Development of Soil Electrical Conductivity (EC) Sensing System in Paddy Field

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Abstract. The amount of fertilisers affects electrical conductivity (EC), and it is one of the major causes of the paddy yield decrease. The overuse of fertilisers can lead to environmental pollution and contamination. This study designed to develop soil electrical conductivity (EC) sensing system in the paddy field using the smart farming application. In this work, the study conducted in Kampung Ladang, Kuala Perlis, and the soil samples collected from a random location at two different depths from the paddy field. The EC value for the developed system was near the calibration solutions (12880µS and 150000µS) and directly proportional to the temperature. From the laboratory soil results, the EC values of the soils were higher with fertiliser. However, the EC values for 0-10cm soil depth were higher than 10-20cm soil depth. The soil EC is inversely proportional to the depth of soil and directly proportional to the amount of nutrients. It observed that the soil EC is linearly related to the amount of nutrients and temperature. The EC value decreases with the increase of soil depth displays a low amount of salts in the deep soil, while, increases with the increase of temperature indicates high current flow.

1. Introduction
Rice is the staple food in most of the developing countries, including Malaysia. With the global demand for rice increases, paddy production must be sufficient to provide the current and future consumptions. Soil nutrients are one of the most critical factors that contribute to yields in paddy production. By measuring the soil nutrients, the amount of required fertilisers can be efficiently determined. Because; a suitable amount of fertilisers is essential for healthy plant growth. Nitrogen, phosphorus, and potassium fertilisers are the primary macronutrients for the paddy plant. Precision Agriculture (PA) offers management of soil properties, including soil nutrients for better crop quality and productivity, by utilizing the communication and information technology. Veris is the existing soil nutrient measurement technology in the field which used electrical conductivity (EC) measured in the soil to estimate the equivalent soil nutrients. This machine-based technology offers accurate measurement; however, it is expensive and requires laborious tasks. Thus, reliable and affordable technology has to be developed to complement the existing technology [1]. With the advancement of
the Internet of Things (IoT) technology, the evolution of an IoT-based EC sensing system in the paddy field using a smart farming application and treatment map is a possible alternative. An IoT-based system for smart farming applications is a tool designed to observe crops in the farm using wireless sensor nodes. This way, crop monitoring will be real-time and more accessible than the conventional approach [2]. The electrical conductivity (EC) sensing system is the most reliable and frequently used sensor to measure soil nutrients. Measurement of soil nutrients in the paddy field is crucial because of electrical conductivity (EC), and soil properties affect crop quality and yields.

2. Literature review
The soil's electrical conductivity is affected by the soil and the temperature of its surroundings [3]. The rise in temperature [3] causes an increase in soil electrical conductivity. As the temperature rises, the mobility of ions under electrostatic potential increases, resulting in higher EC value. The EC value generated from the path of current in the soil allows the mobility of charged ions. Ultimately, at a lower or cooler temperature of water or soil, the mobility of the ions decelerates and starts to idle, thus reducing the activity of the ions and eventually decreases the EC of the soil [4]. On the other hand, the amount of fertilisers in the soil also affects the value of EC [5]. In this work, the electrical conductivity or denoted as EC is described as the amount of electric current flow, as given in (1).

\[
EC_t = EC_{25} \left[1 + \alpha (t - 25)\right] \quad (1)
\]

Where \(EC_t\) is the conductivity at temperature, \(t \, (^{\circ}C)\), and \(EC_{25}\) is at 25°C. The \(\alpha\) is a temperature compensation factor obtained empirically based on soil water content and electrical conductivity (EC) value [6]. The EC determined using the EC sensor is recorded in millisiemens per centimetre (mS/cm). The value of EC depends on temperature; thus, EC measurements must correspond with water temperature. Usually, the equation is valid at a reference temperature (25°C) [7]. Although correlation among EC and temperature of the water being nonlinear, the degree of nonlinearity is too small and trivial for the relationship to be revealed [8]. Figure 1 demonstrates the relationship between electrical conductivity and water temperature. It noted that the EC is linearly related to the water temperature, which indicates that the temperature significantly affects the value of EC. So, for more precise soil nutrients computation, consideration should be given to these parameters when designed and exerted any EC-based measuring system.

![Figure 1. EC versus temperature variations [9].](image-url)

The amount of fertilisers used in the soil influences its electrical conductivity value—the EC measurement based on its soil salinity [5]. The EC described as the flow of current in the soil and
proportional to the total dissolved solids (TDS) in the soil. Generally, using fertiliser is a practical approach to enhance crop production, and a high degree of soil salinity will rise the EC of soil. However, the overuse of fertilisers can result in a salinity accumulation in the soil. Total dissolved solids (TDS) described as a parameter used to determine the number of dissolved substances in solution and the correlation with EC computed by the following equation [10].

$$TDS = k \times EC$$

Where TDS measured in part per million (ppm) and EC in mS/cm. The electrical conductivity typically used to calculate the TDS or salinity in irrigation water [11]. The value of k is TDS/EC ratio and will increase when the ions in water increase [10]. The most prevalent use of conversion factors between EC and TDS are 500 ppm, 640 ppm, and 700 ppm. The 500 ppm conversion factor happens based on how EC and TDS correlate to sodium chloride (NaCl), and the 700 ppm conversion factor happens according to the relationship between EC and TDS that associate to sodium sulphate (Na2SO4). While the 640 scale is a dimensionless value to illustrate small quantities includes mole and mass fractions. According to the guideline for water quality evaluation for irrigation, water with TDS values less than 450 mg/L and EC value less than 0.7 dS/m have a low salinity level and non-restrictions on use [11]. Specific k value for natural water for irrigation under 25°C is 0.55 – 0.75 g/L [10].

Table 1 summarizes various soil measurement techniques previous works done by others since 2011 [12]–[15]. Based on the literature, the best way to measure nutrients in paddy soil is through the soil's EC. Veris technology is one of the existing systems that used the EC to determine the soil nutrients. This work aims to address Veris's limitations by developing an IoT-based EC sensing system for paddy soil nutrients with the treatment map. IoT-based technology appears to have great potential to contribute towards determining soil EC. The benefit of the treatment map is that it cannot only analyse soil and crop properties using a variety of sensors with GPS-enabled to trace the sensor nodes' location for soil treatment mapping purposes. This way, specific points/locations in the paddy field with insufficient fertiliser or moisture can be easily identified for further actions. Although Veris technology can collect the data precisely, the IoT-based technology capable of making the data collection more effective and efficient due to its portability and remotely accessible. IoT-based technology appears to have great potential to contribute towards determining soil EC. Based on the literature survey, this work aims to develop a fully integrated EC-based sensing system for paddy soil nutrients with soil mapping capability. By implementing an IoT-based system in smart farming, the farmers can observe and collect data of soil EC and other soil properties such as temperature, amount of fertilisers, and salinity effectively. Therefore, smart farming technology helps to improve the growth of the plant.

**Table 1. Veris technology.**

| Author, Year | Methodology/Platform | Limitation |
|--------------|----------------------|------------|
| Schirrmann et al., 2011 [12] | Evaluating the Veris pH Manager Multi Sensor Platform (MSP) by monitoring plot from an approximately 10 cm depth together with GPS coordinates | Limited EC input parameters |
| Ezrin et al., 2016 [13] | Developing a system to determine NPK content in soil by measuring EC within depths of 0-30 cm for shallow ECa (ECas) and 0-90 cm for deep ECa (ECad). Site-specific area NPK mapping using Veris 3100 and global navigation satellite system (GNSS) produced by ArcGIS software | No IoT networking to transfer data wirelessly to the cloud platform |
| Hawkins et al., 2017 [14] | Measuring soil EC with maps using Veris 3100 from two different depths (1 foot and 3 feet) with position information provided by Global Positioning System (GPS) | No IoT networking to transfer data wirelessly to the cloud platform |
| Pei et al., 2019 [15] | Collecting soil apparent electrical conductivity (ECa) reading using Veris P4000 to a 1 m depth | No soil mapping to determine the soil profile effectively |
3. Materials and Methods
The block diagram in figure 2 illustrates the developed EC sensing system, and figure 3 represents the flow chart of the overall system operation. The system consists of a soil EC sensor and a soil temperature sensor as the sensor node and connected to the Arduino UNO microcontroller as the gateway node. The EC sensor (Atlas Scientific with K=10) senses electrical conductivity in the soil, while the temperature sensor measures the soil's temperature. These parameters are crucial for determining the soil nutrients before proposing the required amount of fertilisers. The ThingsBoard platform is an open-source IoT platform for device management, data compilation, processing, and visualization for IoT projects. This cloud database used to store all the data reading in the Thingsboard for further monitoring and analysis. The sensor node reads its corresponding electrical conductivity (EC) value and transmits the measured electrical conductivity (EC) values to the gateway unit via Long Range (LoRa) wireless transceiver. The gateway unit transmits data to the cloud for data backup and analysis purposes. The collected data or analysed data from the cloud server can be access via ThingsBoard cloud database by using user smartphones or computers.

![Figure 2. Block diagram of the sensing system.](image)

![Figure 3. Overall system operation.](image)
3.1. **Calibration of the EC sensor**

For first-time use, the electrical conductivity (EC) sensor must undergo a calibration process to ensure the sensor's accuracy. For this procedure, two calibration solutions are used, which are 12880µS/cm and 150000µS/cm. Figure 4 shows the experimental procedure for calibrating the EC sensor. The voltage (VCC) and the ground (GND) of the conductivity circuit connected to 5V and GND on the Arduino UNO board, respectively. Then, the receiver (RX) and transmitter (TX) of the conductivity circuit linked to digital pin 2 and ~3 of the Arduino UNO board. A yellow LED light on the Arduino UNO board, and green LED light on the EC meter will turn on when the power supply is connected correctly. Before using the EC sensor, the probe's cap first removed.

With the probe in the air, the command c,1, which will enable continuous readings once per second, is entered at the Arduino serial monitor command terminal (see Figure 5). Then the probe type is set using the command k,n where n is the k value of the probe. In this work, the EC probe with K =10 used. The probe with K=10 is suitable for measuring electrical conductivity in solid such as the soil in the paddy field as the probe made up of the platinum electrode. The probe type set in the system by entering command k,? from the terminal. First, the calibration starts by sending the command cal,dry to the terminal to set up the sensor's calibration when it is in the dry condition (no liquid/solid attached to it). During this stage, the sensor reading gives an EC measurement of 0.00. The command cal,clear, can be used to delete previous calibration data/readings. Next, the sensor calibrated with the manufacturer's provided two-point calibration solutions (Low (12,880 µS), high (150,000µS)). During this step, each of the calibration solutions poured into different beakers. Then, the sensor probe with the temperature sensor is placed into the beaker (see Figure 4) and stirred around to remove any trapped air. The probe then remains in the solution for stable readings, and then the command cal,n where n is the value of the calibration solution, is entered from the terminal. Note that the temperature has a vital impact on EC values. The Atlas Scientific conductivity probe has its temperature set to 25°C as the default. The solution temperature confirmed with command T,?.

![Figure 4. Connection diagram of the sensing system.](image-url)
After performing the calibration steps, the calibration process continues with the second calibration solution by following the same procedures as conducted on the first calibration solution—the electrical conductivity calibration pseudocode listed in Figure 5.

```
Connect the Conductivity Circuit to Arduino UNO;
Upload the code to Arduino IDE;
Set the baud rate for the software serial port;
Set the number of sample times;
Set the probe type;
The serial monitor prints the value of EC;
If input the 'cal,dry' command, then
The serial monitor prints "0.00"
If input the 'cal,clear' command, then
The serial monitor deletes the calibration data
Set the temperature;
If input the 'cal,n' command, then
The serial monitor prints the EC of the calibration solution
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**Figure 5.** Pseudocode for the electrical conductivity (EC) calibration routine.

### 3.2. Laboratory soil testing

The soil samples collected from the paddy field in Kampung Ladang, Kuala Perlis, from a random location (6.385917, 100.166722) at two different depths: 0cm-10cm and 10cm-20cm. The soil samples scoped using a spoon into containers, and the containers are then labelled. For EC measurement, the soil sample is stirred with the probe for 30 seconds, and the probe remained to stand in the mud for 25 minutes to get a stable reading. The EC probe then rinsed with distilled water, and the steps repeated for other soil samples. This work used NAFAS 17.5:15.5:10 fertiliser compound where the 17.5:15.5:10 ratio represents as NPK composition, which is 17.5% nitrogen (N), 15.5% phosphorus (P\textsubscript{2}O\textsubscript{5}) and 10% potassium (K\textsubscript{2}O). Table 2 shows the percentage of elements found in all three N:P:K composition, as reported by Mikkelsen et al. [16]. The value of nitrogen (N) in the N:P:K composition represented as the actual nitrogen percentage, so it does not need to convert. The phosphate contains 56% elemental of oxygen and 44% elemental of phosphorus; thus, the phosphorus percentage is 0.436 times its P value. The potassium consists of 17% oxygen elemental and 83% potassium elemental, and this shows that the potassium percentage is 0.83 times its K value. Then, the actual percentage of three individual nutrients are as follows:

- 17.5% elemental of nitrogen.
- \(0.44 \times 15.5 = 6.82\%\) elemental of phosphorus.
- \(0.83 \times 10 = 8.3\%\) elemental of potassium.

#### Table 2. N: P: K element percentage [16].

| Composition | Percentage of Elemental                  |
|-------------|-----------------------------------------|
| N           | Nitrogen                                |
| P\textsubscript{2}O\textsubscript{5} | 56% of Oxygen, 44% of Phosphorus         |
| K\textsubscript{2}O | 17% of Oxygen, 83% of Potassium            |
4. Results and discussion

4.1. Result of Electrical Conductivity (EC) sensor calibration

This section discusses the accuracy of the electrical conductivity (EC) sensor from the performed experiments. Table 3 summarizes the calibration results of the EC sensor. Two standard buffer solutions used; 12880µS/cm and 150000µS/cm during the calibration process. The calibration solutions examined on the developed system and the related values recorded. The results indicate that the percentage differences in both calibrated solutions are less than 0.02%, which followed the sensor manufacturers' suggested values.

| Temperature (°C) | 12880 µS/cm Calibration Solution | 150000 µS/cm Calibration Solution |
|------------------|----------------------------------|-----------------------------------|
|                  | Measured EC (µS/cm) | Expected EC (µS/cm) | Difference (Expected - Measured) | Measured EC (µS/cm) | Expected EC (µS/cm) | Difference (Expected - Measured) |
| 5                | 8220               | 8220                 | 0                                | 94002              | 94000               | -2                               |
| 10               | 9330               | 9330                 | 0                                | 108000             | 108000              | 0                                |
| 15               | 10478              | 10480                | 2                                | 121983             | 122000              | 17                               |
| 20               | 11670              | 11670                | 0                                | 135983             | 136000              | 17                               |
| 25               | 12880              | 12880                | 0                                | 149983             | 150000              | 17                               |
| 30               | 14120              | 14120                | 0                                | 164000             | 164000              | 0                                |
| 35               | 15548              | 15550                | 2                                | 177983             | 178000              | 17                               |
| 40               | 16877              | 16880                | 3                                | 191967             | 192000              | 33                               |
| 45               | 18210              | 18210                | 0                                | 206000             | 206000              | 0                                |
| 50               | 19550              | 19550                | 0                                | 220967             | 221000              | 33                               |

Figures 6 and figure 7 show that the temperatures plotted on the horizontal axis and the electrical conductivity (EC) values plotted on the vertical axis. The EC values of both calibration solutions are directly proportional to the recorded temperature. It also noted that the current flow increases with the temperature, as explained in (1).

**Figure 6.** Scatter plot showing a range of EC readings for 12880 µS/cm calibration solution.
4.2. Result of laboratory soil EC
The section discusses the investigation of the relationship and properties between the EC readings versus the depth of the EC sensor’s probe placement in the soil and the effect of applying fertiliser onto the soil. All results were recorded and summarized as in Table 4. The conversion method of EC values to the corresponding ppm values formulated using TDS conversion, as described by (2). Based on the experimental, it realized that the soil EC is inversely proportional to the depth of soil and directly proportional to the amount of nutrients. High EC values display a high amount of salts or nutrient concentration in the soil.

Table 4. Soil electrical conductivity (EC) results.

| Depth     | 0 - 10 cm | 10 - 20 cm |
|-----------|-----------|------------|
| Fertiliser| Without   | With       | Without   | With       |
| EC (µS/cm)| 54696     | 55268      | 52048     | 53131      |
| Temperature (°C) | 28.0   | 28.5       | 26.5      | 28.0       |
| EC (mS/cm)| 54.696    | 55.268     | 52.048    | 53.131     |
| TDS (ppm) | 35005     | 35372      | 33311     | 34004      |

Figure 8 shows that the depths of soil with fertiliser plotted on the horizontal axis, whereas the electrical conductivity (EC) values are plotted on the vertical axis. The EC values for both depths are higher with fertiliser than those without fertiliser. However, the EC values for a soil depth of 0-10cm are higher than those with 10-20cm depth. The EC value decreases with the increase of soil depth and increases with the increase of the nutrient concentration level.
5. Conclusion and future work
The development of soil electrical conductivity (EC) sensing system is significant to determine the amount of fertiliser. The optimum amount of fertiliser could be an essential approach to increase the paddy yield. This sensing system comprises of Arduino UNO R3 microcontroller and Atlas Scientific EC sensor. The sensing system performed the EC calibration on two calibration solutions before performing the laboratory soil sample test. First, the EC algorithm was designed and executed on the microcontroller. Second, the EC sensor calibrated using two calibration solutions, which are 12880µS/cm and 150000µS/cm. Third, the EC sensor performed laboratory soil sample test using soil samples collected from the paddy field at two different depths (0cm-10cm and 10cm-20cm), which contain fertiliser and without fertiliser. Based on the results obtained, the soil temperature affects the EC values. The calibration solution readings were off by +/- 40% and almost the same as the value of the calibration solutions manufacturer's datasheet. The results displayed that soil EC is inversely proportional to the depth of soil and linearly related to the amount of nutrients. For future improvement, the sensing system suggested building with a GPS module such as using the TTGO T-Beam microcontroller to generate a nutrient treatment map and implement the system through ThingsBoard platform to record all soil parameters for ease of monitoring and analysis.

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