughly constant temperature but when the pot was kept outside at night the vmc was fluctuating more and decreased at faster rate over time.
  Time = 18/11/2022 , 22:00 pm.



- When the location of sensor was changed in the pot, there was a variation in uncertainty observed.
  Time = 17:00 pm



This maybe because the moisture content in the pot was not uniform and because of the difference of the sensor reading there was increase in uncertainty.

- The drawbacks of the measurement included and were not limited to experimental and human errors, as well as the choice of piecewise linear calibration functions.

LIMITATIONS

The soil moisture sensor used gives point-based results which has lower influence volume.

- Several soil moisture sensors can be used at different location can be used to detect moisture content for efficient performance.

Not suitable for large area as soil properties will change and as volumetric water content is concerned it will produce wrong measurements.

- Different method can be used to measure the water level (GNSS, Neutron probe).
- Grid wise sensor can be deployed to measure water content.

Sensing accuracy affected by changes in temperature.

- Temperature sensor can be used to eliminate the variation in moisture content or measurement can be done at a controlled temperature.

Sensor is highly prone to electrolysis and corrosion because of the salt present.

No immediate change is observed in reading with change in moisture content, late response

The system requires a continuous power supply.

- Sustainable source of energy of energy can be used for power supply like solar panel or small wind turbine.

FigureXI solar panel and small wind turbine

REFERENCE

- CE-738 Class notes
- https://www.circuits-diy.com/
- www.tinkercad.com
- https://forum.arduino.cc/