Efficacy of Arduino based low-cost Resistive Sensor in evaluating Soil Moisture from different Soil types collected in the Kelantan-Terengganu plain of Malaysia

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Abstract. This paper presents an experimental study on the effectiveness of using Arduino based low-cost resistive sensors to measure soil moisture content from five different soil types. In this experiment, the soil samples were filled in the vases and arranged in a completely randomized design with three replications. The soil samples from the vases were taken for soil moisture evaluation for 28 days. The experiment began with soil samples at fully saturation condition followed by field capacity condition and finished at the dry condition. The sensors used in this study were calibrated with a gravimetric method by using an oven. The results reveal that the Arduino based low-cost resistive sensor is highly capable of measuring suitable soil moisture content of fine sand, loamy soil, and sandy clay loam soil types. However, this type of sensor has poor performance for sandy loam and clay loam soil types due to the high content of organic matter and low bulk density. The performance of this sensor on peat and wetland soil can be further enhanced by using a distinctively developed empirical formula. The system developed in this work allows employing large-scale soil moisture measurement network for irrigation monitoring and controlling in future research due to its low-cost and great simplicity.

1. Introduction
Soil moisture is one of the essential components or indicators in crop water requirement. Estimating crop water requirement is a complicated process and many factors need to be considered for precise irrigation practices [1]. Traditionally, irrigation scheduling is designed to meet full irrigation conditions and improper irrigation management has led to overirrigation or under irrigation practices. Therefore, the concept of precision irrigation scheduling has been introduced to reduce the amount of irrigation water [2]. There are different methods of precise irrigation scheduling selection, for instance, by using plant indicator, soil-media indicator, environmental parameters indicator or combinations of these indicators. Precision irrigation is vital in crop production, water quality monitoring and efficient water use [3]. [4] noted that measuring real-time soil moisture is one of the best methods to improve irrigation scheduling because it provides better timing using soil water sensors [2,5]. High crop yield can be achieved if the correct amount of water is supplied [6].
There are various working principles of soil moisture measurement. Conventionally, the gravimetric or drying method by using a convection oven [2,7,8] and microwave oven [9] have been used to measure soil moisture content. Apart from that, the feel method and calcium carbide technique [10] are also reported as classical methods of obtaining soil moisture content. However, these conventional and traditional methods are time-consuming, high cost and labour dependent [11] and destroy soil around the crops [12]. Therefore, the researchers [13-15] are trying to deploy the soil moisture sensor in irrigation practices. The application of soil moisture sensors for irrigation practices has a tremendous positive impact since it reduces temporal variability in soil moisture substrate by watering based on actual crop water use [16]. Measurement of soil moisture content in real-time and in situ is the challenging task due to time imposed to get the data, equipment cost, labour cost, and other technical issues [11]. Most of soil moisture sensor required calibration for best operation in specific soil conditions.

Despite, the application of resistive soil moisture sensor in measuring soil moisture level is still limited and unpopular due to corrosive issue [17,18], it even cheap and affordable [2,19] compared to others soil moisture sensor. Although various types of soil moisture sensors are well established for soil moisture detection for automatic irrigation and IoT application, the efficacy of in situ resistive soil moisture sensors for used on different soil textures collected from problematic soil in the Malaysian tropical region has not been extensively discovered. Therefore, the main objective of this study was to examine the effectiveness of using in situ Arduino based low-cost resistive sensors to measure soil moisture content from five different soil textures.

2. Materials and Methods

2.1. Soil samples collection & soil characteristics

The locations of the soil samples were decided based on the geomorphology of sampling points (at Terengganu & Kelantan) to represent different soil types. The identified area was cleared from plant roots and debris by using a hoe. The hoe was used to collect topsoil around 0 -30 cm depth for further analysis. The detail information of sampling points is listed in Table 1. Soil bulk density, temperature, and pH were taken in-situ during soil samples collection by using the core ring method [20], thermometer and soil pH meter, respectively. Other parameters, for instance, soil texture by using hydrometer method [21], organic matter by using loss on ignition method [22], electrical conductivity (EC), potential water at field capacity and soil colour were conducted in the laboratory. Total organic carbon was calculated by dividing the percentage of organic matter with a factor of 2 based on the assumption that organic matter is 50% carbon, instead of a common factor of 1.724 [23].

| Sampling Point | Coordinate | Altitude (m) | Description of Location | Name of Sampling Location  |
|----------------|------------|--------------|-------------------------|---------------------------|
| A              | 5° 46' 26.4" N 102° 24' 41.76" E | 15.0          | Paddy field area         | Kg Bukit Kawi, Kandis, Pasir Putih, Kelantan |
| B              | 5° 26’ 57.12" N 102° 53' 54.24" E | 6.0           | Peat soil area           | Hulu Nerus, Terengganu |
| C              | 5° 40’ 40.08” N 102° 42’ 36.36” E | 7.0           | Wetland area             | Setiu Wetland Research Station, Setiu, Terengganu |
| D              | 5° 59’ 48.84” N 102° 24’ 42.12” E | 5.0           | Sweet potato farm        | Kg Baru Perupok, Repek, Bachok, Kelantan |
| E              | 5° 44’ 54.6” N 101° 52’ 8.76” E | 56.0          | Vegetable farm           | Agrotechno Park, UMK Jeli Campus, Jeli, Kelantan |
2.2. Soil sample preparation & data collection
The total numbers of 15 pots were used in this study, where each container was filled with 1 Kg of 5 different types of soils. The resistive type soil moisture sensor was connected to the Arduino microcontroller and pre-programmed using Arduino IDE software. The sensor part of the resistive soil moisture sensor was inserted to around 10 cm depth or up to the maximum level of the lead at the tip of the sensor during data collection. The reading was displayed on the LCD. A plastic bag was used to wrap the pot to prevent water flow at the bottom part of this container. At the first day of the experiment, the water was poured into the pot until the soil samples fully submerged with water which represented saturation conditions at the beginning of the experiment.

Soil samples were taken for soil moisture evaluation by using the gravimetric method [12]. In these procedures, the soil samples were dried in a convection oven for 24 hours at 105 °C. Later, plastic bags were removed from the pots and excess water was allowed to be drained from the pot. On the second day, the data collection was carried out by using a resistive soil moisture sensor and the gravimetric method was repeated for the second day to represent moisture content at field capacity. Soil sample and reading steps were repeated every two days until twenty-eight days of the experiment.

2.3. Sensor performance evaluation
The performance of resistive soil moisture sensor was measured by discrepancy ratio, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and coefficient of determination, (R²) to evaluate calibration curve proposed in this study.

2.4. Experimental design and statistical analysis
The samples were layout in a completely randomized design with five treatments and three replications in laboratory condition. The treatments are Treatment 1 (soil type A), Treatment 2 (soil type B), Treatment 3 (soil type C), Treatment 4 (soil type D) and Treatment 5 (soil type E). The graphs were produced using Microsoft Excel for regression analysis. Data were represented as a mean value ± standard deviation.

3. Results and Discussion
3.1. Effect of soil characteristics on the in-situ soil moisture level
Based on the United States Department of Agriculture (USDA) soil texture analysis classification, soil type A, B, C, D and E were classified as loam, sandy loam, clay loam, fine sand, and sandy clay loam respectively. Table 2 summarizes selected soil properties from different soil types. In general, soil types B and C contain the highest soil moisture since this area located in a low land area, has poor drainage and frequently flooded. This reason explains the high soil moisture level measured from this area. Besides that, the high content of organic matter and active decomposition process in soil type B and C leads to high total organic carbon and low soil bulk density. The dark colour of soil type B and C also representing a high composition of organic matter available on the soil. Soil type D is known as beach ridges interspersed with swale (BRIS) soil and contains more than 90% sand composition. In situ temperature seem to has no direct impact on soil moisture content. The influence of physicochemical properties of soil on soil moisture content is worth and essential to be explored [24].

All soil samples were categorized as acidic soil with a pH range between 3.7 and 5.0. The electrical conductivity (EC) values evaluated in the range of 5.6 – 1160 μS/cm. The lowest EC was detected in soil type B since this area is peat soil and most all the time it is flooded and influence EC values. The highest EC recorded at soil type D might due to fertilizer used since this area is planted with sweet potato. Wetland soil (type C) has the highest capability to retain water at 60 % due highest silt and clay compositions. Meanwhile, soil type D has the lowest ability to keep water (34%) because the sand composition is dominant. The water will move downward fastest due to the highest macropore exist in this type of soil. Besides the methods used to quantify the moisture, the performance of the sensor can
also be affected by other parameters such as clay content, texture, porosity, and bulk density [25,26,27].

Table 2. Selected soil properties of different soil types

| Soil Characteristics                  | Soil Types |
|--------------------------------------|------------|
|                                      | A          | B          | C          | D          | E          |
| In-situ Moisture (%)                 | 25.8       | 100.0      | 100.0      | 12.9       | 16.0       |
| In-situ Temperature (°C)             | 28.7       | 27.8       | 32         | 34.7       | 28         |
| Soil Bulk Density (g/cm³)            | 1.21       | 0.61       | 0.65       | 1.41       | 1.5        |
| Organic Matter (%)                   | 8.03       | 42.16      | 22.30      | 1.89       | 5.27       |
| Total Organic Carbon (%)             | 16.06      | 84.32      | 44.6       | 3.78       | 10.54      |
| Electrical Conductivity, EC (µS/cm)  | 340        | 5.6        | 770        | 1160       | 280        |
| pH                                   | 4.5        | 3.8        | 3.7        | 5.0        | 5.0        |
| Potential Water at Field Capacity (%)| 44         | 36         | 60         | 34         | 38         |
| Soil Colour (Dry)                    | (8,3,2.5) Pale Yellow | (3,2,2.5) Very Dark Greyish Brown | (4,4,10) Dark Yellowish Brown | (5,2,7.5) Brown | (7,4,2.5) Dark Yellow |

3.2. Soil-specific calibration

Figure 1 demonstrates the calibration curves of soil moisture for different soil types. Soil type D has the highest coefficient of determination (R²) value, followed by soil type E, soil type A, soil type C and finally soil type B. There is a significant linear relationship between moisture content from the gravimetric method and resistive soil moisture sensor for all soil types since correlation coefficient, r falls in the range of critical values (df = 26, critical value =0.374). All Soil moisture data from soil type D had the best fitted to the actual soil moisture calculated from the gravimetric method. This is due to the lowest error different compared to other soil types, as indicated in Figure 2. The performance of resistive soil moisture sensor in soil type D was the best compared to other soil types (Table 3). Soil type D had the highest accuracy and lowest values of discrepancy ratio, MAE and RMSE. The lowest RMSE values indicated the highest performance accuracy of the soil moisture sensor [28]. Sandy soil tends to have high hydraulic conductivity [4] where the water moving downward rapidly and caused water losses.

High R² values also recorded for soil type A and E with a correlation coefficient of 0.9735 and 0.9881 respectively. The measured absolute error still in acceptable range when it deviates around -20 and 20 from zero error line. Besides that, discrepancy ratio and MAE measured from these types of soil is less than 1.0 and 3.7 respectively. RMSE values also among the lowest compared to other soil types and verified that resistive soil moisture sensor has an excellent performance in these types of soil. These types of soil were dominated by a high percentage of clay particles size and have low hydraulic conductivity. It can retain more water molecule at their micropore space and slow down water movement throughout soil profile due to gravity. This resulted in high matric potential compared to sandy soil and water is not quickly lost through evaporation or percolation and plant cell required more energy to absorb water at the plant root zone. Based on the performance evaluation of
resistive soil moisture sensor tested by [29], they recommended using this type of sensor in combination with a more accurate sensor to characterize soil properties in the field better. Resistive soil moisture sensor showed poor performance with high saturation and dry soil condition especially in soil type B and C (Figure 1b and Figure 1c). It seems that the resistive soil moisture sensor did not give accurate soil moisture content between field capacity and dry condition range.
Figure 1. Calibration of moisture content for soil type A (loam), B (sandy loam), C (clay loam), D (fine sand) and E (sandy clay loam).

- a) Calibration of moisture content for soil type A
  \[ y = 1.4361x - 6.3362 \]
  \[ R^2 = 0.9477 \]

- b) Calibration of moisture content for soil type B
  \[ y = 0.7203x - 25.001 \]
  \[ R^2 = 0.597 \]

- c) Calibration of moisture content for soil type C
  \[ y = 3.0027x - 3.0708 \]
  \[ R^2 = 0.98 \]

- d) Calibration of moisture content for soil type D
  \[ y = 2.4638x - 6.6156 \]
  \[ R^2 = 0.9765 \]

- e) Calibration of moisture content for soil type E
  \[ y = 2.4638x - 6.6156 \]
  \[ R^2 = 0.9765 \]
The drawback of resistive soil moisture sensors is contributed by soil properties itself where they contain a high amount of organic matter and total organic carbon. Consequently, soil bulk density from soil type B and C are the lowest. The high composition of organic matter influences soil moisture reading by a resistive soil moisture sensor. As explained by [4], coarse texture caused resistive soil moisture sensor to become inefficient due to improper contact with soil and water solution. They also further clarified that the sensor function might be disturbed due to soil impurities and poor water quality. Soil specific calibration is an essential process in smart farming since it does not limit the research work to the particular soil application [30]. Precise knowledge of soil moisture allows water savings and the use of moisture sensors can provide information on a different time scale and subsidies the water application on a sustainable rate [31]. This result suggests that the accuracy of the resistive soil moisture sensor highly depends on the soil mixture constituents [11]. Understanding the relationship between soil-water storage and plant root zone which dependent on accurate soil moisture level measurement is very important for effective irrigation scheduling [38]. Although resistive soil moisture sensor is less and has destructive issues if used in an extended period, it is more sensitive stable compared to a capacitive soil moisture sensor [18] if sensor cost is considered.

![Figure 2](image-url)

**Figure 2.** Error distribution of soil moisture from different soil samples. Notation A, B, C, D and E means soil type A, soil type B, soil type C, soil type D, and soil type E respectively. Dash line indicates zero error line.

**Table 3.** Parameters to examine the performance of resistive soil moisture sensor

| Characteristics | Soil Type | A         | B         | C         | D         | E         |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Equation        |           | $Y=1.4361x-6.3362$ | $Y=0.7203x-25.0010$ | $Y=0.7862x-17.2930$ | $Y=3.0027x-3.0708$ | $Y=2.4638x-6.6156$ |
| $R^2$           |           | 0.9477    | 0.5970    | 0.8217    | 0.9800    | 0.9765    |
| $r$             |           | 0.9735    | 0.7727    | 0.9065    | 0.9899    | 0.9881    |
| Accuracy        |           | 128.34    | 102.98    | 111.94    | 241.98    | 117.63    |
|                 |           | $\pm57.61$ | $\pm33.52$ | $\pm49.67$ | $\pm261.12$ | $\pm39.93$ |
| DR              |           | 0.94      | 1.11      | 1.03      | 0.87      | 0.99      |
|                 |           | $\pm0.43$ | $\pm0.49$ | $\pm0.37$ | $\pm0.80$ | $\pm0.52$ |
| MAE             |           | 3.74      | 19.87     | 13.34     | 1.15      | 1.58      |
|                 |           | $\pm3.32$ | $\pm17.86$ | $\pm11.42$ | $\pm1.31$ | $\pm1.57$ |
| RMSE            |           | 3.61      | 19.26     | 12.67     | 1.25      | 1.61      |

Note: $R^2 = $ Coefficient of Determination, $r = $ Correlation Coefficient, DR = Discrepancy Ratio, MAE = Mean Absolute Error
4. Conclusion
This study compares the effectiveness of using a resistive soil sensor calibrated with a gravimetric method by using a convection oven. Resistive soil moisture sensor performs best in fine sand (BRIS soil), sandy clay loam and loam soil texture. However, sandy loam (peat soil) and clay loam (wetland soil) soil textures have poor performance with resistive soil moisture sensors. This result suggests that the performance of this sensor on peat and wetland soil can be further enhanced by using a specifically developed empirical formula by considering soil properties. This work has amazing potential applications in the automation of irrigation scheduling due to its low-cost sensor type and easy to use even for the novice.

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