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Monitoring rainfall intensity and moisture water content using soil column experiment

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Abstract. Indonesia is a tropical country that has two seasons, rainy season and dry season. The wetting and drying of soil due to changing of the seasons caused change on soil properties such as moisture soil water content, effective soil porosity, soil suction etc. During rainy season, rainfall infiltration caused increasing of moisture soil water content in a soil slope, tends to reduce soil shear strength and followed by slope instability. In this soil column experiment was set up with rain gauge station and YL-69 sensor and capacitive soil moisture sensor to monitor rainfall infiltration and soil moisture water content in red clay soil. A wireless sensor network with low power wide area network technology integrated with the cloud to observe rainfall intensity and soil water content in soil column with realtime monitoring. The focused on improving the accuracy of rainfall intensity and soil water content sensors readings using regression methods. The experiment results showed that rainfall intensity was observed accurately while for the YL-69 sensor, the error reading was 5.15% and the error reading capacitive soil moisture sensor was 2.99%.

1. Introduction

Indonesia is a tropical country located in the Ring of Fire region. This makes Indonesia often suffer from disasters such as earthquakes, tsunami, eruptions, floods and landslides. Based on the National Disaster Management Agency data, 1586 disasters have occurred in Indonesia from January to April 2019. Hydrometeorological disaster is a dominant disaster with a percentage of 98%, while the other 2% is caused by geological disasters. Floods and landslides are the most dominant disasters occurred [1].

Natural disasters are unpredictable events that have a large impact. One example of the impact of natural disaster flooding and landslide occurred in Sentani, Papua, March 2019 caused 112 people died, 82 people were lost 965 injured and losses and damages were estimated at 668 billion rupiah [1].

Slope failure or landslides are usually caused by several factors including soil materials, human activities on slope, topography, hillslide development and climatic conditions, vegetation and rainfall. But, in tropical countries, rainfall becomes a major factor in the cause of slope failure [2,3]. During and after rainfall, parts of the rainwater reach the surface of the slope infiltrate to the ground, while others flow on the surface. When water infiltrating into the slope, metric suction is decreasing due to increased soil humidity. Then, due to this, the soil structure becomes transformed and reduces the frictional and cohesive strength between particles [4]. It gives a negative effect on slope stability because of negative pore water pressure between the soil particles and shear strength is decreasing [5–7].

Soil Moisture water content can be measured using several techniques such as Thermo gravimetric, Neutron moisture meter, Time Domain Reflectometry (TDR), Capacitance technique and Frequency Domain Reflectometry (FDR), Resistive sensor, Thermal Dissipation Block and Tensiometer [8]. Before measurement in the field, water infiltration can be simulated using soil column experiment to analyze soil moisture content [9] using tomography techniques to measure soil water content utilizing Electrical Capacitance Volume Tomography (ECVT). Meanwhile, Ibrahim et al., uses a TDR sensor and a tensiometers to measure soil moisture content [10]. Both methods have good accuracy and non-destructive. However, both of them utilize cables for the transmission of data to the local computer used for data acquisition/data logger. If it wants to be applied to real conditions, it will certainly require expensive costs and monitoring cannot be done remotely.

Internet of Thing (IoT) is a breakthrough that allows to conduct rainfall monitoring and soil moisture water content remotely and realtime. Vani and Rao develops prototype to monitor soil moisture using the YL-69 sensor (resistive soil moisture sensor) [11]. Data that is read is sent through a Wifi-based Wireless Sensor Network (WSN) integrated with a cloud server. Similar research is also conducted by Juca utilizing NodeMCU ESP8266 and YL-69 sensors to monitor the soil moisture content that is integrated with Thingspeak Cloud [12]. Meanwhile, utilize a capacitive soil moisture sensor to read soil moisture and NodeMCU ESP8266 is integrated with Thingspeak Cloud for data acquisition [13]. In addition to the development on the WSN and IoT sides, Sudha and Sinha also conducted an evaluation to calculate the accuracy of the YL-69 sensor on clay soil medium with an average measurement error is 53.14% [14].

Devices capable of realtime and cloud-integrated monitoring is still insufficient if not supported with energy-efficient technology. When the sensor is installed in a disaster prone area where the area is difficult to reach by humans and battery replacement is very rare, of course it is a new problem. In addition, the accuracy of the sensor needs to be improved so that slope stability analysis can be done to the maximum. In this study, we proposed device to monitor rainfall and soil moisture water content with IoT Cloud-based Low Power Wide Area Network (LPWAN) technology using LoRa as WSN.

2. Methodology

2.1. System design

The proposed system of this study is a prototype of soil moisture using low cost soil column experiment consisting of node sensors, LoRa Gateway and Cloud Server. Sensor node consists of rain gauge sensor, soil column made of PVC with resistive soil moisture sensor (YL-69) and capacitive soil moisture sensor, data acquisition device and LoRa transceiver (LoRa MiniDev). The sensor node uses energy from a rechargeable battery using a solar cell. Voltage Input used in the sensor node is 5 volt. Meanwhile, the LoRa gateway consists of NodeMCU and LoRa Bee radio transceiver devices connected to the Wireless Router (WLAN / IEEE 802.11 N). System architecture design can be seen on Fig. 1 and Soil column experiment can be seen on Fig. 2.

The network that was built on this study based on research conducted by Suharjono utilizes IEEE 802.11 N network as network backbone with 4G network as redundant on Gateway side [15]. Meanwhile, on the side WSN based LPWAN, LoRa chosen because of the wide coverage area and energy consumption is more efficient. Soil moisture sensors measure soil moisture water content based on the voltage value caused by resistance or capacitance changes in red clay soils. Water is a good electrical conductor. When water is absorbed into the soil, the sensor's soil moisture electrode will be interconnected so that the electric current can flow on the sensor. Then the voltage read by the sensor is sent to the ATMega328p microcontroller embeded on LoRa MiniDev. ATMega328p reads the input voltage value from the sensor using Analog to Digital Converter (ADC) with 8 bit resolution. Then the ADC value is converted to voltage again using (1). Then the value of the voltage is mapped to the scale of 1-10 adjusts to the scale on the 3 way meter to measure soil moisture water content.

$$Voltage = \left(\frac{3.3}{1023}\right) x\ ADC\ Value \quad (1)$$

Data that is read by the rain gauge sensor and soil moisture sensor is then transmitted using LoRa module to LoRa Gateway. Then LoRa Gateway performs a parsing to separate the data. After that, the data is encapsulated into IEEE 802.11 N format and sent to the cloud using the Message Queuing Telemetry Transport (MQTT) protocol over a Wifi network. The MQTT protocol is used on the uplink side because MQTT is a type of data-agnostic protocol where data that is capable of sending is not limited to certain types of data, but all types of data can be transmitted such as binary, text, XML and JSON data. This protocol implements data compression and data reduction techniques to perform energy efficiency [16,17].

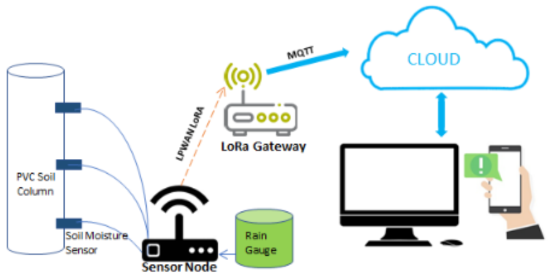

Figure 1. System architecture.

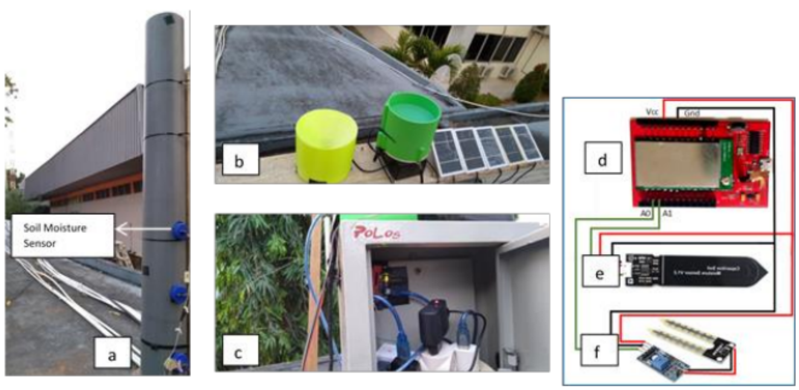

Figure 2. Infiltration column apparatus and instrumentations: (a) soil column, (b) rain gauge sensor, (c) data logger and lora transceiver (sensor node), (d) Lora MiniDev, (e) capacitive soil moisture sensor and (f) resistive soil moisture sensor.

2.2. Testing method

Testing conducted on laboratory environments using artificial rain from showers with constant water discharge. In this study, the measured soil moisture water content is the top layer in the soil column. Resistive and capacitive soil moisture sensor inserted into the soil column along with 3 way meter. Then the soil column was given a rain-made up to 3 way meter indicates a reading ranging from 1 to 10 scales. Each scale reads at 3 way meter, the value of the read voltage of the node sensor will be recorded every 5 second interval. Tests on each scale are done for 5 minutes. The results of the sensor measurements are then compared to the conventional measurements of the 3 way meters using linear regression methods. Error measurement on sensors can be calculated using (2).

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$$Error(\%) = \left|\frac{exact - approximate}{exact}\right| x100 \quad (2)$$

3. Results and discussion

3.1. Resistive soil moisture sensor

The soil moisture sensor consists of two probe's pads which are used to measure the Volumetric content of water. The two probe's pads allow the current to pass through the soil and then it gets the resistance value to measure the moisture value. When there is water, the soil will conduct more electricity which means that there will be less resistance. Therefore, the moisture level will be higher, and the output voltage will be lower. Dry soil conducts electricity poorly, so when there is less water, then the soil will conduct less electricity which means that there will be more resistance. Therefore, the moisture level will be lower output voltage will be higher. The Correlation between output voltage (V) and soil water content is shown in Fig. 3. From Fig. 3 a linear equation of average voltage as a function of soil water content by using resistive sensor-based can be obtain as (3),

$$y = -0{,}2789x + 3{,}4412 \quad (3)$$

Where y is average voltage value and x are soil water content. Variable y as the result of conversion from ADC value to a voltage value, and x as soil water content at real conditions (%). From (3), the value of x can be represented as (4). This equation which is used to determine the soil moisture water content in the Arduino program is (4).

$$x = \frac{y - 3{,}4412}{-0{,}2789} \quad (4)$$

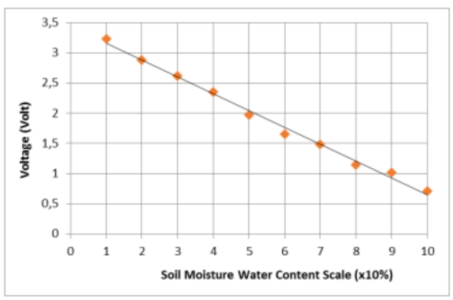

Figure 3. Correlation between output voltage and soil water content in resistive soil moisture sensor.

3.2. Capacitive soil moisture sensor

The electrical component known as a capacitor consist of three pieces. A positive plate, a negative plate and the space in-between the plates, known as the dielectric. The physical form and construction of practical capacitors vary widely, and many capacitor types are in common use. Most capacitors contain at least two electrical conductors often in the form of metallic plates or surfaces separated by a dielectric medium.

A capacitive moisture sensor works by measuring the changes in capacitance caused by the changes in the dielectric. It doesn't measure moisture directly (pure water doesn't conduct electricity well), instead it measures the ions that are dissolved in the moisture. These ions and their concentration can be affected by a number of factors, for example adding fertilizer for instance will decrease the resistance of the soil. Capacitive measuring basically measures the dielectric that is formed by the soil and the water is the most important factor that affects the dielectric. The correlation between output voltage (V) and soil water content is shown in Fig. 4. From Fig. 4 a linear equation of average voltage as a function of soil water content by using capacitive sensor-based can be obtain as (5),

$$y = -0{,}241x + 3{,}5398 \quad (5)$$

Where y is average voltage value and x are soil water content. Variable y as the result of conversion from ADC value to a voltage value, and x as soil water content at real conditions (%). From (5), the value of x can be represented as (6). This equation which is used to determine the soil moisture water content in the Arduino program is (6).

$$x = \frac{y - 3{,}5398}{-0{,}241} \quad (6)$$

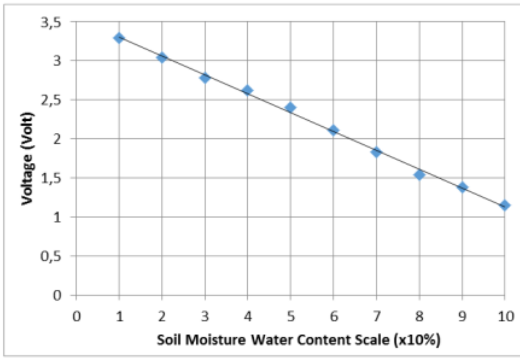

Figure 4. Correlation between output voltage and soil water content in capacitive soil moisture sensor.

Based on the data and equation obtained, the result is then compared to see the level of linearity between resistive-based sensors with capacitive-based sensors. It can be seen in Fig. 5. The comparison results between soil moisture sensor and conventional moisture measurement can be shown in Table 1. From Table 1, the measurement using (4) obtains the average error of measurement of 5.15% and measurement using (6) obtains the average error of measurement of 2.99 %.

Capacitive-based sensor has some advantages. It not only avoids corrosion of the probe but also gives a better reading of the moisture content of the soil as opposed to using a resistive soil moisture sensor. Since the contacts (the plus plate and the minus plate of the capacitor) aren't exposed to the soil, there is no corrosion of the sensor itself. That's why capacitive-based sensors have better accuracy compared to resistive-based sensors. In addition, capacitive-based sensors have more lifespan than resistive-based sensors. Testing errors can be minimized by setting more precise ADC values and soil wetting the red clay on the soil column is done more evenly.

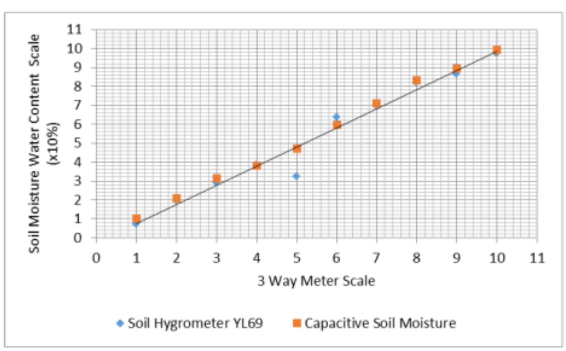

Figure 5. Measurement comparision using (4) on YL-69 and (6) on capacitive soil moisture sensor.

Table 1. Measurement of soil water content using (4) and (6).

3 Way Meter (x10%)	Resistive Soil Moisture (x10%)	Error (%)	Average Error (%)	Capacitive Soil Moisture (x10%)	Error (%)	Average Error (%)
1	0.75013	24.98		1.03473	3.47	
2	2.01836	0.92		2.0694	3.47	
3	2.94404	1.87		3.14734	4.91	
4	3.88996	2.75		3.81169	4.71	
5	3.25207	5.04	5.15	4.71028	5.79	2.99
6	6.41216	6.87		5.94706	0.88	
7	7.03307	0.47		7.10063	1.43	
8	8.23807	2.98		8.3093	3.87	
9	8.68549	3.5		8.95982	0.45	
10	9.78273	2.17		9.90673	0.94	

3.3. Website-based and Android application monitoring system

Soil moisture water content data that is read by the sensor is then transmitted to the cloud server and it's displayed using widgets on the website and the android application, so that it's easily readable by users. It can be seen in Fig. 6. In addition to a website-based monitoring system, data can also be monitored using an android application as shown in Fig. 7. It aims to facilitate the user when they are in a difficult place to use a laptop. By using Android application, monitoring can be done anywhere quickly and efficiently.

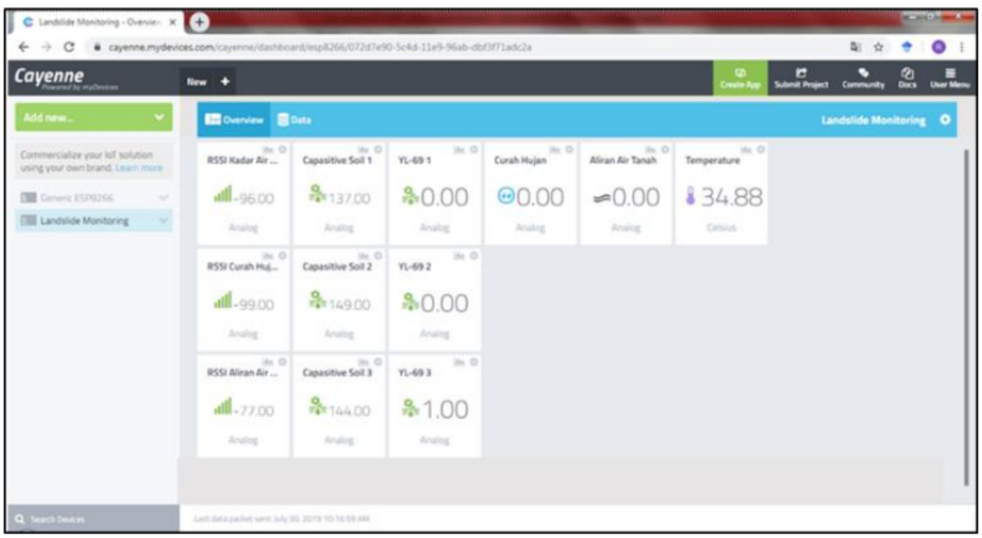

Figure 6. Web-based monitoring system.

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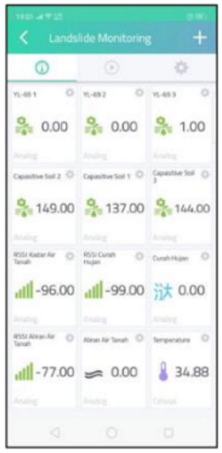

Figure 7. Android application monitoring system.

4. Conclusion

In this paper, the accuracy of resistive dan capacitive soil moisture sensor have been successfully improved. Both of data were compared and sent to the cloud server. Based on data that has been obtained from experiments, the capacitive-based sensor has a better level of accuracy in the soil test medium of red clay using soil column experiment. Corrosion of sensor probe greatly affects the level of accuracy of soil moisture water content measurement. Data's transmitted using LPWAN and Cloud IoT Network can run well. Likewise, with website-based and android application monitoring system, both of them can displayed information according to the data's that has been transmitted.

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