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A NOVEL SOIL MOISTURE, TEMPERATURE AND HUMIDITY MEASURING SYSTEM- AN IOT APPROACH

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ABSTRACT

The world is currently experiencing a rapid population growth resulting in increased food demand. To avoid the risk of famine in especially low-income countries, effective and efficient agricultural practices that will enhance food production at a lower cost is desired. For effective food production, soil quality is very important. There should be improved techniques to determine precise soil moisture, humidity, and temperature measurement to guide farmers to be efficient. In Sub-Saharan African countries such as Ghana, farmers use conventional methods to check how good the soil is for cultivating crops; they examine the soil with their bare hands. This approach has proven to be ineffective as it requires significant amount of human effort. To address this challenge, an IoT based soil moisture, humidity, and temperature measurement system is proposed. It consists of a moisture probe to determine the moisture percentage of the soil, a temperature and humidity sensor for measuring the temperature and humidity of the soil, and a Wi-Fi module for transmitting the data to a data repository for analysis. A prototype is developed based on a conceptual framework which is tested under live conditions. Based on ideal parameters for the cultivation of certain crops which are stored in the data repository, and the live data captured by the sensors, the farmers are alerted electronically on the most suitable crops to plant. The system was tested in five different locations and based on the data gathered, it recommended the products that are suitable for cultivation in a particular field. The proposed system outperformed other referenced models in identifying soil suitability for the cultivation of crops. The system was able to recommend suitable crops for planting based on data on soil parameters, a feature that made it novel.

Keywords: *Automatic, Cloud, Internet Of Things, Sensors, Soil Moisture*

1. INTRODUCTION

Food consumption needs of the global population in the estimation of [1] is expected to rise to 70% by the year 2050. Further, they contend that the current production of food has taken up about 40% of the land surface of the planet, it is therefore expedient that farmers should be presented with easier ways to identify where particular crops could thrive better. In developing economies such as Ghana, most farmers usually test how good the soil is for planting particular crops by inserting their fingers into it; if the soil feels dry then it may not be good. The soil may be damp if it clings to one's finger. The farmers also take a glance at how dry or wet the soil is when they are trying to get a general idea of the moisture level. If it is bright as well as hard and/or compact, then the soil will most likely be dry. With this approach, farmers are unable to determine which crops are suitable for planting just by looking at how dry or moist the soil looks or feels. The farmers also would not have any idea about the temperature and humidity levels around the soil. Monitoring soil parameters remotely is an evolving trend and has the potential of transforming agricultural practices to increase productivity [2]. Automating the choice of crops to be planted can go a long way to make the work of farmers less tedious and also will result in precise and quality outputs, thereby increasing productivity. The Internet of Things (IoT) which is a recent invention is revolutionizing the agriculture industry and resolving the enormous challenges confronting farmers in their pursuit for increased production. By automating farm activities, the agricultural sector can be transformed from a manual and static system to a more dynamic and intelligent system resulting in higher agricultural productivity with minimal human intervention [3].

The advent of the Internet of Things (IoT) is positively transforming the agricultural sector [25] and is contributing significantly to solving the major difficulties currently confronting crop farmers [27]. The IoT is a collective network of things that are capable of communicating with each other through the internet [4] and is expected to play a significant role in boosting agricultural production to feed 9.6 billion people in the world by the year 2050 [5]. The IoT is a new phenomenon and is a concept that is multidisciplinary and incorporates a wide range of devices and applications [6]. A significant number of research presented in literature all agree that accurately measuring soil temperature, moisture, and humidity is challenging; enhanced techniques are thus urgently desired to boost food production. With the failure of other systems, the IoT is seen as the panacea to the problem, however, the accuracy of the IoT techniques presented also require further enhancement. Data storage and its subsequent communication to farmers to enable them make quick and effective decisions also require improvement.

This paper aims to present an IoT-based soil parameter measuring system with intelligent moisture, humidity and temperature measuring mechanism. It will enable farmers to test moisture content, humidity and temperature of the soil accurately and timely. This will allow farmers to decide on which crops to cultivate in order to maximize output. With the IoT, connecting digital devices through the internet to physical objects to enable them communicate and share data is enhanced greatly. The collected data is stored and managed in a cloud data repository and is shared between persons, machines, or persons to machines.

The proposed system will initially capture the documented ideal soil moisture, humidity, and temperature for cultivating particular crops and sensors are used to gather the actual data from the soil. The data is analyzed and the farmers, using a mobile device can query the system with the crops they are interested in cultivating and the system will report whether based on the data available the crop is suitable or not. In validating the IoT System, it was deployed in different areas and was able to accurately measure the moisture, humidity, and temperature of the soil and ideal crops for planting in a particular area based on the data gathered is highlighted by the system.

2. BACKGROUND STUDY

The food industry is reputed to play a significant role in the economy of every country [24]. On a global scale, climate change and agriculture are related activities [7]; climate in Ghana as well as some parts of the world is erratic. From historical data, the amount of rainfall has been decreasing and patterns have been erratic over the years [7]. Globally, temperature is on the rise, and this has had adverse effect on agriculture [8]. Crop yields have reduced with the reduction in rainfall and increase in temperature in most parts of the world. Most farmers in especially developing countries such as Ghana are unable to manage these changes as they have no medium of predicting climate change. Also, most of the farmers are subsistent, and thus lack the technology to cope with these climatic changes [7]. For agricultural applications, soil humidity and moisture measurement is very critical. Where irrigation is used, farmers will be able to manage the irrigation systems more efficiently and also prevent wastage of water. When farmers know the exact composition of the soil, less water could be used for the cultivation of crops and the right crops suitable for that environment would be planted. According to Pinnington et al. [9], in areas where the masses rely on subsistent farming, soil moisture rather than precipitation is the most important element in growing crops. Variations in temperature has different effects on agricultural production, some crops such as pineapples are particularly sensitive to minimum temperature which accounts for up to 82% of yield variability in Ghana [10]. Crop production, especially rain fed, is sensitive and affected by variations in climate, and the change mostly has a negative impact on agricultural production [10]. Accurate and reliable data on soil moisture and temperature will greatly increase crop yield in the world as it will guide farmers in selecting suitable land and crops for planting.

The agricultural sector in developing countries such as Ghana is characterized by low technological adaptation, and this contributes to low agricultural productivity [11]. The overall response to climate change using modern technology is low. Although farmers are adapting to variations to climate by changing farming practices [12], they are unable to maximize crop yield as there is still a decline in agricultural produce over the years [13]. Significant adaptation of technology in developing countries' agricultural sector can complement efficient farming practices to increase crop yield even in the face of adverse

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climate change. In developing countries, most farmers use conventional techniques to check the levels of humidity, temperature, and moisture of soil by turning over soil samples with their cutlasses. When the soil looks very dry and hard, it indicates the absence of moisture in the soil. When the soil feels wet and soft, then the farmers conclude that the soil is moist. This existing technique which is being used by farmers is limiting because they will not know the exact measurements of temperature, moisture and humidity levels of the soil. Figure 1 shows a local farmer using a cutlass to determine the moisture level of the soil by the soil turnover technique. An innovative approach in agriculture has to be adopted by the use of smart soil monitoring tools.

Figure 1: Farmer Testing Soil

Various techniques for measuring temperature, moisture, and humidity levels of soil to aid farmers in their decision making have been presented. A system that monitors soil moisture, temperature, and relative humidity and acquires data by means of sensors connected to a microcontroller with signals transmitted using radio frequency has been presented by Coelho et al. [14]. This system is however constrained by its inability to detect moisture at different depts. Radio waves also have a problem with transmitting large volumes of data at the same time since they are of low frequency. Using a combination of ZigBee technology, artificial intelligence, and decision support technology, Zhang et al. [15] developed an IoT system for monitoring citrus soil moisture and nutrients in real time. It has a drawback of being able to only measure soil moisture, other important parameters such as temperature and humidity cannot be measured. It is alluded by Gondchawar and Kawitkar [16] that about 70% of India’s population are reliant on farming culminating in the nation’s one-third capital coming from farming which is bedeviled with challenges. They thus propose a smart agriculture to modernize farming utilizing automation and IoT based techniques. The major feature for the improvement of yields from crops is the monitoring of environmental factors which has to be driven by evolving smart technology. Prathibha et al. [17] also presented a system that monitors humidity and temperature to ensure efficient choice of crops for planting through sensors using CC3200 single-chip interfaced with a camera and sends pictures to mobile devices of farmers through Wi-Fi. It measures temperature and humidity of the air in an agricultural field and so will not be effective in measuring actual soil temperature and humidity.

Rao and Sridhar [19] also presented a Raspberry Pi based IoT automated irrigation system for the modernization and improvement of crop production through efficient water management. Data on the humidity and temperature of the soil and the period of sunshine for the day is gathered by sensors and transmitted to a base station, the quantity of water required for irrigating the soil is then estimated. The advantage of the proposed system lies in the optimization of water usage while crop yield is maximized through the implementation of precision agriculture with cloud computing, however, the system only ensures an efficient irrigation of crops but lacks the capability of giving feedback on ideal crops for planting based on data gathered. In [20], a smart system based on a smart algorithm that predicts the irrigation requirements of a land through the sensing of soil moisture, temperature, and weather forecast from the internet was also presented. The system has a hybrid machine learning approach for the prediction of soil moisture for future days. The system’s drawback is that data is gathered through forecasting models which may lack accuracy. Nath et al. [21] allude that there is the need for a more

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efficient and cost effective system which will enable farmers to monitor environmental factors such as temperature, relative humidity, and moisture that is required for the growth of crops. They therefore presented a system that uses DHT11, capacitive soil moisture sensing circuit, and resistive soil moisture sensing circuit that measures the temperature, relative humidity, and soil moisture of a land and the data is transmitted to a cloud repository for analysis. The system did not provide for mechanism for the data to be processed, also there is no medium for transmitting the data to farmers and interested persons. Dasgupta et al. [22] proposed an IoT Based Smart Irrigation System that will ensure that the use of resources are optimized in solving water shortage. It is made up of a DH11 temperature and humidity sensor and a hygrometer sensor for the measurement of ambient atmospheric temperature and humidity and has wireless communication modules for data transmission to a cloud repository. The major drawback of this system is that it is not automated as the system administrator is provided with the option of switching to a special mode which enables the change in moisture content and the soil's acidity to be managed. In [23], an integrated farm management system that utilizes smartphone application and the Internet of Things (IoT) was presented. This system provides farmers with the capability of monitoring a farm remotely for soil moisture, pH level in the soil, humidity and temperature in the environment. The weather and soil conditions in an area is rapidly analyzed for decision-making. The proposed system monitors the condition of plants by collecting real-time data from the environment through sensors, this cannot aid farmers to decide on which crops to plant. In order to assist farmers with plant watering automatically without staying on the field for a whole day, Ahmed et al. [18] presented an IoT Based automated plant watering system by using soil moisture sensing, and based on this, the water pump is automatically turned on or off depending on the detected moisture level. This system only tests for a single parameter which is not adequate to determine the crop that is suitable for a particular soil. In [26], M. A. Mondal and Z. Rehena contend that the adoption of smart farming could help improve the adverse effects of food production. They thus presented an IoT system for the accurate control of crops, and capable of collecting useful data and automatic farming techniques. The system is an intelligent field monitor that monitors soil humidity and temperature and the data is stored on ThingSpeak to be analyzed in the future. An Arduino board is used to control the high voltage farming equipment automatically, using soil moisture and temperature values that have been predefined. Changing the threshold values of the soil moisture and temperature involves updating the middleware manually which represents a major drawback of the system. In the estimation of [28], to achieve a good harvest, the farming field has to be monitored periodically. They therefore proposed an IoT based field monitoring system to provide quick information on soil moisture, humidity, and temperature of the farming field to farmers. Based on the data received, farmers can take quick action on the crops to be planted. Data gathered by the sensors are transmitted to a mobile device using Bluetooth and ZigBee technologies. Both technologies are hampered by low speed of data transmission and work within a short range with weak security as compared to other wireless data standards such as WI-FI.

In summary, all the research that have been studied confirm that accurate measurement of soil moisture, humidity, and temperature will boost food production and ensure food security. Techniques to ensure timely and efficient gathering of data, its analysis, and transmission requires improvement to enable farmers make informed decisions on the most suitable crops to plant based on the available data. There is also agreement amongst researchers that an inexpensive IoT based smart device is the best solution for accurately measuring soil parameters. None of the literature perused proposed a system that stored data on the ideal soil moisture, humidity, and temperature for planting particular crops. This cost-effective device should have the capability of being inserted into soil samples to measure the temperature, humidity and amount of moisture in the soil. The system should have the capability to allow the input of staple crops and their ideal soil humidity, moisture, and temperature data. The proposed system should be able to analyze the data collected by the sensors and recommend to farmers which crops to plant considering the conditions of the soil after actual measurement of the parameters which represents a major gap in the systems presented. The IoT system should transmit the collected data to an online data repository for further analysis. Users should be able to gain timely access to the data using mobile devices.

3. THEORITICAL FRAMEWORK

The theoretical framework underlying the proposed IoT based soil moisture, humidity, and

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temperature measurement system to aide farmers in measuring soil parameters to enable them take timely and precise decision is presented in Figure 2. Each crop has its ideal soil humidity, moisture, and temperature level that makes it to flourish. In most countries, each community have their staple crops, therefore based on the crops planted in a particular area, data is collected on the ideal soil moisture, humidity, and temperatures required for planting such crops and is stored in a data repository.

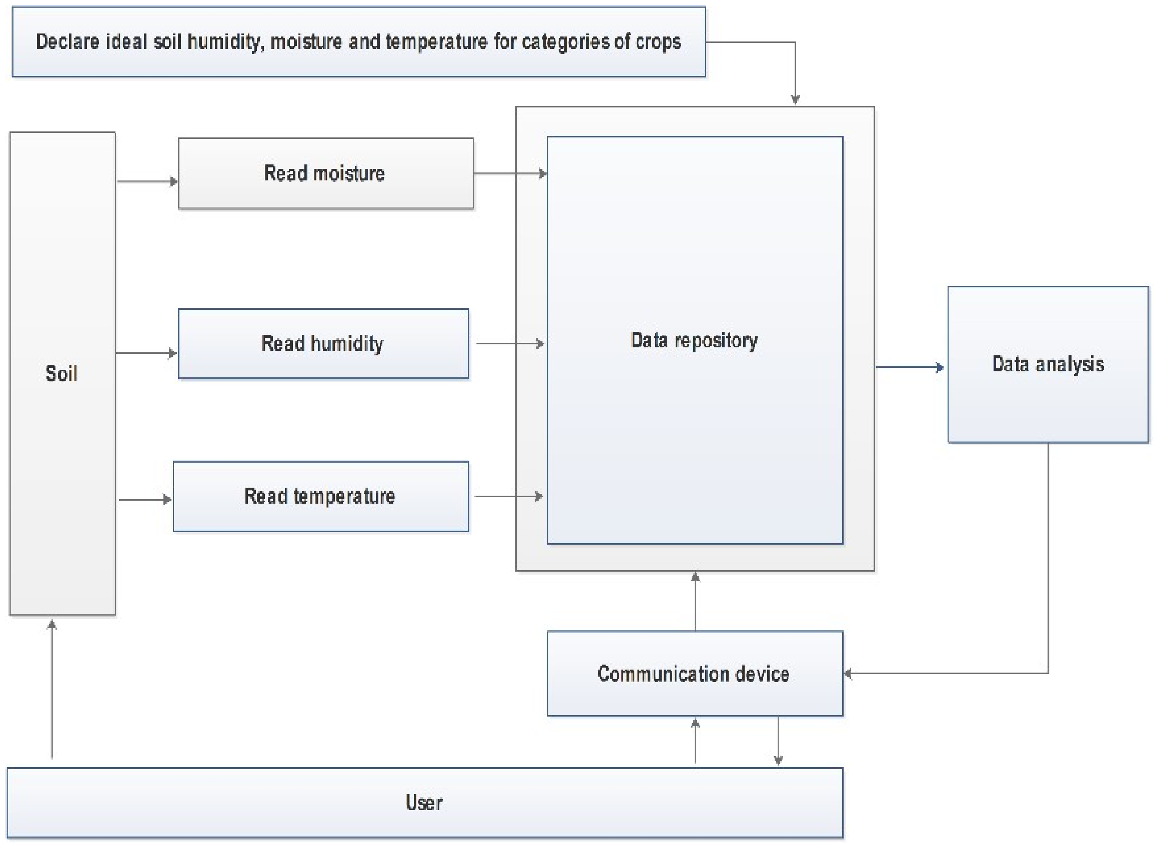

Figure 2: Theoretical Framework

Within the theoretical framework as depicted in Figure 2, the actual moisture, humidity, and temperature levels of the soil is gathered by the user and transmitted to the data repository. Since the data repository already contains the ideal soil parameters for the cultivation of certain crops, the user has two options in the choice of crops. One option is to query the system to recommend the most productive crop to be planted based on analysis of the data captured by the sensors compared to the soil parameters that are ideal for such crops. The other option is for the users to query the system to find out whether their preferred crops could be suitable for cultivation on a field based on the actual data gathered from that particular field. The systems' response will be either the crop is suitable or unsuitable for planting on that particular field. The user can communicate with the system using a mobile device.

4. SYSTEM COMPONENTS, CONFIGURATION AND IMPLEMENTATION

The IoT based soil moisture; humidity and temperature measurement system consists of readily available and inexpensive components which are easy to assemble. These devices are Arduino Uno microcontroller, Moisture Probe, DHT11 Sensor, LCD Screen. The devices are configured to communicate with the ThingSpeak data repository through the internet.

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4.1 System Components

The components used in designing the system are depicted in Figure 3 below.

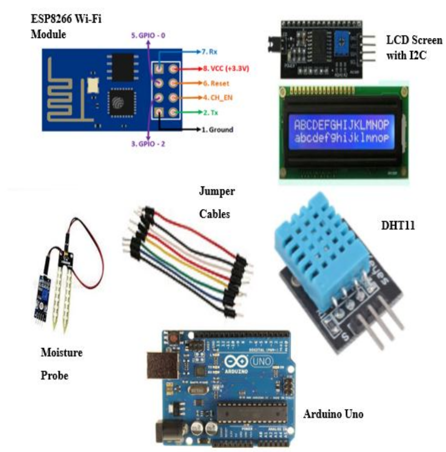

Figure 3: System Components

a. Arduino Uno microcontroller

The Arduino Uno is an ATmega328P-based microcontroller module. It has 14 digital input/output pins, 6 of which are PWM, 6 analogue input, 16 MHz quartz crystal, a USB interface, a power jack, an ICSP and a reset button. The board has 2 digital input/output pins. It includes everything needed for the microcontroller to function.

b. Moisture Probe

The soil moisture probe measures the soil moisture levels by capacitive sensing technique rather than resistive sensing and, since it is made of more durable material, it is less susceptible to corrosion.

c. DHT11 Sensor

The DHT11 is a temperature and humidity sensor that generates a calibrated digital output. The sensor comprises of 3 main components, an NTC thermistor that tests the temperature and an 8-bit microcontroller, which translates analogue signals from the sensor and transmits a single digital signal. DHT11 reads the moisture and humidity values and sends it to the Arduino Uno microcontroller for processing.

d. LCD Screen

The LCD screen is made up of 16 pins. However, an I2C is fixed on these pins to make it easier to connect. Instead of connecting 16 jumper cables, the I2C makes it possible to connect 4 jumper cables, namely the GND, VCC, SCL and SDA. The LCD screen displayed the data that sent was from the moisture probe and the DHT11 to be processed by the Arduino Uno microcontroller.

e. ESP8266-01 Wi-Fi Module

The ESP8266 is an open-source firmware that helps to build Internet of Things (IoT) products. The ESP8266 -01 when connected to an Arduino Uno, helps transfer all data from the Arduino Uno onto a different platform wirelessly. In the developed IoT system, the ESP8266 was used to transmit the data processed by the Arduino Uno microcontroller to the ThingSpeak database online

4.2 Hardware Configuration

This section outlines how the hardware components of the system are assembled to achieve the proposed system.

a. Setting up the Arduino and LCD

The Arduino Uno has a USB port to connect to a computer to which verified codes can be uploaded. The LCD has an I2C at the back that allows 4 pins to connect to the LCD screen rather than 16. The VCC-pin, GND-pin, SCL and SDA are the 4 pins of the I2C. The VCC pin enters the 5v slot, the GND pin enters the GND slot as well. The SCL and SDA pins are respectively positioned in A4 and A5 slots as shown in Figure 4.

Figure 4: Installation of Arduino Uno and LCD

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b. Installing the moisture probe

The moisture sensor has 4 pins on it, the VCC, GND, A0 and D0. The GND pin is attached to the Arduino Uno GND slot and the VCC pin to the Arduino Uno 5V slot. The experimental signal is transmitted from the sensor to the Arduino Uno through the A0 pin to the A2, as seen in the Figure 5.

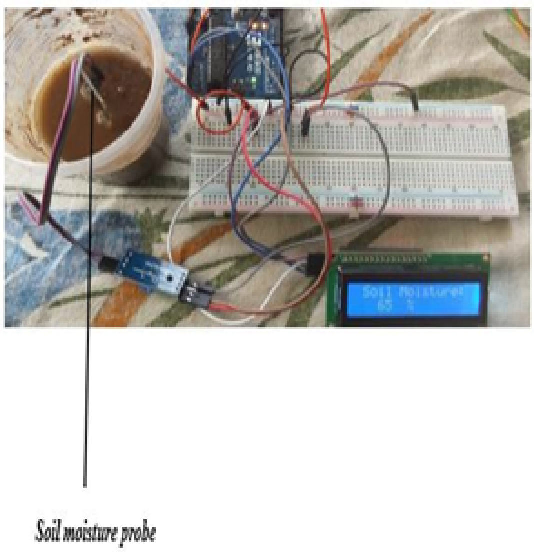

Figure 5: Soil Moisture Probe Testing

c. Installing the DHT11

The DHT11 is made up of 3 pins, VCC, GND and SIG pin. The GND pin is connected to the Arduino Uno GND slot and the VCC pin to the Arduino Uno 5V slot. The digital slot 2 is connected with the SNG pin, which sends the signals from the DHT11 to the Arduino Uno microcontroller as shown in Figure 6 below.

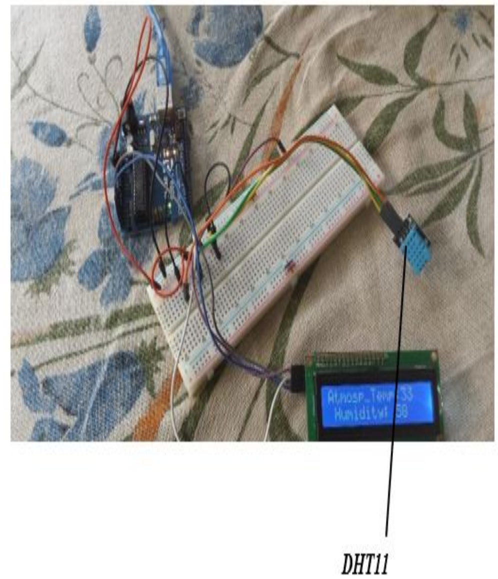

Figure 6: System design showing the installed DHT11

d. Installing the ESP8266-01

The VCC is connected to the Arduino Uno 5V when the ESP8266-01 is mounted. The CH EN is connected to a 10 K resistor that is connected to the Arduino Uno 5V as well. The TX is linked to the Arduino Uno's D3 and the GND to the Arduino Uno's GND. The ESP 8266-01 RX is attached through a 3-1 K resistor loop to the D2 of the Arduino Uno, where the GND is passed to the Arduino Uno.

4.3 System Implementation

The software used for this system was programmed using an Arduino IDE. An Arduino IDE is an advanced open-source software environment used for IoT devices and other smart applications. It supports C++ and C language microcontrollers. A code editor, notification and text, tool and menu bar are also included in the Arduino IDE. Figure 7 shows the installation of the ESP8266 module.

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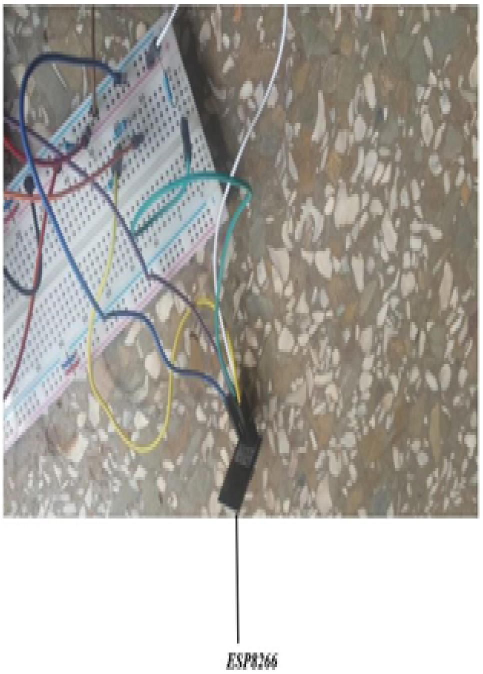

Figure 7: Installation of the ESP8266 Module

Programs written with Arduino are referred to as sketches. The sketches are transferred to the Arduino hardware through a computer. The project sketches are written in C language in the Arduino IDE code editor. The microcontroller board based on the ATmega328 was used for developing the IoT system. Figure 8 shows how the Arduino board was connected to a computer.

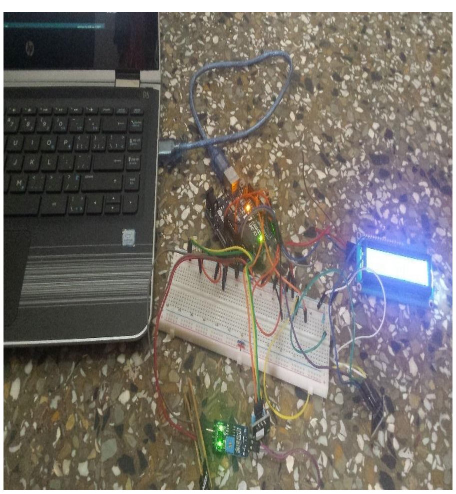

Figure 8: Connecting the Hardware System for Software Upload

5. RESULTS AND DISCUSSIONS

The proposed IoT soil moisture, temperature, and humidity measuring system was built using the concepts outlined in the Theoretical Framework shown in Figure 2. The soil moisture, humidity, and temperature sensors were installed on an Arduino microcontroller board. A Wi-Fi module is connected to the system and actual data captured from the sensors are transmitted to the cloud data repository, ThingSpeak. The ideal data on soil moisture, humidity, and temperature required to plant particular staple crops are captured into the data repository. Farmers using the IoT based system can measure the soil parameters of a field and also check if particular crops are suitable for planting in than area. The resultant prototype of the developed IoT based soil moisture, humidity, and temperature measurement system is depicted in Figure 9. The testing of the prototype is done in the wet season, which is the ideal season in West Africa for planting crops for those without irrigation facilities. The testing is done in two ways, first, the test is conducted on the same field for a number of times in different time intervals. This is to establish whether at particular times of the day when the weather is hot or cold the measurements would differ. The readings collected at different times of the day will confirm whether the data gathered is accurate. Soil temperature is expected to be low and moister in the morning when the sun is coming up; also soil temperature is higher and is less moist in the afternoon when the weather is hotter. Secondly, the test is done in five (5) different locations at the same time. The second criteria is also very vital as different fields could have different soil moisture, humidity, and temperature at the same time and the proposed system must be able to depict that to ensure its accuracy.

During the testing phase, the IoT system indicated that the amount of moisture displayed on the LCD screen increased when checking the moisture level in wet soil. In addition, the DHT11 reported low humidity levels as the temperature level increased, and high humidity levels as the temperature level went down as depicted in Table 1. It demonstrated clearly that the amount of humidity falls with a rise in temperature.

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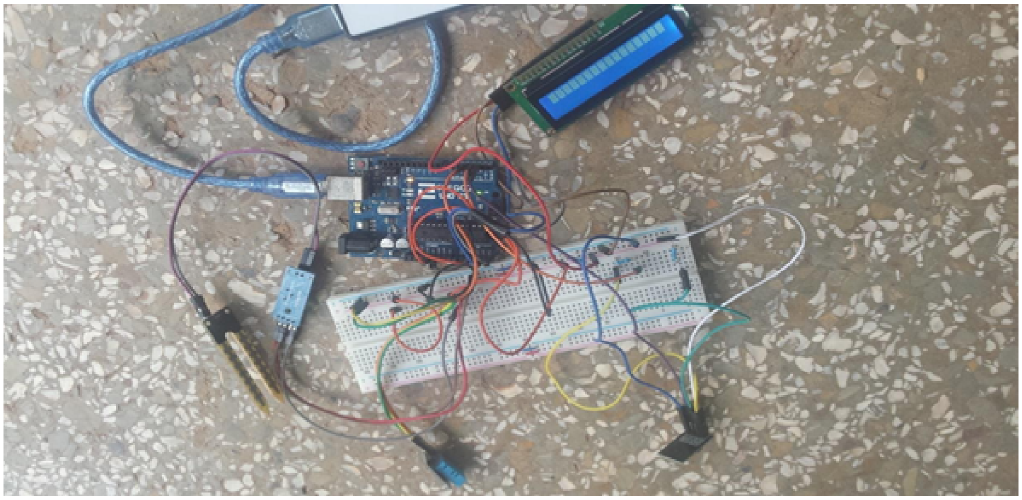

Figure 9. A Prototype of the IoT based System

The resultant prototype illustrated in Figure 9 is inexpensive as it was built with readily available sensors and a microcontroller which are inexpensive and easier to install. It is portable enabling users to carry it easily to where ever they desire, it is also easier to use.

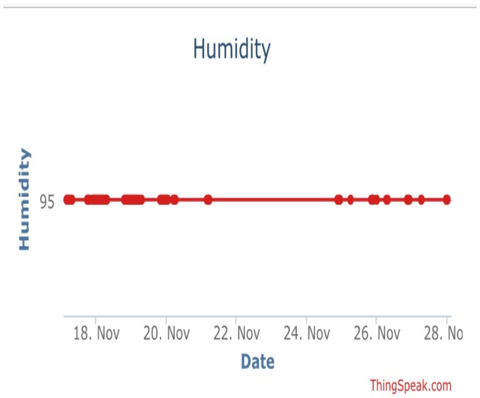

Figure 10: Periodic Humidity Levels

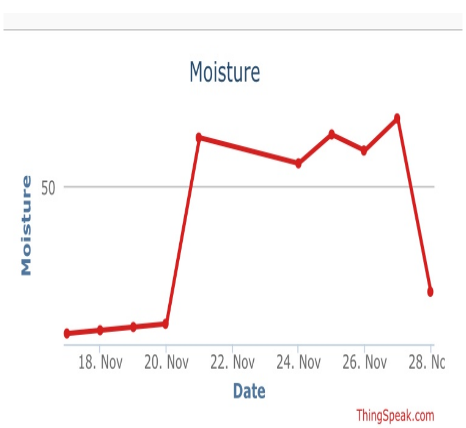

Figure 11: Periodic Moisture Levels

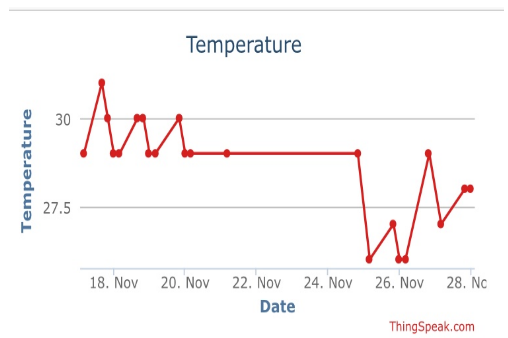

Figure 12: Periodic Temperature Levels

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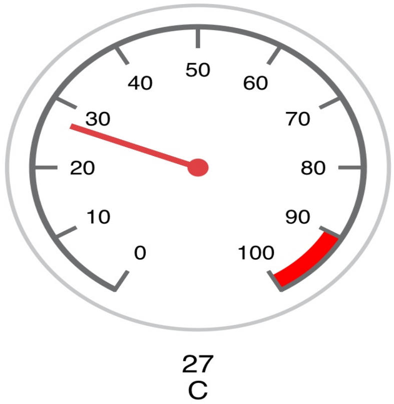

Figure 13: Temperature Monitor

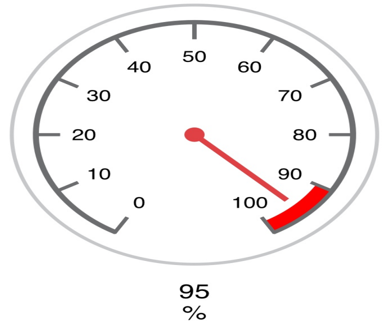

Figure 14: Humidity Monitor

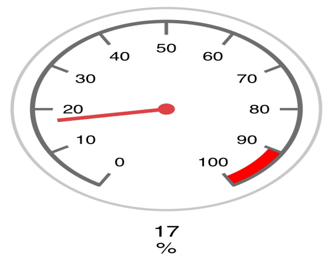

Figure 15: Moisture Monitor

The prototype was used to test soil humidity, moisture, and temperature of the same area a number of times on different dates at different times and the results were transmitted to the ThingSpeak data repository and visualized which is depicted in Figures 10 to 12. Figures 13 to 15 also show the data when a single temperature, humidity, and moisture value is read. Figure 11 shows soil moisture levels taken periodically at the same location for a number of days, it indicates that soil moisture readings are different when taken at different times. However, the variations should not be much and should be within the normal range for the cultivation of chosen crops. In Figure 12, soil temperature is also measured over a number of days at different times and also depicting that soil temperature also differs from time and days taken but should also fall within an acceptable range to enable choice of crops for planting.

Table 1. Measurement of Soil Parameters

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5
Soil moisture (%)	82	75	90	65	85
Soil temperature (°c)	20	22	18	30	19
Soil humidity (%)	53	52	60	40	56

The ThingSpeak online database was used for the analysis of the data collected. Table 1 shows the measurement of soil moisture, temperature, and humidity taken at five different locations at the same time. In Test 3, soil moisture is 90% and soil temperature is 18 degrees Celsius; in Test 4 soil moisture is 65% and soil temperature is 30 degrees Celsius. This confirms that when soil moisture is low, soil temperature is higher. Soil moisture is lower where soil temperature is higher. Test 3 recorded the highest humidity of 60% and the soil moisture of 90% with the lowest soil temperature of 18 degrees Celsius. Test 4 also recorded the lowest humidity level of 40%, the highest temperature of 30 degrees Celsius and the lowest moisture level of 65%. This confirms that when soil temperature is low, both the soil humidity and moisture are higher. However, where soil temperature is higher both the humidity and moisture of the soil are lower. This confirms that the proposed system measures the soil parameters accurately.

With this system, farmers have been presented with the capability of keeping track of the soil state (moisture, temperature and humidity) of a particular area and are able to know the crops that are suitable for planting based on the measurements taken. With an online database, they have the opportunity to use mobile devices to access data wherever they may find themselves.

6. COMPARISON WITH RELATED WORK

To confirm the novelty of the proposed system, it is compared against other state-of-the art referenced

soil parameter measuring systems that have been discussed in Section 2 and presented in Table 2.

Table 2: Comparison with Related Work

Authors	Soil Parameter	Cloud Data Storage	Capture Crop Data	Propose Crops
R. K. Jha et al. [28]	Moisture, humidity, temperature	Yes	No	No
R. K. Kodali [1]	Soil moisture	Yes	No	No
X. Zhang et al. [15]	Soil moisture	Yes	No	No
M. A. Mondal [26]	Humidity and temperature	Yes	No	No
M. A. Patil et al. [23]	Moisture, humidity, and Temperature	Yes	No	No
Proposed System	Moisture, humidity, and Temperature	Yes	Yes	Yes

These systems as shown in Table 2 use newest technologies and have been published in reputable journals and have also been well cited. In our estimation, a soil parameter measuring system should be able to accurately measure soil moisture, soil, humidity and soil temperature. The system should also be equipped with the capability of storing data in an accessible cloud data repository and should also store the ideal soil parameter for planting staple crops in a geographical area. The system should also be equipped with the capability to propose crops to be planted by farmers in a particular area based on the data. The parameters for comparison are tabulated in Table 2. None of the systems presented capture data on crops and the ideal soil parameters required for their planting. None of the systems presented earlier also has the capability to propose crops for planting based on the actual data collected in a particular area. From Table 2, it is evident that the proposed IoT system has the capability of measuring soil, humidity, moisture and temperature a feature it shares with a few systems. The proposed system has the added advantage of capturing soil moisture, humidity, and temperature levels that are ideal for planting specific stable crops. It is then able to recommend crops to farmers based on the field data gathered and transmitted by the sensors to the data repository, a feature that makes it novel. The proposed system is therefore the only system as shown in Table 2 that satisfies the parameters that this research recommends as the ideal to make an IoT based soil moisture, humidity, temperature system effective in enhancing crop production and food output.

7. CONCLUSION

The increased demand for food worldwide has presented challenges in food production; the quest to employ efficient techniques to boost food production to meet the increasing demand is currently being pursued. Manual methods of determining suitability of soil for cultivating staple

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crops continue to lower food production due to their inefficiency. Various automated methods have been proposed but they require enhancement. In this paper, an IoT based system to accurately measure soil moisture, humidity, and temperature has been presented with inexpensive and readily available sensors and microcontroller. The proposed system is portable and easy to use and was tested on different days and times in the same area. Further test was conducted on different fields at the same time. Data gathered from the experiment shows that soil humidity and moisture are higher when soil temperature is lower. However, soil humidity and moisture are lower where soil temperature is high. Based on ideal soil moisture, temperature, and humidity data that was captured initially, the system was able to recommend crops that can be planted in particular fields based on their actual soil parameter data collected. The proposed system was compared against other benchmark models that have been presented. It was able to accurately measure soil moisture, humidity, and temperature and also has the capable to recommend crops for planting in a particular field when the actual data collected is compared to the ideal data for such crops as stored in a data repository. None of the benchmark models has the capability to recommend crops to farmers based on actual data gathered.

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