# Calibration of Capacitive Soil Moisture Sensor (SKU:SEN0193)

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***Abstract*— The new model of a soil moisture sensor is capacitance type sensor which designed from two parallel-plates, in which, soil being measured is located between both electrodes and act as a dielectric material of the capacitor. The sensor model is claimed with a number of advantages especially to solve the problem on the application of conductance type sensors. SKU:SEN0193 is one of a low cost soil moisture sensor which is available on the commercial market. Before applied, it is necessary to know the performance and characteristic of the sensor for local soil application. The purpose of this research is to calibrate the soil moisture sensor for soil humidity measurement. For this, the sensor coupled with such signal conditioning circuit is connected to an Arduino microcontroller and LCD for data acquisition system. The sensor responses to varied moisture of soil samples are compared to the gravimetric methods. In this research, the sensor is calibrated for sandy loam soil texture obtained from Bangka Regency. The result showed that soil moisture content readings by SKU:SEN0193 is not affected by different volume of soil and soil temperature, but is little affected by ambient environmental temperature conditions. There is direct relationship between the soil moisture content (y) and the sensor response (x), sensor performs well so it can be used to measure the moisture content of sandy clay soil sample.**

***Keywords— soil moisture sensor, moisture content, capacitive sensor, calibration***

## I. INTRODUCTION

Water and soil are natural resource that have a huge role as supporting life in the biosphere. The interaction energy between both compounds are important in order to maximize the function and role of each. According to [1], inside of soil, water has position as ground water and soil water. Ground water is stored in aquifer layer as free water that can be used directly, while soil water is categorized as non-free water since it is bound by the force of adhesion and cohesion which are located inside the pores spaces of the soil.

Water availability in the soil, either as ground water or soil water, is influenced by physical properties of soil such as structure, texture, porosity and fraction. Those properties indirectly effect on the soil water holding capacity. The availability of soil water can be measured by direct and indirect method [2]. Measurement of the soil water level with direct method can be determined by using the mass difference of soil sample between before and after dried. While, determining the soil water using indirect method is usually conducted by using calibrated variable which has relation to the water content.

Direct method for soil moisture measurement bases on the separation of water from the soil matrix. The separation can be conducted by three methods: (1) heating, (2) extraction and replacement by a solution, or (3) a chemical reaction. The amount of separated water is determined by: (1) measuring the change of mass (weight) after heating, and (2) a quantitative reaction result. The separation of water through heating called as gravimetric method that include as direct measurement.

According to [3], indirect method is a method to measure soil moisture content from some physical or chemical properties of the soil related to the parameter. The indirect method predicts the soil moisture content of sample based on the change of soil water electrical properties, which varies according to the changes of soil validity [4]. Since that it can measure continuous, the method is able to be use for monitoring purpose, thus it is often called as non-destructive approach. The method can be done by using some approaches, namely dielectric constant (relative permittivity), electrical conductivity, heat capacity, the H-ionic content and magnetic sensitivity. Indirect method is non-destructive measurement because it does not change the water from soil during measurement. This measurement is divided into two methods. The first is called as conductance method, by which, a sample being measured, is placed two electrodes. Electrical current is flowed on the two electrodes. The second is conducted by using two parallel plates, then the sample being measured is placed between both electrodes. The plates are

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functioned as capacitor where the sample of material works as a dielectric material. Thus, the moisture content of the sample is predicted from the capacitance of the capacitor. The second approach is also called as capacitance method.

Today sensors for soil moisture measurement are available in market, not only conductance type sensors but also capacitance type sensors. Among them, capacitance type sensors may have advantages due to their ability to minimize the influence of ionic activities which commonly happened in cultivated soil. Since that computing water balance of a soil system is very complex because soil water move in a multidirectional process [5], calibration of the sensors on target soil where they will be applied is necessary. Therefore, the objective of this study is to calibrate a capacitive soil moisture sensor for local soil.

## II. Materials and Methods

### A. Experimental Site

This study was carried out in Laboratory of Land and Water Resources Engineering, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada.

### B. Tools and Materials

The materials used are: the soil with sandy loam structure (39.3% of clays, sand 47.5% and 13.2% silt); container (18.5 cm diameter and 14.3 cm of high); scales with 0.01 accuracy level; and the oven; and a set of soil moisture sensor completed with appropriate data acquisition device (consists of microcontroller Arduino, liquid crystal display and real time clock).

Soil moisture sensor used being calibrated is SKU:SEN0193, product from DF Robot (Fig. 1). This sensor is one of capacitive soil moisture sensor with small-thin size. Refers to [6], this sensor is made of corrosion resistant material which gives it an excellent service live. This module includes an on-board voltage regulator which gives it an operating voltage range of 3.3-5.5 V. The output of this sensor is given as frequency variables range from 260 Hz (high moisture) until 520 Hz (low moisture). The sensor is calibrated by using gravimetric method.

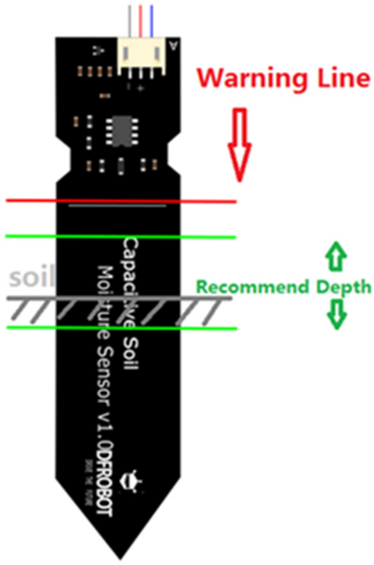


Fig. 1. Capasitive Soil Moisture Sensor SKU:SEN0193

### C. Research Procedure

This study was conducted in a series of stages. The research begins with literature study, followed by designing of the experimental hardware, namely as a sensor system, which consists of a set of capacitive soil moisture sensor, signal conditioning circuit, and data acquisition system. After the hardware has functioned properly, the study continued with the calibration stage. In this case, the sensor system is used to sense the soil samples that have been prepared. Sensor response in the form of voltage data (conversion from frequency data) is recorded. The actual moisture of samples is measured with gravimetric approach. Both data of sensor system and gravimetric are then compared and analyzed. By using regression, appropriate calibration trend can be obtained from the analysis. Procedure of this research is shown on Fig. 2.

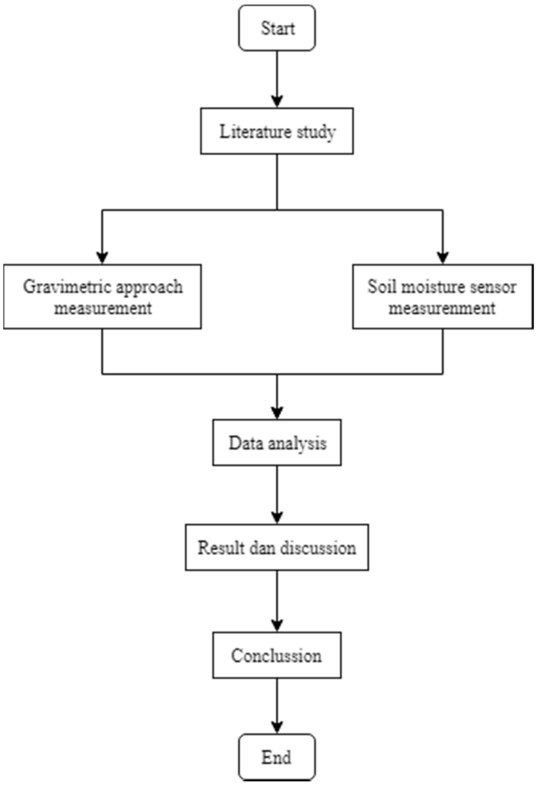


Fig. 2. Research procedure

Measurement of soil moisture content by gravimetric approach is conducted as follows. First, prepares five container/pot then weighed each of weight empty pot. Second, prepare dry soil samples and put in each pot and then weighed as pot and dry soil. Third, soak the pot which containing dry soil for 24 hours until the soil became saturated then weighted as pot and wet soil. The soil in pot is weighed once a day during 8 days data retrieval. Degradation of soil weight in the pot is defined as water that evaporates within one day of experiment. Then, the soil moisture content is calculated with the following equation:

$$Soil\ moisture\ (\%) = \frac{weight\ of\ water\ contained\ in\ the\ soil}{weight\ of\ dry\ soil\ samples}$$

$$Soil\ moisture\ (\%) = \frac{(b-a)-(c-a)}{(c-a)}\ x\ 100\%$$

Where a is weight of the empty pot (gram), b is weight of pot and wet soil (gram), c is weight of pot and dry soil (after evaporated in the oven for 24 hours) (gram).

## III. Result and Discussion

Calibration of the soil moisture sensor is performed by using different treatment on temperature and volume of soil sample. Both treatments are selected in this calibration because these two factors play important role in the field. There are five sensors tested, so the experiment obtains five data replications on each treatment. Before conduct experiment, the stability of the sensor is tested. The test is done by recordimg data of soil moisture on saturated and dried soil sample for 20 minutes with a minute of period. The result of this test is presented on Fig.1. It shown that the sensors perform well with stable data.

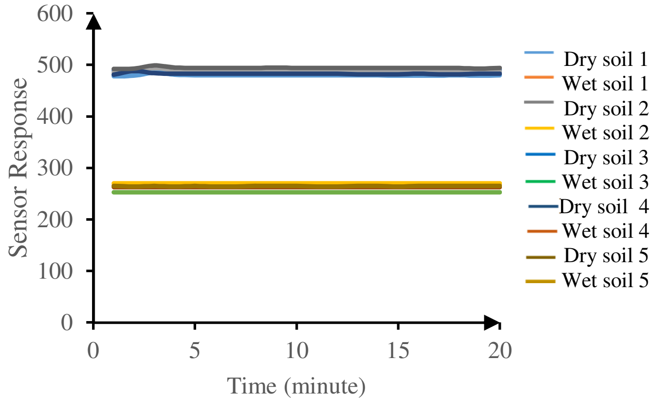


Fig. 3. Graph stability sensor readings SKU: SEN0193

For testing sensor with different treatment of volume, two different size of pots are prepared, i.e. pot with a diameter of 8 cm (small pot) and 20 cm (large pot). We prepare 5 pots per each size category and those are placed in outdoor and indoor to vary different soil temperature. The average indoor temperature is 26 °C and the average outdoor temperature is 30 °C. Data retrieval starting from saturated soil condition until soil moisture content reaches 10%. With gravimetric approach, the soil samples with 10% of moisture content is dried in an oven with a temperature of 105°C for 24 hours.

Actual soil moisture content of sample is analized using data of water mass in the soil and dry soil weight. From the results of the measurements, then calculated using Equation 1 (Eq. 1). The test results for each treatment are plotted on the graphs then do the power regression analysis, because the data trendline is formed on the chart follows the trendline of power regression. The power regression equations obtained are presented in Table 1.

TABLE I. Calibration of Soil Moisture Sensor Testing by using Different Treatment of Soil Volume (Indoor)

| Treatment | Sensor | Calibration Equation | $R^2$ |
|---|---|---|---|
| Small pot indoor | 1 | $33950x^{-2.015}$ | 0.981 |
| | 2 | $37196x^{-2.048}$ | 0.975 |
| | 3 | $9737.9x^{-1.839}$ | 0.982 |
| | 4 | $621995x^{-2.54}$ | 0.966 |
| | 5 | $33712x^{-2.022}$ | 0.972 |
| Large pot indoor | 1 | $26861x^{-2.008}$ | 0.988 |
| | 2 | $18555x^{-1.94}$ | 0.983 |
| | 3 | $19754x^{-1.95}$ | 0.979 |
| | 4 | $3E+06x^{-2.927}$ | 0.842 |
| | 5 | $19010x^{-1.964}$ | 0.989 |

Large pot indoors sensor number 4 obtained value $R^2$ below 0.9 (from Table 1). This result indicates an error on the use of the sensor that causing inaccurate readings of soil moisture content by the sensor. It can be said that one of these samples can not be used for further validation. The above results also show the equations obtained based on each sensor. Table II shows the result of calibration analysis on outdoor treatment obtained value of $R^2$ on small pot sample all repetition value which close to same for other sensors that is above 0.9. This value indicates that the capasitance value can describes the moisture content of the soil. as well as on the large pots treatment.

From these results there is a difference in the value of r between small pots and large pots. But the difference can not says there is a significant difference between the two, therefore it's necessary to be validated using SPSS analysis. SPSS analysis is done by determining correlation coefficient value and calculation of error value on each sensor. From that analysis, each sensor has a different equation so that further analysis is validation. The result of validation shown in Table III.

Analysis by using the correlation coefficient (R) is a number that describes the relationship between X axis and Y axis. The results of which the correlation analysis presented in Table III shows almost all relatively high R values that is in the range above 0.98, but in large pot indoors for sensor number 4 it is seen that the correlation coefficient is the lowest at 0.91 where it indicates that the strength of the second relationship the variable is weaker due to error reading. Coefficient correlation has a positive value that means both variables have direct relationship.

In addition to analysis of correlation coefficient to see the error caused by sensor readings and know that sensor readings are really precise, it is necessary to analize the deviation value on sensor readings. The value of the obtained deviation is the difference of sensor readings with the actual value so that the resulting readings are added or subtracted, then the result will be precision. The value of the deviation is obtained from the difference between the value obtained from the data retrieval and the predicted value of the equation obtained during the analysis of the relationship of the two data.

TABLE II. CALIBRATION OF SOIL MOISTURE SENSOR TESTING BY USING DIFFERENT TREATMENT OF SOIL VOLUME (OUTDOOR)

| Treatment | Sensor | Calibration Equation | $R^2$ |
|---|---|---|---|
| Small pot-outdoor | 1 | $46355x^{-2.138}$ | 0.984 |
| | 2 | $345996x^{-2.489}$ | 0.986 |
| | 3 | $8E{+}06x^{-3.048}$ | 0.976 |
| | 4 | $50564x^{-2.156}$ | 0.983 |
| | 5 | $8E{+}06x^{-3.051}$ | 0.978 |
| Large pot-outdoor | 1 | $34706x^{-2.092}$ | 0.972 |
| | 2 | $46016x^{-2.144}$ | 0.971 |
| | 3 | $73671x^{-2.224}$ | 0.987 |
| | 4 | $40291x^{-2.119}$ | 0.978 |
| | 5 | $57224x^{-2.18}$ | 0.984 |

TABLE III. VALIDATION OF SOIL MOISTURE SENSOR TESTING BY USING DIFFERENT TREATMENT OF SOIL VOLUME

| Treatment | Sensor | R | RMSE |
|---|---|---|---|
| Small pot outdoor | 1 | 0.992 | 0.97 |
| | 2 | 0.993 | 0.53 |
| | 3 | 0.988 | 1.23 |
| | 4 | 0.992 | 0.96 |
| | 5 | 0.989 | 0.77 |
| Large pot outdoor | 1 | 0.986 | 1.42 |
| | 2 | 0.985 | 1.30 |
| | 3 | 0.993 | 0.90 |
| | 4 | 0.989 | 1.10 |
| | 5 | 0.992 | 1.12 |
| Small pot indoor | 1 | 0.990 | 1.19 |
| | 2 | 0.988 | 1.15 |
| | 3 | 0.991 | 1.19 |
| | 4 | 0.983 | 1.31 |
| | 5 | 0.986 | 1.74 |
| Large pot indoor | 1 | 0.994 | 1.56 |
| | 2 | 0.992 | 0.84 |
| | 3 | 0.989 | 1.12 |
| | 4 | 0.918 | 2.09 |
| | 5 | 0.994 | 1.00 |

At the small pot treatment, the highest error value on the sensor number 5 that placed indoor is 1.74. At the large pot treatment, the highest error value on the sensor number 4 that placed indoor reaches 2.09. The greater the error value indicates that each sensor is used in the sample, the precision reading for the sensor must be increased or reduced by the error. Through the validation results note that the differentiation of soil volume does not affect the result of reading the capacitance value by the sensor. it can be known from the high correlation value and small errors in both treatments. while for indoor treatment (26 °C) has a high error both in small pots and on large pots compared to outdoor treatment. for it is necessary to know the effect of temperature to the reading of capacitance value by the sensor.

Calibration of soil moisture sensor testing by using temperature treatment of soil is done by using pots with a diameter of 8 cm (small pot) in 40 °C. To know the effect of temperature, the treatment of capacitance value reading when the soil at 40°C, where the soil in the oven in advance at the temperature 65-68 °C. The result of calibration obtained are presented in Table IV. Results of sensor calibration to the soil temperature treatment of 40 °C obtained the same $R^2$ value on the five sensors that is in the range 0.97. The value is considered very high because almost close to 1 so proceed to be validated using SPSS analysis.

TABLE IV. CALIBRATION OF SOIL MOISTURE SENSOR TESTING BY USING TEMPERATURE TREATMENT (40 °C)

| Treatment | Sensor | Calibration Equation | $R^2$ |
|---|---|---|---|
| Temperature 40°C | 1 | $1050.3x^{-1.489}$ | 0.969 |
| | 2 | $3435.5x^{-1.68}$ | 0.974 |
| | 3 | $3882.5x^{-1.711}$ | 0.974 |
| | 4 | $2118x^{-1.611}$ | 0.977 |
| | 5 | $1679x^{-1.558}$ | 0.968 |

TABLE V. VALIDATION OF SOIL MOISTURE SENSOR TESTING BY USING TEMPERATURE TREATMENT (40 °C)

| Treatment | Sensor | R | RMSE |
|---|---|---|---|
| Temperature 40°C | 1 | 0.984 | 0.89 |
| | 2 | 0.987 | 0.78 |
| | 3 | 0.987 | 0.72 |
| | 4 | 0.988 | 0.69 |
| | 5 | 0.984 | 0.99 |

At the treatment of temperature of soil 40° C obtained error values are almost similar on all sensors that is below 1. The smallest error value is on sensor 4 is 0.68. For the largest error value is on the sensor 5 is the value 0.99. This indicates that the higher temperature treatment does not affect the reading of the capacitance value by the sensor. the resulting error value is smaller than the reading at room temperature (26 °C).

By testing the calibration equation of each sensor on each test is obtained. To simplify the use of calibration equations simplified equations by finding the combined equations of each highly validated test (low error value). In simple way, the relationship between actual soil moisture and sensor response for all treatments are presented in the Fig.4 to Fig.8.

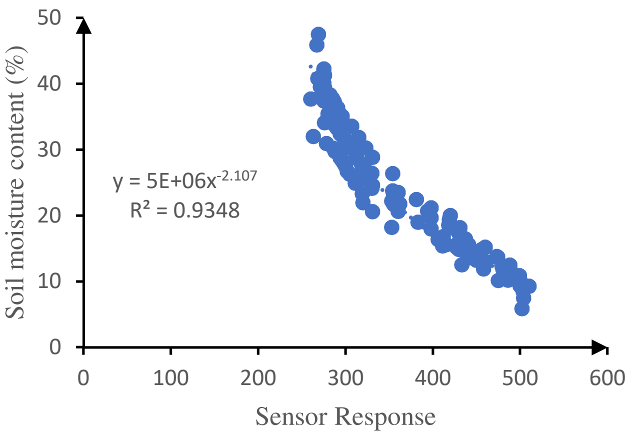


Fig. 4. Combination of power equation on small pot indoor (26 °C)

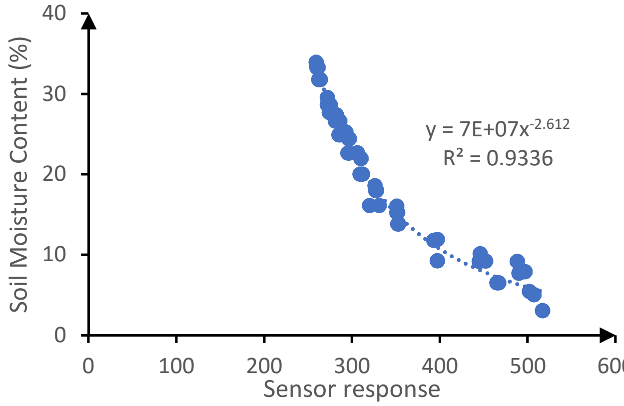


Fig. 5. Combination of power equation on small pot outdoor (30 °C)

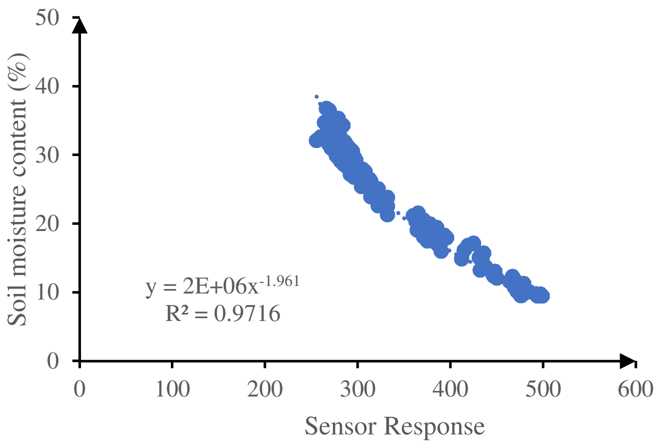


Fig. 6. Combination of power equation on large pot indoor (26 °C)

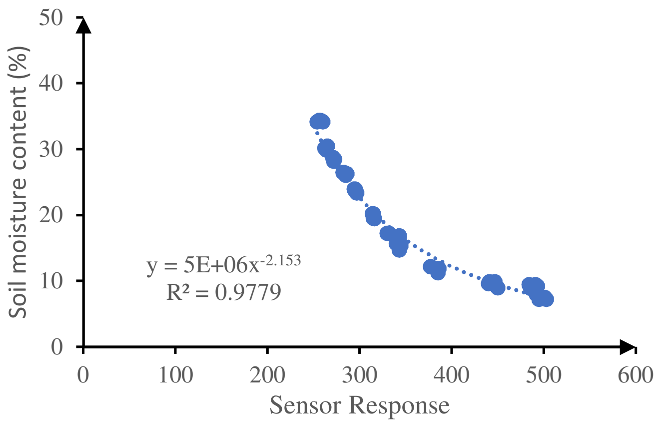


Fig. 7. Combination of power equation on large pot outdoor (30 °C)

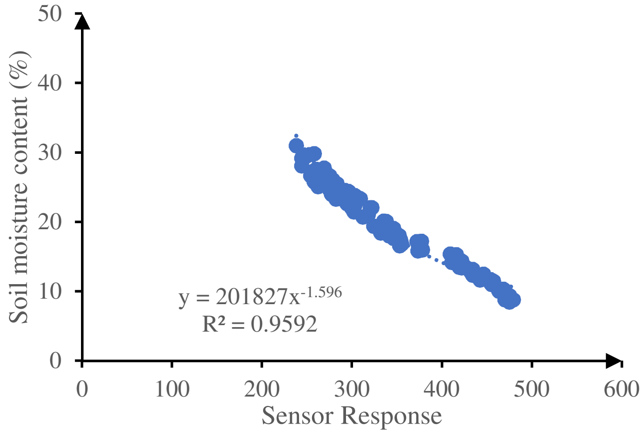


Fig. 8. Combination of power equation on small pot (40 °C)

Fig.4 presents combination power equation on small pot indoor. $R^2$ value obtained from power trendline is 93.48%. It means that 93.48% variation of soil moisture content can be explained by variable capacitance while the remaining is influenced by unknown variables. Fig. 5. $R^2$ value is 93.36%, Fig. 6. $R^2$ value is 97.16%, Fig. 7. $R^2$ value is 97.79%, Fig. 8. $R^2$ value is 95.92%. The closest relationship to the large pot treatment outside the room with $R^2$ value 97.79% and power line equation $y = 5E{+}06x^{-2.153}$.

## IV. Conclusion

Based on the test results and analysis of the data, it can be concluded that the capacitive soil moisture sensor of SKU:SEN0193 has good response to the moisture change of the local soil. With simple regression, relationship between actual soil moisture (y) and sensor response (x) of indoor (26 °C) for small pot is $y = 52206x^{-2.107}$ ; large pot is $y = 2E{+}06x^{-1.961}$. while for outdoor (30 °C) for small pot is $y = 669288x^{-2.612}$ ; for large pot is $y = 5E{+}06x^{-2.153}$. It means that the sensor performance is is not affected by soil volume and is little affected by ambient environmental temperature conditions.


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