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Original Research Article

Optimized Internet of Things Model for Smart Agriculture and Irrigation Water Management in Nigeria

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Abstract: Agriculture serves as a fundamental pillar of Nigeria's economy. A significant portion of the available freshwater resources is allocated to agricultural activities. In Northern Nigeria, irrigation systems are essential. Over the years, farming practices have remained largely primitive, particularly in sub-Saharan Africa. This situation arises from a lack of advanced technological knowledge that could enhance agricultural practices. Various challenges hinder agricultural practices, including reliance on traditional farming methods, limited understanding of concepts and practices, policy issues, environmental concerns, and financial constraints. The purpose of this study was to optimize an IoT-based model for smart agriculture and irrigation water management. The study aimed to design, implement, test, and evaluate the performance of this optimized IoT-based model. The proposed system utilized the prototyping model as its methodology. The design was created using the Balsamiq application. The system is intended to feature a login page, a dashboard, a system use case diagram, an actuators page, a sensor page, and an application interface design. The Justinmind tool was employed to illustrate the flow of information within the system, encompassing data input and output, data storage, and all subprocesses through which the data traverses. The optimized IoT model was developed using four primary platforms: the ReactJS frontend application development platform, Amazon Web Services IoT Core for the backend, the Arduino development platform for sensor node creation, and the Python programming language for the actuator node based on the Raspberry Pi board. When compared to existing systems using the specified parameters, the optimized model demonstrates superior performance, particularly in terms of measurement accuracy, irrigation water management, operational modes, platform accessibility, real-time video capabilities, user-friendliness, and overall efficiency. The performance evaluation clearly indicates the advantages of the optimized model over the existing model.

Keywords: Water Management, Smart, Agriculture, Irrigation Systems, Model, Optimization.

INTRODUCTION

The globe is undergoing a shift from analogue systems to digital formats, or from manual operations to automated processes. This transition is attributed to the observable impacts of scientific theories. Beyond the Internet of Things, advancements in smart agriculture and irrigation water management stand to gain from this technological evolution. One notable innovation developed by humanity in the realms of communication and information technology is the Internet of Things (IoT). The IoT is a device that was established in the domain of information dissemination, having been either introduced or discovered in 1999 (Point, 2016). Its swift expansion, particularly in radio coverage, was initiated by a member of the Radio Frequency Identification Development Community (RFIDC) to enhance communication within cloud computing and data analytics. The Internet of Things can be categorized into three distinct types: (1) interaction between humans; (2)

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interaction between humans and objects or machines; and (3) interaction between objects or machines. In all instances, the Internet of Things (IoT) plays a crucial role in enabling communication among a diverse array of devices (Dickson, 2024).

The growing population indicates a persistent demand for increased food production. By the year 2050, the global population is projected to reach 9.7 billion, representing an approximate 33 percent rise from the current figures (United Nations, 2021). To accommodate this population growth, the food supply must expand by at least 70%. Nevertheless, due to various factors such as temperature, climate, terrain, soil quality, and technological advancements, only a small portion of the Earth's surface is suitable for agriculture. Political and economic challenges, including land tenure patterns, environmental regulations, and population density, significantly affect agricultural land use. In fact, over the past few decades, there has been a consistent reduction in the land dedicated to farming and food production. In 2014, approximately 37% of the Earth's surface area, equating to around 18.6 million square miles, was allocated for agricultural activities. In contrast, these figures were 19.5 million square miles and 39.47% in 1991. Consequently, the world faces the daunting challenge of feeding a growing population on diminishing land resources (World Bank, 2021).

The Nigerian economy is fundamentally dependent on agriculture. Agriculture utilizes a considerable share of the global fresh water resources. In Northern Nigeria, irrigation is primarily managed through manual systems. Farmers in sub-Saharan Africa are often recognized for their reliance on outdated agricultural techniques. This situation arises from a significant lack of advanced technical expertise necessary for modern practices. In contrast, agriculture in Western and developed nations is profoundly shaped by technological innovations. This is not the scenario in Africa, and specifically in Nigeria. Both Africa and Nigeria are experiencing food scarcity as a direct result of farmers' unwillingness to embrace new agricultural technologies.

Smart agriculture can be described as a framework for understanding how the effective use of advanced technology and networks is guiding us towards a more advanced society. The concept of 'smart agriculture' aims to shift from specialized problem-solving to generalized problem-solving approaches. The objective of this research was to identify the most effective configuration for an IoT-based model that incorporates both Device-to-Gateway (D2G) and Gateway-to-Cloud (G2C) communication frameworks. Utilizing a Long Range (LoRa) radio module, sensor nodes transmit data to the gateway, which subsequently synchronizes the information to the cloud via an HTTP/TCP connection. The system consists of four nodes, each strategically located in different areas of the farm. The gateway serves as the central control unit for the entire water management system. Farmers can monitor and manage the farm in two distinct ways: as long as the system is operational, they can log in from any network. Alternatively, on a smaller scale, farmers can connect to the system using a wireless LAN (WLAN). Following the development of a prototype of the complete model and its deployment for testing on the farm, the robust model for optimizing IoT-based smart agriculture is rigorously evaluated. The prototype's results are then compared against those of established models (Dickson & Ukegbu, 2024).

Statement of the Problem

Agricultural practice is constrained with some major challenges ranging from traditional way of farming, understating of concepts, practices, policy, environmental and financial factors. The field of irrigation farming becomes less productive due to the use of obsolete agricultural technology. Many farmers still use the traditional methods of irrigation farming which results in low yield of crops. This has been attributed to lack of technological approach and devices put in place by science and technology towards enhancing the conventional approach. Agriculture cannot be practiced traditionally like in the dark ages without a clear-cut device and analytical system towards security of food, especially in Sub-Sahara Africa in general and Nigeria in particular. IoT therefore, is one of such scientific Internet-based technology designed to ameliorate the nagging problems facing this critical sector of the economy, agriculture. The study proposes a system which sensor node reads and broadcast temperature, humidity and soil moisture content after every two seconds in other to improve and conserve battery power. The pump is connected to an actuator node through an electronic relay driver that is in turn controlled by a raspberry Pi controller. The controller also serves as a gateway for sensor nodes to communicate with the cloud server.

Aim and Objectives

The aim of this study is to optimized IoT-based model for smart agriculture and irrigation water management. However, the objectives of the study are to;

1. Design an IoT- based model for smart agriculture and irrigation water management.
2. Implement the optimized IoT-based model for smart agriculture and irrigation water management with python programming language.
3. Test and evaluate the performance of the optimized IoT-based model for smart agriculture and irrigation water management.

RELATED LITERATURE

Adaptive Structuration Theory

Adaptive Structuration Theory (AST) ranks among the leading three theories concerning group communication. It draws inspiration from Anthony's concept of structuration. Developed by Scott *et al*., in 1994, AST builds upon the critical perspective offered by Poole *et al*., (1994), who argued that group dynamics are too intricate to be simplified into a few propositions or a predictable sequence of events. Poole posits that group members influence outcomes, coining his theory as adaptive because he believes that these members consciously modify rules and resources to achieve their objectives. AST serves as a framework for examining the impact of advanced information technologies on organizational transformation.

The theory aims to comprehend the types of structures facilitated by advanced technologies and the structures that genuinely arise from human interactions with these technologies. The current study is motivated by technological advancements, specifically focusing on optimizing the Internet of Things (IoT) for smart agriculture and water irrigation, which aligns with the study's objectives. This theory is pertinent to the current research as the researcher seeks to enhance IoT applications to promote smart agricultural practices and irrigation methods, moving away from the traditional techniques employed by many Nigerian farmers.

IoT Structure Theory

Michael *et al*., (1999) proposed a theory concerning the structure of the Internet of Things. This theory claims that knowledge about the world has been a fundamental aspect of both computer science and cognitive science. Historically, computer scientists and logicians could define the semantics of items in their knowledge representation models and methods for describing the world largely without an explicit connection to reality. However, as networked devices are not only aware of their environment (they can perceive the world via sensors) but also capable of triggering changes in the world through actuators, there arises a need to update previous theoretical foundations of data management and logical languages that did not consider these new dynamic scenarios in which software components perceive and act in the real world in an automated fashion. In scenarios surrounding the Internet of Things in particular, changes in the represented world immediately influence changes in the real world, and vice versa. The theory identified several aspects to help provide theoretical foundations for the scenarios that emerged in the context of the Internet of Things and cyber-physical systems; inter-subjectivity between machines and humans: On the Internet of Things, machines should perform tasks for humans. For this to work effectively, humans need to be able to communicate with machines, and vice versa.

Internet of Things

The Ministerial Meeting on the Digital Economy (MMDE, 2016) characterizes the Internet of Things (IoT) as an ecosystem where applications and services are fueled by data obtained from devices that sense and interact with the physical environment. In the realm of IoT, devices and objects possess communication capabilities, either through a direct internet connection or via local or wide area networks.

The IoT is anticipated to proliferate swiftly in the forthcoming years, and this convergence is poised to unveil a new array of services that enhance consumer quality of life and enterprise productivity, thereby unlocking an opportunity termed the 'Connected Life' by the GSMA. Although the potential ramifications of IoT are significant, a unified effort is essential to progress beyond this initial phase. To optimize market development, a shared comprehension of the unique nature of this opportunity is necessary. Thus far, mobile operators have recognized several key distinguishing characteristics: The Internet of Things can facilitate the next wave of life-enhancing services across various essential economic sectors, addressing customer needs may necessitate global distribution models and uniform global services, the Internet of Things offers a chance for innovative commercial models to support extensive global deployments, the majority of revenue is expected to stem from the provision of value-added services, and mobile operators are developing new capabilities to support these emerging service areas, while device and application behavior will impose new and diverse demands on mobile networks.

According to Keyur and Sunil (2018), the Internet of Things (IoT) refers to a network comprising physical objects. The internet has transformed from being merely a network of computers to a comprehensive network that includes devices of various types and sizes, such as vehicles, smartphones, home appliances, toys, cameras, medical instruments, industrial systems, animals, people, and buildings. All these entities are interconnected, facilitating communication and information sharing based on established protocols to enable smart reorganizations, positioning, tracking, safety, control, and even personal real-time online monitoring, online upgrades, process control, and administration. Tutorialspoint (2016) noted that IoT represents an advanced automation and analytics framework that leverages networking, sensing, big data, and artificial intelligence technologies to provide complete systems for products or services. These systems enhance transparency, control, and performance across any industry or system.

Internet of Things Technology and Protocol

The Internet of Things (IoT) primarily utilizes standard protocols and networking technologies. Nevertheless, the key enabling technologies and protocols for IoT include RFID, NFC, low-energy Bluetooth, low-energy wireless, low-energy radio protocols, LTE-A, and WiFi-Direct. These technologies facilitate the specific networking capabilities required in an IoT system, distinguishing it from a conventional uniform network of standard systems.

NFC and RFID: RFID (radio-frequency identification) and NFC (near-field communication) offer straightforward, low-energy, and adaptable solutions for identity and access tokens, connection initiation, and payment processing.

RFID: Technology employs 2-way radio transmitter-receivers to identify and track tags associated with objects.

NFC: Consists of communication protocols for electronic devices, typically a mobile device and a standard device.

Low Energy Bluetooth: This technology supports the low-power, long-use need of IoT function while exploiting a standard technology with native support across systems.

Low Energy Wireless:

This technology replaces the most power hungry aspect of an IoT system. Though sensors and other elements can power down over long periods, communication links such as wireless must remain in listening mode. Low-energy wireless not only reduces consumption, but also extends the life of the device through less use.

Radio Protocols:

ZigBee, Z-Wave, and Thread are radio protocols for creating low rate private area networks. These technologies are low-power, but offer high throughput unlike many similar options. This increases the power of small local device networks without the typical costs.

LTE A or LTE:

Advanced, delivers an important upgrade to LTE technology by increasing not only its coverage, but also reducing its latency and raising its throughput. It gives IoT a tremendous power through expanding its range, with its most significant applications being vehicle, UAV, and similar communication.

WiFi Direct:

Eliminates the need, for an access point, it allows P2P (peer-to-peer) connections with the speed of WiFi, but with lower latency. WiFi-Direct eliminate an element of a network that often bogs it down, and it does not compromise on speed or throughput.

Electronic Mail (e-mail) for IoT, Smart Agriculture and Water Irrigation

Electronic mail presents various English spelling alternatives (e-mail, email, mail, eMail, EMail, E-mail, Email) (Long, 2012). Most commonly known as email, electronic mail serves as a means for transmitting digital messages from a sender to one or more recipients (Wood, 2011).

Email, e-mail, or electronic mail refers to the process of sending messages (which can be as simple and straightforward as traditional letter writing) through electronic networks such as the Internet (Heinz, 2014).

Electronic mail constitutes a letter dispatched via the internet to a designated recipient (Karen, 2014). Thus, the author characterizes e-mail as the process of sending messages across communication networks: these messages may consist of notes typed on a keyboard or electronic files saved on a disk.

Delivery of electronic messages to a specified recipient is made possible with the services of unique electronic address (e-mail address) of the user. The term e-address is commonly used as an abbreviation for e-mail address. E-mail address is a name that identifies an electronic post office box on a network where e-mail can be sent (Webopedia, 2014). The author emphasized that different types of networks have different formats for e-mail addresses. On the Internet, all e-mail addresses shave the form:

Smart Agriculture and Irrigation Water Management with IoT

The Internet of Things (IoT) technology is anticipated to significantly enhance agricultural productivity to satisfy food demand. Smart agriculture integrates advanced IoT-based technologies and solutions to boost operational efficiency, optimize yield, and reduce waste through the real-time collection of field data, data analysis, and the implementation of control mechanisms. Various IoT applications, including variable rate technology, precision farming, smart irrigation, and smart greenhouses, will be crucial in improving agricultural processes. IoT has the potential to tackle agriculture-related challenges and enhance both the quality and quantity of agricultural output, rendering farms more intelligent and interconnected.

Recently, the world has experienced a remarkable agricultural boom due to innovations and advancements in genetics, particularly the Genome project. Once again, another boom appears to be on the horizon, driven by the potential to harness significant improvements in information and communication technology (ICT), especially through IoT applications and solutions that are increasingly recognized as pivotal innovations in geo-positioning systems, Big Data, UAVs (Unmanned Aerial Vehicles, drones), remote sensing, and robotics. These technologies are progressively entering the production arena and practical applications, and when integrated through IoT (Internet of Things), they form a powerful force that many researchers believe will propel the anticipated boom. This new wave of technological innovations and capabilities is undoubtedly ushering in a Third Green Revolution within the agricultural sector. It is important to note that the practical application and utilization of the aforementioned technologies and innovations by farmers is referred to as "smart farming." In essence, smart farming represents the extensive application of integrated ICTs for agricultural activities and objectives. This is no longer merely a trend; it has become a reality not only in more developed economies but also in developing nations such as Nigeria, where the adoption of Information and Communication Technology is gaining traction.

As a result, there is ongoing pressure on the limited agro-hydro-ecological capacity of these regions. Such pressures related to land use have led to, and continue to lead to, conflicts. The authors firmly assert that the resolution will ultimately stem from the implementation of Smart agriculture and land management practices. Similarly, numerous environmentalists in Nigeria contend that effectively monitoring Nomadic cattle-grazing and their movements through smart tracking technologies would significantly reduce the frequency of community clashes between nomadic herdsmen and the established rural sedentary farming populations. This approach would greatly contribute to alleviating the ongoing strife and communal disputes, tensions that frequently escalate into communal conflicts among the communities.

Structure of IoT in Smart Agriculture

Essentially, this system architecture is composed of three layers: the sensor layer, the transport layer, and the application layer. The functions of these layers are outlined below:

1) Sensor Layer:

A significant challenge faced by the sensor layer is to achieve automated and real-time conversions of actual agricultural production figures into digital information that can be processed in the virtual realm through various means. The data collected includes:

a. Sensor data - humidity, temperature, gas concentrations, pressure, etc.
b. Product data - name, model, price, and features.
c. Operational conditions - parameters of various equipment and apparatus.
d. Location data.

The primary challenge of the information layer is to identify different types of information or data and to gather both the information and the identified data from the real world using sensing techniques, subsequently transforming them for processing into digital information. This sensor layer employs several strategies, including RFID tags, cameras, two-dimensional code labels, and sensor networks.

2) Transport Layer:

The role of this layer is to collect and summarize agricultural data obtained from the previous layer for processing. It is regarded as the nerve center of the Internet of Things (IoT). This layer encompasses a combination of telecommunication management centers, internet networks, information centers, and smart processing centers.

3) Application Layer:

The purpose of this layer is to analyze and process the information gathered to foster a digital understanding of the real world. It is viewed as a convergence of IoT and agricultural market intelligence.

Applications of IoT in Smart Agriculture

According to Huawei (2018), various IoT-based applications in smart agriculture are developed to improve productivity. The primary applications of IoT in smart agriculture encompass:

Precision Farming:

This method of farm management utilizes IoT and information and communication technologies (ICT) to maximize returns while ensuring resource conservation. Precision farming involves acquiring real-time data regarding the conditions of crops, soil, and air. The objective of this approach is to guarantee profitability and sustainability while safeguarding the environment.

Agriculture Drones:

Unmanned aerial vehicles (UAVs) are applicable in numerous agricultural functions, including crop health monitoring, agricultural photography for site-specific development, variable rate applications, and livestock management. Drones can efficiently scan extensive areas at a low cost and utilize various sensors to effortlessly collect a broad spectrum of information.

Smart Irrigation:

There is a growing necessity to improve the efficiency of irrigation processes and reduce water wastage. Awareness regarding the conservation of current water resources is increasing, leading to the adoption of sustainable and efficient irrigation systems. IoT-based smart irrigation assesses multiple parameters such as humidity, soil moisture, temperature, and light intensity to determine the exact water requirements. Evidence suggests that such mechanisms can enhance irrigation efficiency.

Soil Monitoring Systems:

These systems aid farmers in monitoring and enhancing soil quality to prevent degradation. They facilitate the observation of various physical, chemical, and biological properties, including texture, water-holding capacity, and absorption rate. Soil monitoring can help mitigate erosion, densification, salinization, acidification, and pollution from toxic elements that may compromise soil quality and optimal yield.

METHODOLOGY

The approach employed in this system was the prototyping model. The prototyping model facilitates the swift development and evaluation of functional models (prototypes) for new applications via an iterative and interactive process, which is frequently utilized by information system professionals. The research work was structured by segmenting the comprehensive development plan into manageable portions. Initially, it focused on the most crucial elements before progressing through the entire project. By dividing the project into smaller components, it allowed for the independent optimization of each section.

Analysis of the Existing System

The researchers assessed various IoT-based models for smart agriculture, including the IoT-Based Smart Agriculture Monitoring System and the Intelligent IoT-Based Automated Irrigation System. Yuthika *et al*., (2018) performed a study on the Intelligent IoT-Based Automated Irrigation System in India. Agriculture significantly influences the country's economy. Extensive research has been conducted on automating irrigation systems through the use of wireless sensors and mobile computing. Additionally, studies have explored the application of machine learning within agricultural systems. Recently, "Machine to Machine (M2M)" communication has emerged as a technology that enables devices and objects to communicate with one another and transmit data to servers or the cloud via the core network. Consequently, we have developed an Intelligent IoT-Based Automated Irrigation System that captures sensor data related to soil moisture and temperature. The KNN (K-Nearest Neighbor) classification machine learning algorithm has been employed to analyze this sensor data for predicting the necessary irrigation of the soil. This system operates semi-automatically, allowing devices to communicate with each other and apply intelligence in the irrigation process. It has been constructed using high-cost embedded devices such as Arduino Uno and Raspberry Pi 3, which may not be considered smart by 21st-century standards. Furthermore, this system is not cost-effective and is user-unfriendly. Sensors collect agricultural field data periodically (every 30 minutes), which is logged and stored online using cloud computing and the Internet of Things. Users can remotely monitor and control the system through an application that provides a web interface. However, due to its centralized nature, this system is vulnerable to hacking, and transmitting data to the cloud can be challenging. Any malfunctioning component can adversely affect the entire system. The existing system discussed above is a centralized system.

Architecture of the Existing System

The current architecture of the system, which is a centralized IoT-based smart agriculture framework, involves all connected nodes (devices) transmitting data directly to a remote or local server via a designated gateway or network router. The nodes lack the capability to communicate with each other directly, as all data traffic must be routed to or from a central server. The farm owner is able to monitor the farm remotely, and the farmer can access the system from any location globally, provided that the system is connected to the Internet. Alternatively, the farmer can connect directly to the system through a wireless local area network (WLAN).

The system architecture of the existing sensor-based irrigation monitoring system is structured into two layers: the bottom layer and the upper layer. The bottom layer features a hierarchical sensor network where nodes are distributed across widely separated clusters. These nodes transmit data to a Base Station (BS), which is connected to a Wireless LAN that hosts the data logger software.

The upper layer comprises five modules: the acquisition module, the network management module, the alarm/network status display module, and the business module. Real-time and non-real-time data are collected through the data gathering modules from the sensor network and stored in a database for decision-making and alert notifications. The Alarm/Network status display module is responsible for alert notifications and for presenting information to end users. This module serves as an access point between the end users and the other modules or networks.

In the architecture of the existing system as described by Yuthika *et al*., the irrigation system is limited to a single pump, which has led to reduced crop yields and inadequate food supply. This single point of failure poses a risk to the entire system, and the management of irrigation water is ineffective. Due to limited resources and sporadic communication, particularly in regions where farmlands are situated, the network is prone to losing sensor readings or generating unreliable sensor data that.

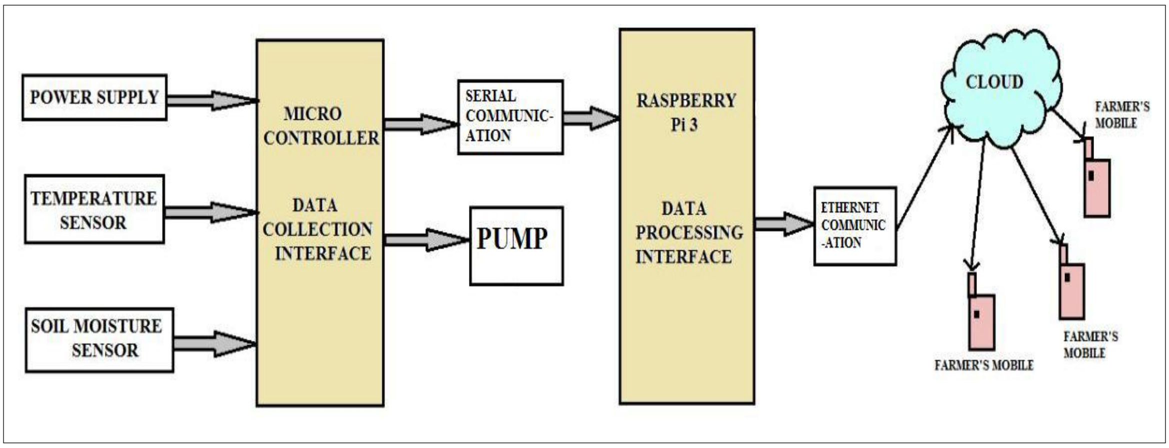

Figure 1: Architecture of the Existing System (Yuthika *et al.*, 2018)

Constraints of the Existing System

The following outlines the limitations of the current system.

Insufficient Gateway Reliability:

The IoT gateway may serve as a single point of failure within IoT networks. In a centralized IoT framework, if a gateway fails, essential operations such as decision-making, analytics, and data storage cease, rendering the entire system inoperative. Consequently, data collected from the farm cannot be monitored, and moisture management through a remote application becomes impossible for the user. Furthermore, local automation cannot be executed since the gateway is responsible for these critical decisions in the smart farm.

Insufficient Network Reliability:

Due to limited resources and sporadic communication, particularly in regions where agricultural lands are situated, the network is prone to losing sensor readings or generating unreliable sensor data, which undermines its effectiveness for decision-making and data analysis. The possibility of dropped readings, inherent to IoT networks, raises significant concerns, especially since IoT infrastructure often oversees mission-critical applications.

Insufficient Privacy and Security:

Public acceptance and trust are pivotal for the successful implementation of IoT. Nevertheless, a primary concern regarding IoT security and privacy is the flow of data into the network, which will be shared and utilized by various applications (service providers). Therefore, it is imperative to establish different levels of policies and access rights. Regarding privacy, users must be granted the authority to determine who can access their data. In summary, users should maintain control over their private information. However, in terms of security, it is crucial to develop new security mechanisms and encryption techniques tailored for energy-constrained devices. Additionally, large-scale networks will face certain limitations concerning authentication and authorization methods.

The drawback of this approach is that it necessitates human involvement and is labor-intensive. However, its effectiveness is compromised due to the uneven distribution of water, and there is a significant risk of water loss.

Analysis of the New System

The proposed system represents an optimized model based on the Internet of Things (IoT) for the management of smart agriculture and irrigation water. It operates as a decentralized system, facilitating the intelligent transmission, reception, and sharing of data with a server. This functionality is enabled through sensor-based variables, including light, humidity, temperature, and soil moisture sensors. The system is specifically designed for monitoring crop fields and automating the irrigation process.

Data collected from each sensor is transmitted to the cloud via a gateway for processing, analysis, and storage. Local automation is implemented at the gateway level, while the status of the farm is continuously synchronized with the cloud. The system is structured to accommodate two distinct authorized users: one designated as the farm administrator and the other as the farm manager. The farm administrator is responsible for adding both sensor and actuator nodes to the platform and determining whether operations are automated or managed by the farm manager. The farm manager is tasked with controlling both the sensor and actuator nodes, as well as receiving notifications via SMS or email regarding any modifications to the farm's operations. A dynamic and responsive web application has been developed to serve as the interface for monitoring sensor readings and also grants the farm manager the ability to activate the irrigation system either locally or remotely. The irrigation system comprises a main intake structure or pumping station, a conveyance system, a distribution system, a field application system, and a drainage system.

System Design

The system's design was created utilizing the Balsamiq application. It will feature a login page, a dashboard, a system use case diagram, an actuators page, a sensor page, and the design of the application interface. The Just in Mind tool was employed to illustrate the flow of information within the system, encompassing data input and output, data storage, and all the subprocesses through which the data traverses. This was accomplished by employing Figma symbols and notations to depict the various entities.

Architecture of the Proposed System

An optimized architecture based on the Internet of Things (IoT) consists of three layers: the cloud layer, the IoT layer, and the physical layer. This optimized IoT system enables any node within the physical layer to communicate with each other independently, without requiring a central system or gateway. An actuator node can receive commands from a user via a gateway or directly from another sensor node, allowing it to either initiate or halt the irrigation system. The implementation of a drip irrigation system can significantly reduce water wastage, as it operates based on data from water level sensors. Additionally, various other sensors are employed to monitor environmental conditions, enhancing the system's reliability and minimizing dependence on the Internet.

Nodes interact with each other and the gateway through a Long Range (LoRa) radio communication network. This constitutes the physical layer, while the IoT layer can function without relying on a TCP/IP network. The architecture facilitates the automation of agricultural activities with ease. The physical layer serves as an automation layer that governs the smart agriculture system, designed specifically to manage and control the sensors and actuators involved. The sensors utilized in this automation process include soil moisture sensors, temperature sensors, and humidity sensors. These devices are tasked with assessing the soil's moisture content, determining the water requirements for crops, measuring plant temperature, and monitoring environmental humidity. The actuators are responsible for regulating the water supply within the farm's irrigation system.

The IoT layer is responsible for collecting data from the physical field and transmitting it for further processing in the cloud layer. Within this layer, a system controller functions as both local storage/server and a network gateway to the cloud layer. This layer connects to the physical layer via the LoRa radio network and to the cloud layer through a secure TCP/IP network. IoT devices provide alerts every second, notify any changes, and transmit data to the controller, which is subsequently forwarded to the cloud for analysis.

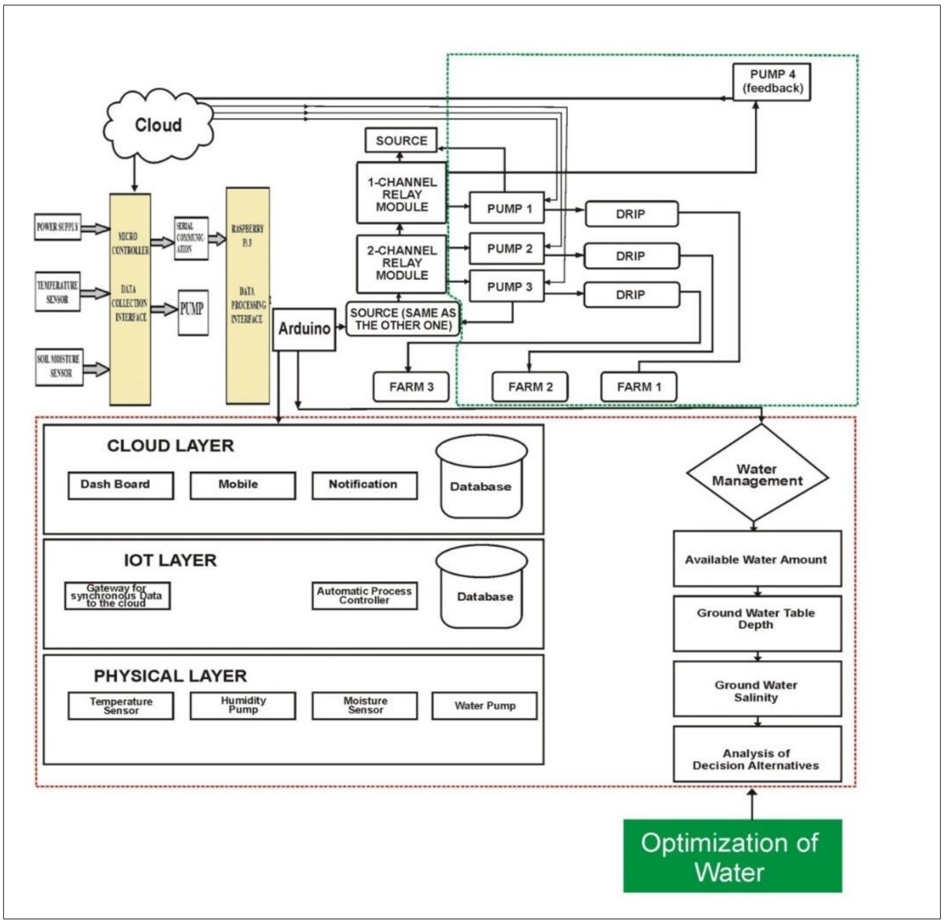

Figure 2: Architecture of the system

Results and Discussion

The Schematic Optimized IoT

Illustrates the block diagram of the entire process, which encompasses the irrigation control system, live surveillance feed, water tank, sensor node, actuator node, wireless sensor network, cloud, and user terminal.

An edge device is employed to gather data from the environment. The sensors detect physical parameters and collect the data, which is subsequently transmitted to the microcontroller for additional processing. The figures below depict the block diagram of the configuration.

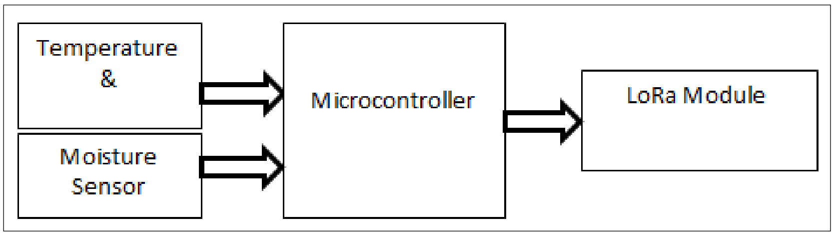

Figure 3: Smart Agriculture Sensor node gateway

A pivotal component of an IoT system, serving as a connection point between the nodes and the internet. The actuator, which is an edge device, responds to environmental inputs (such as humidity and soil water level) and can independently make decisions based on the installed program. It activates or deactivates devices (for instance, the pump) according to the immediate requirements.

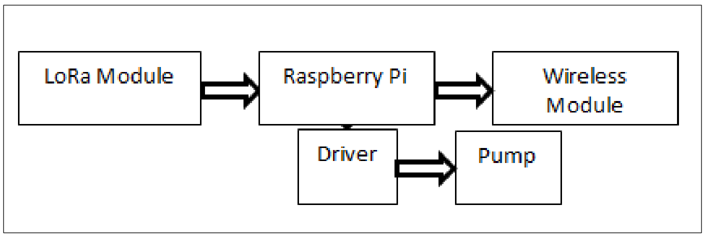

Figure 4: Irrigation Gateway

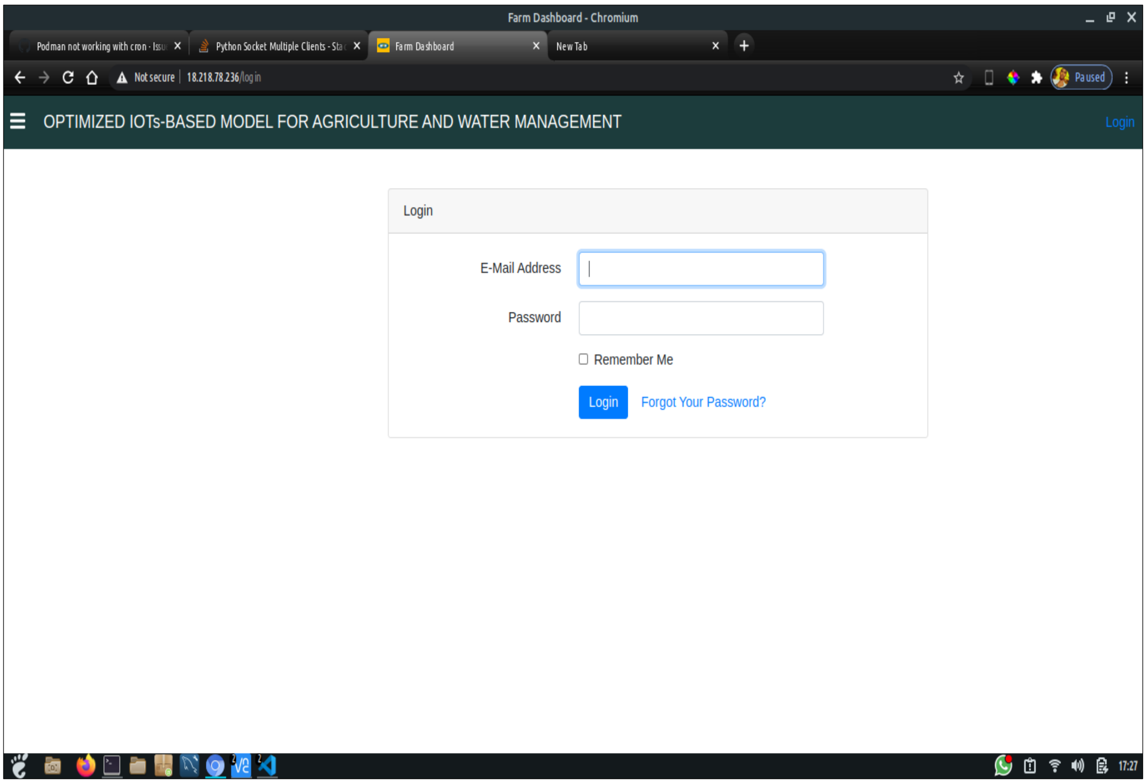

Figure 5: Login form

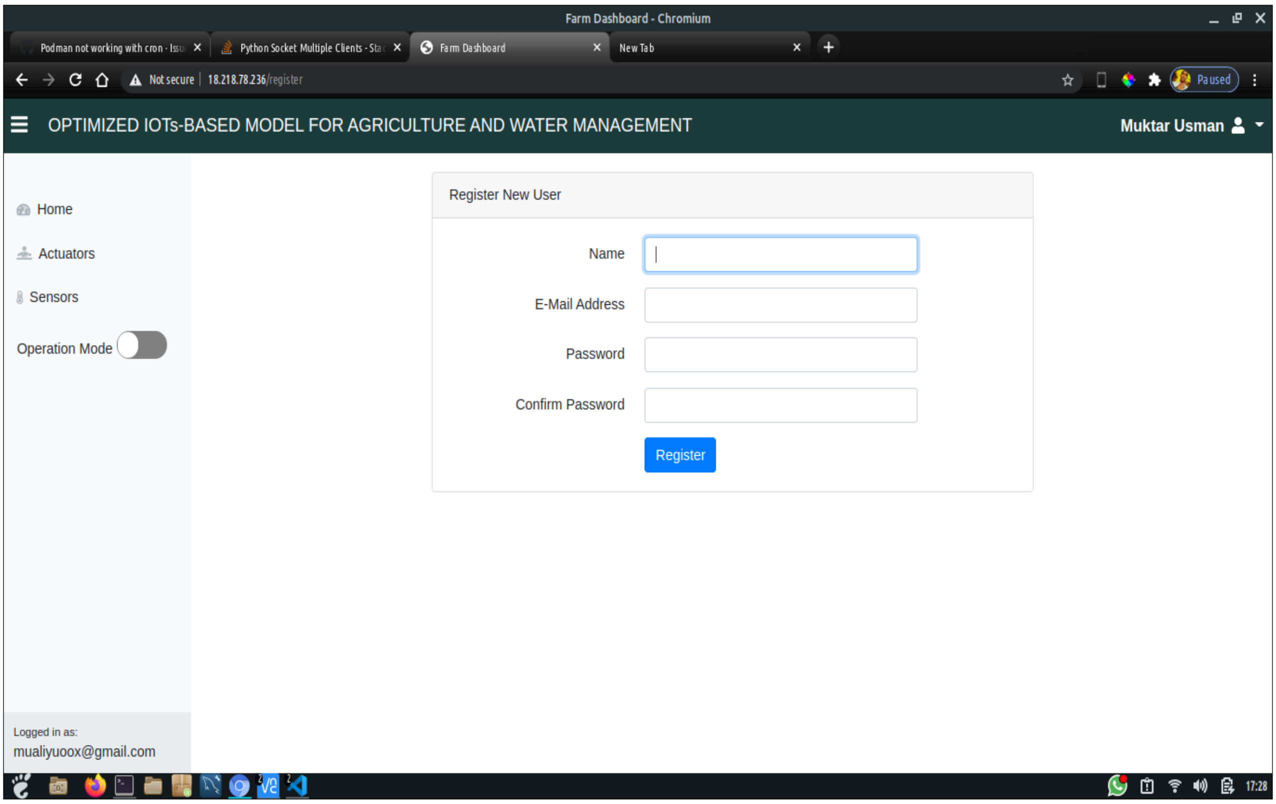

Figure 6: Registration form

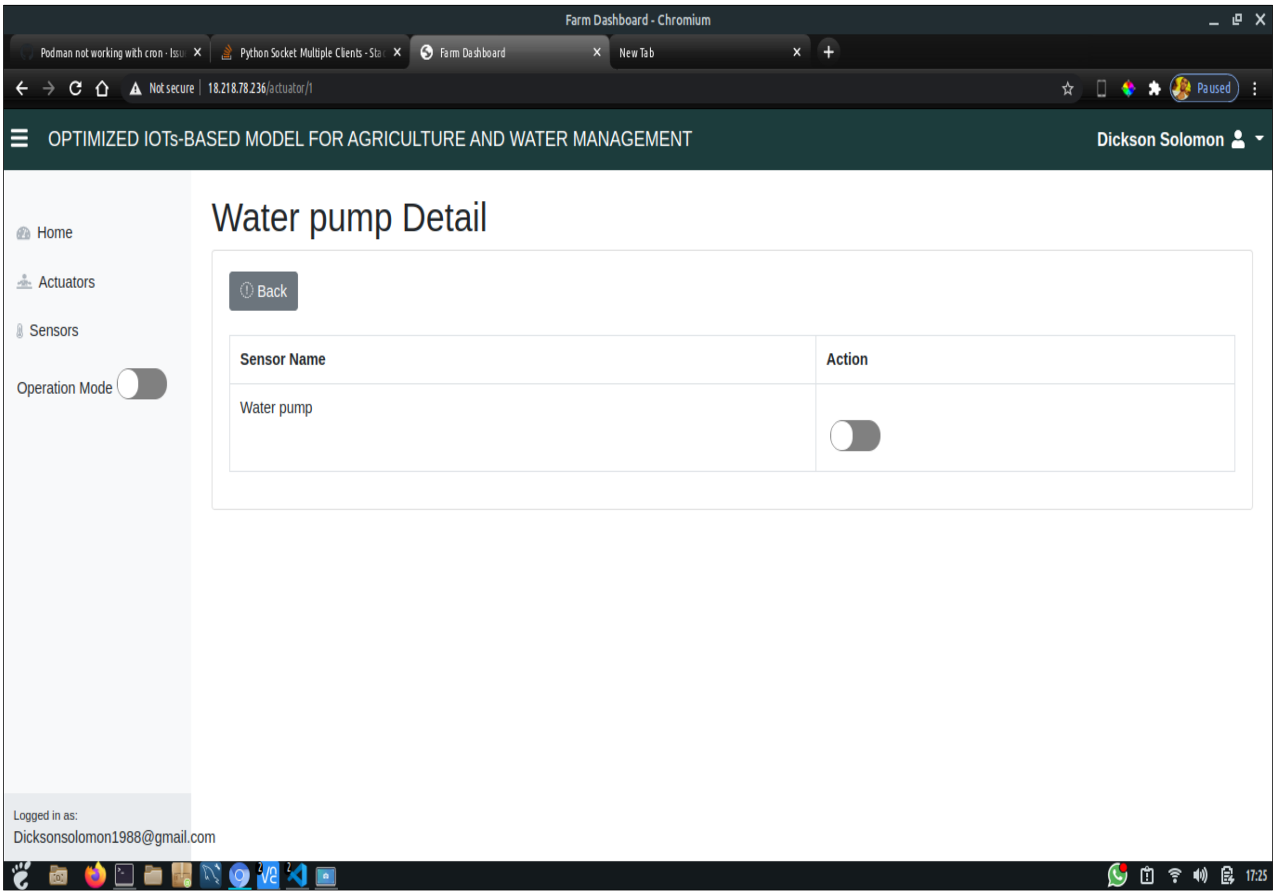

Figure 7: Water Pump Detail

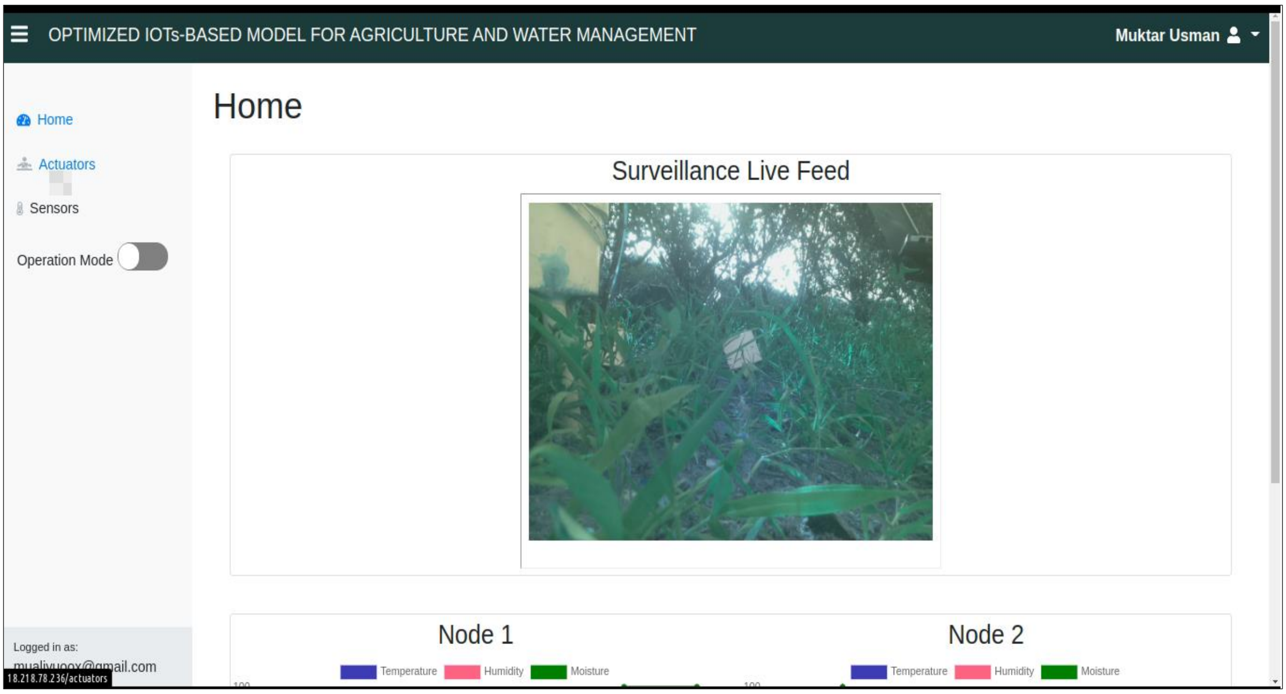

Figure 8: Home Page

Output Model of the Proposed System

A dynamic responsive web application is designed to serve as the interface for viewing readings from the sensors and also provides farm manager access to locally or remote active the irrigation system of the farm.

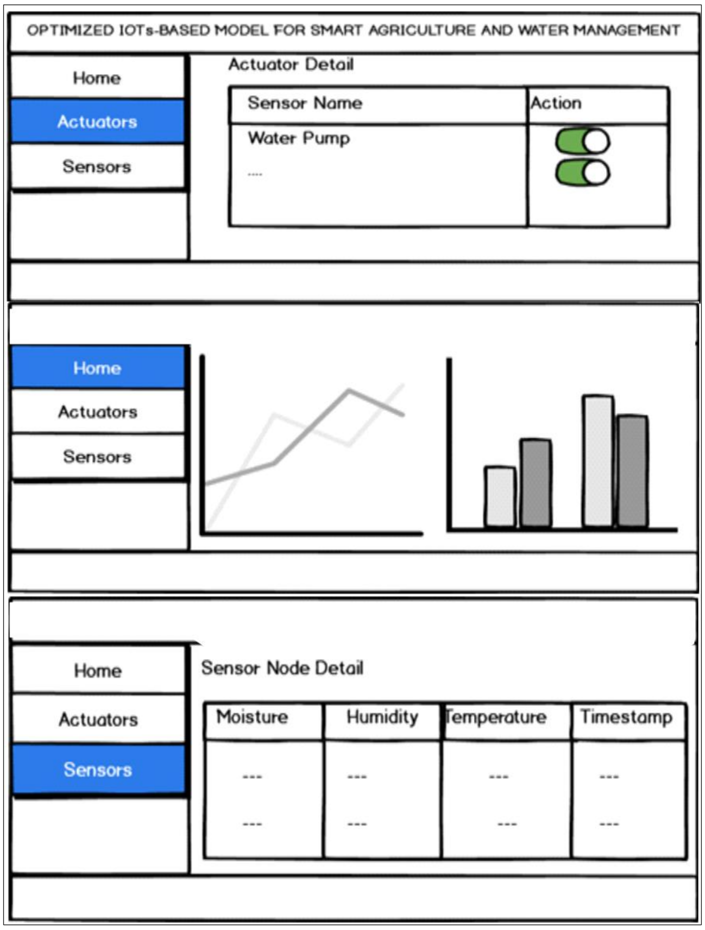

Figure 9: Output Design

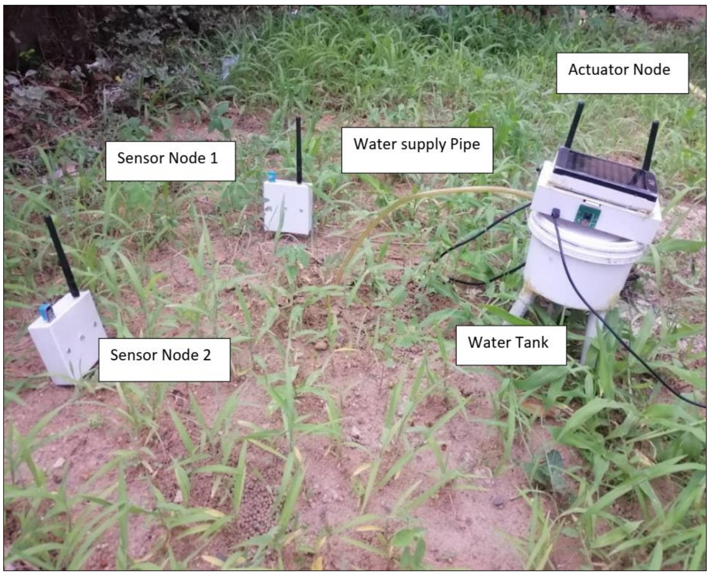

Figure 10: Optimized IoT

The Mathematical Model for the performance Metric of the Optimized IoT Model

Water Flow Rate $= \frac{Q_{wi}}{Q_{wu}} X \frac{100}{1}$

Where,

Q_{wi} = quantity of H_20 in the source

Q_{wu} = quantity of H_20 used from the source

Irrigation H_20 management

Quantity of $H_20 = Q_{wi} - Q_{wu}$

Reserved

Quantity of H_20 reserved from sprinkle $= Q_{wi} - Q_{ws}$

Q_{ws} = quantity of H_20 sprinkled

Quantity of H_20 reserved from drip $= Q_{wi} - Q_{wd}$

Q_{wd} = quantity of H_20 dripped

Quantity of H_20 served from sprinkle $= Q_{wi} - Q_{wst}$

Q_{wst} = quantity of H_20 at sprinkle time

Where

Drip time = stoppage time of sprinkle

Quantity of H_20 saved from from drip $= Q_{w-} Q_{wdt}$

Q_{wdt} = quantity of H_20 at sprinkle time

Where drip time is the time the sensor trigger off, which is the time at which the crops are saturated with water.

Quantity of H_20 reserved from mean the balance of H_20 in the source

Quantity of H_20 sarved simple mean the amount of H_20managed from either the sprinkle or drip irrigation method.

Total H_20 saved $= Q_{wi\,-} (Q_{wst} - Q_{wdt})$

Where

T_{H20} – saved = total H_20 saved which is the actual water management

User Friendly: $U_f\ H_20\ \frac{NT}{NPt} X \frac{100}{1}$

NT = total number of tests or trals

NP_t = total number of positive test or trals, where a positive test is a test where the indurated used for the reports friendliness

System Testing

Bottom-up approach was used to test the optimized model for evaluation against the existing model.

Testing Sensor Node:

The two sensor nodes were installed on the model farm and powered ON. Power indicator show the green light signaling that the nodes have started transmitting moisture level, temperature and humidity.

Testing Actuator Node:

The actuator serves two purpose; gateway for the sensor nodes and video server. After powering the actuator node, read light indicator near the camera module signify that the actuator is fired ON and sending the every that is measured on the farm including live video feed to the cloud Platform.

Testing Cloud Platform:

The cloud platform aggregates all the transmitted signal to a database and provide a user-friendly display of the information sent from the farm model.

1. User registration and authentication were tested by registering and login new user using their email and unique password.
2. Sensor node data was visualized on the dashboard page as a chart and on sensor page in tabular form.
3. Actuator node data was visualized on the dashboard page as video feed and on actuator page in tabular form.
4. Operation mode switch located on the dashboard page was tested to switch the operation into either manual mode or automatic mode.

Performance Evaluation

The table 4 compared the existing method against the optimized model for farming and irrigation. The performance indices were selected to reflect effectiveness of both existing and optimized methods.

Table 5: Performance evaluation of the old and optimized model

Performance metric	Existing method	Optimized method
Water flow rate	5 L/S	10 L/S
Irrigation Water Management	Based on time	Based on Sensors
Surveillance live feed	Absent	Yes
User Friendly	Semi friendly (%)	Friendly (%)

Tables 5: The findings of this research present a comparative analysis of both the existing and proposed systems, detailing the parameters utilized in the comparison. These parameters include water flow rate, irrigation water management, surveillance live feed, and user-friendliness. The comparative analysis indicates that the proposed system surpasses the existing system, particularly in terms of water flow rate, irrigation water management, surveillance live feed, and user-friendliness. Consequently, based on the performance evaluation, it can be concluded that the optimized model significantly outperforms the current method of farming and irrigation.

RESULTS

The study achieved the following results, it;

1. Designed an optimized IoT-based model for smart agriculture and irrigation water management.
2. Implemented the optimized IoT-based model for smart agriculture and irrigation water management with python programming language
3. Tested and evaluated the performance of the optimized IoT-based model for smart agriculture and irrigation water management.

Documentation

The system is an open system which captures Optimized IoT-based model for smart agriculture and irrigation water management system was developed using a sequential order. The first step covers the research study, problem encountered on the cause of the study, its aim and objective and so on. The second step covers related literature of the study. The third step covers the methodology adopted in the research which is the waterfall model. The program includes an electronic registration of the user/login form.

Architecture: Wireframe application was used for the architecture. This is a method of module description of the architecture.

Coding:

This is the method of translating device design into a machine language format. ReactJS Frontend Application development platform, Amazon web services IoT Core backend, Arduino Development platform for developing sensor nodes and Python programming language for the actuator node based on Raspberry Pi board.

Implementation:

Turning the concept into something concrete means that this process has steps that include gathering specifications, finding potential solution, evaluating and those solutions.

Testing: the test was carried out in following part:

i. Registration: the farmer or the user shall supply the system with their information.
ii. The web Server: this conducts a series operation on local server structured input data to test processing efficiently.

Database module: Store and save the structured data from the process module for use.

Deploy: these are various forms of research that involve the smart agriculture and irrigation water management;

a. Sign in with a local server
b. Built on Web Server
c. Type or select the address.

The user will need little knowledge of mobile phone or computer, as the assigned smart agriculture and irrigation water management are view using mobile phone or computer.

System Setup and User Manual

This model required little knowledge of computer or electronics to set it up on a farm. The following step by step procedure details how to setup and use the model on a farm.

1. Divide the farm into zones e.g. A, B C etc.
2. Slot the sensor nodes in the middle of each zone. Make sure that the node antenna is pointing upward.
3. Turn the sensor nodes ON
4. Install the water tank that contains the water pump at the farm edge and lay out the pipe to supply water to the farm.
5. Fix the actuator node on top of the water tank and turn it ON. Make sure the camera module is facing the farm
6. Goto register/login to monitor and control the farm.

Conclusion

This study achieved its target; an optimized IoT model for smart agriculture and irrigation water management in Nigerian. The program has made the following functionality: login page wireframe, dashboard wireframe, system user case diagram, actuators page wireframe, sensor page wireframe and application interface design. The model was tested and approved to fulfill its mission and objectives such as design an IoT- based model for smart agriculture and water irrigation, implement the optimized IoT-based model for smart agriculture and water irrigation with python programming language, test and evaluate the performance of the optimized IoT-based model for smart agriculture and irrigation water management was then deployed to the farm.

The study have successfully optimized IoT-base model for smart agriculture and irrigation water management in Nigerian. Also help to solve the problem of scarcity of empirical evidences in the area of the study. Through this study, an optimized model for smart agriculture and irrigation farming was developed which has a better functionality and flexibility when compared to that of the existing system. The study provides the relevant design information and approach needed for system developers who would want to venture into developing similar application in the future. Lastly, the study opens up more research areas as it applies to IoT for smart agriculture and irrigation water management.

Recommendations

The study recommends the following:

i. The farmers must be adequately trained on computer skills to comply with management, maintenance and operation of the model.
ii. The government through the Ministry of water resources should publicize IoT-base model for smart agriculture and irrigation water management.
iii. Policy makers and other stakeholders in Nigeria interested in the IoT should design compactable curriculum for study in this area. This will help in knowledge capacity building and documentation.

Conflicts of Interest: The authors declare no conflicts of interest regarding the publication of this paper.

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