

IoT-Based Electronic System for Real-Time Soil Nutrient Detection in Precision Agriculture

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Abstract

In crop development, the presence of soil nutrients plays a very remarkable role due to their capability to determine the productivity of the planted crops. There is a traditional method for determining the level of nutrients in the soil, but it is laborious and ineffective. In addition, it is often not a profitable method due to its labour-intensive nature. In recent years, the emergence of contemporary electronic-based technologies for measuring the level of nutrients in the soil has been embraced. The technique has enhanced soil nutrient management, leading to higher crop yields. In the context of a modern smart agricultural farm, the application of programmable Internet of Things (IoT) with integrated artificial intelligence (AI) technology for the easy identification of soil nutritional deficiencies. Therefore, the focal objective of this study is the design, implementation and testing of an IoT-based soil nutrient detection device utilizing intelligence techniques. The unfamiliarity of the farmers with the level of soil nutrient composition and the environmental conditions might limit the productivity of the soil for the farmer. Therefore, the performance of the instrument designed and developed was tested experimentally on two different farmlands. Measurements were conducted for soil temperature, moisture content, pH value and humidity. It was found in farmland 1 that the corresponding average values of the soil temperature, moisture content, pH value and humidity are 32.12°C, 29.66%, 5.58 and 72.06% while the values obtained from the farmland were 32.28°C, 30.16%, 6.00 and 72.96% with satisfactory outcomes based on small error margins.

Keywords: Artificial Intelligence, Electronic Technology, Food Production and Internet, Precision Agriculture.

Introduction

Soil is the essential supporting structure for the growth of plants and human existence. The fertility of the soil determines the health of soil particles to support the quality of air and water, as well as the standard condition of the food chain in agricultural production and other ecosystems on Earth. The human population on Earth has kept on expanding rapidly, such that the demand for farming activities is also growing to cater to the need for the required quantity of food production for sustainability. In the face of increasing demand for food production, the application of precision farming methods is inevitable and thus requires a suitable soil nutrient analysis. The yield of a crop significantly depends on the

quality of the nutrients in the soil because the soil gives the required nutrients to the crops (Reddy et al., 2024). With the correct determination of the nutrients in a soil, farmers can take proper measures to maintain or replenish the quality of the nutrients in the soil for the healthy growth of crops and agricultural production. An insufficient nutrient in the soil is detrimental to the proper growth of a crop planted in the soil (Guan et al., 2024). However, with the application or adoption of a proper method, farmers can reliably maintain the nutrient level of the soil for the healthy growth of plants through the application of organic or inorganic fertilizers.

Ideally, before the application of a fertilizer to the soil, the nutrient status of the soil must be determined accurately to know the actions that need to be taken for better crop productivity. Presently, the entire world is facing the challenge of food insecurity and environmental degradation. These problems have contributed immensely to the challenge of poor agricultural production, consequently, from poor soil nutrient management assessment. Reliable soil nutrient management revolves around some important soil nutrient indicators such as soil moisture, soil pH value and other micronutrient substances required for sustainable soil fertility enhancement (Kumar et al., 2025). Agricultural production of planting and harvesting of crops usually reduces the level of nutrients in the soil and consequently needs to be restocked for better soil conditions. Traditionally, fertilizers are added to the soil to boost its fertility level and enhance agricultural productivity. When the nutrient levels in the soil are low, fertilizers are applied to make the soil productive. Most farmers roughly estimate the quantity of fertilizers with much accuracy because too much or too little fertilizer can harm plants and reduce yields. It is important to apply the right amounts of fertilizer to a plant using modern techniques. Therefore, this study proposes a new Internet of Things device that can track soil nutrients through the use of intelligent programming. The emergence of the Internet of Things (IoT) and the quick development of intelligent programming approaches have made this pertinent and created new opportunities to enhance agricultural practices.

Problem Statement

The testing of soil nutrients is a crop production technique that is connected with several problems. The common soil testing problems are related to detection and analytical techniques. The incursion of modern technologies has made solving the problems associated with soil testing techniques simple. Traditional approaches for formulating soil samples for examination usually involve several laborious procedures. The importance of developing appropriate micronutrient testing through the use of modern technology has increased in recent times. One of the most significant problems to be addressed is the enhancement of the calibration technique. In consequence, research efforts to generate a simple and active technique for determining the nutrients in soil need to be stimulated.

Objectives

Using embedded systems with distinct sensors with integrated Internet of Things, an intelligent programming system is designed and developed to continually monitor

agricultural soil's moisture, humidity, temperature and NPK level of agricultural soil. This tool facilitates rapid and accurate agricultural decision-making by providing real-time data-based nutrient management characteristics. Therefore, the main objectives of this study focus on the following:

- To create a system that supports agricultural production decisions through various soil nutrient sensors.
- To give farmers real-time information and assistance based on user-friendly technology, a system that provides real-time data on the nutrient level in soil for cropping is being developed.

Literature Review

Soil nutrient concentration determination is established through the application of chemical technology. Farmers are required to determine the amount of fertilizer needed based on the cultivated area, the quantity of the crop to be planted, and the required nutrient level. The deficiency of fertilizers in the soil may call for the application of fertilizer to restock and maintain the fertility of the soil. The estimation of the required quantity of fertilizer in farmland is an initial step required for enhancing soil nutrient levels. Most of the farmers usually prefer manual application of chemical fertilizer to the soil, but such a method may be cumbersome. In some cases, the manual application of fertilizers may be reliable as expected. The incursion of modern automation systems into the practice of agriculture has brought a dramatic change in agricultural production (Ananthi et al., 2017). Automation can ensure the reduction of unwanted uses of fertilizers to avoid economic loss and overconcentration of nutrients in the soil, which may be harmful to crops through the application of modern technologies, especially IoT-based technologies. An IoT for soil nutrient levels is an emerging technology in agricultural production through the application of precision farming methods (Babu et al., 2019; Zhang XueYan et al., 2017). An IoT-based technology is an internet-based network of physical things that can communicate and exchange data with other systems and devices, known as the Internet of Things (IoT). IoT devices can have software, sensors, and other technology integrated to perform the desired function (García et al., 2020). The system uses the technique with wireless sensor technologies to collect soil data in real time. For example, in agricultural production, such as fertilizer application to the soil, mobile robots and vehicle-based sensors can be used as the physical system for spatial mapping of the farmland area under consideration to determine the accurate quantity of fertilizer to be applied.

IoT technology can pointedly improve farming in the agricultural sector. It will be stimulating to advance a new farming area if the dynamic soil attributes are not appropriately monitored. The need for food production and the desire for high yields of crop production require the application of chemical fertilizers. The level of concentration of the required nutrients in the soil determines the amount of chemical fertilizers that need to be added to the soil. From this perspective, the determination and application of the chemical fertilizer to the soil can be handled by an IoT-based system (Ramson et al., 2021).

At first, the IoT system can be used to determine the level of fertilizers in the soil and subsequently can be used to ascertain the quantity that may need to be applied. The basic function of an IoT system in this circumstance is to connect and exchange measured nutrient data with other devices and systems over the Internet, a network of physical items that are integrated with sensors, software, and other technologies based on the Internet of Things (IoT). The instrument is a cutting-edge technology to enhance crop production. IoT soil nutrient devices are usually portable and suitable systems with convenient measurement procedures designed and produced for monitoring soil fertility (Ge et al., 2019). In recent times, the emergence of varieties of IoT technologies has reinforced the different aspects of human endeavours, especially agricultural production for the regulation of some digitally controlled soil parameters such as moisture content, soil pH and soil temperature, among others, in real-time (Hengl et al., 2017). The application of an IoT system can enhance the tracking of soil conditions and decision-making in real-time (Zerihun et al., 2022).

Decision-making regarding soil nutrients is usually required before farming to attend to any problem regarding any deficiency in the nutrients present in the soil. This is why it is essential to have a better understanding of a system that utilizes IoT technologies in agricultural production to ensure that factual farming information is obtained before agricultural production. The application of information and communication technology in sensors in network-based farming cycles has accelerated the technological development of smart farming. Cloud and IoT-based technologies and electronic state-of-the-art concepts are anticipated to spur growth and introduce the usage of artificial intelligence and robotics in agriculture (Blesslin Sheeba et al., 2021; Qiu et al., 2021). These revolutionary technological upgrades are speeding up advancement in agricultural practices. Therefore, in this study, the design and implementation of a nutrient IoT detection system are prioritized such that farmers can benefit from the technological knowledge from the time of land preparation, crop planting, to harvest. Due to the outstanding benefits of IoT systems, such as fast response time and high measurement precision, it has the potential to ease agricultural soil quality measurements and supply the right amounts of nutrients and water for plants to thrive (Lean et al., 2024). In consequence, this paper presents a novel approach to an IoT smart farming system with the potential to measure soil nutrient parameters through a smartphone app that enables users for automatic control.

Materials and Methods

Through this research, the methods and materials will include the application of smart agricultural farming concepts and electronic technological systems such as Arduino and IoT-based soil nutrient detection and motoring systems. Since the basic system of agricultural production hinges on the availability and quality of soil, the physical and chemical characteristics of the available soil are extremely important. Therefore, the materials required for the implementation of the research objective include using a hardware device to measure the soil characteristics, such as moisture content,

temperature, and amount of nitrogen, phosphorus, and potassium present in the soil, using a range of integrated hardware sensors.

Smart Agricultural Concept

The concept of a farm area network, which depicts the entire farm in real-time, is shown in Figure 1. In Figure 2, the applications, facilities, and devices of smart farming systems are shown, along with the associated technologies at different levels, to improve efficiency and transform agricultural production. In the present electronic revolution, every aspect of traditional agricultural methods can be accomplished using modern sensors and IoTs. Conventional agriculture challenges, such as the determination of soil moisture, drought monitoring, irrigation, pest control, and yield maximization, can be resolved by integrating wireless sensors and IoT through smart farming concepts. Smart agriculture technologies include the following:

- Precision agriculture: On-farm technologies such as yield mapping, GPS guiding systems, and variable-rate applications.
- Internet of Things (IoT): the application internet-based platform using a web application.
- Unmanned Aerial Vehicles (UAVs): An agricultural technology that can be incorporated using drones and other automobile technologies.
- Smart Agriculture Management System (SAM): an electronic integrated circuit technology that can be incorporated into agriculture for the management of agricultural practices such as crop planting, crop processing and land preparation.

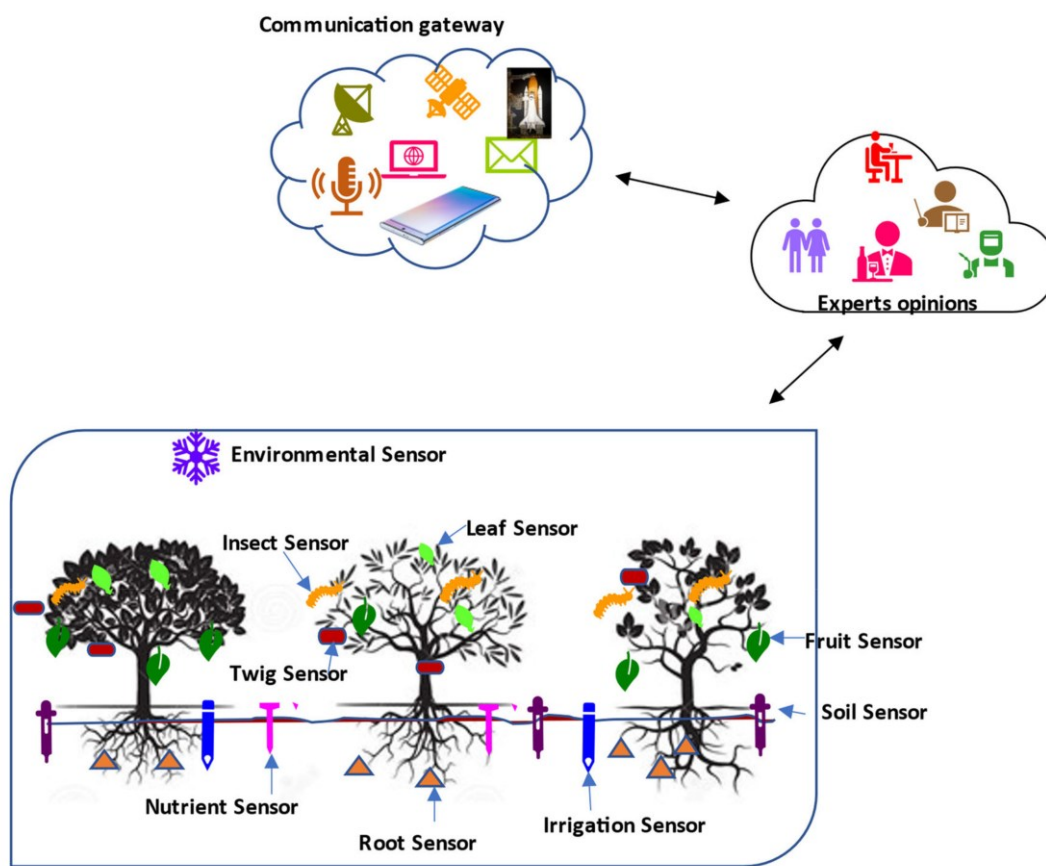


Figure 1: Depiction of an IoT network for smart farming (Dhanaraju et al., 2022)

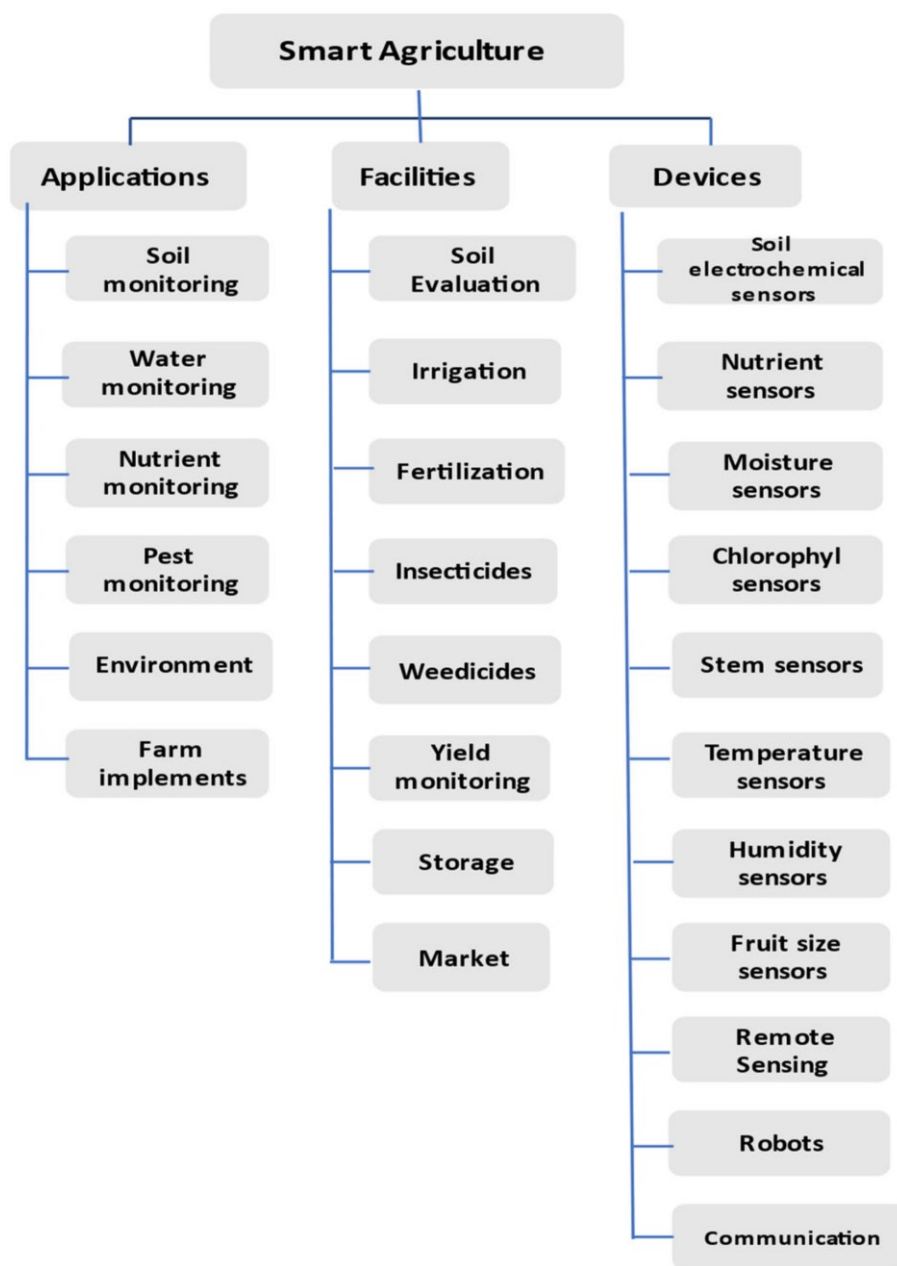


Figure 2: Hierarchy of probable applications, facilities and devices for smart agriculture (Dhanaraju et al., 2022)

Integrated Hardware Configuration

The integrated hardware components used for the implementation of the physical system include the Raspberry Pi, PH sensor, temperature sensor, moisture sensor, NKP sensor and Node MCU. The circuit diagram of the hardware configuration for the soil nutrient measuring system is displayed in Figure 3. The foremost objective is to analyze the nutritional content of the soil. Figure 4 describes the block diagram of the proposed system, which links many sensors with the Raspberry Pi microcontroller. The sensors are developed

to overcome the conventional approach of intrusive and time-consuming wet chemistry for soil nutrient detection, allowing quantification for optimization of agricultural production.

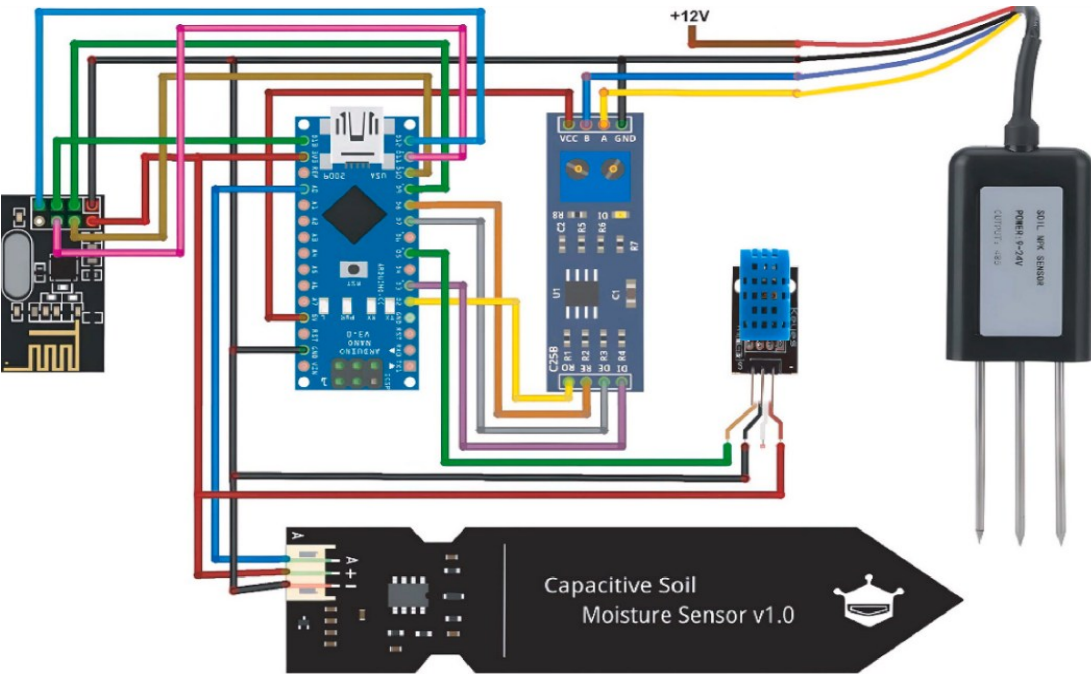


Figure 3: Circuit diagram implementation (Islam et al., 2023)

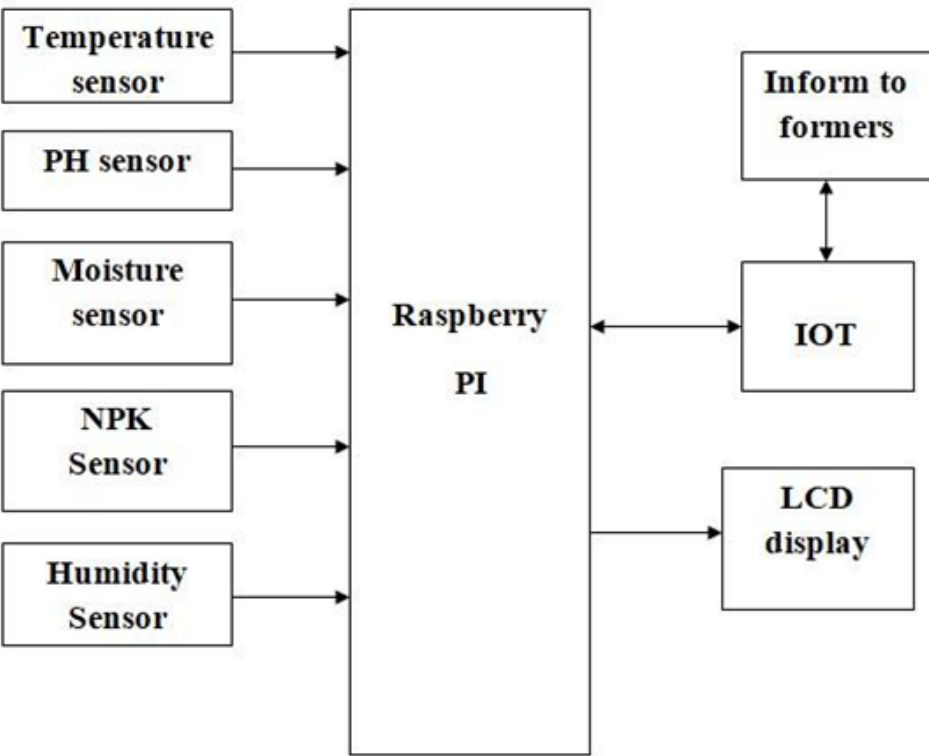


Figure 4: Hardware configuration with Raspberry Pi with other integrated components

Raspberry PI

With its very small size, the Raspberry Pi can accomplish the same functions as a desktop computer, such as word processing and electronics project processing capability to facilitate coding. Raspberry PI assists in facilitating automating data collection with larger, more comprehensive and consistent datasets. Additionally, its remote monitoring features can minimize disruptions, diminish human observer bias, and lower possible measurement errors (Gurdita et al., 2016; McBride & Courter, 2019).

Temperature Sensor

This study uses a system of temperature sensors that is equipped with thermistors and thermocouples. The electrical impulses that the sensors transmit are converted into other measurement units of degrees Celsius, and the device operates on the voltage variances to produce an analogue signal that is directly proportional to the temperature of the soil when used for the measurements.

Soil Moisture Sensor

Soil moisture sensors are used to assess the soil's volumetric water content through the soil's characteristics, such as electrical resistance and dielectric constant, as a stand-in for the moisture content. Soil moisture sensors can estimate the volumetric water content indirectly. This is because a sample must be removed, dried, and weighed to evaluate free-soil moisture directly using gravimetric methods. The link between the measured property and soil moisture must be calibrated because it can vary depending on environmental factors, including soil type, temperature and the electrical conductivity of the soil.

Humidity Sensor

A humidity sensor can be used to measure the quantity of water vapour present in the soil. The processes of water adsorption and desorption are linked to humidity and humidity sensors are used to monitor a wide humidity conditions of the soil. A humidity sensor is an electrical device that measures the relative humidity of an environment in the form of an electrical signal using various embedded systems.

pH Sensor

For the detection and measurement of the concentration of hydrogen ions in the soil, a pH sensor was employed using a pH electrode sensor. The sensor utilizes a signal transmission and chemical detection component. The measurement range covered by the digital depiction ranges from 0 to 14. Seven (7) is a number that depicts neutrality, while the higher number indicates alkalinity, and the lower numbers indicate acidity. In industrial applications, the pH sensor is often employed for the measurement of water and solutions.

Intelligent Coding

This part of the study approach focuses on using programming in a C++ environment to give the device intelligent operating behaviour. This programming language is a good general-purpose programming technique with the capability to support a wide range of programming techniques. Thus, C++ is both versatile and strong with high-performance applications. Considering its potential to work closely with hardware resources and use memory efficiently, C++ is a popular programming language for creating embedded programs in IoT devices.

Results and Discussions

The device designed and implemented was used to take soil fertility measurements at two different locations on different cultivated farmlands in Nasarawa, based on the study location shown in Figure 5. It was found that every cultivated farmland had its soil parameters measured for 10 minutes. The average values for each case were determined using the data that was gathered. The soil's temperature, moisture content, and pH value were all measured. For every farmland, three sample measurements were made. The collected data from the two farmlands used for the experimentation are shown in Tables 1 and 2. Going by the comparative analysis, the percentage errors of the measured parameters of soil temperature, moisture content and pH values were calculated. The percentage error computed for the soil temperature measured in the two farmlands is given as approximately 0.5°C . this variation can be attributed to the variation in the soil structure at different locations. It is, however, important to point out that a difference of 0.5°C is sufficient to judge the reliability of the measuring instrument.

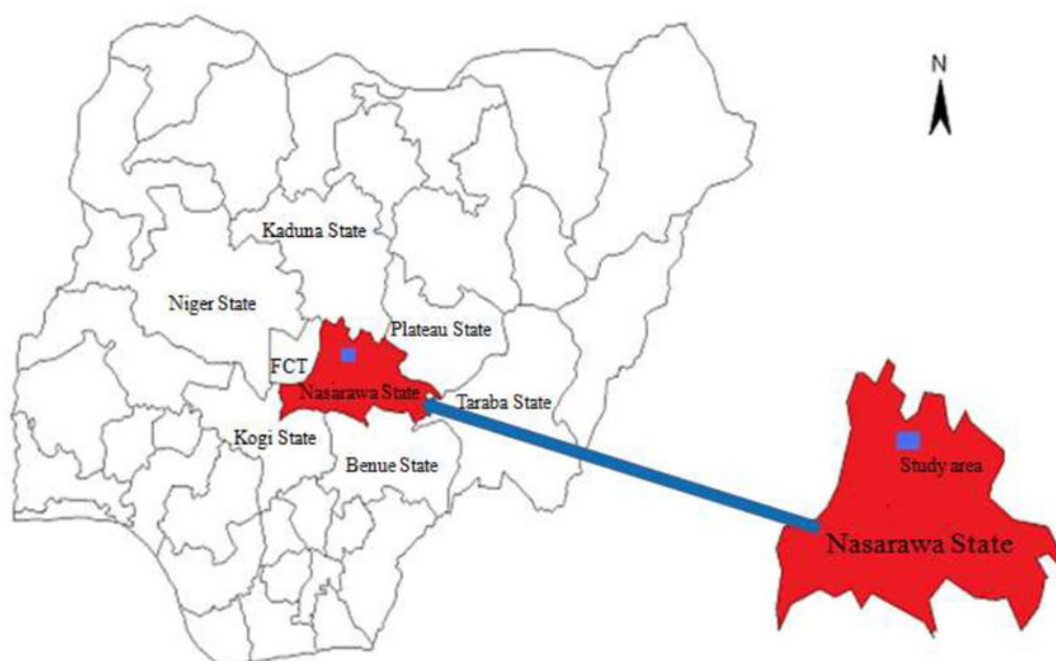


Figure 5: Map of the study location

Table 1: Collected data from farmland 1

Measurement	Soil Temperature (°C)	Moisture Content (%)	pH Value	Humidity (%)
1	31.80	29.80	5.50	72.30
2	32.20	29.60	5.60	72.20
3	32.40	29.70	5.50	71.90
4	31.90	29.50	5.70	71.80
5	32.30	29.70	5.60	72.10
Average	32.12	29.66	5.58	72.06

Table 2: Collected data from farmland 2

Measurement	Soil Temperature (°C)	Moisture Content (%)	pH Value	Humidity (%)
1	32.20	30.30	6.60	73.10
2	32.60	30.30	6.70	73.00
3	32.50	29.90	6.50	72.90
4	32.10	30.10	6.60	72.80
5	32.00	30.20	6.60	73.00
Average	32.28	30.16	6.00	72.96

Furthermore, the error differences of approximately 1.66 % and 7 % for the moisture content and pH value were obtained, respectively. The percentage error difference obtained for humidity is approximately 1.2 % . The differences recorded for all the parameters measured can be justified because they naturally increase or decrease with time due to unstable environmental conditions and the situation of the measuring devices, coupled with the time measurement taken. The errors obtained are within the acceptable limit in all the tested soil cases. However, the sensor precision makes a significant contribution to the values obtained for the error differences. Practically speaking, the data values gathered from every measurement showed that the instrument can measure precisely in a variety of settings with good error results. Because of the accuracy of the sensor, the device demonstrated better results for measuring soil moisture at lower temperatures (less than 35°C), and the decreased error % is noteworthy. The two locations' varying cropping intensities could be the cause of the large error value for the pH values of the soils at the various locations.

Conclusion

In summary, an effective and practical tool for assessing soil and environmental characteristics is the Internet of Things-based agricultural measuring equipment. The equipment that was designed and put into use has produced findings that show an acceptable degree of accuracy. The farmers find the equipment to be both portable and easy to use. Since the fabrication technology is simpler, the overall cost is fairly reasonable. Due to the effective measurement values provided for the measured parameters, the

device could easily measure the parameters for soil fertility and environmental conditions. The findings showed that the device stayed undamaged during the measurements and that the system operated as intended in the experimental setting. In the field experiments conducted with the device, it was found that the readings obtained were satisfactory in comparison with standard values. In addition, the error margins obtained were also within the accepted range. Users may make informed judgments regarding watering, fertilization, and plant selection by measuring important characteristics, including soil pH, temperature, moisture, and humidity. In the end, this greater knowledge might lead to more sustainable and effective farming methods.

Recommendations

The following recommendations are made concerning the study conducted:

- Future improvements of the device might investigate different sensor configurations and capabilities.
- The integration of wireless connectivity and data logging features must be designed and developed in a way to facilitates easy data gathering and analysis over time, allowing users to more efficiently monitor and track changes in environmental and soil conditions.

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