Soil Moisture Monitoring System using Wireless Sensor Network

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Abstract: Monitoring the soil moisture generally done by manual observation of researchers in agriculture area. It is obviously take a long time, especially when monitoring the declining level of soil moisture. This practice is less efficient especially when examining the level of soil moisture contained plants in it. For that we need a solution to improve efficiency in terms of use of time and in terms of facilitating the monitoring of soil moisture conditions. Our proposed system to monitor soil moisture uses Libmium Wasp mote as a microcontroller. The process of sending data from the sensor to the Internet network and then to the database server took about 10-15 seconds. This was influenced by the process of taking data from the board and also the delay when the sensor connected to the available network. The results of system testing showed that the system can work in a way if researchers leave the soil with high humidity then researchers want to monitor soil moisture at a certain moisture level, then the researchers simply set the level of humidity that wants to be maintained by the application system. If the soil moisture content is equal or less than the point set on the system, the system provided notification immediately.

1. Introduction
Nowadays sensor technology is one of the fastest growing technologies. A sensor is a device capable of detecting a change in the physical or chemical environment which then converts it into electrical signals both electric current and voltage [1]. Sensor technology is also related to wireless technology, this technology is known as wireless sensor network (WSN). Wireless sensors are standard measurement devices that measure one or more physical quantities and use transmitters equipped with the conversion of measured physical quantities into radio signals and transmit radio signals through a communication model. The radio signal is interpreted by the receiver or electronic instrument which then converts the wireless radio signal into the desired output [2]. The role of wireless sensor technology can be applied in human life to help people obtain information quickly and more accurately. One application that can be done by this technology is in the application of soil moisture sensors. This sensor will provide information about the moisture content in the soil.
The soil is a medium for growing a variety of plants. The soil is composed of minerals and organic matter. The soil is vital for all life on earth because the soil supports plant life by providing nutrients and water as well as the support of roots [3]. As Adam describes the definition of soil, in the soil there is water between soil particles and this is known as soil moisture. Soil moisture is water absorbed bound on the surface of grains of soil. In the field of agriculture to monitor and control soil moisture content in agricultural land is one of the things that important, because with the appropriate soil moisture the growth plants will be maximized. However, most researchers in the field of agriculture in monitoring soil moisture are generally still using manual methods, and to get moisture results (soil moisture content) tend to take a long time, at least within 24 hours.

One example of manual observation is done in monitoring humidity levels by using a tensiometer. Tensiometer is a measure of water pressure in the soil with centibar (cb). Monitoring results from soil moisture are also obtained within 24 hours. This tool is planted in the ground within 24 hours to see the reaction of water pressure in the soil and wait for changes to the results that occur. When the tensiometer is planted, the first needle on the tool will point to one unit of pressure measure, and after 24 hours the needle will change. Measuring soil moisture manually as using this tensiometer will take a long time. Therefore we need a system that can monitor the water content (moisture) in the soil with a relatively shorter time and easier to use.

Several studies have been conducted to monitor soil moisture levels. One of them is research conducted in 2013. Research conducted to monitor soil moisture using sms service, and monitoring of soil moisture is displayed through LCD screen [5]. A second study in 2014 was conducted to compare two electrical conductivity using Verris 2000XA and DUALEM 1S sensors aimed at monitoring and mapping the soil physical properties as well as to study the effect of ground cover vegetation through measuring the electrical conductivity generated by the two sensors [6].

In 2013, a study was conducted on a soil moisture meter based on PIC 16F84 microcontroller [7]. The results of this study show the humidity sensor ground output through the lcd screen. Subsequent research in 2014, conducted research to make the application of soil moisture sensor (soil moisture) with electro kinetic ion trap mechanism. This sensor consists of a pair of stainless electrode and planar meter capacitance that serves to monitor in real-time moisture content in the soil [8].

The purpose of this research is to develop automatically monitoring system of soil moisture by using wireless sensor network.

2. Material and Method
This study consists of several steps that begin with data collection which was done automatically through the sensor. For more details about the input and output processes of the application system will be illustrated through the general architecture that can be seen in Figure 1.

2.1. Hardware and Sensor Monitoring Application System
2.1.1 Hardware Sensor
The input of the system are the data taken from sensors grown in soil by the soil moisture sensor which then the data will be sent to Wasp mote, after which the data will be stored on the micro-sd card, and the data will be sent to in the monitoring application system with the help of 3G board.

The process of collecting and transmitting data starts from the ground-implanted sensors detecting the frequency of soil moisture; then the data will be obtained by Wasp mote's main board via digital pin 3. On the Wasp mote main board, the system uploads a program that serves to store data into micro-sd. The soil moisture data stored inside the micro-sd can be seen by the user by removing the micro-sd from the Wasp mote board first, then to see the data contained in the micro-sd. Then the system also upload a program that serves to send data from Wasp mote board to internet. The data obtained was sent to the monitoring application system via the 3G board, and then from this 3G board the data was sent to the nearest base transceiver station (BTS) to connect to the internet and from internet communication data is sent to the database server (mysql) using POST method.
Data sent from Waspmote board is not only the soil moisture data, but also data from room temperature, ground temperature, and battery capacity. However, in this study we focused on analysis and data processing only on soil moisture alone. From this soil moisture data, we designed and built a web-based soil moisture notification system using PHP.

Before designing the system and determining the notification parameters to be built, it is necessary to calibrate the tool. The purpose of this tool calibration is to convert the output value of the sensor that is in the form of frequency (Hz) to change the unit into a percentage (%). The purpose of this conversion is that in the field of agriculture, the soil moisture unit is measured by a percentage (%). Therefore calibration tool is needed to convert the unit value of frequency (Hz) to percent (%).

2.1.2 Web Server
The web server used is a web server that built as standalone. This web server will serve as a place of service and data processing between Waspmote, database, and client.

The web server received soil moisture data, ground temperature, and room temperature and battery capacity sent directly by Waspmote board with the help of 3G module. This data then be stored in the database and ready to be processed to be represented back to the client in the form of graphs and widgets. These charts then displayed within a certain time interval and always move automatically updated as long as the sensor sends data to the system. The processing of data from the sensor board into the monitoring application system will always be represented both when the client accesses the web server and when the client does not access the web server.
In monitoring application system, the client can set notification parameters about soil moisture to be monitored, in this case, the notification parameter scale is 1-100%. When the client set the notification parameters, for example, the set parameter of 39%, then when the web server receives data from the soil moisture sensor with the same percentage level with the regulated notification parameters, the client will receive a notification that the soil moisture content monitored or monitored reaches set parameter limits. Then if the data received server percentage is less than or smaller than the notification parameters are set, then the client will receive notification also about percentage levels are less than the parameters set and also the system will tell the client about what percentage levels of preset humidity and levels percentage of humidity upon receipt of notification.

2.1.3 Client Side
When accessing the monitoring application system, the client will open a web page on the web server to perform monitoring, and only the specific client gets permission to access the page. This page will
contain a soil moisture graph derived from the planted sensors, and each of these graphs will always move and update automatically without the need for the client to refresh the web page.

On the web page, there is also a display of information about soil temperature, room temperature and also the remaining battery capacity. Information about this data will also be updated automatically without the need to refreshing the web page. In addition, on this web page, the client will also see a notification if the adjustable humidity parameters reach the limit or smaller than the set limit and the client can see the soil moisture data before.

2.1.4 Data Used
The data used derived from the sensor and has been calibrated. The calibration of the sensors can be seen in Figure 2. The calibration tool aims to convert the output value obtained from the sensor that is the frequency (Hz) to be converted into a percentage (%). The purpose of this conversion is that in the field of agriculture, the soil moisture unit is measured by percentage (%). Therefore calibration tool is needed to convert the unit value of frequency (Hz) to percentage form (%).

![Figure 2. Calibration Process](image)

2.1.5 Calibration
The data collection process begins by planting the sensors into the ground. This sensor is planted in a bucket container with a depth of 40cm (top soil depth). From the embedded sensor, the main Waspmote board will hold the data received via digital pin 3. Then the data will be stored into micro-sd in .txt format. The data obtained can also be monitored through the xbee 802.15.4 gateway. This gateway will communicate with xbee on the main Waspemote board.

Furthermore the data will be stored in micro-sd. Data from micro-sd can be seen by the researchers by first removing the memory card from Waspemote board and then the data on the memory card can be read by using a card reader. The data obtained and stored is still in the form of frequency.

In the embedded sensors in the soil, watering is done until the soil reaches a field capacity condition and experiences saturation point, that is where the soil cannot hold water anymore so that water will flow to the lower place. Then the data will be collected for twenty days. From this data collection will be obtained the lowest frequency point and highest frequency point as shown in Figure 3 and Figure 4. From both of this frequency points will be made by data comparison as in equation 1, so that it can be determined the percentage of soil moisture.

\[
\text{Interval Soil Moisture} = \frac{\Delta F}{100} = \frac{(F_2 - F_1)}{100}
\]
Figure 3. Interval Frequency of Calibration dated 20-09-2016 – 29-9-2016

Figure 4. Interval Frequency Callibration dated 30-9-2016 – 09-10-2016

The highest frequency data obtained from the calibration is 8159 Hz, and the lowest is 59 Hz. To convert the value from frequency to percent form is done with equation 1. as follows:

\[
\text{Interval Soil Moisture} = \frac{\Delta F}{100} = \frac{(F_2 - F_1)}{100} = \frac{(8159 - 59)}{100} = 81
\]

From the result of equation 1 we obtained value of interval increase percentage equal to 81 Hz. For each increase in the frequency of 81 Hz, the percentage of soil moisture will increase by 1%. For more details, the percentage incremental percentage incremental value can be seen in Table 1.

Table 1. Frequency Calibration in Percentage

| Soil Moisture (%) | Interval Frequency (Hz) | Frequency Gap (Hz) |
|-------------------|-------------------------|--------------------|
| 1                 | 59 – 140                | 81                 |
| 2                 | 140 – 221               | 81                 |
| 3                 | 221 – 302               | 81                 |
| 4                 | 302 – 383               | 81                 |
| 5                 | 383 – 464               | 81                 |
2.2. Monitoring and Notification System of Soil Humidity

2.2.1 Monitoring procedures
Any soil moisture data generated by Waspmote will be sent directly to the web server with the help of 3G modules installed on the board. This data is then ready to be represented to the client in the form of a fully updated graph, and the client can see all the information about the good sensor information about soil moisture, room temperature, soil temperature, and also battery capacity.

2.2.2 Soil Moisture Notification System
Data from Table 1 can be directly implemented into the coding board or can also be implemented when the data has entered into the database server then the data will be processed in accordance with the data in Table 1.

In this case, we implemented data processing calibration results on the web server side. The reason for implementing calibration data processing on the web server side is because if we directly implemented calibration results on the board, it will greatly bulk the performance of the board itself in terms of collecting and sending data since the calibration data is large enough to be directly uploaded to in board. This calibration data has a hundred parameters, so to reduce the workload of the sensor, the system will implement data processing calibration results on the server side by using PHP.

On the client side, if the client accesses the website then the soil moisture graph that appears on the client side is a percentage graph from 0 - 100%. The pseudocode to implement the calibration result is as follows:

```
Save frequency data (data from sensor);
Send frequency data to server ();
Calibration data (data from Table 3.1);
While (frequency data);
    If (frequency data >= calibration data 1 &&
        Frequency data < calibration data 1);
        Percentage = 1;
    Else If (frequency data >= calibration data 2 &&
        Frequency data < calibration data 2);
        Percentage = 2;
    Else If (frequency data >= calibration data 3 &&
        frequency data < calibration data 3);
        Percentage = 3;
    Else If (frequency data >= calibration data n &&
        frequency data < calibration data n);
        Percentage = n;
    Else
        Percentage = 100;
End While
Show percentage to graph ();
```

After the data is converted to percentage form, then the system activate the notification procedure implemented the web-based system. Stages of the notification system built can be seen in the flowchart in Figure 5.
The process of the application system work when the sensor then read the data soil moisture (sensor_value), the data will be stored first in the memory card, after the data is stored then the data will be sent to the database server via the internet. The data stored in this database will be represented in graphical form. Then on the client side will be provided form input parameter (parameter_notification) from 1 - 100%. The input data will be stored in the database server. Then from the soil moisture data (sensor_value) and parameter data (parameter_notification) will be compared, if the soil moisture data (sensor_value) is smaller or equal to the parameter data (parameter_notification) input, the notification will appear, and the system notification process is completed. However, if the soil moisture data (sensor_value) is greater than the parameter data, then the notification system process will recur to the data input process from the sensor (sensor_value) until the soil moisture data (sensor_value) is equal to or less than the parameter data.

Notifications will continue to be displayed before the client reads the notification on the notification page. This notification page contains the date, time, percentage of soil moisture, and set notification parameters.

3. Results
Performance test system was done to determine the performance of the system in monitoring whether the system is running well. In this case, the test was done as a calibration process, only at the time of
this test data frequency results that have been converted to a percentage form will go directly to the application system. The tests used several containers and the data obtained will be compared. The containers used are containers having dimensions of diameter and depth as shown in Table 2.

| No. | Diameter Container (cm) | Depth of Sensor (cm) |
|-----|-------------------------|----------------------|
| 1.  | 8                       | 14                   |
| 2.  | 15                      | 20                   |
| 3.  | 35                      | 45                   |

The design of sensor testing can be seen in Figure 6.

![Figure 6. Testing Scheme](image)

At the time of the test, the sensor will initially be planted in a container containing very dry soil. Once the sensor is planted, it will be watered by paying attention to the volume of water splashed to the ground. Slowly the water will seep into the ground (infiltration), and moisture sensor data readings will begin to rise when the water starts to propagate to the sensor.

In testing the performance of this soil moisture monitoring system, it can be seen that the graph moves automatically between 10 - 15 seconds. The readings from the sensor to the application system cannot be done every second; this is because to connect the 3G module board installed on Wasp mote to the internet network took 10-15 seconds. The readings and transmission of sensor data performed every 10 - 15 seconds is rapidly draining the battery power. Therefore for testing the performance of the system the sensor should be programmed to read and send data every 20 or 30 minutes. The purpose of this is to save battery power so that the sensor can last long in terms of reading and sending data to the application system. Then, another reason to modify this program is that at the time of reading the percentage decrease of moisture, the percentage decrease is very slow, therefore if reading and sending data every 20 - 30 minutes will be appropriate if we want to maximize battery power. The results of system performance in soil moisture monitoring can be seen in Figure 7.
Figure 7. Display Result of Soil Moisture Monitoring System

Based on the results of the first, second and third test, the percentage increase in soil moisture percentage is strongly influenced by the volume of water given to the soil contained in each container. The response from the detection in the test indicates that the sensors and the system are running well. If we want to increase the percentage of moisture quickly, then the water given into the container must be large. As for the rate of percentage, the decline is strongly influenced by the level of evaporation. Evaporation takes a long time to evaporate water from the soil. When observing the level of moisture decline required a notification system that if the researchers leave the soil with high humidity and researchers to want to monitor soil moisture in moisture percentage, the researchers simply set the level of humidity that wants to be monitored by the application system and if the moisture content of the soil is equal to or smaller from the point set on the system, then the system will immediately provide a notification.

The result of comparison of sensor testing can be seen in Table 3.

| Depth Sensor (cm) | Diameter Container (cm) | Lowest Frequency (Hz) | Highest Frequency (Hz) | Percentage Moisture (%) |
|------------------|-------------------------|----------------------|------------------------|-------------------------|
| 14               | 8                       | 59                   | 8196                   | 100                     |
| 20               | 15                      | 59                   | 8123                   | 100                     |
| 45               | 35                      | 59                   | 8159                   | 100                     |

4. Discussion
Soil moisture is one of the important things for plants. In soil moisture, there are grains of water that are bound adsorptive on the soil grains. The water contained in this soil grain is water that can be consumed by plants for its developmental process [4]. Monitoring the soil moisture level is necessary for researchers in agriculture, especially if we want to examine the level of water intake received by plants in the process of development of these plants. For that, a system is needed where the system can record the data obtained and give notification to the researcher about the percentage of monitored soil moisture.

Based on the frequency comparison value of the first, second and third tests on the percentage of values from the calibration results obtained data that the highest frequency value of humidity of each test slightly different. Although the highest frequency value of the test is different, the frequency value is at the same percentage interval that is 100%. This shows that the conversion value of calibrated frequency values to percentages tends to be stable and precise.

5. Conclusion
The rate of percentage increase in data readings by sensors concerning soil moisture conditions tends to increase faster depending on how much water volume is given to the soil. This indicates that the performance of the sensor and monitoring system goes according to the process of infiltration of water into the soil and runs well. The rate of moisture degradation in data readings by the sensor tends to be slower, as this depends on the evaporation processes occurring in the soil. The faster the evaporation process will decrease soil moisture will be faster too. However, if the evaporation process is slow, then the percentage decline will be slow as well. This rate of percentage decline will require a notification system capable of informing the researcher if the monitored soil is equal to or less than the parameter limit monitored by the researcher.
For further development, it is advisable to pay more attention to aspects of power use of the sensor so that the sensor can work longer. In subsequent research, it is also recommended to conduct research on land that has plants and expected the system is also able to store data about the plant.

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