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Procedural Framework for Internet of Things (IoT) Implementation in Crop Production

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ABSTRACT

The world population growth predictions by the United Nations and other researchers are a serious indicator that special attention should be given to smart agriculture to enhance productivity and close the demand and supply gap. In this paper, the concept of IoT was discussed and related literature was reviewed to present the state of the art in IoT technology. A conceptual framework for IoT implementation in crop farming was presented which can provide farmers with enough information to apply soil nutrients with precision, thereby enhancing crop yield and cutting down on wastage of resources from uniformed soil nutrient supplementation.

INTRODUCTION

The Agricultural Internet of Things (AgriIoT) can be described as the incorporation of sensing, automation and analytics technology into agricultural procedures (Subeesh & Mehta, 2021). The regular IoT applications in smart agriculture entail wrapping, incorporating, and integrating IoT tools and techniques into agricultural practices to enhance and empower agricultural procedures for smartness. That is to make efforts and devices cleverer, and more productive taking advantage of sensors and satellites. Monitoring and management in the various areas of agriculture such as crop production and protection, soil nutrients and component analysis, animal production and protection, storage services, smart agricultural vehicles, drones, robots and actuators, greenhouses and climate change, data analytics, predictions and agribusiness can be made easier and smarter with IoT devices. This incorporation is depicted in Figure 1.

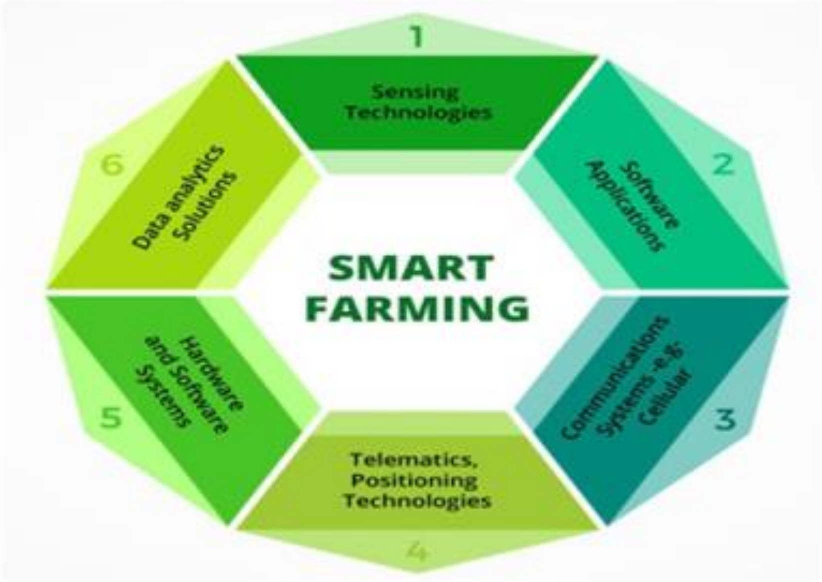

Figure 1: Integration of IoT into Agriculture (Gowda et al., 2021)

IoT is based on the fundamentals of already existing Internet and Cloud computing technologies. Connectable devices are being empowered to participate in computing-based networks and internet communications at various levels. IoT devices connected to existing internet technologies have made IoT device communication easy from remote areas without having to be physically present on the field all the time. Field data reporting is also made easy for information dissemination. The major attributes of IoT devices are the empowerment of tools/objects for communication/participation in networking to achieve: sensing and responding, automation, precision and accuracy, analytics and prediction in various fields of life including agriculture. Sensors and satellites which are being used to monitor crops, soil, fields, animals, and storage facilities among other things are having an immense impact on agricultural product production, protection and management. Smart agricultural technologies include drones, autonomous robots of various functions, as well as actuators. These can be used in connected agricultural settings such as smart greenhouses and hydroponics (Gowda et al, 2021).

Precision is the application of an exact amount of nutrients required to augment the available essential soil nutrients to measure up to the required value for each crop for maximum yield. In this paper, literature was reviewed to explore the usage of the Internet of Things in agriculture, IoT devices were discussed, a framework for the implementation of IoT in Agriculture was presented and a procedure for its actuation in maize production was provided.

Rathod~~,~~ (2020) proposed a smart IoT-based agriculture stick that can be used to get real-time readings of temperatures, soil moisture, and other data points which can help farmers efficiently monitor their environment thereby make smart decisions which will help them to farm smartly, and increase their overall yield and quality of produce. The agriculture stick made use of Arduino Technology, breadboard and various sensors which streamed the live data to a mobile phone through an online platform. They recorded high accuracy in data feed as the stick was tested in several fields with varying soil conditions across different locations.

Arumugam et al (2018) designed an automated irrigation and water monitoring system to facilitate the effective use of water resources and fertilizers. The design proposed using a microcontroller-based automated irrigation system that allows remote control using an Android smartphone. The methodology involves the use of embedded systems, MPLAB and PROTEUS software.

In an attempt to harness automation and IoT technologies for smart agriculture, Gondchawar (2016) developed a smart GPS-based remote-controlled robot to perform common agricultural tasks like weeding, spraying, moisture sensing, and bird and animal scaring among other things. It also featured smart irrigation with smart control and the ability to make intelligent decisions based on accurate real-time field data collected from the sensors and cameras. Control of the operations was achieved through a remote smart device which was connected to the internet and communicated with the devices on the field through a Wi-Fi module on board.

Similarly, Taris et al. (2022) aimed to monitor and control a field's water level, which substantially impacts energy efficiency and water consumption. They created an IoT-based intelligent irrigation system for rice fields, to make it easier for farmers to effectively manage the frequency and appropriate levels for irrigation based on their crop, soil type, and climate. They developed a smartphone app using MIT App Inventor with three primary components: humidity, altitude, a fill column and a flow button. The system was fitted with a rice field controller with an ultrasonic sensor component (HC-SR04) and a soil moisture sensor to collect data from the field. Firebase was then utilized to receive data sent by the field controller, while NodeMCU works as a microcontroller to process data received from Firebase and then transfer the data to the output section. The application was able to monitor the field, collect data about it, and administer the appropriate quantity of water.

In another research, Senapaty (2023) proposed an IoT-enabled soil nutrient classification and crop recommendation (IoTSNA-CR) model which could help improve productivity while minimizing the use of fertilizers. The model was divided into four phases, which are the collection of data from cultivated fields using IoT sensors, storage of the data in cloud services, access to this data via an Android application, and pre-processing and periodic analysis of it using various learning approaches. A low-cost system made up of soil temperature, soil moisture, pH, GPS, and colour sensors, a water level indicator, as well as an Arduino UNO board was created. Through this sensory system, moisture, temperature, water level, soil NPK, colour values, date, time, longitude, and latitude were collected and stored on the Firebase cloud storage. The farmers would then be able to periodically retrieve and analyze data from the Firebase cloud service using an Android application.

In this study, a novel approach was identified via the hybridization of algorithms for the analysis of the data collected. An algorithm was developed using a multi-class support vector machine with a directed acyclic graph and optimized using the fruit fly optimization method (MSVM-DAG-FFO). This algorithm has the highest accuracy rate of 0.973, compared to 0.932 for SVM, 0.922 for SVM kernel, and 0.914 for decision trees. It was observed that the algorithm outperformed other methods in terms of accuracy, recall, precision, and F-Score.

Pest detection and control is another activity that can be effectively managed using IoT systems as demonstrated by Ezeofor et al. (2021) in their research. They proposed an IoT architecture to detect maize maize stem borers in real time using sensors. The system monitors the farm for the presence of insect pests (e-scouting) and communicates to the farmers remotely, thereby relieving them of the stress of visiting the farms frequently. The system hardware was made up of two modules the first module being the slave device, which includes the camera, motion sensor, superlight LED, battery, GPS, antenna, etc. The second module, the master device, includes the power supply, Jetson Nano, 4G wireless router, Wi-Fi dongle, SD card, etc. The slave devices were placed throughout the farm at various coordinates and connected to the master through Wi-Fi technology and an antenna. The master device receives the detected insect pest data, analyses and recognizes the insect using a machine learning algorithm/trained model, and then provides the data to a designated cloud storage location for farmers to use. The prototype of the IoT system was tested successfully at the University of Port Harcourt’s Farm for Teaching and Research.

Sundaresan et al. (2023) created a system to recommend crops based on local climate and soil characteristics, automatically water plants when needed, and recommend the best fertilizers based on crop type. A system was developed by combining IoT and machine learning technology that integrates agriculture's three core operations: crop selection, autonomous watering, and fertilizer suggestions. The study considered the following crops, Apple, Rice, Maize, Grape, Banana, Orange, Cotton, and Coffee. The paper discussed three systems: Before selecting a crop, the crop recommendation system uses machine learning to assess characteristics such as nitrogen (N), phosphorous (P), potassium (K), pH, and weather. The fertilizer recommendation approach bases its suggestion on two primary determinants: crop type and current soil nutrient levels. The crop was irrigated using an automatic irrigation system while considering current soil moisture levels and weather forecasts.

Muangpathhub et al. (2019) proposed a wireless sensor network-based method for optimally watering crops. The goal of this project was to design and develop a control system in the agricultural field employing node sensors, with data management through a smartphone and a web application. The hardware component was designed to include different sensors which monitor the field and communicate with the control panel. The mobile application component mainly controls the crop watering process. This allows the user to control the system either automatically, using data from soil moisture sensors, or manually in the functional control mode. On the other hand, the web-based application component was more robust and enabled farmers to edit crop data and other details about the farmland. Data mining techniques were also implemented to analyze the data to predict ideal temperature, humidity, and soil moisture for optimal crop growth management in the future. Notifications from the system are sent to the LINE application through the LINE API.

To effectively manage scarce resources like water, labour and data in India, Mohanraj (2016) in their paper titled "Field monitoring and automation using IoT in agriculture domain" suggested a dual connection mode IoT-based agricultural monitoring system. They posited that in comparison with others, the agricultural sector had not experienced significant technological advancements which has hampered the growth of the industry making it essential to constantly innovate and develop solutions to help grow the sector. They developed a framework with a focus on knowledge management and monitoring to enable the automation of the agricultural sector and minimize the wastage of resources. Their framework made provision for both online and offline modes of operation to guard against the challenge of networks and connectivity in rural areas which can limit the use of the technology.

Raikar et al. (2018) in their paper titled "Blend of Cloud and Internet of Things (IoT) in Agriculture Sector using Lightweight Protocol" proposed a system to help manage poor crop production during the monsoon period due to unpredictable rainfall. Most of the rainfalls in India, up to 80% are between June and October, which means that during the other months with little to no rain, irrigation needs to be carried out efficiently for optimal yields. The authors developed an intelligent irrigation system using the lightweight MQTT (Message Queue Telemetry Transport) protocol to build a smart watering system. The MQTT protocol was used because it provides efficient and secure user-device and sensor connections. It is approximately 23% more energy-efficient, 15% faster, and more secure when compared with other protocols. Data on moisture and temperature were gathered and sent to Amazon Web Services and Weka was used to analyse sensor data to control the water supply to plants and determine the appropriate amount of water flow to plants based on their needs per time.

In a similar work, Pachayappan et al. (2020) in their research titled "Technological Implication and its Impact in the Agricultural Sector: An IoT-Based Collaboration Framework" created an IoT-agriculture framework to manage sugar cane production. The system enables monitoring of the farmland, water supply, plant type and health, temperature and humidity, use of insecticides, machines for harvesting and cultivation, and tracking of labourers on the farm in real-time. Their framework is built on an existing model by integrating a large number of devices forming a surveillance network by tracking and recording all activities on a farmland. The soil and other agricultural resources as sensory devices were tagged using RFID tags to closely monitor the environment. These RFID tags provide real-time information about the crop performance, state of the environment, and farm activities to the different stakeholders, government, farmers, and producers, who are all connected to the network. The feature that allows all stakeholders to connect to the system and have access to all the data that concerns them means that they will be able to make proper and timely decisions when needed. For instance, the government can readily decide how much it wants to invest in sugarcane production during a given season. They can also view live feeds of damaged farmlands in the event of a natural disaster and can then easily decide how much support to give as relief to the affected farmers if need be. Also, sugar production companies can easily predict the supply of the crop within a certain period, and adjust their manufacturing capacity accordingly.

IoT-based smart agriculture has enabled farmers to increase crop yields, maximize irrigation efficiency, and lower operating expenses. The incorporation of IoT technology in agriculture has brought about precision agriculture, facility agriculture, and contract farming which has greatly improved the agricultural systems. However, a major challenge is the security of the systems and confidentiality of data collected as observed by Ferrag et al. (2020) in their publication titled "Security and Privacy for Green IoT-based Agriculture: Review, Blockchain Solutions, and Challenges". The authors identified five security risk groups which are intrusions into personal information, identity theft, confidentiality, availability, and integrity. Furthermore, there is a need for more research on methods and protocols to better manage security risks. Some of the areas that could be considered are machine learning techniques, blockchain, and lightweight cryptographic protocols.

Ukarande et al. (2022) in their research titled “Smart Farming System Using IoT”, proposed an approach to the smart farming system, built on mobile computing, microcontroller and NodeMCU, and the Internet of Things. It collected and transmitted real-time data on garden environmental factors through a mobile application so that farmers could make the right decision promptly. They further proposed a smart garden with the Internet of Things (IoT) based NodeMCU ESP8266 Module that can be fitted with various hardware components and software support and controlled with the Blynk android application to meet the needs of the farmers.

Awan et al. (2022) in their paper titled “Design and Implementation of IoT-Based Smart Precision Agriculture Farming “, proposed a low-cost and reliable solar-powered precision agriculture farming system which is designed to provide an alternative source for electric power generation and monitoring of the farming system which would help farmers to use water, chemicals, fertilizers, etc. efficiently for productivity. The solar-powered system provides an alternative way to counter the electricity demands for farming especially in rural areas. The proposed system is easy to implement and provides environment-friendly solutions to manage the energy crisis. This system also reduces the wastage of water as the sensor indicates when the soil requires water thereby optimizing water usage. As the system is self-starting it requires minimal human intervention. The system illustrates the feasibility and usage of solar PV applications for AgriIoT.

MATERIALS AND METHODS

IoT-Based Concept for Smart Crop Production

The concept of IoT in smart farming entails the usage of IoT technological tools and wireless technologies to make agricultural practices smart, provide information to aid farmers in making informed decisions, manage resources and gain maximum produce from their labour and investment. Soil nutrient, Temperature, moisture and humidity sensors along with relevant gateways and cloud services on suitable networks get services rendered to farmers even in their comfort zones. Figure 2 depicts the conceptual framework for this concept.

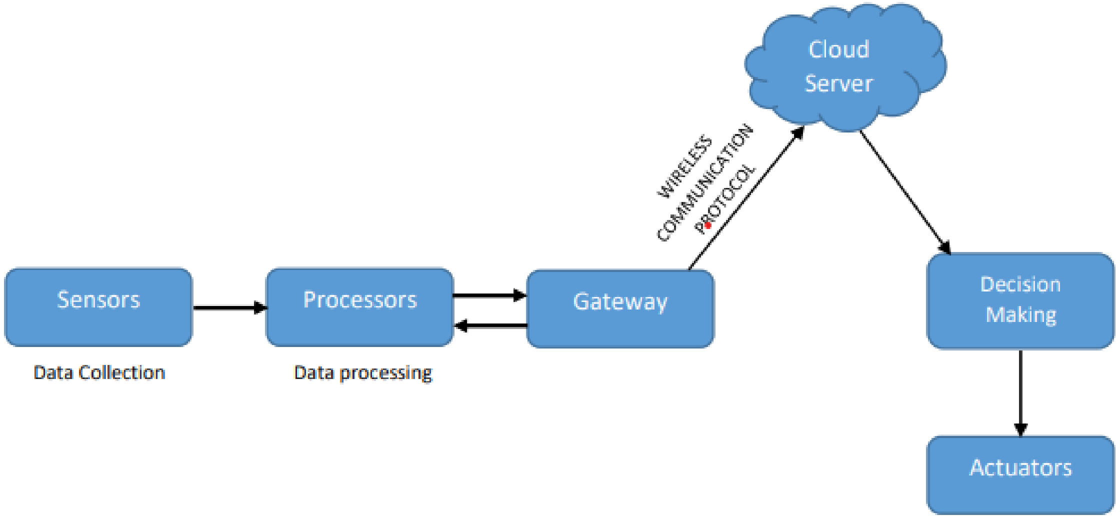

Figure 2: Conceptual Framework

IoT Procedures

The implementation of the IoT Concept in Agriculture entails the following

a. Smart data collection
   i) Soil temperature is paramount to the growth of crops, some are more temperature-sensitive than others. The rise and fall of soil temperature can be influenced by the size and direction of soil heat flux, and soil thermal properties such as soil heat capacity, thermal conductivity, density, specific heat and porosity. The temperature should be measured periodically for informed decisions. A sample of this sensor is shown in Figure 3a
   ii) Another data collection device is a soil moisture sensor. The connection of this sensor to an LCD enables the reading to be taken and displayed on the spot. The pins should be inserted to reach the root depth of the soil. Soil moisture sensors measure the water content in the soil and that determines the amount of stored water in the soil horizon. A sample of this soil moisture sensor is shown in Figure 3b.
   iii) The soil NPK sensor is suitable for detecting the nitrogen, phosphorus, and potassium content of the soil. The fertility of the soil for an informed decision is possible by detecting the amount of N, P, and K in the soil. A sample of this is in Figure 3c. The pin should be inserted about 10cm deep into the soil.

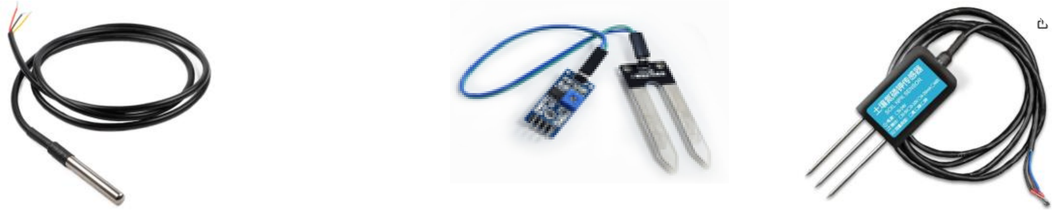
(a) (b) (c)

Figure 3: A picture of the sensors. (a) Temperature sensor (b) Soil moisture sensor (c) NPK sensor

Table 1: Soil Resources Table for Maize

Sensors	Data/unit	Expected Range for Maize
Temperature	Temperature	21 - 27°C
Moisture	Water content	60%
NPK	Nitrogen	90
	Phosphorous	60
	Potassium	60

b. Processors And Connectors

i) Arduino UNO Board: The Arduino Uno is a microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analogue input/output (I/O) pins that can be interfaced with other expansion boards and other circuits and enable communication between other devices.

Figure 4: Snapshot of an Arduino board

ii) ThingSpeak Platform: This is an IoT analytics platform service that allows users to aggregate, visualize, and analyze live data streams in the cloud. Sensor data will be sent to ThingSpeak from sensory devices, create instant visualization of live data, and send alerts to connect stakeholders.

c. Decision Making and Actuators

Information from sensors such as soil nitrogen, phosphorus, potassium, moisture and temperature values are to be compared with the required values of those resources for optimal yield. The recommended values are usually based on the soil type, crop variety, and the stage of growth of the crops, among other factors. This information reveals to the smart farmers the situation of the soil and the necessary quantity of supplements required for the crop to do well without wasting resources. In cases where actuators are implemented, the actuators are triggered based on the readings to supply the required nutrients.

d. Data analysis and interpretation

The barrage of sensor data may not always be meaningful to farmers if it is not properly analyzed and interpreted. Data analytics procedures and result presentation enable farmers to make sense of the data and come up with important predictions for the future such as crop harvesting time, risk of disease, yield volume and crop vulnerability.

Procedural flowchart for IoT in Maize farming

The following steps are to be followed to achieve the implementation of smart farming practices in maize farming. They are depicted in Figure 5

i. Choice of land and its preparation
ii. Dividing the land into equal two to use part as a control plot and the other with IoT involvement.
iii. Soil sampling in a sequence for IoT investigation
iv. Interfacing NPK sensor with Arduino board and LCD
v. Device programming (to obtain sensor values)
vi. Placing sensors in soil and monitoring readings
vii. Comparing the nutrient value with the required values
viii. Application of specific nutrient deficient and precise amount to measure up
ix. Periodic repeat of the measurement for proper evaluation.

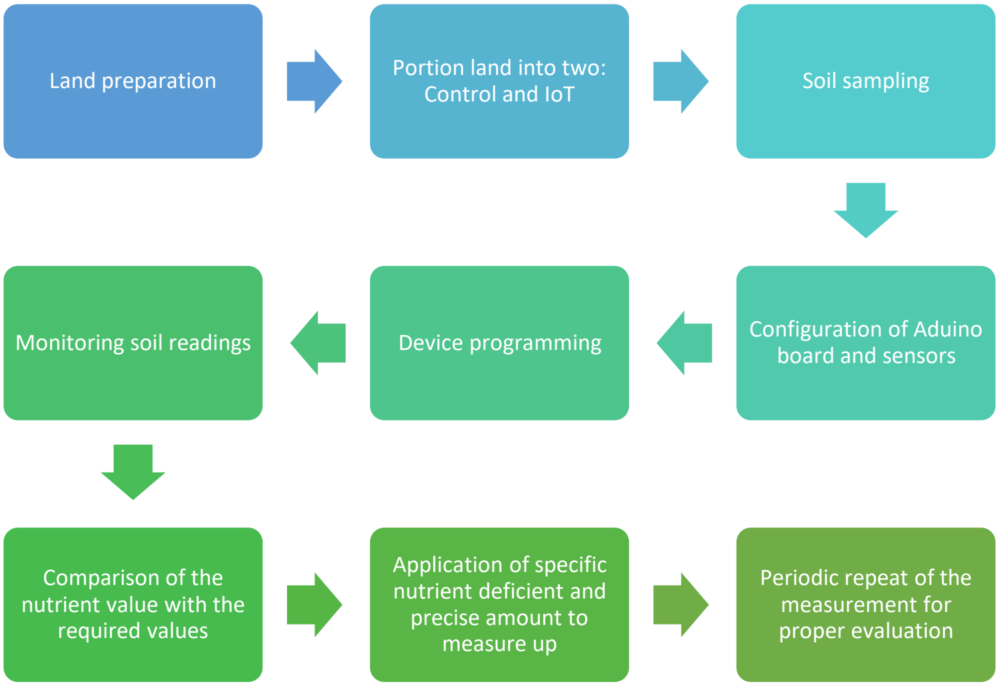

Figure 5: Procedural Framework for IoT implementation

Consideration for Smart Farming Solutions

IoT agricultural solutions are becoming very numerous, therefore the following can be considered in the choice of IoT devices

1. Hardware technology - the hardware to be used should be easily accessible and affordable
2. The brain – the sensors should be chosen to measure the required soil components in line with the project objectives and the actual prediction needed
3. Maintenance – ease and cost of maintenance of the devices is also very crucial
4. Mobility – one of the advantages of IoT is the ability to make work easier and more convenient. The wireless coverage, remote control, and battery power of the device must be considered and found suitable.
5. Infrastructure – internal structure according to the farm's need and compatibility should be considered along with the project fund
6. Connectivity- communication limitations, weather, and line of sight are factors that affect connectivity and it could frustrate the communication efforts if not properly considered.
7. Transmission frequency - timely and distribution ability to connect to cloud services.
8. Data security and integrity – robust security protocols and their compatibility with IoT devices must be taken into consideration.

CONCLUSION

Real-time information for informed decisions and precision farming enables efficient resource management and demand-based fertilization which is made possible with IoT. It makes farming interesting, maximises the use of resources, reduces stress and motivates youth who are put off by the traditional methods and stress of farming to take on smart farming as a profession. This will produce a new generation of technologically inclined farmers and agronomists opened to innovations that will revolutionise the agricultural sector. The envisaged challenges include the affordability of IoT devices by small-scale farmers, technical knowledge and accessibility of the required infrastructure which in time will be overcome with technological growth, smart Agro-services and global awareness.

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