An IoT-based Soil Moisture Monitor

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Abstract
Over the years, monitoring soil moisture level of farmland have been performed manually. This is often time consuming and less efficient, hence necessitating a solution that is efficient in controlling and monitoring soil moisture conditions. This work therefore proposes an Internet of Things (IoT)-based soil moisture monitor that observes soil moisture level using Arduino Uno microcontroller and a Wireless Fidelity (Wi-Fi) module to send data from the board to the user's cell phone or Personal Digital Assistant (PDA). The soil moisture monitor works by observing the water level of the soil and alerts the farmer when the predefined threshold rate of the moisture sensor goes above or beneath, thus indicating over watering and under watering.
This process also involves sending data from the sensor to the internet cloud and then to the database server. Evaluation of the proposed soil moisture monitor using thinspeak shows that the system is dynamic and efficient as it ensures water is not wasted. It is also cost effective as it eliminates the huge budget for hiring farm workers.

Keywords: internet of things, microcontroller, moisture monitor, soil sensor, Thingspeak

1. Introduction

With the advancement of technology globally across all sectors, the agricultural sector has not been left behind, with farmers wanting to boost their daily production with ease and comfort [19]. This is evident from various technological inventions and development of machines. With the drastic improvement in technology (especially in wireless technology), people's expectation based on improvement in the quality of plants is increasing [13]. As such, there is need for affordable and reliable devices, such as smart system/control device, that can contribute immensely towards the ease to farm [20].

The soil moisture monitor is a device with the ability to facilitate a successful communication and interaction between the farmer, his plants and soil, thereby ensuring proper monitoring of plant growth [14]. This device is not only applicable for use in gardens, it can also be used in small and large farms. A soil moisture monitoring device is a combination of both software and hardware component, integrated with a microcontroller and Wireless Fidelity (Wi-Fi) module to limit the need to always be physically present to monitor the moisture content (level) of the soil.

The most significant factors responsible for plant growth are temperature, water, light and carbon dioxide [15]. Over watering and under watering are destructive to plants as roots want air and water. If the soil is continuously saturated, air will not spread to the roots and the roots may asphyxiate. Underwatering is also harmful as roots not getting enough water drops while leaf edges turn brown. Also, planting trees or starting gardens in locations where the seed or plant would not get water sufficiently through natural sources like rain or ground water in its early phases has always been a worry to the farmers. This is one of the factors that necessitated moisture monitoring device. During the monitoring period, the device determines the moisture level of the soil. If lower than predetermined, it will raise an alarm which will be received by the farmer or the farm manager.

Often at times, many people tend to forget to water their plants due to their busy schedule which may result into the disorder in plants growth and eventually death. On another hand, overwatering plants in the quest to make it growth faster is also disastrous. Tied with this problem is over watering and shortage in the supply of water in cities and towns. This work therefore proposes the design and implementation of an internet of things (IoT) based soil moisture monitor that comprehensively monitors the soil moisture level to aid the growth of plants and protect them from diseases due to over watering or under watering. This monitor design consists of two parts, the hardware and the software. The hardware design consists of the controller hardware, Arduino Uno and the Wi-Fi module; while, for the software design, Proteus and Arduino IDE were used. The soil moisture monitor works by observing the water level of the soil and alerts the farmer when the predefined threshold rate of the moisture sensor goes above or beneath, thus indicating over watering and under watering.

The rest of the paper is organised as follows. Section II describes the background of the study while Section III presents closely related works. The system design and implementation are presented in Section IV while Section V presents the result and discussion. Finally, Section VI concludes the paper.

2. Background

IoT is the organization of unified computer systems, digital machinery, persons, objects, or animals, with exclusive identifiers and a network capable of transmitting information (data) that does not need interaction between humans. An entity in IoT can be a patient with a body (heart) monitoring device, a farmland with moisture sensor device, a smart home that has a sensor which makes it possible to switch on/off devices, a smart dust bin or other accepted object that can be allocated an IP address and is able to transmit data through a network [1]. The advent of IoT has resulted in an increase in its number of use cases.

IoT is a recent technology, however, since the beginning of the 1800s, there have been visions of communicating machines. The telegraph (the first landline) was technologically advanced in the 1830s and 1840s and has provided direct communication for machines. The initial transmission of a radio voice occurred on the 3rd of June 1900 and is described as "wireless telegraphy", providing another component necessary for the IoT to develop [2]. IoT is a network sensor of billions of intelligent devices which link people, computers and other applications to collect information and share information, therefore taking machine to machine (M2M) to the next level. IoT allows communication between M2M without human involvement [2].

Supervisory Control and Data Acquisition (SCADA), a software program category for process control and collection of information from remote locations in real-time for the control of devices and conditions, also extends the IoT. SCADA systems comprise of hardware and software. The hardware collects and supplies the information to a SCADA-installed computer where it is then processed and displayed promptly. The development of SCADA has led SCADA systems of late generation to develop into IoT devices of the first generation [1].

IoT bionetwork comprises of intelligent web enabling systems which assemble, sends and act on the information they obtained from their environment by means of integrated processors, sensors and communications equipment. IoT devices share their accessed data by using an IoT gateway or other edge system, which transmits information to the cloud to be evaluated [2]. These devices sometimes interact with other associated technologies and use the data they receive from each other. The systems often operate without human intervention, but persons can communicate with the systems, for example, to set it up and to provide guidance or to obtain the data [2]. The network, communication, and connectivity protocols employed with these web enabled devices rely mainly on IoT apps.

Soil moisture sensor evaluates the soil's volumetric water content (VWC), since direct gravimetric measurement of soil free moisture needs samples to be removed, dried, and weighed. These sensors indirectly measure the volumetric water content by using some other soil features, such as electric or neutron-related properties, for the soil moisture sensors. It is necessary to calibrate the relation amongst the measured property and soil moisture. This can differ according to environmental variables such as soil, temperature or electrical conduction. Today, many sensors, with variable performances, are accessible. Some evaluate the humidity content of the soil while others assess the capacity of soil water and dielectric. While several methods exist in the literature for the sensing of soil humidity, we will review and discuss four sensors based on soil tension and soil moisture content, namely; Tensiometer, Granular Matrix Sensor, Time domain reflectometry and VH400 soil moisture sensor. Nuclear sprinkling and gamma ray diminution methods are not discussed because they use radioactive materials that could prove to be harmful.

Tensiometers are measuring instruments for soil humidity tension commonly used for irrigation planning. The tensiometer of the porous ceramic tip linked to a vacuum measuring device through polyvinyl chloride (PVC) pipe is shown in Figure 1. The tube contains water and air free. The pore ceramic cup is placed in the soil so that soil water pressure can pass through the pressure sensing device to the tensiometer. The soil humidity content is not directly

d by this device, but rather by soil water voltage. The response time is generally 2-3 hours for a tensiometer. There are available tensiometers which are mechanized with an irrigation structure with the aid of pressure gauge [4].

Figure 1 Tensiometer [3]

Another soil sensor technology is the Granular Matrix Sensor (GMS) which is made up of a permeable ceramic outer layer consisting of two electrodes and an inner matrix structure. The probes in the GMS can be implanted in the granular fill material directly above the gypsum wafer. In granular matrix, moisture surroundings are modified in respective soil aquatic circumstances. These modifications continually bear witness to differing electrical resistance amid two sensor probes. The strength amongst the electrodes is inversely associated with soil water [6].

Time domain reflectometry (TDR) is a soil sensor monitor that inserts a radio frequency pulse power into a transfer line in the time field reflectometry. Thereafter, the rapidity is evaluated through sensing the replicated pulsation from the termination of the line. The speed is determined by the dielectric and is used to determine the content of humidity by calculating the time needed to return to the reflected pulse, as the TDR reacts rapidly (to 28 seconds) [7]. Frequency domain reflectometry (FDR) sensors consist of a few metal rings in the form of a condenser while the soil function as a dielectric. Its electrical sensor capacitance can be a measure of soil volumetric content and the code of operation is likened to that of TDR sensor.

VH400 soil moisture sensor are small in size and has jagged design for lengthy use. It is conductivity-based, indifferent to salt level and its probe do not rust over time. Devours less than 600uA of current for actual low power operation and gives accurate readings. It determines volumetric water content (VWC) and gravimetric water content (GWC). Its output voltage is proportional to the water content and it is waterproof and can be buried in the soil. The probe is long and slim; hence it is often used with smaller canned crops [8].

3. Related Work

Aprajita et al. [10] developed a GSM based Agriculture monitoring system using ATmega328, GSM module, temperature sensor, soil moisture sensor and a motor. The sensor senses the moisture content while the temperature sensor senses the temperature of its surroundings. The values from both sensors are conveyed to the ATmega328. The received and stored threshold values are compared to make necessary decision which is thereafter communicated to the user via the GSM module. In a situation where the received value is lower than the threshold, the user switches on the motor pump. This system is effective; however, it cannot communicate with multiple users.

Kushmithaa et al. [11] proposed an Arduino automatic plant irrigation using message alert system. This device uses soil sensor to monitor the moisture level, which has automatic irrigation system attached to it. If the moisture level of the soil is low, its unit output is at a high level, otherwise the output is at a low level. The proposed system is economical for improving water supply for agricultural production and can adjust to variations in crop needs with less maintenance. Despite its efficiency, this system lacks the ability to communicate with the user without interruption, due to poor cellular network and also lacks a buzzer for alarm.

Srinath et al. [12] proposed a GSM based automatic irrigation control system for efficient use of resources and crop planning by using an android phone. This device uses an ARM7 microcontroller, a GSM module, a temperature sensor, a motor pump and moisture sensor. The moisture sensor and temperature sensor detect the moisture level and temperature condition of the soil. The GSM module and ARM7 are linked through UART (universal asynchronous receiver and transmitter). If the sensor detects that the moisture content of the soil is less, it gives a message to the ARM7. Subsequently, it gives a command to the cell phone (which is kept in an auto responding mode). The cell phone activates the buzzer which in return indicates that the valves should be opened. If the call function button is pressed, the feedback is given back to the ARM7. It sends command to the valves and permits it to open. Once the moisture content turns out to be adequate, the sensor detects this and sends a message to the microcontroller and the buzzer goes off. By touching the button in the call function again, the valve is turned off. This system is flexible, evades over and under irrigation, stop soil erosion and reduces water wastage. For large-scale application, it will require a standby battery or solar to enable long lasting power supply.

Nawandar and Satpute [16] have proposed an IoT based low cost and intelligent module for crop monitoring and automatic irrigation system. This system interacts with users to get plants details and soil characteristics to know when to carry out evapotranspiration and neural based irrigation decision. Rahman et al. [17] proposed the use of raspberry Pi to achieve a real-time and IoT based farming. Additionally, the system can measure soil moisture using soil moisture sensor, detect flood water, measure the pH of soil and finally humidity and temperature measurement.

Abba et al. [ ] designed and implemented a prototype senor interface that automate the control and monitoring of irrigation system in remote locations to ensure water for irrigation is optimized.

Unlike previous related works that have been reviewed, this work presents a low-cost moisture monitor that observes the soil moisture level in real-time and provides an ease to use interface through the web portal, where farmers can remotely monitor the moisture content of their farmlands in real time to either dynamically add or stop the watering of the farmland.

4. System Design and Implementation

In this section, we present the design and implementation to achieve our proposed IoT-based moisture monitor. The proposed solution is made up of two parts, the hardware and software design. The hardware design consists of the controller hardware, Arduino Uno and the Wi-Fi module; while, for the software design, Proteus and Arduino IDE were used. The device is designed as shown in Fig. 2.

A. *LCD (Liquid Crystal Display)*

The Liquid Crystal Display (LCD) is an automated device that displays a visible image. This system it used to display the messages (i.e. soil moisture level (low or high)), in response to the input of the soil sensor. It works on 5V dc supply and has a current consumption of about 1mA without the backlight. 16x2 LCD is used having 16 columns and 2 rows. It consists of 16 pins which interfaces with a microcontroller [28]. In the LCD, each character/word is presented in a 5x7 display pixels which are chosen over seven segments and multi-segment LEDs because they are cost-effective and programmable with no restriction for demonstrating special and custom characters. A 16x2 LCD has two registers, the command and the data. The register “select” is used to change from one register to another. RS=0 is for command register, while RS=1 is for data register.

The command register saves the command orders specified to the LCD and processes the commands received. A command is a set of instruction given to the LCD to perform a predefined task, for example, resetting the LCD, clearing its screen, changing cursor position and controlling its display. The data register, on the other hand, saves the data on the LCD to be displayed. The data could be the character's American Standard Code for Information Interchange (ASCII) value to be displayed on the LCD. When data is sent to the LCD, it goes to the register of data and is processed [9].

B. *Arduino Uno*

Arduino Uno is an ATmega328P microcontroller board with 14 digital input or output pins (6 can be used, for example, as outputs for Pulse Width Modulation), 6 analog inputs, 16MHz quartz crystal, USB connection, power jack, ICSP header and a reset button.

The Arduino Uno board is the main functioning system in this monitor as it reads and deduces the data from the soil sensor outputs. Arduino Uno can be powered through the USB connection or from the use of an external power supply. The external power is either an AC to DC adapter or battery. The Arduino Uno board can function on an external supply of between 6-20 V. If provided with less than 7 V, the 5 V pin may supply less than 5 V and the board may wobbly. If more than 12 V is used, the voltage regulator can overheat and destroy the board. The recommended range is between 7-12 V.

C. *Wi-Fi Module (ESP8266)*

ESP8266 is a Wi-Fi module which is often used for IoT applications and function as a microcontroller to link directly to Wi-Fi and create a TCP/IP connection. It has an on-board processing and storage unit which permits integration with other sensors and application devices through its general-purpose input/output (GPIOs) with negligible loading during runtime. This module requires about 3.3 V power and has 8 pins, namely; rx, tx, Vcc, RESET, CH_PD, GPIO 0, GPIO 2 and GND. The 'rx' and 'tx' pins are used for interconnection. To communicate with the ESP8266, most microcontrollers use sets of AT commands. This module has the capacity to carry out analog to digital conversion, Pulse-Width Modulation (PWM) and Serial Peripheral Interface (SPI) communication protocol.

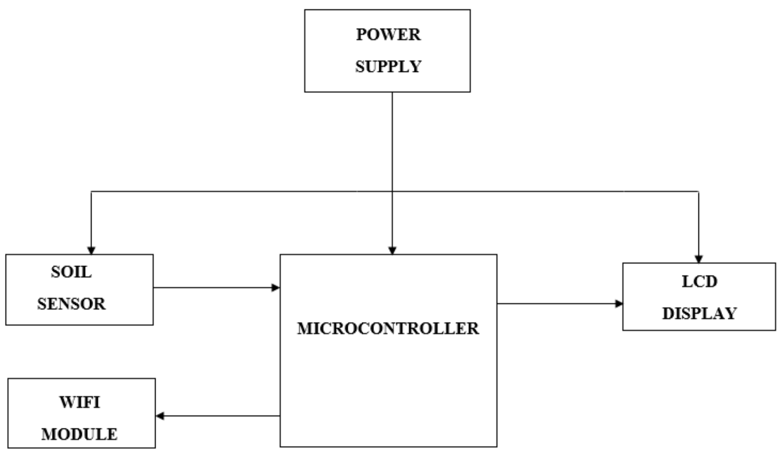

Fig. 2. IoT based Soil Moisture Monitor Block Diagram

D. *Soil Moisture Sensor*

Soil moisture sensor measures the volumetric water content in the soil. This sensor is made up of two probes which is used to ration the volumetric content of water. These probes are dipped into the soil which permits current to pass through the soil to get the resistance value used to obtain moisture value. If the water level is high, the soil conducts electricity more, which means that the resistance of the soil will be low, therefore, the moisture content is high. On the other hand, if there is less water, the dry soil tends to conduct electricity poorly, which means that the resistance will be higher, and the moisture level is lower.

The soil moisture content can be expressed using the volumetric or gravimetric method [5]. The gravimetric water content (θg) can be defined as the mass of water divided by the mass of the dry soil. It is determined through taking soil sample, weighing the sample (mass of the wet soil) and drying the sample (mass of the dry soil). This is shown by Equation (1);

$$\theta_g = \frac{mass\_water}{mass\_soil} = \frac{mass_{wet} - mass\_dry}{mass\_dry} \times 100\% \quad ....(1)$$

The volumetric water content (θ*v*) can be defined as the volume of water divided by the volume of the soil. Volume is a ratio of mass of water to density (ρ), as shown in equation (2):

$$\theta v = \frac{Volume\_water}{Volume\_soil} = \frac{mass\_water / \rho\_water}{mass\_soil / \rho\_soil} = \frac{\theta_g \times \rho_{wet}\,soil}{\rho_{water}} \quad ...(2)$$

E. *Power supply*

This is the unit responsible for supplying power to the entire system. The functionality of the system depends on the power supplied to it. A transformer is used to step input voltage up (220/240 V) or down to 12 V. A block rectifier is thereafter used to alter the alternating current 12 V to a DC. An electrolytic capacitor (filter) is used to smoothen the DC voltage to filter the noise produced in the process of regulating the voltage. A voltage regulator is used to select the desired regulated output voltage and connected in series.

Alternative parameter for direct volumetric water content (VWC) is the soil bulk density ($\rho bulk$) used for ρ_soil . It is expressed as the proportion of dry mass soil to volume of its sample. The density of water is approximately one, hence ignored. Also, soil porosity can be determined. Soil porosity (ε) can be related to soil bulk density as shown by Equation (3);

$$\varepsilon = 1 - \frac{\rho\_bulk}{\rho\_solid} \text{ ....(3)}$$

F. ***System Implementation***

The circuit diagram of the IoT based moisture monitor is shown in Fig. 3. The circuit was designed and simulated using the proteus application program. The code was written in C programming language and compiled using the Arduino IDE. A multimeter was used to examine the polarizations of the components used, such as the resistors, capacitors, voltage regulator, and the continuousness in the circuitry.

The Arduino Uno board was coupled to the entire component of the circuit and the C program was uploaded to the Arduino through the universal serial bus for testing. The test was carried out by collecting samples of loamy soil. During testing, the system was turned on and the moisture sensor was buried into the soil at a depth of at least 2cm. Once it reaches the desired depth, the sensor sends a signal to the microcontroller to take readings, compare them with the stored data and display the moisture state of the soil on the LCD.

The processed data is conveyed to the webserver through the IoT platform, Thingspeak, where farmers can assess the monitored data, then take necessary action. To access the information from the website, it is required to register and create an account from which the moisture level can be monitored. The flow chat of the procedure of the IoT based moisture monitor is shown in Fig. 4.

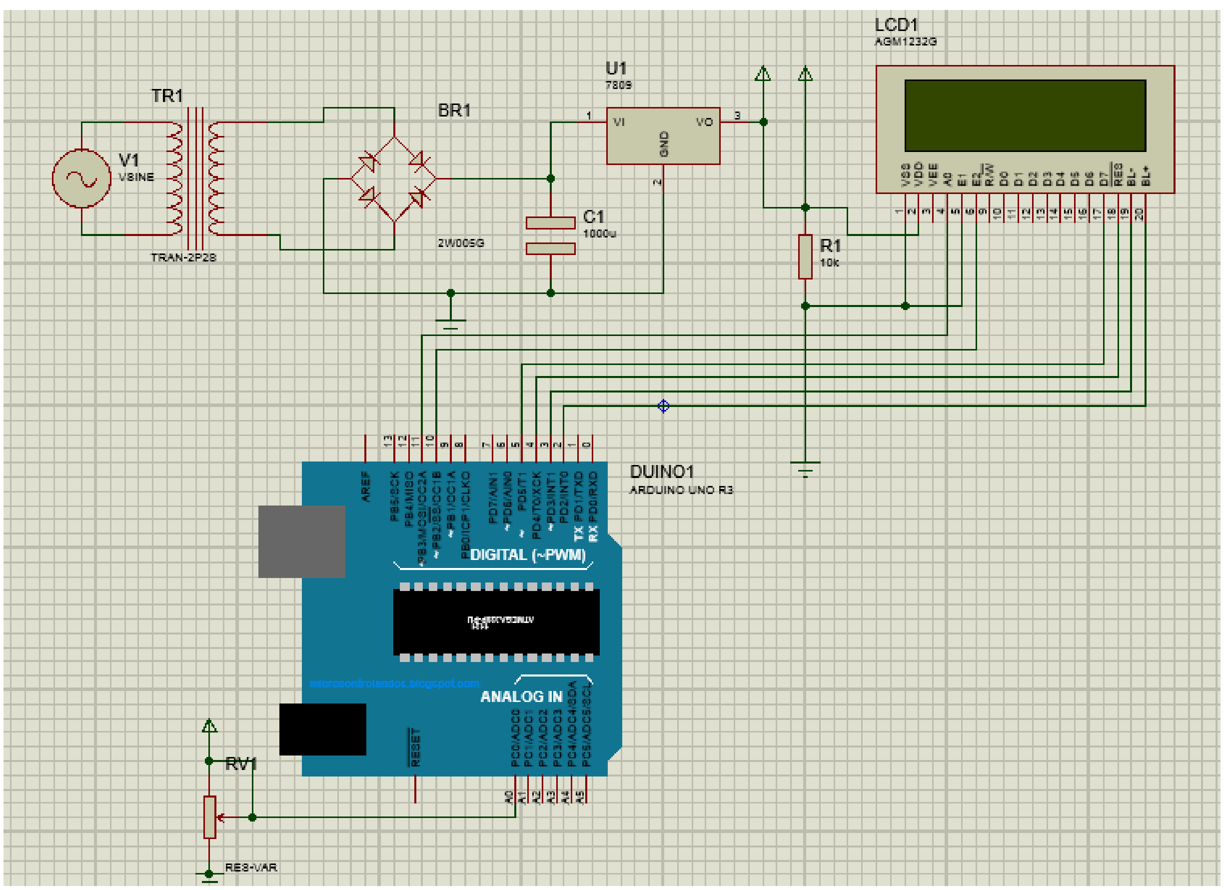

Fig. 3 Circuit diagram of the IoT based soil moisture device

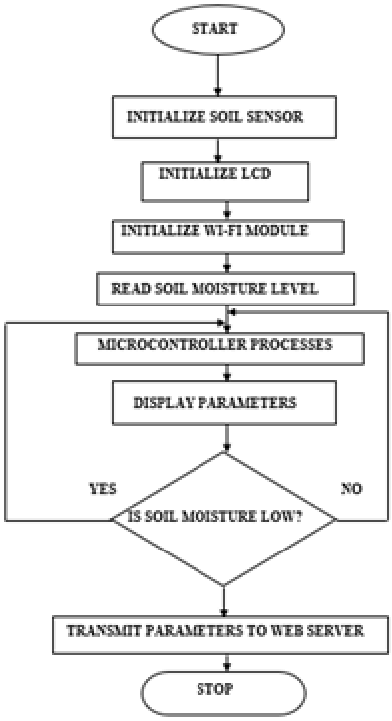

Fig. 4 Flow diagram of the procedure of the moisture monitor

5. Results and Discussion

In this section, we carryout two basic test on our proposed soil moisture monitor, namely; the response of the monitor when there was no moisture and the response of the monitor with some amount of water when there was a lot of moisture.

The Fig. 5 to Fig. 8 show the results obtained when there was no moisture in the sampled soil and when there was moisture in the sampled soil.

Fig. 5 response of the soil sensor when moisture content is low

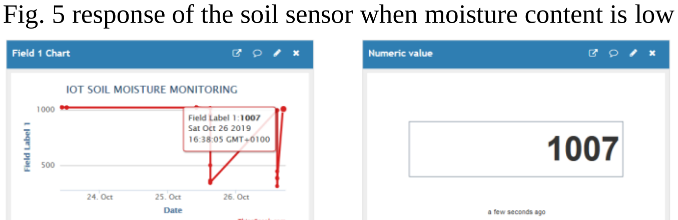

Fig. 6 Moisture level against date obtained from http://thingspeak.com (API key PPWDON43ZXN1XVRB) for low moisture content.

Fig. 7 Response of the soil sensor when the water content is large

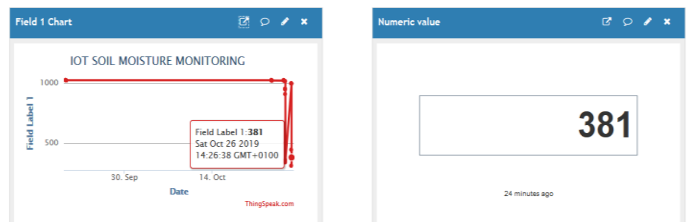

Fig.8 Moisture level against date deduced from http://thingspeak.com (API key PPWDON43ZXN1XVRB) for high moisture content.

From the Fig. 5 to Fig. 8, it is observed that the system responds when there is an alteration in the moisture level of the soil. Furthermore, from Fig. 5 and Fig. 6, it can be observed that the sensor reading is relatively low which is due to the soil high resistance indicating a low moisture level. As water is been poured to the soil, it can also be seen that the soil resistance reduces, and its moisture level increases (See Fig. 7 and Fig. 8).

6. Conclusion

In this work, we presented the design and implementation of an IoT based moisture monitor to aid farmers in the monitoring and control of their farmland to increase farm produce. Our proposed monitor determines the level of water in the soil by deploying a moisture sensor and use Wi-Fi module to transmit the sensed and processed data to the farmers via the internet. The webserver serves as the database for the sensor readings and also scrutinize information (data) from the webserver. The performance metering of the monitor is consistent with the data taken which helps the farmers to determine whether a plant is healthy, with regards to the moisture content of the soil. The monitor notifies the farmer of any insufficient or surplus water supply to the farmland and help farmers to improve the quality of agricultural produce.

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