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Development of an Internet of Things System for Smart Crop Production

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Abstract**—**Nutrients are required for any soil with which plants thrive to improve efficient growth and productivity. Amongst these nutrients required for proper plant productivity are nitrogen, phosphorus and potassium (NPK). Due to factors like leaching, nutrient uptake by plants, soil erosion and evaporation, these elements tend to be in low quantity and the need to replenish them arises. However, this replenishment of soil nutrients cannot be done without a timely soil test to enable farmers to know the amount of each element in short quantity and evaluate the amount required to be added. Though wet soil analysis is good, it comes with a lot of challenges ranging from soil test gargets availability to the technical knowledge of how to conduct such soil tests by the common farmer. The Internet of Things test kit was developed to fill in the gaps created by wet soil analysis, as it can test for NPK, soil temperature and soil moisture in a given soil at the time of test. In this implementation, a sample test was carried out within 0.2 hectares of land divided into smaller plots. The kits performed adequately well, as the range of values obtained across the segments was within a very close range.

Keywords**—**Internet of things, soil nutrients, test kit, soil temperature.

I. Introduction

THE integration of agriculture and the Internet of Things (IoT) has emerged as a revolutionary way to address the major obstacles facing the agricultural sector in an era marked by advances in technology. The demand for food and agricultural products rises along with the growth of the world's population. According to [1], to feed the planet's growing population, the world ought to produce 70% more food in 2050 in comparison to 2006. It is essential to create an IoT device for smart agriculture in order to meet this growing demand while maximizing resource utilization, improving crop yields, and advancing sustainable farming practices.

With the help of IoT technology, this study seeks to promote an era of precision agriculture by monitoring, automating, and controlling various farming operations. Our IoT device will offer real-time insights into conditions of the soil, climate trends, crop health, and more through the use of sensors, actuators, and data analytics. With the understanding needed to make data-driven choices, farmers will be better equipped to increase yields, reduce resource waste, and improve sustainability in general.

A critical step toward tackling the problems of food security as well as ensuring the long-term economic and ecological viability of farming practices is the development of an IoT device for smart agriculture. This study will transform the way we think about farming and pave the way for a more intelligent, productive, and sustainable farming sector in the future.

II. Literature Review

The study of [2] asserts that cutting-edge IoT technologies can observe the conditions in farms and ensure the production of high-quality goods. However, there is still a lack of advancements in research on smart sustainable agriculture (SSA), which is exacerbated by complex issues like managing and sharing data, operating IoT/AI devices, compatibility with other devices and processing and organizing huge quantities of data. These issues are brought on by the fragmentation of agricultural processes. Because of this, the study examines IoT/ AI technologies that are already being used for SSA and discovers an IoT/AI technical architecture that will facilitate the development of SSA platforms.

According to [3], palm cultivation is the primary agricultural activity in Saudi Arabia. As a result, there is a rising demand to use smart agriculture technology to increase date production and prevent diseases. The red palm weevil, an insect that may destroy extensive tracts of palm trees, is one of the most dangerous diseases that affect palm plants. The most challenging issue is that humans do not see the weevil's effects until the palm has reached a highly infested stage. As a result, cutting-edge technology needs to be used to identify infestations early on and stop them from spreading. They consequently created an IoT-based smart palm monitoring prototype that (1) enables remote palm monitoring using smart agricultural sensors and (2) aids in the early detection of red palm weevil. Through web and smartphone applications, users can interact with their palm farms and help them in the early detection of possible infestations. They interfaced between the sensor and user layers using the IoT platform provided by Elm Company. Additionally, they have used accelerometer sensors to gather data, which they have subsequently analysed using statistical and signal processing techniques to identify the infestation's fingerprint.

In agricultural management, [4] proposed a Block Chain powered Internet of Nano-Things (BC-IoNT) system for chemical level sensing. This is a crucial use case for smart farming, which tries to enhance environmentally friendly farming practices by regulating the application of pesticides. The BC-IoNT system, which functions as a smart contract for chemical level sensing, has a unique machine learning model created by combining the Langmuir molecular binding model and Bayesian theory. To ascertain whether farms are in

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compliance with the chemical standards, a credit model was employed to measure the traceability and credibility of the farms. The centralized approach had an accuracy of ≤ 80% in chemical detection, while the distributed BC-IoNT approach had an accuracy of ≥ 90%. Additionally, the variation in chemical levels among farms and the frequency of sampling affect how well farms can detect the presence of pesticides.

A novel IoT, embedded systems, and unmanned aerial vehicle (UAV)-based portable agro-application that utilizes contemporary data and communications technology was put forward by [5]. Water pumps, Wi-Fi components, Arduino-based circuit boards, and digital environmental sensors that recorded humidity, temperature, and moisture levels in the soil were used in the design and construction of the agricultural monitoring system. In the study, the UAV's function is to acquire information regarding the environment from different points on the farm. The amount of water needed for irrigation is then calculated for each cloud location automatically. Additionally, the device can remotely monitor agricultural conditions, including water demands, and provide guidance to farmers using an Android mobile application.

A study by [6] proposed a distributed data flow (DDF)-based smart farming model comprising interconnected modules. The proposed model for application was evaluated by employing two strategies for deployment: cloud-based and fog-based. These strategies involved distributing the application modules across the fog and cloud data centres. A comparison was made between the cloud-based and fog-based strategies in relation to end-to-end latency and network usage.

Furthermore, [7] put forth a Smart Farming anomaly detection approach based on an unsupervised auto-encoder machine learning model. An auto-encoder was chosen because it encodes and decodes data while attempting to ignore outliers. When it encounters anomalous data, it produces a high reconstruction loss value, indicating that these data were unlike the others. The model was trained and tested using a specially created greenhouse test-bed data. The auto-encoder model-based anomaly detection obtained 98.98%, trained in 262 seconds, and detected anomalies in .0585 seconds.

Another study, [8], introduced an innovative approach to risk-sensitive reinforcement learning for scheduling Aerial Base Stations (ABSs) tasks in the context of smart agriculture. The focus of the study revolved around task offloading, with a crucial requirement that the IoT tasks must be completed within their designated deadlines. Moreover, the algorithm needed to account for the limited energy capacity of the ABSs. The findings demonstrated that the proposed approach surpassed the performance of various heuristics and the conventional Q-Learning method. A mixed integer linear programming solution was devised to establish a lower bound on performance and elucidate the disparity between the risk-sensitive and optimal solutions. The ensuing comparison yielded comprehensive simulation results, showcasing the ability of the method to furnish guaranteed task processing services for IoT tasks in a smart farm, while simultaneously prolonging the hovering time of the ABSs in said farm.

A study by [9] directed their efforts towards the creation of an enhanced irrigation scheduling tool by integrating IrrigWeb with WiSA. The primary objective was to establish a system that would enhance the management and scheduling of irrigation in sugarcane cultivation. Subsequently, a program was developed for the purpose of automatically downloading, calculating, and implementing irrigation schedules. This automated process would significantly diminish the amount of time spent by sugarcane irrigators in manually configuring irrigation schedules. The analysis of simulation results indicated that the aforementioned program, through the incorporation of practical constraints on the farm such as pumping capacity or pumping time limitations, could potentially enhance scheduling.

Also, [10] concentrated on augmenting agricultural productivity by employing a farmer-centric design, development, and implementation approach. The design thinking technique was utilized to ascertain the specific requisites of farmers in designated regions; ideas were generated through collaborative brainstorming sessions with domain experts, and prototypes were constructed and implemented to evaluate the performance impact. The findings reveal that the system increased the cost-benefit ratio of crop cultivation from 2.14 to 2.26. This signifies a 12% boost in production.

A research conducted by [11] put forth a novel proposal for an electronic irrigation system that effectively alleviates the burden on users when it comes to planting care. The central component of this system is a self-learning Kohonen Neural Network that is constructed based on the data collected from soil moisture sensors, plant classification, and forecast information. Given the variation in soil wetness levels among different plant species, three distinct types of plants were selected for the purpose of this investigation. To gauge the level of soil wetness, a soil moisture detector is used. Consequently, the system is programmed to initiate automatically in cases where the moisture level is deemed inadequate for optimal plant growth. Furthermore, the system is designed to halt operation once a specific threshold of soil wetness is achieved, thereby allowing for a predetermined duration of rest in both the morning and evening periods.

III. Methodology

Through the help of various devices and sensors, traditional farming methods will be transformed. The conditions to be monitored influence the choice of tools to be used. The test kit was developed for NPK measurement, soil moisture measurement, and soil temperature measurement from the following IoT components: (i) An ATMEGA328 microcontroller, (ii) an NPK sensor module, (iii) a Modbus data communication module RS458, (iv) a soil moisture sensor, (v) a soil temperature sensor, (vi) a DC-to-DC voltage converter and regulator module, (vii) A 20 X 4 Liquid Crystal Display (LCD) module, (viii) a 10 KΩ preset resistor, (ix) a 100 Ω 1/4watts resistor, (x) 30 pF ceramic capacitor, (xi) a 16 MHz crystal oscillator, (xii) four Lithium batteries of 3.7 v, (xiii) a battery Holder Male header, (xiv) Female to Female connector wires, (xv) A 100 cm-by-100 cm Polyvinyl Chloride Plastic

(PVC).

The system was developed using the architecture in Fig. 1. Each sensor handles the specific task it was meant for.

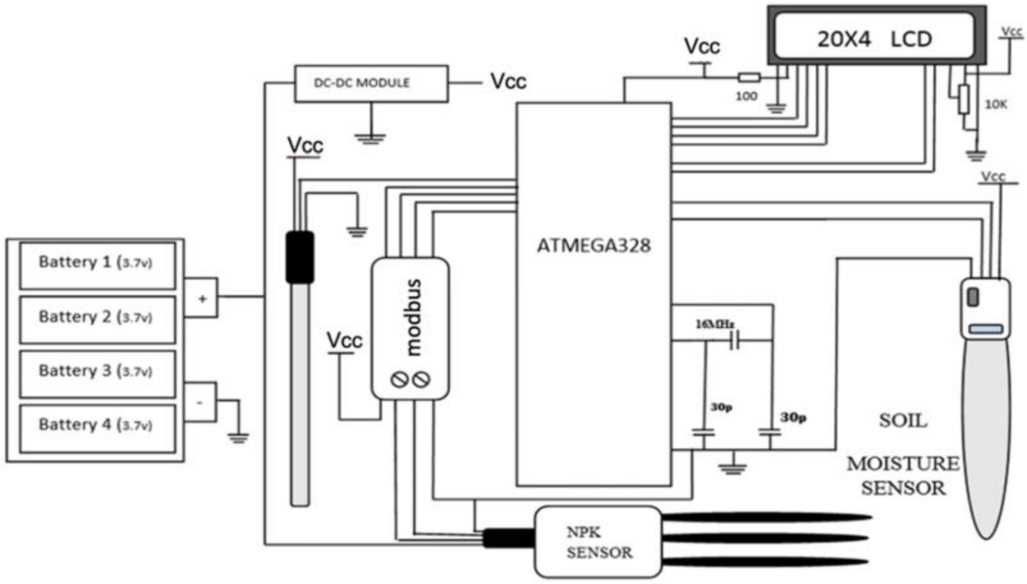

Fig. 1 The Complete Circuit Diagram of IoT Soil Testing System

The system is sectioned into four units: Power Supply Unit, Sensor Unit, Processing Unit, Output Unit

a) The Power Supply Unit

This unit comprises of the battery pack, the batteries and the DC-to-DC voltage converter module. The battery pack was used to hold the four 3.7 V batteries in place and the total output of the batteries provided was 3.7 v x 4 = 14.8 V. From the manufacturers manual of the other components modules, only the NPK sensor runs on voltages between 9 V to 30 V but the others require 5 V for proper operation, as a result of that, the DC-to-DC converter was used to source voltage from the batteries and output a fix voltage of 5 V. This 5 V represents Vcc as indicated in Fig. 1.

b) The Sensor Unit

In this unit, the NPK sensor module, soil moisture sensor module and soil temperature sensor module were used.

i. *The Soil Moisture Sensor:* The sensor used here is the capacitive moisture sensor. The capacitive moisture sensor works like a capacitor. This analogue capacitive soil moisture sensor uses capacitive perception to determine the amount of moisture inside the soil by adjusting capacitance. Basically, the capacitance is rendered into a voltage level between 1.2 V and 3.0 V at its maximum. The beneficial feature of a capacitive soil moisture sensor lies in the fact that it has an extended service life due to the material's resistance to corrosion. This generates analogue data that can be processed. This module, shown in Fig. 2, has an internal voltage regulator that allows it to operate between 3.3 and 5.5 volts.

Fig. 2 Soil moisture sensor [12]

ii. *The Soil Temperature Sensor:* The sensor operates on the basis of the thermoelectric effect. It is primarily made up of thermistor and wire. The resistance value of the thermistor varies with temperature, causing the current in the circuit to change. The actual temperature of the soil is easily calculated simply by gauging the current in the circuit. The thermoelectric principle serves as the framework for the Soil Temperature Sensor's operation. The main components are a cord and thermistor. The current in the circuit changes as a result of the thermistor's resistance level fluctuating with temperature. By measuring the current in the circuit, it is simple to determine the real soil's temperature. Temperature will be tracked using the DS18B20 resistant single wired Temperature Sensor (Fig. 3). The 1-wire protocol-compliant DS18B20 Digital Temperature sensor has an accuracy of +-5% and is able to monitor temperatures from -55 °C to +125 °C (-67 °F to +257 °F). The single wire may transmit data between 9-bit to 12-bit range. An address is assigned to the sensor attached and by calling the address, one can get that sensors' value.

Fig. 3 Soil temperature sensor [13]

Fig. 4 Soil NPK Sensor [14]

iii. *Soil NPK Sensor:* The NPK soil sensor can be used to measure the proportions of nitrogen, phosphorus, and potassium in the soil as well as determine the chemical makeup of the soil by measuring these elements' concentrations. The soil NPK sensor's stainless-steel needles are resistant to salt, alkali corrosion, and prolonged electrolysis, allowing it to be immersed in the ground for an extended period of time. The shell is totally watertight and vacuum-potted. It can communicate with any device due to RS485 connectivity. The sensor uses relatively little power and runs on 9–30 V. Based on the data sheet the device is able to obtain measurement with a detection limit of up to 1 mg/kg (mg/l). The RS-485 transceiver module, which translates a UART serial stream to RS-485, is necessary for the sensor to be attached to an MCU. The NPK sensor is shown in Fig. 4.

Processing Unit

An Arduino Uno is a Microchip-based freely available microcontroller board. The ATMEGA328 used, receives data from the sensors, processes the data and provides the corresponding output to the display unit. The source code which is uploaded into the MCU controls the processing of the data received. The 30 p and 16 MHz operate together to provide clock pulses for the proper code execution of the MCU.

Fig. 5 Arduino UNO Board [15]

d) Output Unit

This uses a 20 x 4 LCD meaning 20 rows and four columns, it has data lines which receive the data from the MCU and command line which determines how the data should be displayed. The 10 K preset is used to set the right contrast for the LCD while the 100 Ω resistor controls the LCD illumination.

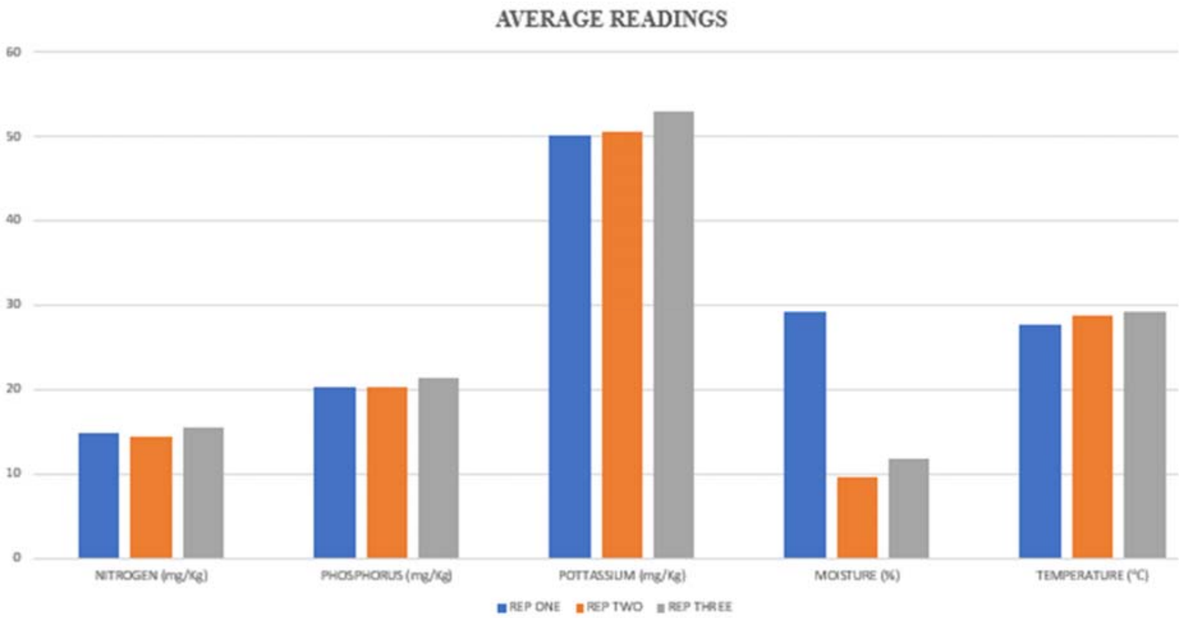

Fig. 6 Comparative Values for the three reps

IV. Results and Discussions

The IoT test kit module was used to measure the NPK values, soil moisture and soil temperatures. The various outputs are presented in this section.

The experimental test field was in the agricultural farm in Dutsinma, Katsina state in Nigeria. The 0.2 hectares of land was divided into three reps of three plots each. The average values from the three plots representing a rep each are placed in Table I. From the readings, it can be observed that the average NPK values from the reps have a very close range. The range in values from the three reps are nitrogen 14.8-15 mg/kg, phosphorous 20.2-21.4 mg/kg, and potassium 50.2-53 mg/kg.

TABLE I
Average Reading Per Rep

	Rep of 3 Plots	Nitrogen (mg/Kg)	Phosphorus (mg/Kg)	Potassium (mg/Kg)	Moisture (%)	Temperature (°C)
1	Rep One	14.8	20.2	50.2	29.3	27.7
2	Rep Two	14.5	20.3	50.5	9.5	28.7
3	Rep Three	15.4	21.4	53	11.8	29.3

Fig. 6 is the histogram plot of the average values obtained from three reps. The values are within a close range, the entire plots are within 0.2 hectares of land. Only the moisture in rep one differs considerately.

V. Conclusion

The process of creating an IoT device for smart agriculture seems revolutionary and holds great promise. This research has laid a solid groundwork for farming to become more intelligent, effective, and sustainable in the future. Precision is made possible for farmers with the IoT test kit. Well packaged in a way that farmers can pick their readings and take it out by themselves to obtained the exact type of fertilizers their crop required to supplement whatever is available without the stress of looking for soil analyst. The range of values obtained from the smart device developed gives acceptable range values for NPK, temperature and soil moisture testing. So, the device readings confirm the test kit functions well and appropriate for farmers usage.

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