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Development of an IoT-Based Soil Monitoring System

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Abstract *- Agriculture is one of the trending areas that provides economic livelihood in most developing countries like Nigeria. Considering the standard farming procedures, farmers need to visit the agricultural sites frequently throughout the crop life to have a better idea about the crop health conditions. Therefore, there is a need to develop an IoT-based Soil Health monitoring system using Internet of Things (IoT) technology. Its architecture comprises of both hardware and software parts, which were designed, constructed and tested separately before integrating them together to form a complete system. The major components of the system include NodeMcu Microcontroller, Arduino Uno, sensors for temperature, humidity and soil moisture for monitoring the soil properties. This project uses a webpage on the internet to display data from sensors using the NodeMCU microcontroller. The web application is built in JavaScript and Python. The result shows data transfer speed from the farm to the web application regardless of the distance. This IoT-based soil health monitoring system has the potential to revolutionise agriculture by enabling farmers to monitor their crops remotely, reducing the need for frequent on-site visits, saving farmers time and cost while improving crop yields and productivity. Overall, this work has the potential to contribute significantly to the sustainable development of agriculture in developing countries, which is crucial for global food security.*

Keywords**—**IoT, Soil Health, NodeMcu Microcontroller, Arduino Uno, sensors, Web development

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I. INTRODUCTION

As the world's population grows exponentially, it is essential that there is a boost in food production to accommodate the ever-rising global population (Calicioglu et al., 2019). In recent times, there is a need for Nigeria to diversify its economy from crude oil to agriculture to increase the country's gross domestic product. There is a need to embrace the evolving technology in order to enhance food sustainability and improve food security (Khan et al., 2021). For sustainable food systems, the crucial factors to be considered are fertile land, organic matter, water, fertilisers, favourable climate conditions, and energy. Morawicki, R., & González, D. (2018). Some soil content factors, like moisture content, temperature, and humidity, cannot be measured accurately by traditional means, thereby reducing crop productivity. In developing countries like Nigeria, the agricultural sector has been a major source of income and has contributed immensely to the development of the economy. The fundamental aim of agriculture is to ensure stronger and more fruitful crops and plants, and to help them grow by improving soil fertility. Similar to many other countries, Nigeria is also grappling with two significant issues pertaining to agriculture. The foremost challenge is to cater for the burgeoning demands of the ever-growing population, while the other relates to the imbalanced progress of agriculture and the evolving landscape of agricultural land use. The implementation of technological methods in the field of agriculture can bring about fundamental changes in the productivity of crops due to improved efficiency in farming techniques. Amongst all the various advantages that IoT brought, Myeko, Z. & Rambe, P., (2024) says its ability to innovate the current scenario of farming methods is absolutely groundbreaking. The Internet of Things (IoT) technology has brought a revolution, most especially in the agricultural sector. Smart farming IoT-based systems are now replacing the traditional ways of farming, controlling and monitoring the environmental conditions and the farm at large. This smart farming is developed for the benefit of farmers and greatly minimises the human interaction, labour cost and wastage of water. The system utilises IoT technology, making it unique and suitable for modern-day agriculture.

The IoT-based smart farm monitoring system will be able to provide a means for farmers to monitor their farmlands from the comfort of their homes, chase away rodents without being present in the farm, and get the accurate measurements for soil moisture content, temperature and fertility. (Bas A., et al 2023). The reliable transfer of information speed will be offered by the smart farm monitoring system alongside all of these features (Daud, S., et al 2025)

II. REVIEW OFTHE LITERATURE

It is expected by the United Nations that the population of the world by 2050 would reach 9.7 billion, which would require a rise in the global agricultural goods production to about 69% (Meola, A. 2020). To reach this target, the agricultural sector adopted the Internet of Things technology for accurate analysis and higher production of agricultural goods and services.

Smart farming using IoT is a technology that came out to help in elevating agricultural fields to an advanced level. Nowadays, smart farming is already adopted by several modern farmers, and its practice is increasing and becoming more and more common among the new generation of educated young farmers. In modern agriculture, the use of sensors, drones, and high-tech agriculture technologies is becoming quickly the new norm. Meola, A. (2020).

Rajak, P., et al (2023) developed a system to monitor crop fields using different sensors (motion, soil moisture, temperature, humidity, Light) and also automate the irrigation system. The data from these sensors is sent to the web server database

using wireless transmission. In this database, the data are encoded in JSON format. Also, Vandôme, P., et al (2023) states that smart agriculture will be more useful in areas with insufficient water supply. The use of wireless transmission of sensor data from the field and storing in a database, along with control through a mobile application, proposed a proof of concept to automate the irrigation system.

Rubi, J., et al. (2024), proposed a method that can be employed in protecting farms and their produce from wild animals. In this research, Sensors and operational amplifier (Op-Amp) circuits were utilised mainly for the detection of animal intrusion from the outsidefarms. The proposed monitoring scheme is to provide an early notification or information to the farmer about likely invasion and damage by wild animals.

III. METHODOLOGY

This research involves the design and construction of a soil health monitoring system using Internet of Things (IoT) technology, which comprises an irrigation subsystem, a real-time monitoring system and an intruder alarm subsystem. The entire system functionality is mainly dependent on the Node Mcu microcontroller, on which the web-based software programming is based on the waterfall model. The irrigation subsystem makes use of a soil moisture sensor to check the soil moisture content of the soil and control the water source based on the values read. This system incorporates real-time monitoring, which is enabled by the use of an IoT Wi-Fi module. Its function is to aid in the remote monitoring of the farm and the activities happening on the farm. It sends a notification to the web-based software every 2 seconds. The web-based software is built in such a way that two or more farm data sets can be controlled by one software. The intruder alarm incorporates a Passive Infrared Motion Sensor to detect motion of living objects, and give off an alarm. The functional block diagram is shown in Fig 1.

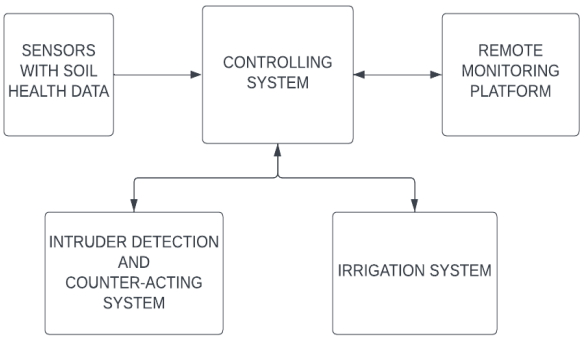


Fig. 1. Main block diagram

A. Materials

The block diagram showing the components and materials used is shown in Fig 2.

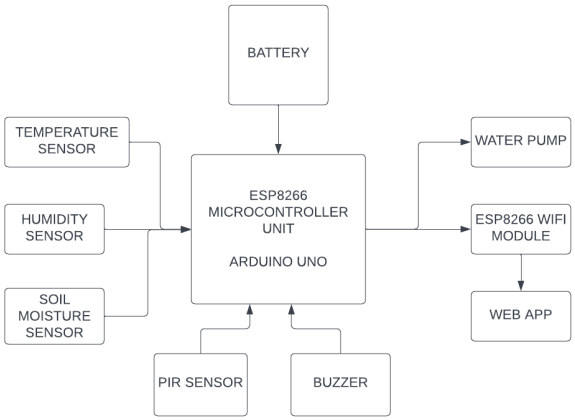


Fig. 2. Block diagram showing main components

Also, the software and hardware components utilised are as follows: Python, FastAPI, Next.js, Typescript, MongoDB (a document-based NoSQL Database), SocketIO are among the software components, whereas microcontroller, sensors, IoT WIFI module components and their design specifications are shown in Table 1.

Table 1: Specifications of components

Name of Component	Brand Name	Type	Quantity	Function
Battery and Power	Li-ion (3.7v). Stepped up to 5v.	D.C Lithium Reacharge able	4	Power Supply
IoT Wifi Module	Esp8266 Node mcu	Esp-12 Module	1	Real-time data transfer to a web application
Passive Infrared Sensor (PIR)	SR501	IR motion Sensor	1	Motion detection
Humidity and Temperature Sensor	DHT11	Digital Humidity and Temperature sensor	1	Measure Humidity and Temperature

i. Li-Ion Battery And Charger: The 18650 battery is a model of rechargeable battery of lithium of 3.7 volts. These rechargeable batteries are very similar to AA batteries but a little bit bigger size. The advantage of these rechargeable batteries is due to their lightweight.

ii. IoT Wifi Module (ESP8266 NodeMCU): NodeMCU is an open-source firmware and development board specially targeted for IoT-based applications. It includes firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems and hardware which is based on the ESP-12 module.

iii. Passive Infrared (PIR) Sensor: A Passive Infrared (PIR) sensor is an electronic device that can sense infrared (IR) rays reflected or radiated by objects. They have small, inexpensive, low-power, easy-to-use properties, and they hardly wear out.

iv. Humidity and Temperature Sensor Dht11: A humidity sensor is an electronic device that measures the humidity in its environment and converts its findings into a corresponding electrical signal. A humidity sensor senses, measures and reports both moisture and air temperature. The DHT11 is a commonly used Temperature and humidity sensor that comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data.

v V. Soil Moisture Sensor: A typical Soil Moisture Sensor consist of two components. A two-legged Lead that goes into the soil where water content has to be measured. This has two header pins which connect to an Amplifier/ A-D circuit, which is in turn connected to the MCU esp8266. The Amplifier has a Vin, Gnd, Analogue, and Digital Data Pins. This means that the values can be gotten in both Analog and Digital forms.

Most soil moisture sensors are designed to estimate soil moisture content based on the dielectric constant (soil bulk permittivity) of the soil. Qi, Q., et al (2024). The dielectric constant of soil increases as the water content of the soil increases. This response is because the dielectric constant of water is much larger than the other soil components, including air.

vi. Buzzer: An audio signalling device like a beeper or buzzer may be electromechanical, piezoelectric or mechanical type. The main function of this is to convert the signal from audio to sound.

vii. 5V Relay Module: A 5v relay is an automatic switch that is commonly used in an automatic control circuit and to control a high current using a low-current signal. The input voltage of the relay signal ranges from 0 to 5V.

viii. 5V Dc Water Pump: This is a low-cost, small-sized Submersible Pump Motor which can be operated from a 2.5 ~ 6V power supply. It can take up to 120 litres per hour with very low current consumption of 220mA.

ix.Arduino Uno: The Arduino Uno is a kind of microcontroller board based on ATmega328. This board includes digital I/O

pins-14, a power jack, analogue I/ps-6, ceramic resonator-A16 MHz, a USB connection, an RST button, and an ICSP header. All these can support the microcontroller for further operation by connecting this board to the computer.

B. Methods

The IoT-based soil health monitoring system was achieved using sensors to obtain data from the farm, convert the data to a readable format, send it to the backend of the web application, which in turn sends it to the frontend webpage in real-time with the use of Socket.IO. The system also detects when the water level is low (below 30%) in the soil and turns on a water pump for irrigation. It also detects motion of living things in the farm and gives off a sound to scare rodents away. The data obtained by the sensors, which include the temperature, humidity and soil moisture content, are displayed on the webpage with a graph showing their changes over time.

As the battery powers the system, the ESP8266 NodeMCU module connects to the Wi-Fi network in order to allow the system to access the internet, and as the system is connected to the internet, the sensors on the farm start reading data from the environment. Thereafter, it sends the data to the backend server through an API. The sensors get readings for the temperature, humidity and soil moisture content. The backend server, in turn, sends the data to the frontend in real-time through the means of WebSocket technology, which then updates the data on the webpage for the user to see within a 2-second interval. Which is faster than previous implementations of smart farms. Also, there's a PIR sensor in the farm environment to monitor heat signals and give an alarm to chase the intruders away. With this series of activities set up automatically, the system is effectively monitoring, controlling and ensuring optimum content of soil health properties with a reasonable time interval of 2 seconds, respectively.

i. Data Storage and Data Communication to the Frontend

When the data is received on the backend, it is stored in a MongoDb Database and then sent to the frontend in real time through Socket.IO.

ii. Frontend features and usage

The frontend of the page involves a user signing up as a new user or signing in as a former user. The user is also allowed to signup/in with Google authentication.

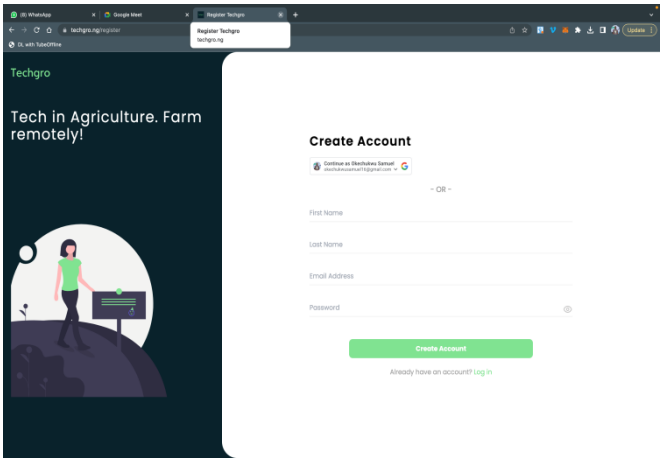


Fig. 3. Authentication on the frontend

After the authentication stages are done, the user has access to their dashboard, where they can create a farm.

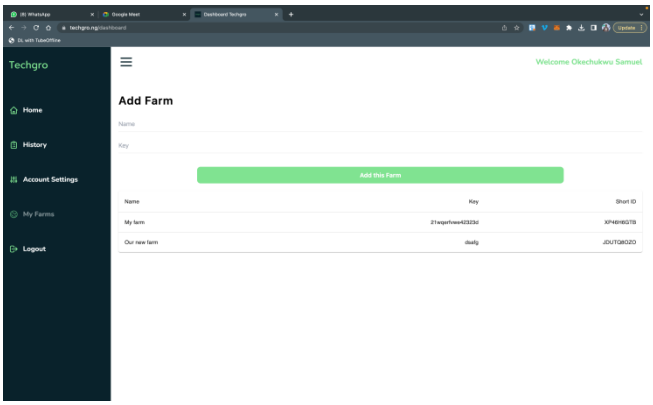


Fig. 4. Creating a farm on the Frontend

After creating a farm, the key can be used

to send data from the NodeMCU. The user can then receive data from the farm on the dashboard. The data is also being used to plot a graph for further visualisation. The dashboard displays a user-friendly format of data.

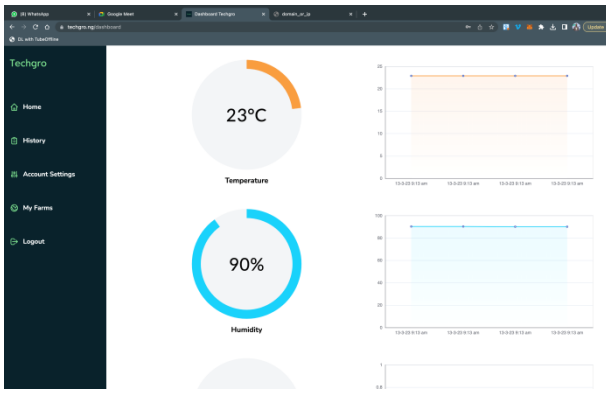


Fig. 5. Dashboard on the frontend

iii. Automatic Irrigation System

Using the values gotten from the soil moisture sensor, the water pump motor can be toggled on and off.

When the soil moisture percentage is less than 30%, the motor is turned on, and the farm is watered, and when the percentage is above 30%, the motor is turned off.

iv. Intruder detection

The PIR sensor is active to detect any motion. Once it detects any motion, it reads high on the Arduino and set the buzzer on, and when it reads low, it turns off the buzzer.

C. *Simulation Circuit Diagram*

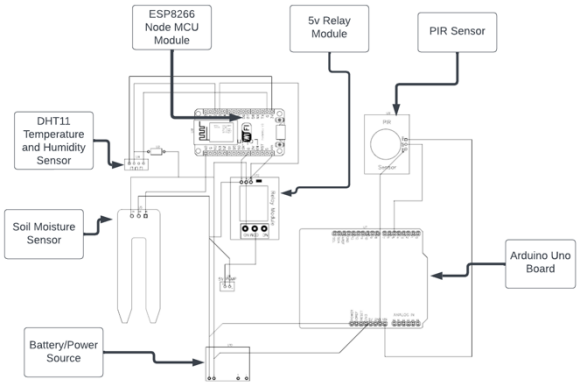


Fig. 6. Simulation Circuit Diagram of the System

D. *Flow Chart/ Algorithm*

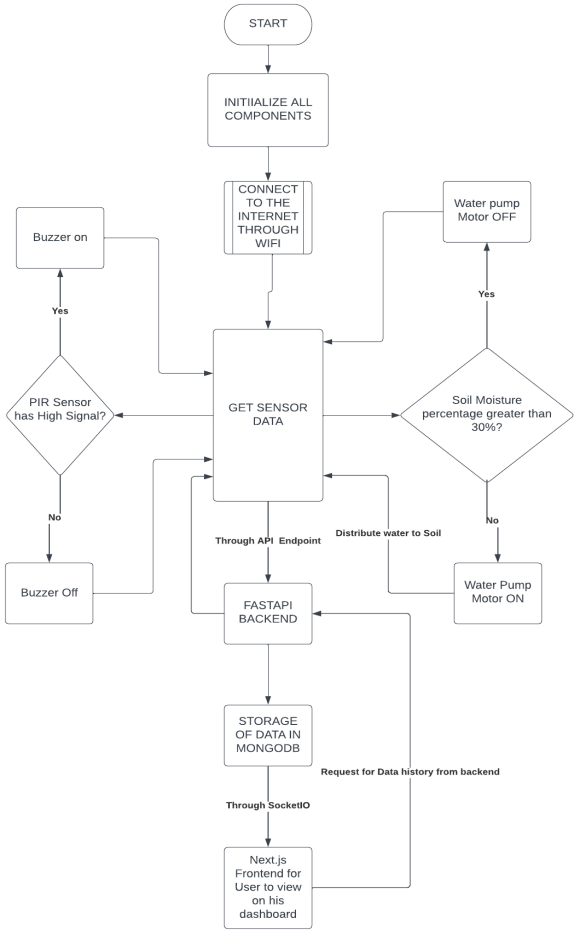


Fig. 7: Flow Chart of Soil Health Monitoring System

IV. TESTS, RESULTS AND DISCUSSION

i. Hardware Testing

The Li-ion battery, which has 3.7 volts per cell, is the source of power for the system. A power bank was used to step up the voltage to 5 volts, which is better for the circuit to function properly. To avoid unexpected failures, tests were done to make sure the battery's capacity was intact.

The PIR sensor is responsible for monitoring the farm environment to detect movement of intruders at a range of 3 to 5 m close to the farm. It was tested by moving towards the farm, and then when it detects an intruder, the microcontroller triggers the alarm. The Passive infrared (PIR) sensor is very smart and accurate in detecting motions near the farm and hence fulfilled the need for it in this project. During the test, it was observed that it was able to detect motion of an object that is at least 3meters closer to the farm.

The PIR sensor and buzzer are joined so that obstructions can be quickly identified. Through the use of loud noise in the field, invaders (people or animals) are frightened away.

NodeMCU is an open-source software and hardware development environment built around an inexpensive system-on-a-chip called ESP8266. It was tested by sending AT commands to the ESP8266 and checking that it responds as expected.

A table gotten from the frontend application shows values gotten from the system at different intervals in time, and also the difference in time intervals. The table is shown in Fig 8

Date	Soil Moisture	Temperature
May 3rd 2023, 5:08:45 pm	61%	27.80°C
May 3rd 2023, 5:08:44 pm	61%	27.80°C
May 3rd 2023, 5:08:42 pm	61%	27.80°C
May 3rd 2023, 5:08:39 pm	61%	27.80°C
May 3rd 2023, 5:08:37 pm	61%	27.80°C
May 3rd 2023, 5:08:36 pm	61%	27.80°C
May 3rd 2023, 5:08:35 pm	61%	27.80°C
May 3rd 2023, 5:08:33 pm	61%	27.80°C
May 3rd 2023, 5:08:32 pm	61%	27.80°C
May 3rd 2023, 5:08:31 pm	61%	27.80°C

Fig. 8: Table displaying sensor values on the frontend.

ii. Software Testing

The project's software component passed through program design, walkthrough, testing and debugging process to guarantee flawless operation and the eradication of all defects. The microcontroller program was tested alongside the user interface, which is a simple app created for farmers to use to monitor their farmlands using smartphones.

User Interface (UI) was integrated by making sure that it receives data from the Wi-fi module and that the execution buttons were able to control and activate different things remotely. Data was sent from the UI to the server, and checked if it properly reflected on the NodeMCU microcontroller, and data was sent from the NodeMCU controller to the web server to display on the UI.

iii. Summary of Results and Discussion

Each component of the complete system played a unique role in how the project ran as a whole; each component was tested separately. On the other hand, testing the software part faced different difficulties than testing the hardware component; the most frequent was the regular fluctuation in the internet connection. At the conclusion of our testing, it was found that the prototype design of the IoT-based smart farm monitoring system met our expectations.

V. CONCLUSION

The purpose of this research was to showcase a potential installation of an IoT-based soil health monitoring system on a farm. The system employed multiple sensors to detect and deter agricultural intruders, and a web application interface permitted remote monitoring and control over the internet. In addition to enhancing the farm's productivity by utilising machine learning algorithms, the system can learn from the data it gathers and make more precise predictions and recommendation it could also reduce the

expenses associated with maintaining farm security and conducting constant monitoring. Consequently, this could increase the farm's yields and productivity.

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