Design and characterization of capacitive sensor for soil water content measurement

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Abstract. Soil water content is one of the measurable parameters which can be used as a reference in the selection of efficient land use. The methods used for measure the soil water content is gravimetric method which is commonly used for direct measuring and indirectly method with the measurement of traits related to water content, namely the dielectric constant (relative permittivity). Interdigital capacitor sensor is designed as a unit of measurement of soil water content. Interdigital capacitor sensor (IDC-S) is a capacitive sensor which is able to change the value of the physical parameters to electrical quantities (capacitance). The measurement of IDC-S capacitance value of soil water content variety was done. It is shown that greater percentage of soil water content cause greater value of capacitance. The greater number of sensor electrode increases its sensitivity. IDC-S has sensitivity of 5.589 pF for N=200 electrodes, 4.6362 pF/% for N=150 electrodes and 3.8865 F/% for N=100 electrodes.

1. Introduction
Soil has various function in various fields of life such as agriculture, settlements, or even tourism. In the construction field, soil has an important function as a supporter of the strength of a building structure, such as buildings, transportation facilities, etc. Study of soil properties is essential in the selection of efficient land use. Physical and mechanical properties of soil that affect the carrying capacity is soil water content [1]. In the determination of appropriate land use, soil water content has an influence on soil stability. When the rainfall rate is high, the water content in the soil will increase. Increased water content in the soil that cause by can stretch the bond between the soil and eventually push the soil details to the landslide [2]. The increase in soil water will reduce the physical and mechanical properties of the soil and increase the pore pressure (μ) which will reduce the shear resistance of the slope mass which eventually decreases the slope stability factor [3].

The soil condition can be determined by measuring the electrical and physical properties of the soil as an indicator [4]. One of the methods to obtain information about soil conditions is to utilize the dielectric properties of the soil. Utilization of soil electrical properties can be done using capacitive sensors. Capacitive sensors worked by utilizing the change capacitive value, which is caused by the change of geometric or materials of dielectric. Capacitive sensor has been widely used in various applications. Research of capacitive-based sensor utilizing dielectric-capacitance has been done as in water level measurement [5], water content of bricks [6], and determination of sugar content in sugar solution [7]. On this research, capacitive sensor will be used to detect changes in water content of soil. Changes in soil composition as a dielectric material will affect the sensor’s capacitance value.
Based on ASTM D4643, water content of soil is the amount of water contained in soil, commonly expressed as mass ratio of water and dry soil or volume ratio of water and soil. Water content of the soil is one of the measurable parameters which can be used as a reference in the selection of effective land use. The direct measurement of water content is done by measuring the quantity of water which separated from the soil matrix. The indirect method is done by measuring the physical or chemical quantity of soil which is related to its moistures content. These quantities include dielectric constant (relative permittivity), electrical conductivity, heat capacity, hydrogen ion content and magnetic sensitivity. The indirect method is non-destructive so that the water content in the sample does not change during measurement [8].

Research on capacitive sensors are designed with the model of Interdigital Capacitor Sensor (IDC-S). This sensor works based on the periodic coplanar electrodes. Operationally, the IDC-S principle is similar as parallel plate capacitors [5]. One of the poles are connected to power source and the other is connected to the ground. Stimulus on dielectric field, will change in the sensor capacitance. The sensor geometry parameters are shown on Figure 1.

Figure 1. indicates the electrode geometry parameters, namely width (W), gap width between the electrodes (G), length (L), periodic electrodes (λ), and number of periodic electrodes (N). IDC-S capacitance value can be calculated using the equation (1) [9].

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C = \frac{\varepsilon_0 \varepsilon_r (L \cdot W \cdot N)}{G \cdot (N - 1)}
\]

2. Methods

2.1 Making of Interdigital Capacitor Sensor

*Interdigit Capacitor Sensor* (IDC-S) was made on three different configurations with specification shown on Table 1.

| Sensor     | L  | W  | G  | N  |
|------------|----|----|----|----|
| Configuration 1 | 10 | 0.3 | 0.3 | 100 |
| Configuration 2 | 10 | 0.3 | 0.3 | 150 |
| Configuration 3 | 10 | 0.3 | 0.3 | 200 |
Interdigit Capacitor Sensor (IDC-S) is printed on FR-4 (Flame Resistant 4) printed circuit board made of a fiber glass coated in epoxy resins with a layer made of copper. FR-4 has a low water absorption property, great insulation properties and temperature resistant up to 140°C. This material has a great physical durability with those of 4.75 F/m relative permittivity. The results of Interdigit Capacitor Sensor (IDC-S) printing is shown on Figure 2.

![Printing result of Interdigital Capacitor Sensor (IDC-S) on PCB FR-4; (a) Configuration 1, (b) Configuration 2 dan (c) Configuration 3.](image)

**Figure 2.** Printing result of Interdigital Capacitor Sensor (IDC-S) on PCB FR-4; (a) Configuration 1, (b) Configuration 2 dan (c) Configuration 3.

### 2.2 Sensor Characterization

The characterization of Interdigital Capacitor Sensor (IDC-S) to changes in soil water content was done by measuring the capacitance value of the IDC-S which was given addition of dielectric. Capacitance measurements is done using the standard capacitance meter. Dielectric used in this study is clay soil with water content variation of 0-70%.

The variation soil moisture content of test samples obtained by weighing samples of clay before and after drying. Drying process is done using oven with temperature 105-110 °C until the moisture content of the soil is lost. The dry clay then added to the water. The addition of water is adjusted to the desired percentage of water content. In this study, clay soil samples were made in 0%, 10%, 20%, 30%, 40%, 50%, 60% and 70% water variation. Scheme of sensor characterization is shown on Figure 3.

![Scheme of sensor characterization](image)

**Figure 3.** The Scheme of IDC-S Capacitance Characterization on Variety of Soil Water Content
3. Results and Discussion
The experiment using three different configuration of IDC-S shows the relation between capacitance of IDC-S and variation of soil water content, as shown on Figure 4.

**Figure 4. The Relation of Capacitance and Soil Water Content**

Figure 4 shows that the capacitance of IDC-S with three different configurations is increasing along with the increase of water content of the soil. The increase in capacitance value caused by the addition of dielectric, which is soil with a certain water content.

The dielectric that filled the gap between IDC-S electrode was in an electric field. The electric charge of the dielectric has a slight shift from its equilibrium position, resulted in dielectric polarization. This polarization caused an internal electric field (in dielectric material) opposed the electric field enclosing them, thus decreasing of total electric field enclosing the dielectric. For a certain amount of charge on conductor strips in the capacitor, decrease in the electric field around the capacitor causes the potential becomes smaller and the ratio Q/V is getting larger, resulted in the increase of IDC-S capacitance. The soil is the dielectric of the IDC-S. The greater soil water content will cause the greater dielectric constant, because water is polar dielectric material which its electric charges will easily polarized in an electric field. The increasing water content of the soil means the increase of polarized charge and eventually make a greater electric field induction resulting in greater IDC-S capacitance.

Figure 4 shows that the relation between capacitance of the sensor and water content of the soil resulting a positive linear regression. The correlation coefficient is $R^2 = 0.9826$ for sensor with N = 200 electrode configuration, $R^2 = 0.9549$ for N = 150 and $R^2 = 0.9713$ for N = 100. The linear regression between the sensor capacitance and soil water content inform the sensitivity and offset value of the sensor. The configuration of the sensor will affect its sensitivity. Sensor with greater number of electrodes will have greater sensitivity. Linear regression for IDC-S with a configuration of N = 100 ($y = 3.8865x + 563.78$) with y is IDC-S capacitance value and x is the percentage of water content, shows that IDC-S can convert 1% of soil water content change to 3.8865 pF of capacitance change. This indicates that IDC-S has a sensitivity of 3.8865 pF per percentage of soil water content and its offset value is 563.78 pF. Linear regression for N=150 IDC-S configuration ($y = 4.6362x + 655.61$) indicates that the sensor can convert 1% change of soil water content to 4.6362 pF capacitance change, which means this sensor have sensitivity of 4.6362 pF/% and offset value of 655.61 pF. The regression N=200 IDC-S sensor
configuration can convert 1% change of soil water content to 5.589 pF capacitance change. This sensor has sensitivity of 5.589/\% and offset value of 1141.3 pF.

4. Conclusions
The results obtained from the experiment shows that the increase of soil water content affect the increase of sensor capacitance. Sensor capacitance has a great correlation to the water content of soil which is created with standard gravimetric method. Furthermore, the capacitance value of sensor is affected by its geometry parameters. The greater the number of sensor electrode then the greater its sensitivity in measuring water content of the soil. IDC-S with a configuration of N = 200 have greater sensitivity 5.589 pF/\% compared to IDC-S with a configuration of N = 100 and N=150 with sensitivity of 3.8865 pF and 4.6362 pF/\%.

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