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Key words: *generalized Zhurkov equation, errors, durability prediction, thermal fluctuation concept, economic efficiency*

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INCREASING THE MEASUREMENT OF SOIL WATER CONTENT WITH THE CHARACTERIZATION OF MAGNETIC FIELD INDUCTION SENSORS USING MODEL EQUATIONS FOR THE INTERNET OF THING APPLICATION

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This study proposes an increase in the measurement of soil water content with sensor characterization that can be integrated with the internet of things. The main contribution of this work is the improvement in measurement accuracy compared to measurements using a moisture meter. This is achieved through an electromagnetic approach using a pair of transceiver coils as a sensor. Determination of water content in the soil is carried out through the formulation of an equation model that connects the measured voltage on the receiving coil with the mass of water contained. It is known that the use of the equation model in the test data results in better accuracy with an error of 2.03% - 17.43%, compared to measurements using a moisture measuring device with an error of 13.21% - 32%. This equation model that uses the electromagnetic method provides an alternative solution for determining the soil water for wider land use so that can be used for internet of things application.

Key words: measurement, soil content water, sensor characterization, magnetic field induction, equation model, internet of things

INTRODUCTION

The soil is composed of minerals, organic material, air, and water, with each performing a role in plant growth and development [1,2]. Among these components, water has a significant function as a delivery system, and in the activation of nutrients needed for plant growth and development [3,4]. Therefore, information about the water content in the soil is very important. Various approaches have been developed to measure the volume of water using different techniques, such as thermo-gravimetric, calcium carbide, dielectric capacitance, electrical impedance sensor, tension meter, optical and thermal remote sensing [5,6,7]. In [8], sensor-specific procedures based on the proposed reference media for low-cost groundwater content sensor calibration. The thermo-gravimetric approach is carried out by drying the soil sample in an oven. This technique is quite accurate and often used as a standard. However, it requires a long time, special equipment [9], large amounts of energy, and un-portable [10]. The Calcium Carbide Gas Pressure (CCGP) approach is reliable for small specimens up to 20% SWC [11]. However, it requires consumables and applies to a limited area. Another technique for measuring soil water content (SWC) is through an electrical phenomenon approach, namely capacitance and resistance. In addition, this method is used to distinguish soil types and the temperature sensitivity [12]. Through the information on the electrical conductivity of the soil, the calibration problem which ensures precision is carried out easily [13,14]. This phenomenon is easy and does not require a lot of power consumption. However, soil moisture sensors for the resistance measurements, are prone to corrosion on the probes, which causes inaccuracy [15]. The capacitive humidity sensor is less susceptible to erodibility because, it is made of a more resistive material, which provides more reliable results [16,17]. However, this measurement still requires the process of taking the test soil sample, which has contacted the soil. Meanwhile, the use of electrical phenomena, such as dielectric capacitance and electrical impedance techniques [18], are faced with the same problem as the resistance measurement, namely the corrosion of probes that are in contact with the ground. Furthermore, another test method used the tension meter, which was buried deep in the soil. The drawback observed was the temperature dependent reading errors, due to the formation of air bubbles on the shaft [6], or on its dielectric properties [19]. The use of non-destructive techniques, such as frequency domain reflectometry (FDR), high-frequency capacitance (HFC), and time domain reflectometry (TDR), was introduced in the SWC [20]. Gao et al. reported that the accuracy of TDR sensing is only ensured, when the rise time of the drive signal is shorter than 200ps. This requirement limited the application of this method in monitoring soil moisture profile. However, the FDR technique requires a complex secondary calibration before use, due to the sensor which is affected by various factors, such as soil type, conductivity, and volumetric weight at low frequency measurement [18]. The simple method that obtained

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higher efficienc than FDR is the HFC. This technique is able to meet the demand for online measurements in real-time because, it is not affected by soil texture in the field [21]. However, the HFC approach requires the penetration of the sensor probe into the soil vertically, therefore, it only provides moisture content information at the point where the probe is planted. To determine the moisture content in a larger area, horizontal scanning of the measurement becomes impractical. After studying these various techniques, the dominant problem is the contact of the sensor probe with the ground, which causes various damage and affects accuracy. In addition, measurements are only carried out at a certain point, and it is impractical, when the water content information in question is lateral. In this study, the measurement of water content through an electromagnetic approach is carried out using a pair of transceiver coils. Evelyn J.L. et. had studied the influence of static magnetic fields on the chemical and physical properties of liquids [22]. The transmitter coil generated a magnetic field which was induced on the soil. The use of a magnetic field as a variable stimulus was possible because, it application to the soil affected various parameters including conductivity [23,24], salinity [25,26], water quality [27,28], pH levels [29,30], evaporation [31], reduction in specific heat [32], and boiling point [33, 34]. The principle of inducing a magnetic field [35, 36] is used to provide a stimulus to the soil and the response to the induced voltage is captured using a receiver coil [37,38, 39]. This principle of induction is carried out without contact with the soil. Therefore, this technique is expected to provide a solution to the sensor probe problem, which is often damaged due to contact. The application of the internet of things is also expected to facilitate monitoring of water content anywhere and anytime [40]. In addition, the transceiver coil used is placed above the soil surface, and not to be shifted laterally. Therefore, moisture content information is obtained at several points quickly, by shifting the transceiver coil pairs.

MATERIAL AND METHODS

The Sensing Principle

Soil water generally contains compounds, such as sodium, calcium, iron, and magnesium ions, making it to become a conductor. When water mixes with soil, there is a change in the conduction level [41]. Therefore, the value of the electrical conductivity of dry soil is different from that of the wet, due to the influence of the additional ions the in water. The galvanic properties of the soil used as a basis of electrical phenomena in the water content [42]. Determining the value of soil connectivity was used as a basic principle for measuring water content in the soil. And this was done by passing current flow i.e., inducing magnetic flux into the soil, and the voltage that appears in it was measured [43]. Induction was completed by exposing the flux of the magnetic field which changes every time. This process is known as the principle of magnetic field induction, as shown in Figure 1

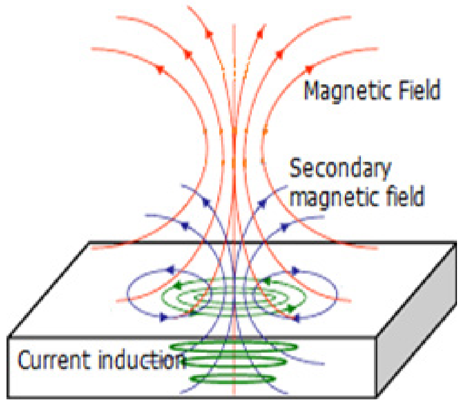

Figure 1 Principle of magnetic field induction

The magnitude of the induced voltage is defined by Faraday's Law, shown in equation (1).

$$\varepsilon = -N\frac{d\emptyset}{dt} \tag{1}$$

For a fixed coil surface area, the flux change occurred due to a differ nce in the magnitude of the magnetic field that induced the object, therefore, equation (1) becomes equation (2).

$$\varepsilon = -N\frac{dB}{dt} \tag{2}$$

This induced voltage (ε) caused an induced current in the soil. The amount depends on the value of the soil conductivity where (ε) was generated. The induced current that occurred in the soil caused a secondary magnetic field (Bi), which penetrated the surface of the secondary coil and again caused an induced voltage in the secondary coil /receiver. The amount of induced voltage in the secondary coil also fulfilled equation (2) with the magnetic field being the secondary (Bi). Kleinberg, R. L. et al. (21) calculated the induced voltage of the sensor when near the homogenous formation, as shown in equation (3).

$$\varepsilon i = 2\pi f 2\mu 2 I N_t N_r \sigma G \tag{3}$$

Where f = frequency, μ = magnetic permeability of the medium, I = current of the transmitter, Nt = number of turns of the transmitter coils, meanwhile Nr = number of turns of the receiver coils, σ = conductivity of the formation, G = a geometrical factor. Equation (3) shows that the conductivity affects the amount of voltage induced in the receiver coil. The amount of conductivity is infl - enced by the amount of water content in the soil, therefore by measuring the induced voltage in the receiver coil, the water content in the soil was estimated.

Structure Design of the Sensor

To generate an inducing magnetic field, a current energized coil was used, namely the transceiver coil. The current that flowed was alternating therefore the magnetic field it generated varied. With a certain cross-sectional area, the magnetic field that moved out of the transceiver coil produced a magnetic flux that was ready to be induced. To measure the change in the flux of the secondary magnetic field, which was generated by the change in the induced current in the soil, another coil was used that was placed parallel to the first, namely the receiver coil. The design of the pair is shown in Figure 2.

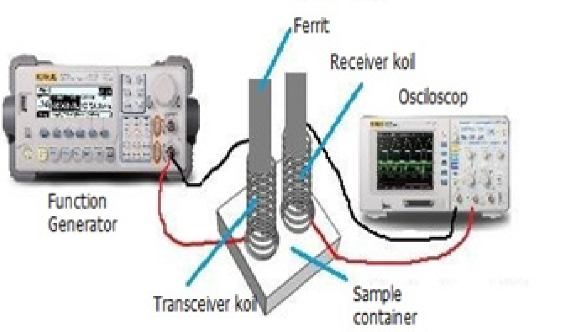

Figure 2: Design sensor and measurements on a laboratory scale

Schema of Experiment

To determine the water content in the soil in this study, the following steps were taken: The first stage was the characterization of soil and a pair of transceiver coil. This stage was carried out to obtain soil morphology and its composition. This information was used to determine the initial conductivity value of the ground before it was given water. Meanwhile, specification of coil was, length 3.5 cm, 400 turns, 0.5cm for distance between coils, and 20 Volt (peak to peak) for the voltage source. The soil sample used weighed 135 gram that was placed in a 6 cm x 6 cm x 3.5 cm container. The voltage response measured on the receiver coil was an indicator of the available frequency from the induction source. The second stage was to obtain the measured voltage value in the receiver coil due to induction by the transmitter coil on dry soil, without water content. This phase was carried out to determine the available frequency of voltage which was used for the transmitter coil. That which produced the largest receiver coil voltage was determined as the candidate frequency to be used in determining the sensor characterization model. Also, the frequency which resulted in the greatest sensitivity of the coil to induce soil was determined. The third stage was the induction of the soil which was filled by water with a mass that was regulated and increased gradually, there were 10 gr, 15, 20, 25, and 30 gr. For each mass of water applied to the soil, the voltage of the receiver coil was measured. This stage was performed to obtain a linear relationship between the receiver coil voltage and the soil water content. The fourth stage was to determine the equation which stated the relationship between the voltage of the receiver coil with the variation in the mass of water that was added to the soil. The model equation for determining water content, with the voltage measured in the receiver coil as the independent variable, was derived by reversing the experimental equation results where water content was the independent variable. The fifth stage was to test the model equation with some data in the form of soil water content. The results obtained from this model was compared with the actual water content and the results from a moisture meter. The resulting data will be sent mobile by utilizing technological advances for the monitoring process [44].

RESULT AND DISCUSSION

Soil characterization

In the first stage of this study, soil characterization had been carried out by using Scanning Electron Microscopy (SEM) [45,46,47] to identify the surface of the soil samples. The results of SEM are observed in Figure 3. It shows the SEM images in three different magnific - tions,1000, 5000 and 10000 times. Figure 3 (a) and (b) are the images in the low magnification, 1000 times at different spots. From the images it is shown that the soil composed of small particles. The size of soil's particles was about 50 – several hundreds of micrometers. The small particles are joined together to form the bigger particles, agglomerating each other. It was observed that there were small empty areas between the small particles, as indicated in Figure (c) and (d). The presence of this spaces was believed to be the media for water to be trapped, this condition met the ability of the soil to save water inside its structure.

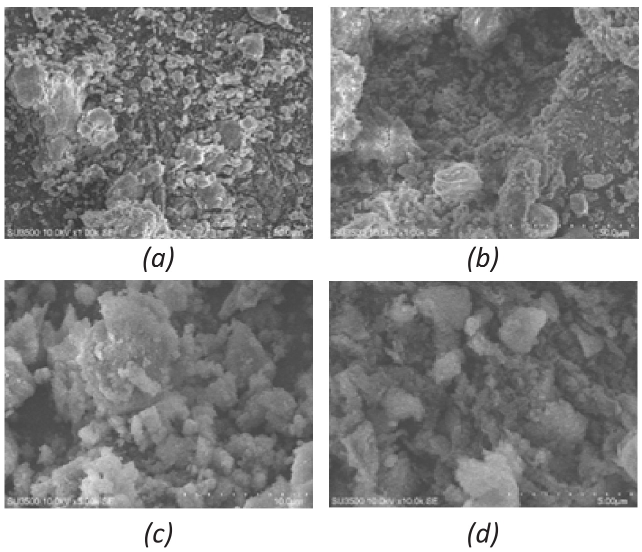

Fig. 3. SEM result for soil morphology at (a) and (b) 1000 magnification at different spots, (c) 5000 times magnification and (d) 10.000 times magnification

X-Ray Dispersive Analysis (EDAX) was used to identify the composition in soil samples. This was carried out to determine the metal content in the soil which causes it to be conductive.

Table 1: EDAX result for soil composition

Element	Weight %	Atomic %	Error %	Net Int.	K Ratio
C K	29.73	40.68	9.2	443.83	0.0847
O K	44.28	45.48	8.07	1653.87	0.158
Al K	10.13	6.17	4.05	837.18	0.072
Si K	10.33	6.04	4.08	849.83	0.0765
Fe K	5.53	1.63	6.07	92.81	0.0449

Determination of available frequency for induction

The observable frequency determination was conducted by induction through the transmitter coil without soil. The observable voltage response (V > 1 volt) was taken as a candidate for the optimal frequency range. The measurement of the receiver coil voltage was carried out with an initial frequency range from 100 Hz to 290 Hz with results as shown in Figure 4.

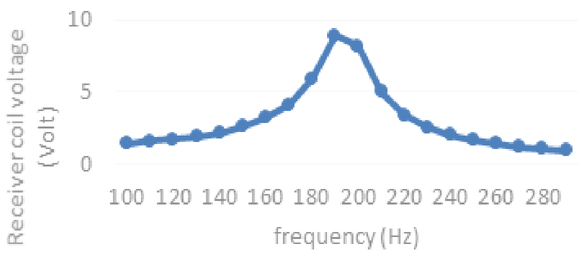

Figure 4: Induction without soil samples

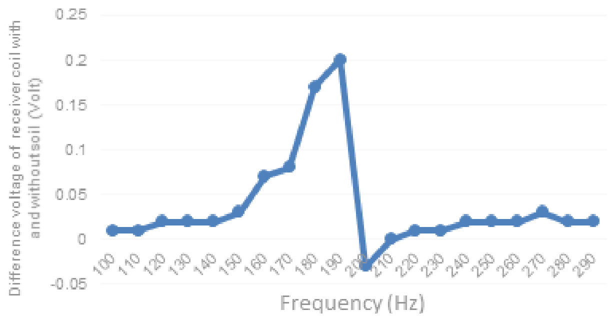

Figure 5: Difference in receiver coil voltage between without soil and dry soil

These results indicates that the source frequency that produced the greatest voltage response in the receiver coil occurred at 190 Hz. However, the measured receiver coil voltage for these various frequencies still showed an observable value (V > 1 volt). The second experiment was carried out through induction on dry soil (without water content). The voltage in the receiver coil was again measured for the various frequencies of the inducing source. The different voltage of the receiver coil between condition without soil and with dry soil for all frequencies is shown in Figure 5.

Measurement of receiver coil voltage with water content variation

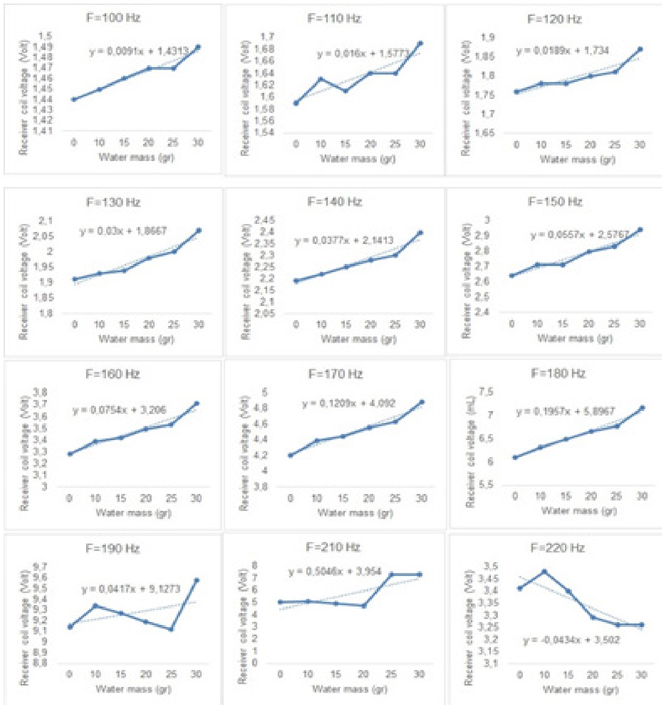

Figure 6: Receiver coil voltage with variations in water content for various frequency

At this stage the soil sample was induced using the frequency range obtained in the previous stage. The indicator used to select the optimal frequency was the voltage difference between the receiver coil with and without the soil sample. The largest voltage difference was used as the induction frequency at a later stage. The results of induction with various frequencies at variations in the mass of water in the soil are shown in Figure 6. Frequency variations, such as the results in Figure 6, were carried out to obtain the largest and most linear voltage change in the receiver coil with respect to changes in water mass. Figure 6 shows that the comparative relationship between the voltage in the receiver coil and the water content in the soil occurred from 120 Hz to 180 Hz. Starting from 190 Hz the relationship did not show a regular trend correlation model. Where the relationship between the voltage in the receiver coil and the soil water content at the frequency interval of 120 - 180 Hz was linearized, the highest sensitivity was obtained at 180 Hz, which was 0.1957 Volt/gr. The sensitivity, which is related to the water mass detection ability, for these various frequencies can be seen in Figure 7. The highest sensitivity, according to Figure 7, occurs at a frequency of 210 Hz. However, at this frequency the relationship between sensitivity and frequency is not linear, as shown in Figure 6. Thus, in this step, the frequency is not directly correlated with the mass of the water. The mass of water is obtained and is correlated with the voltage on the receiver coil, as shown in Figure 8.

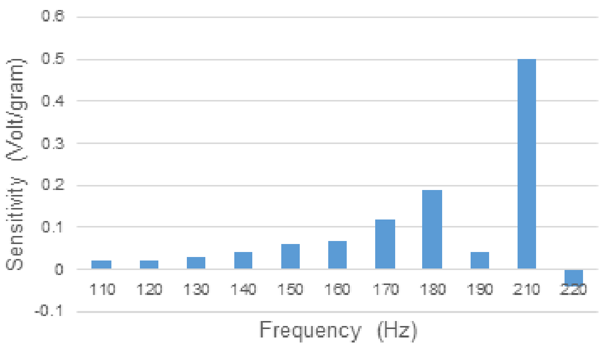

Figure 7: Sensitivity of mass water detection with frequency

The sensor characterization model was determined from the response of the receiver coil to the addition of water to the soil sample. Which was indicated by the difference in the voltage of the receiver coil between the dry soil and the sample containing a certain water content.For the results of measurements made at 180 Hz, the response of the receiver coil was the difference between its voltage when the soil sample was dry (V = 6.1 volts) and for each additional mass of water, as shown in Table2.

Table 2: Receiver coil response

No	The real water content (gr)	Receer coil voltage (volt)	Difference of receier coil volage with dry soil (volt)	Soil water cotent by model eqution (gr)	Error of model (%)
1	10	6.31	0.21	11,16	11,55
2	15	6.49	0.39	15,48	3,21
3	20	6.66	0.56	19,57	2,16
4	25	6.77	0.67	22,21	11,16
5	30	7.16	1.06	31,59	5,28

When the results of Table 2 were plotted the water mass graph as a function of the difference in the voltage of the receiver coil, the graph in Figure 8 was obtained.

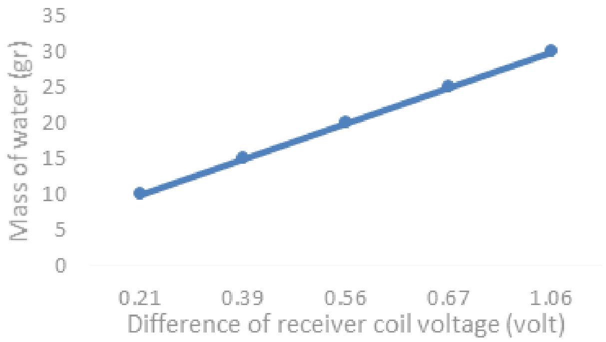

Figure 8: Relation of soil water content with difference of receiver coil voltage

Where y shows the mass of water, in gr, and x indicates the difference of receiver coil voltage, in volt, then the sensor model equation to determine the soil water content was.

$$y = 24{,}036x + 6{,}107 \quad (4)$$

This equation was then defined as a sensor characterization model. This linear model of equation (4) produced an error for each addition of water mass to the soil as in the last column of Table 3, with an average error value of 6.67%. This error value (<10%) indicates that the equation of the sensor characterization model is appropriate for estimating the mass value of water in the soil using the receiver coil voltage measurement data.

Testing the sensor characterization model

Testing of the sensor characterization model was carried out on several other data samples. The test data was taken partially from within the model forming data interval to test the interpolating capacity and partially from outside to examine the extrapolating ability. The testing experiment in the model-forming data interval was carried out on the water content in the 18 and 22 gr soil, while that outside the interval were at 35 and 40 gr. The results of the measurement of the receiver coil voltage, the determination of the soil water content based on the model, the comparison with the real soil water content and the measurement results using a moisture meter are shown in Table 3. Table 3 shows that the measurement of water content using a moisture meter is still not accurate. This inaccuracy is measured against the value of the actual water content added to the soil. Meanwhile, the measurement using the sensor characterization model, which was carried out in this study, gave results that were closer to the actual value. Calibration can be done by inducting the sensor into a container filled with water completely. Under these conditions, the equation is rearranged to produce an output value according to the mass of water in the container. Table 3 shows that the prediction of water content in the soil using the sensor characterization model which resulted in an average

Table 3: The results of sensor characterization model testing

No	The real water cotent (gr)	Receier coil voltage (volt)	Water content by Sensor characteriztion model		Water cotent by Moisture meter	
			Mass (gr)	Error (%)	Mass (gr)	Error (%)
1	18	5.06	18.37	2,03	17.6	32.00
2	22	5.22	22.21	0,96	19.7	20.89
3	35	5.59	31.10	11,13	22.5	13.21
4	40	5.67	33.03	17,43	24.4	17.65

error of 7.89%. It is inferred that this result is better than measuring SWC using a moisture meter which produces an average error of 20.94%. These results indicate the validity of measurements using the sensor characterization model gives better results than measurements using a moisture meter. While the reliability is shown by the consistency in the repetition of the voltage measurement on the receiver coil. Measurements were made with variations in the mass of water in the soil, as shown in table 4. For each mass of water in the soil, three measurements of the receiver coil voltage were carried out at different times.

Table 4: The results of repeated measurement of receiver coil voltage

No	Mass water (gr)	Receiver coil voltage (Volt)		
		1	2	3
1	10	6.31	6.31	6.31
2	15	6.39	6.46	6.49
3	20	6.66	6.67	6.66
4	25	6.7	6.7	6.77
5	30	7.16	7.16	7.16

Table 4 shows that the value of the measurement results is consistent so that the reliability is good.

CONCLUSIONS

This study showed that the use of sensor approach, based on the magnetic field induction method is capable of being evaluating the water content in the soil. The estimated results from the equation of the sensor characterization produced a better error, than the measurement of water content using a moisture meter. The use of this magnetic field induction method required sensor voltage measurement data, when the soil conditions are dry, i.e., without water, and performed effectively at a certain frequency. Using the modeling data, the effective frequency which resulted in a linear relationship between soil water content and the measured receiver coil voltage was obtained at 180Hz.

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