Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

The Design and Performance Evaluation of a Wireless Sensor Network Based Irrigation System on Different Soil Types

Buhari Ugbede UMAR[1] (✉)
[1]Federal University of Technology, Minna, Niger State, Nigeria
buhariumar@futminna.edu.ng

Eustace Manayi DOGO[2]
Bello Kontagora NUHU[3]
Arifa Khatoon HAQ[4]
Paul Tobi OLALEYE[5]
[2, 3, 4, 5] Federal University of Technology, Minna, Niger State, Nigeria

Abstract— In the Nigerian economy, agriculture plays a significant role, and most of its people depend on it for their livelihood. Agricultural practices in the country are still mainly based on conventional, traditional methods of farming which usually result in wastage of water resources and low production of crops to meet the country's demand. There is a need to transform farming from the traditional way to a more efficient method with optimum water utilization. Irrigation is an assistive measure to salvage the problem of inadequate water for dry season farming. Irrigation requires a lot of water and time, and it must be completed on time. Overwatering and soil underwatering are two issues that the controlled irrigation system helps to solve. This research proposed an Arduino-based smart irrigation system using a wireless sensor network to overcome the problem of overwatering, underwatering, and efficient time utilization in farming. The system is implemented using Arduino IDE, Proteus Simulation Tools, and Blynk Platform. The effect of the four-mobile network: MTN, GLO, Airtel and 9mobile on response time for Gidan- Kwano area was evaluated. Testing carried out on the system resulted in a response time of 0.75 seconds for the Glo 2G network and 0.45 seconds for the Glo 4G network. Less than 1sec in the worst-case scenario. Also, 0.72 and 6.073 seconds respectively was achieved for loamy soil average response time and average saturation time. Average response time of 0.85 seconds and 4.906 seconds for saturation time, while 0.77second and 6.366 seconds as average response time and saturation time for clay soil. This makes the system effective in terms of time response, thereby eradicating the time wasted by manual system operation to irrigation scheduling. Also, the appropriate soil moisture content is maintained, whether it rains or not. This reduces excesses and ensures healthy plant growth, increasing agricultural productivity, and cultivating crops are made possible throughout the year. The system will also help drive agricultural innovation through the use of IoT.

Keywords— IoT, ZigBee, WSN, Wi-Fi Module, Arduino, Irrigation System

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

1 Introduction

Agriculture has a significant economic impact on Nigeria. Agriculture, along with crude oil, is the backbone of the Nigerian economy. The bulk of the freshwater resources available is used for agricultural purposes [1]. Nigeria's population is expected to exceed 300 million by 2050, and the currently available food is not adequate for the increasing population. As a means of subsistence, most of the population relies on agriculture. To date, the majority of farmers do use conventional farming techniques. This may be the reason behind the decline in the production of crops and the country's food shortage. Nonetheless, few farmers have used an irrigation system that operates manually with high water waste.

For as long as humans have grown seeds, irrigation has been around. Irrigation procedures rely mainly on the availability of water [2]. Irrigation is essential in semi-arid and arid areas for food, pasture, and fiber production [3]. To increase food security while saving water, irrigation methods around the world are evolving. Developed and developing countries are moving from pure supply to a system centered on a demand-based model [4]. In a nation like Nigeria, where water supplies are manually regulated and managed, and water is unevenly distributed in time and space, demand-based practices are not feasible. Due to limited sweet water supplies, an efficient and cost-effective way of irrigation has emerged as the need of the hour, especially in countries severely affected by a lack of sweat water reservoirs. Most water is lost due to insufficient plant irrigation [5]. The efficient use of water in agriculture is one of the most important agricultural challenges that modern technologies are helping to address [6]. Agriculture is one of the most water-intensive businesses on the planet. Due to a lack of updated technology, more than 80% of water resources are squandered in this business. The efficient use and management of water are one of many countries' major challenges today. Irrigating 25% of the world's crops, which provide 45 percent of the world's food, is predicted to require around 70% of the world's freshwater. Industrial and domestic water usage accounts for roughly 20% and 10% of total water consumption, respectively [3,7]. As a result, by conserving water and managing plant development conditions at the same time, a low level of water consumption can be attained.

Freshwater demand is rising, and this trend is expected to continue as the world's population grows, resulting in higher food and fiber demands, as well as a predicted negative influence on climate change. The need to have enough water to support other ecological functions is becoming more well recognized [3]. To practice smart farming, it is vital to combine new technologies with agriculture [8].

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

A Wireless Sensor Network (WSN) is a wirelessly connected collection of spatially dispersed sensor nodes (motes) [9]. WSNs consist of several small sensor nodes networked by a low-power wireless communication scheme and are adopted for data extraction and transmission [10,11]. WSN is adopted for a wide range of applications, ranging from continuous patient monitoring in healthcare to environment-connected vehicles in transportation and even smart irrigation in agriculture [12,13]. Due to water scarcity and drought being faced in the agricultural sector, WSN is being adopted in smart irrigation to foster the efficient utilization of resources, resulting in minimization of human labor, improved yields, and profits [14,15,16].

As a result of this study, an Arduino-based smart irrigation system with a wireless sensor network was built to address the issues of overwatering, underwatering, and efficient time utilization in agriculture. This improves the system's response time by eliminating the time spent preparing irrigation for manual system service, such as present irrigation systems that need farmers to irrigate crops in the field manually. System automation enables remote agricultural monitoring and effective resource utilization, saving time and energy for farmers [17]. The suitable soil moisture content is also preserved with the assistance of weather prediction, whether it rains or not. This reduces surpluses and ensures healthy plant growth, increases agricultural productivity and makes it possible to grow crops throughout the year. The system would also help fuel and push agricultural innovation by using the internet of things (IoT) system.

2 Related Work

Agriculture must discover strategies to make efficient use of this finite resource as the demand for water continues to grow [18]. Water is commonly considered to be the most critical resource for long-term agricultural development. Irrigated lands will develop in the next years, while agricultural freshwater supplies will be redirected to satisfy rising residential and industrial demands. Furthermore, irrigation efficiency is low, as the crops only use about 65 percent of the water applied. In dry places, irrigation water sustainability is a top problem for agriculture.[19]. Several prototypes have been developed to address these problems, some of which are presented, and analyses in this section range from the application of IoT, WSN, and weather prediction models.

Their research employed an automated watering system with a wireless sensor network and a General Packet Radio Service (GPRS) module [20], which included a unit with a dispersed wireless network of soil moisture and temperature sensors in the plant's root zone.

On the other hand, a gateway device was in charge of sensor data, actuators, and data communication with a web application. To measure the amount of water, an algorithm was developed with temperature and soil moisture threshold values that were encoded into a microcontroller-based gateway. Photovoltaic panels were used to power the device. Their work was distinct in that it was wireless and trackable. Similarly, [21], Developed a smartphone app that expanded the use of a team of Colorado State University Researchers' Water Irrigation Scheduling for Efficient Application (WISE) scheduling tool. Users could easily monitor and operate their irrigation projects using the smartphone application. This software can track soil moisture deficits and weather data and input and compute the amount of irrigation needed. However, the app is limited by its underutilization of WISE's full capabilities, which allowed users to create field boundaries using a web browser and a base map layer. Furthermore, the software was exclusively available for iOS users. In addition, the YL-69 sensor technology was used as a data input in [22] to monitor the land's humidity. An ESP8266 module, which served as a Wi-Fi network server, was used to process the data. The humidity data was sent to a web server over a Wi-Fi network, where it could be accessed using a web browser. The ESP8266 module served as a microcontroller and also a transmitter through the Wi-Fi network. It used wired sensors, which could cause wire crowding in the farmland. Real-time control could be added to the system to be more dynamic and efficient. The sensors could also be made wireless using wireless sensor networks.

The authors in [23] designed an architectural structure and performance evaluation of a sprinkler irrigation robot using two assemblies of ZigBee technology to enhance prototyping efficiency. ZigBee technology covered a larger communication area. The robust design could not carry more than 5litres; this may not be recommendable for a large farm. Adding an automation system would further enhance system performance. Weather forecasting was added to the authors' automated irrigation system for more efficient use of water resources (AISWP) in [24], which was an improvement over the previous system' automated irrigation system with partitioning system for efficient irrigation of small farms' (AISPF). The proposed model was able to address the AISPF Process issues using a weather forecast, and the water supply efficiency was increased by 20%. It isn't as efficient. The device may become more functional after the Wireless Sensor Network is established. Using a wireless sensor network and GPRS module, the automated irrigation system in [4] used soil water balance concepts to plan irrigation levels and duration. To receive ETo data, these controllers employed a wired (phone) or wireless (cellular or paging) interface. The challenge with this research is that the data provided might not be accurate. Their concept might be expanded by including XBEE / Bluetooth technology, which would allow data on the state of the water pump to be transferred to a smartphone or XBEE transceiver unit when the pump is turned on or off. The authors of the study [25] looked at the necessity for perfect uniformity in plant watering, which led to the development of an automated irrigation system. The irrigation system operated in a way that if one part had its requirement met and other parts were over watered or under watered, technologies that existed should indeed give the water level and detect the water required by the plant in a specific area. The proposed system provided many benefits, like operation with less workforce, due to the transfer of water directly to the root zone of plants. It had two nodes and a central node that coordinated the information provided by the sensors in each node. The resulting analysis showed that it was insufficient, and there was a need for the system to be more robust.

The authors in [22] used a moisture sensor to determine the level of the water content of the soil and turned on the pumping motor when detecting a level of moisture content of the soil. Their project had a simple design and not too much complexity, but also, cannot make an efficient prediction. Compared to an automated system, it was less efficient. In this type of project, more environmental conditions could be accessed for proper investigation and precise irrigation, such as using a rain sensor to determine when rain is falling. The researchers designed a metering network using GPRS and backend server services to report flow discharges (water discharged) in real-time. An analytical roster was created by comparing the acquired water distribution data. It had the advantage of having a large number of smart eater meters with high sampling and transmission frequencies deployed on a huge scale. More features, such as the use of weather prediction to predict rainfall could be added to the system to make it more robust and efficient, assisting in regulating the system's operation. In [27], the authors introduced a model-based method for determining seasonal irrigation regimes that are sub-optimal. According to their findings, Re-computing the sub-optimal solution minimized the detrimental impact of faulty weather forecasts. Wireless sensor network technology could be used to improve its efficiency.

The fundamentals of several irrigation schemes utilized by Indian farmers to nurture their crops were presented in detail in [20]. A multitude of irrigation technologies are utilized around the world to protect the plant's thrust, including surface, sub-surface, sprinkler, drip, and sophisticated smart irrigation. The typical procedure had not been effective enough, creating eater logging and salinity problems. Deficient utilization of weather is vital for productivity sustainability. This article presented a substantial disparity between irrigation systems. The researchers employed MQTT and HTTP in their work in [28] to keep the user up to date on the present agricultural situation from a faraway place. They used a neural network to supply the device with the essential intelligence. Its intelligence, low cost, and portability gave it an advantage. [29] To achieve a smart energy system, they applied approaches in their system. They created a software framework to improve the system's intelligence. This technology had an advantage in that it used renewable energy sources. A wireless sensor network could help

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

them optimize their system even more. [30] They deployed a wireless sensor network in their suggested concept to optimize crop watering. Hardware, a web application, and a mobile app were all utilized. The component employed data mining to estimate optimal temperature, humidity, and soil moisture for future crop development control. Weather forecasting technology could help the system improve even more.

3 Materials and Methods

A built-in system for autonomous irrigation monitoring and control is included in this study. A wireless sensor network is used in this project to monitor, detect, and regulate an irrigation system in real-time. When the sensor goes below the process's limit at the root level of the crop, this technique maintains consistent water use on agricultural land and prevents water waste. The system then turns on the pump's motor. When a standard level is reached for a particular soil, it automatically turns off. The sensor data was acquired by a ZigBee system and sent to another ZigBee setup. Using the Arduino-interfaced open-weather.org API, the irrigation system also serves as a weather prediction for the area, allowing the system to be more conservative with the usage of available water. Irrigation is crucial in producing delicate plants such as tomatoes, peppers, and various vegetables. Because these plants are shallow-rooted, they require frequent irrigation, particularly when frost is a threat. About 100-110cm of irrigation is needed for a thriving plantation. Irrigation of Nigeria's plain fields must be done every four days during the dry season and every 10-15 days during the rainy season.

Table 1. Percentage of Dry-Weight of Soil [31]

Soil	**Field capacity (%)**	**Permanent wilting point (%)**	**Available Moisture (%)**	**Dry Density (kg/m3)**
Sand	5	2	3	1500
Sandy Loamy	12	5	7	1400
Loamy	18	10	8	1350
Silt Loamy	24	15	9	1300
Clay Loamy	30	19	11	1300
Clay	40	24	16	1200

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

3.1 Irrigation Planning

Irrigation planning calculates the amount of water to apply and the interval at which it should be used based on the soil's Available Water Holding Capacity (AWHC) and the crop's evapotranspiration (ET) need. The depth of water applied was calculated using Equation 1[31].

$$d = AWHC \times pw \times dr \quad (1)$$

Where d is the applied water depth in centimeters, AWHC is the soil's available water holding capacity in centimeters, pw is the percentage of wetted soil, and dr is the root zone depth in centimeters (cm). Soil conditions, discharge, and emitter spacing all influence the percentage of soil wetted. The wetting diameters of two neighboring emitters must not overlap by more than 60%. The empirical equation for WD was utilized in Equations 2, 3, and 4 [31].

$$WD = 3.936 + 74.456_{qe} \text{ for fine soil} \quad (2)$$

$$WD = 2.296 + 81.90_{qe} \text{ for Medium soil} \quad (3)$$

$$WD = 0.984 + 89.34_{qe} \text{ for coarse soil} \quad (4)$$

Here in equations 1-4, *qe* is the discharge of an emitter, while WD is the wetting diameter

3.2 Field Capacity

The maximum moisture that the soil can hold after gravity water has been drained is known as field capacity. The field capacity of the soil refers to the amount of water that remains in the soil. Large, non-capillary pores are filled with air, whereas small, capillary pores are filled with water at field capacity moisture content, which is the amount of water available to the plant's root zone. Equation 5 gives the Field Capacity (FC), while equation 6 gives the Available Moisture (Aw) [31].

$$FC = \left(W_s * 100\right) W_w \quad (5)$$

$$Aw = \frac{W_s}{W_w}\left(FC - \text{permanent wilting}\right) \quad (6)$$

Where W_s is the weight of the soil while containing moisture and W_w is the dry weight of the soil.

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

3.3 Mathematical Approach

Some calculations will be required by a control system that will perform irrigation depending on the factors used to adjust the soil moisture content in the present and future states. In this computation, some parameters are employed, such as the Minimal volume of water moisture maintenance and the Mean soil moisture decay rate [32]. Various parameters must be considered before the magnitude of the above variables can be determined. These equations are meant to cover all irrigation areas.

$$d = a_1x_1 + a_2x_2 + a_3x_3 \cdots a_nx_n \tag{7}$$

$$d = \sum a_1x_1 \tag{8}$$

Where X_1 = predicted parameter affecting d, and a_1 = Coefficient attributed to each parameter.

Imprecision in parameters such as humidity, pressure, temperature, and so on is considered for various climatic scenarios. Affect the amount of water that the soil loses, i.e., its moisture content. Irrigation is carried out to compensate for losses. Equation 9 gives the total volume of water lost in 24 hours Wd:

$$W_m = p\left(\omega_{op} - < \omega > Ah \times 24\right) \tag{9}$$

Where Wm denotes the minimum volume of moisture maintenance; h denotes the effective depth (where water is available to the roots); and = Soil Moisture Average for the Previous 24 Hours.

3.4 Integration of WSN

Climate variables such as temperature, humidity, and other factors influence plant water requirements. Various sensors in a WSN will detect these parameters. Any irrigation management system that is designed must start with such components. Using Zigbee technology, the XBee s2c module networks the sensor parameter for the required action.

3.5 Data Collection Level (Router)

Different sensors can be used to acquire environmental data. The gateway sends the data received by the sensor nodes to the controller, which helps the controller decide on an irrigation operation. If the measured temperature or humidity falls below predefined criteria, it initiates the irrigation system. The Zigbee 802.15.4 interaction mechanism is employed in this case. It is the most appropriate communication protocol for

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

this type of application. It allows for the transmission of small amounts of data (environmental data) over vast distances with minimal power usage. A smartphone, PC, or tablet can be used by the irrigation system user or management to operate the irrigation operation.

3.6 Control Level (Coordinator)

At this point, the microcontroller compares the sensed data to pre-defined threshold values. Assume the microcontroller determines that the measured values are less than a certain threshold. The auto irrigation system will be activated in that situation. Otherwise, the system will be turned off until the opposite outcome is achieved.

3.7 Gateway Level

The esp8266 and an Arduino Mega for control are found on the gateway level, which delivers sensor data to the internet and waits for a control signal from the internet via a mobile app. The central Arduino Mega esp8266 is used to accomplish this.

.

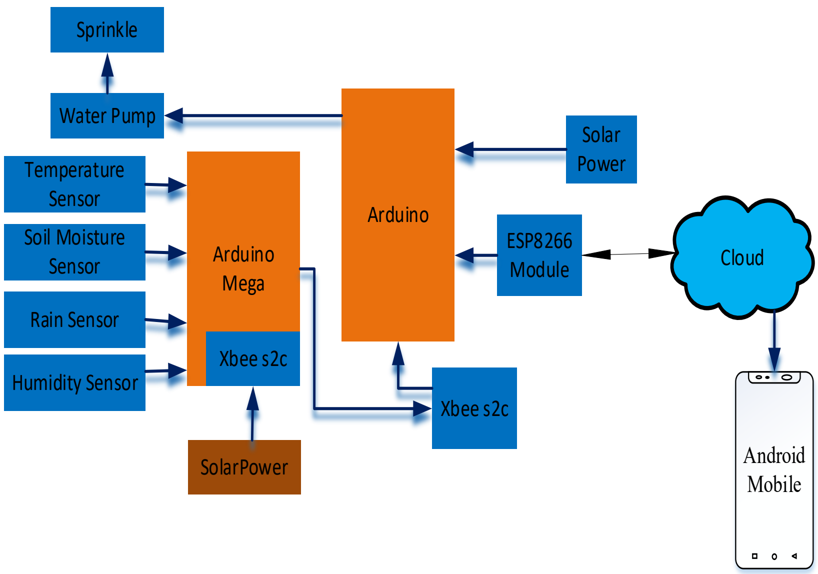

Fig. 1. Block Diagram of Arduino Based Smart Irrigation System

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

The system connection is depicted in Figure 1 by a block diagram in which the router module is wirelessly connected to the coordinator node using the ZigBee connection protocol. The entire sensor is connected to one component of the system and wirelessly transmits data to the other portion for decision-making. The purpose of using WSN is to eradicate the problem of wire crowding in the farmland, especially on a large farm. The flowchart in Figure 2 depicts the actions that take place in the router module. The microcontroller takes sensors data. The gathered data is compared to the threshold that is predefined in the router microcontroller. If the threshold is meant, the data is sent to the coordinator via the XBee device. Figure 3 shows the operation of the coordinator module; the data sent by the XBee attached to the router module is collected by the XBee s2c attached to the coordinator module. The system checked for a reached packet on the XBee serial, extracted the data and compared it to the predefined threshold in the coordinator module using the gathered weather data to operate the system.

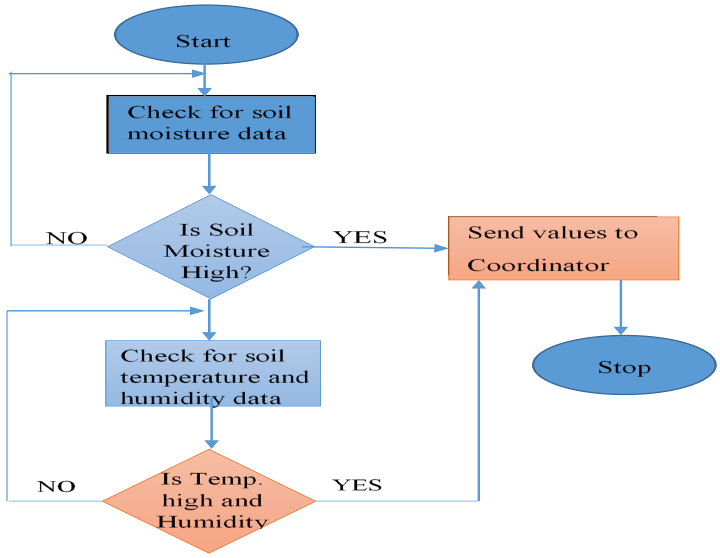

Fig. 2. Operation of the Router Module

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

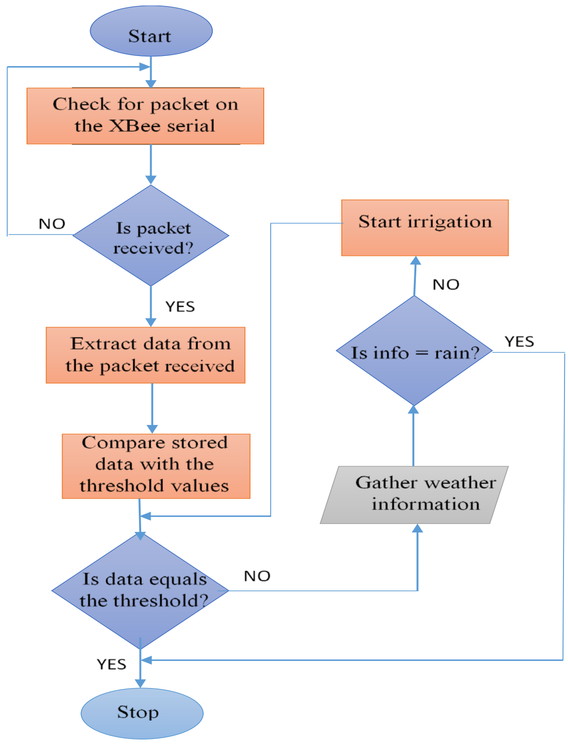

Fig. 3. Operation of the Coordinator Module

3.8 Design and Overview of the System

The system connection is depicted in Figure 1 by a block diagram in which the router module is wirelessly connected to the coordinator node using the ZigBee connection protocol. The entire sensor is connected to one component of the system and wirelessly transmits data to the other portion for decision-making. The purpose of using WSN is to eradicate the problem of wire crowding in the farmland, especially on a large farm. The system overview in Figure 4 shows the physical representation of the system integrated into farmland. The system is networked to form a smart farm where the user can monitor and control the activities going on the farm through the use of the internet. Remote monitoring and management software can also be used to manually turn on and off the water supply. Figure 5 shows the flow of operation that happens within the system. The user has control over the operation of the system. And the system administrator has access to the code controlling the system and inputting the necessary updates.

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

Figure 6 shows the model of the entire system; the model describes the activities involved in each of the three segments of the system. Segment 1 represents the coordinator module which serves as the main brain of the entire system. Segment 2 represents the end node module, where the sensor data is read and transferred to the coordinator module for the necessary action. Segment 3 represents an android mobile platform, where the user can easily monitor and control the event on the field.

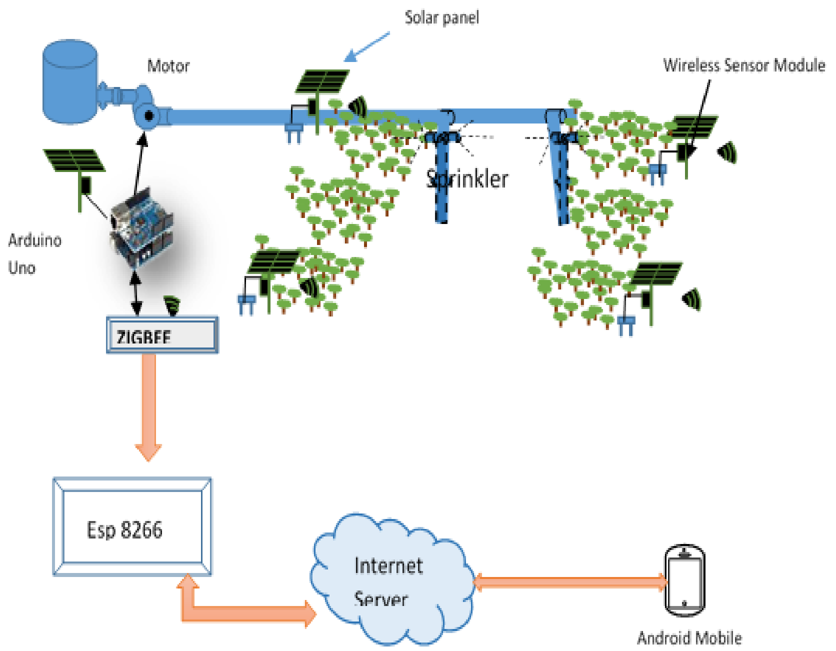

Fig. 4. System Overview

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

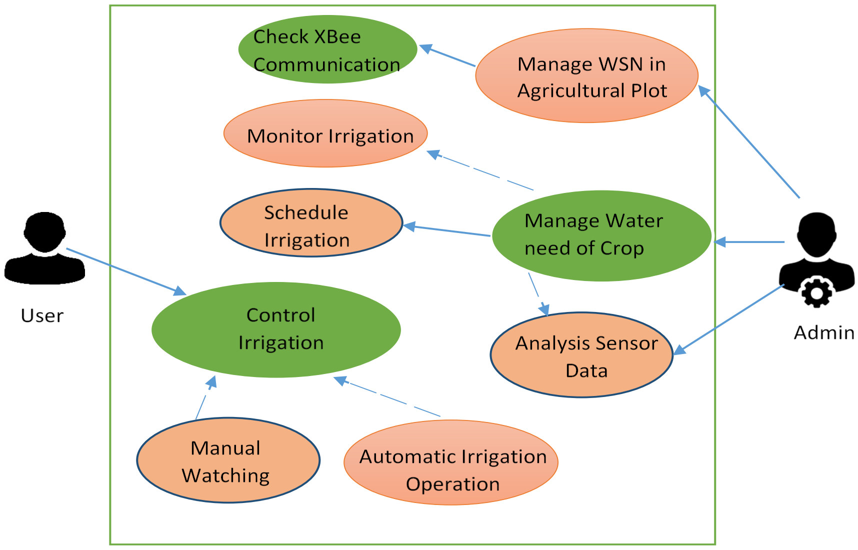

Fig. 5. Use Case Diagram to Show the Operational Process of the System

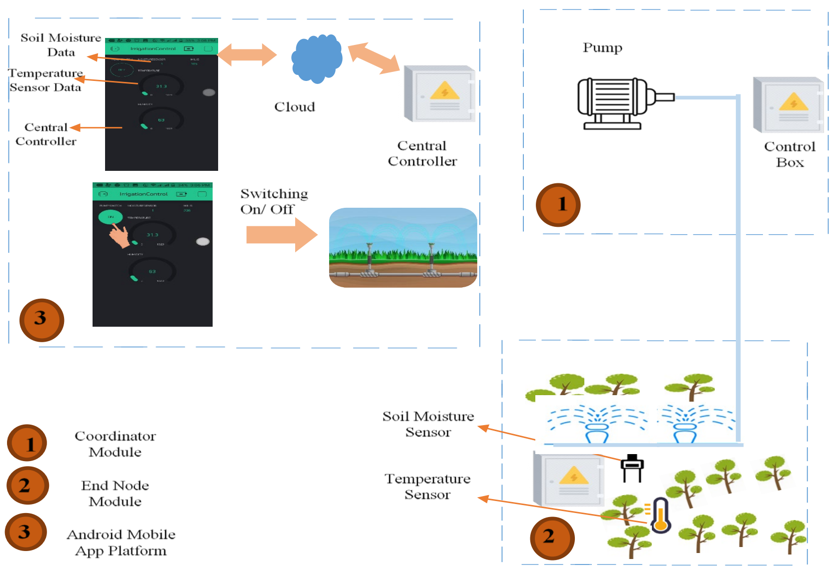

Fig. 6. The Model for the System Setup

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

3.8 Performance Evaluation Metrics

The performance of the system was evaluated based on its Response time and Saturation time of the soil. The response time is used to determine the length of time taken by the system to react to events, commands, and subjection to a change in the input signal. It is necessary to know the amount of water at the right time to increase irrigation efficiency. The saturation time of each type of soil used in the test was determined to see how effective the system is to different soil types [31].

$$T_{response} = T_{think} \tag{10}$$

T_{think} is the thinking time of the system (in seconds).

$$\text{Average Response Time} = \frac{\sum \text{Response Time}}{\text{Total Number of Trials}} \tag{11}$$

Saturation time = Time taken for soil moisture to be at 60% in sec

$$\text{Average saturation Time} = \frac{\sum \text{Saturation Time}}{\text{Total Number of Trials}} \tag{12}$$

4 Result and Discussion

As stated in the methodology, the sensor data collected at the location is communicated via a router module to a coordinator module via a wireless sensor network protocol. The coordinator module will compare this information to a specified value stored in the microcontroller. The esp8266 node MCU is used to make the prediction, and the information obtained is shown in Figure 7. The Android app also shows a live readout of the moisture sensor for remote monitoring and control.

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

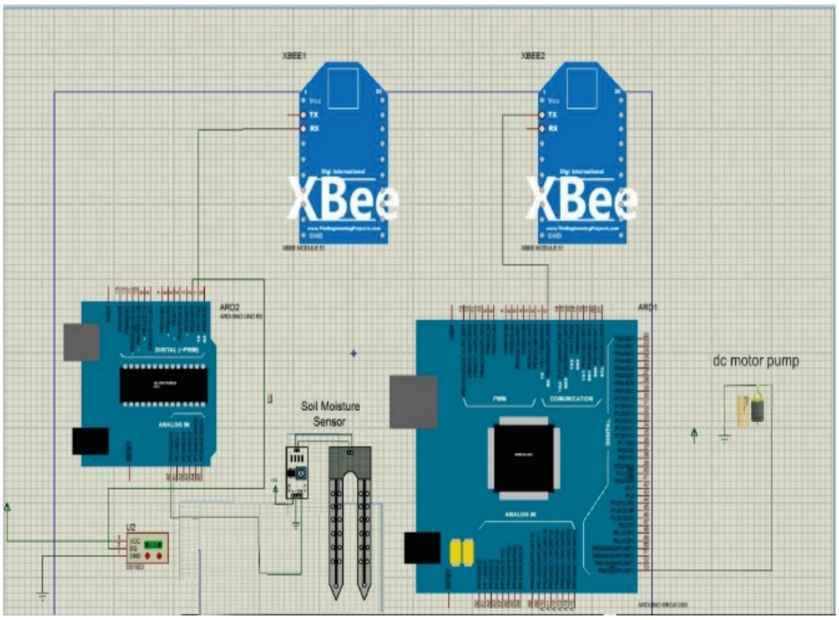

Fig. 7. Simulated Work on Proteus

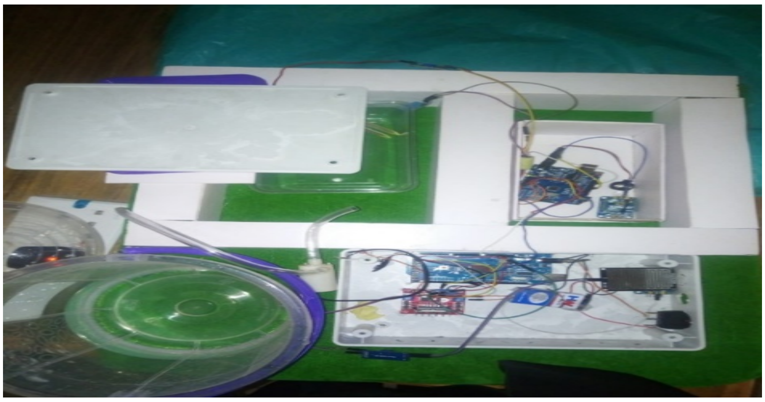
Fig. 8. Working Prototype

Figure 8 depicts a working system prototype. It is also possible to manually turn on and off the water supply using Android software, which can be accessed from anywhere on the planet. Sensor data will be collected and delivered to a microcontroller for processing, as well as to a Wi-Fi module, which will send the data to a web server and allow the user to interact with the data by sending a control signal back to the Wi-Fi module, which will then send the data to the microcontroller. The simulated work on Proteus is shown in Figure 7. Proteus is used to simulate the irrigation system to confirm

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

that it is operating properly. Also, to make the process of connecting the entire system and verifying communication and synchronization between the two modules easier. The benefit of simulating the system before fully implementing it is that you may get a sense of how it will act in real life and ensure that the system will work well for full integration of the subsystems and components.

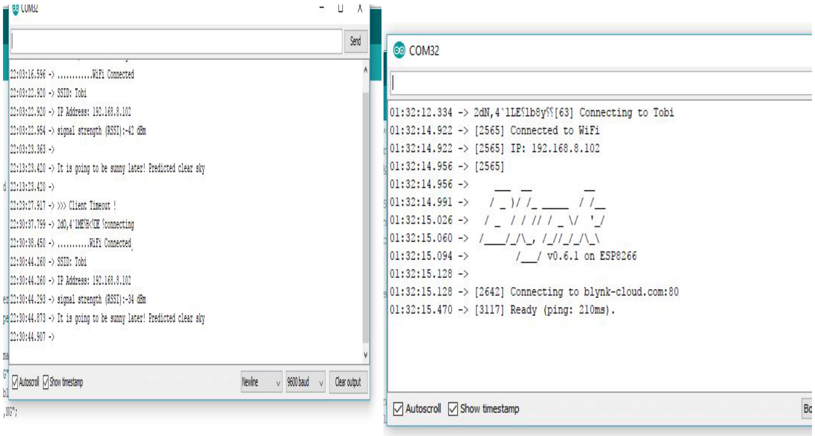

Figure 9 depicts the system's weather information-sourcing at a certain point in time for the system's location, in this case, Minna, Nigeria. The system will behave following the weather information obtained from openweather.org. In the case of the depiction in Figure 9, irrigation will be allowed because there is no likelihood of rain on this specific day. "It's going to rain later!" says the warning. Unless the weather forecast changes, the system will not irrigate on that particular day. This is not ideal for predicting the weather; instead, a locally-based weather station is recommended, but it is fairly costly to set up, whereas the source for broad weather data is the cheapest. The cloud connectivity of the system is depicted in Figure 10. According to the message displayed on the Arduino serial monitor, the esp8266 is connected to the android app powered by blynk. The module is connected to the application and ready to accept data when the system prints (ping: "number in ms"). If the serial monitor does not print anything, restart the system by hard-pressing the RST pin on the esp8266 node MCU. The bylnk is a platform that simplifies the process of connecting a system to the internet and gives it an IoT feel. As a result, the app may now be used to monitor sensor readings.

The application interface is used to display the soil moisture content at a given moment. The temperature and humidity of the soil at a certain point in time are depicted in Figure 11. The ON/OFF switch widget is used to control the system from afar. The

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

farmer will be able to review soil data and, if necessary, alter the system without having to go to the field. The advantage of such an interface is its simplicity, or how easy it is to use, especially for non-experts. The Android application was built for anyone who works in the agricultural industry. The interface is also necessary to connect the sensor to the internet, allowing the farmer or user to examine field data without being physically present. There are various ways to make the user interface easier for the user; another benefit of this development is that the user's interaction with the interface is fluid and straightforward due to the way it is created. The advantage of this innovation over the previous system is that it simplifies complicated ideas for non-specialists, such as a regular farmer, to comprehend through easy user interface interaction, allowing the farmer to administer the system without any complexity. The temperature panel receives the live reading from the same DHT 11 sensors implanted at the plant's root region to monitor the root area's temperature at any given time, while the humidity panel receives the humidity reading from the system's DHT 11 sensors.The soil moisture panel monitors the soil moisture level at a given time, the Millis panel displays the system connection time, and the on/off panel remotely operates the irrigation system. This method has several advantages over the previous strategy, including reduced labor input, efficient water resource management, comprehensive control of farm activities, and effective and efficient administration of the irrigation procedure on the farm.

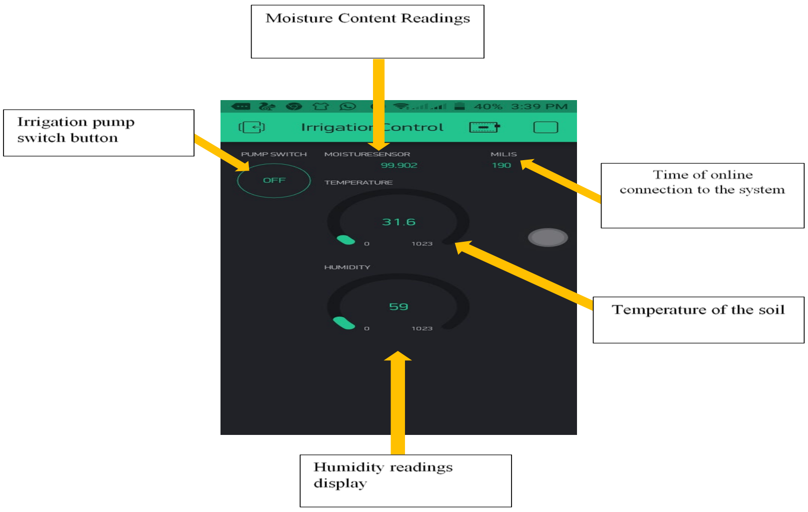

Fig. 11. Label Diagram of the Android App Interface

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

Fig. 12. Android Interface Readings Taken at Different Interface

The Android app User interface is depicted in Figure 12 at various readings taken at various intervals. This is to show how the app uses the internet to communicate with the system. The app widgets update themselves to reflect the real-time sensor data as the system's sensor reading parameters change. Every second, this page is refreshed. As seen in Figure 12, the displayed value is updated every zone second, as previously indicated. The user can also manually turn on/off the system using this panel if necessary. This function has been implemented to provide the user with a sense of control over what is happening at the farm. Assume that the farmer or users desire to irrigate land using a unique irrigation method and timetable. In that situation, the manual on/off switch will, of course, come in handy. Figure 13 depicts the system's response time or the amount of time it takes for the system to respond when it is operated over the internet over the Glo 4G network. It displays the number of tries with a 4G network response time equivalent. This facilitates the operation of the system and the integration of smartness, promoting the usage of IoT in agriculture. The system provides other benefits in addition to the ones already discussed. The system offers the impression that the farmer or farm user has complete control over the technology. The signal analyzes the sensor readings and sends them to the Blynk app via Wi-Fi for remote monitoring and control through the 4G network, which is fast and reliable for this type of operation.

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

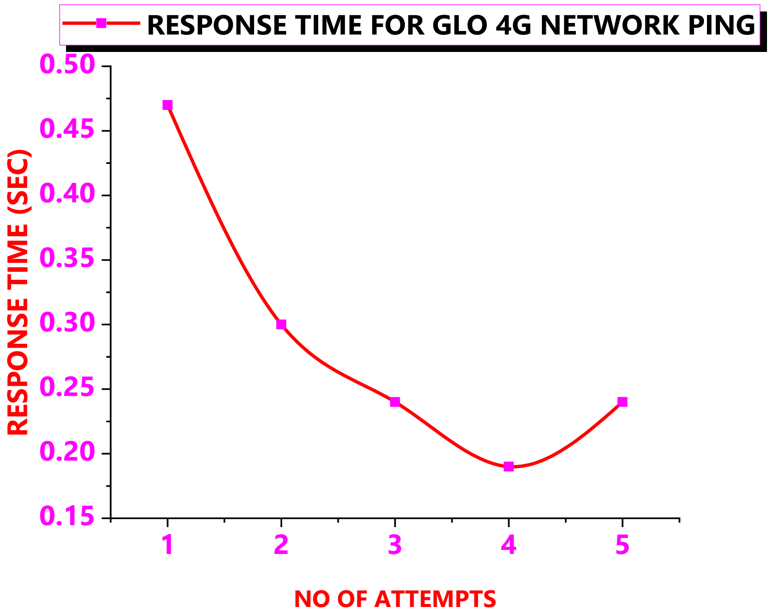

Fig. 13. The Response Time of the System using 4G Network

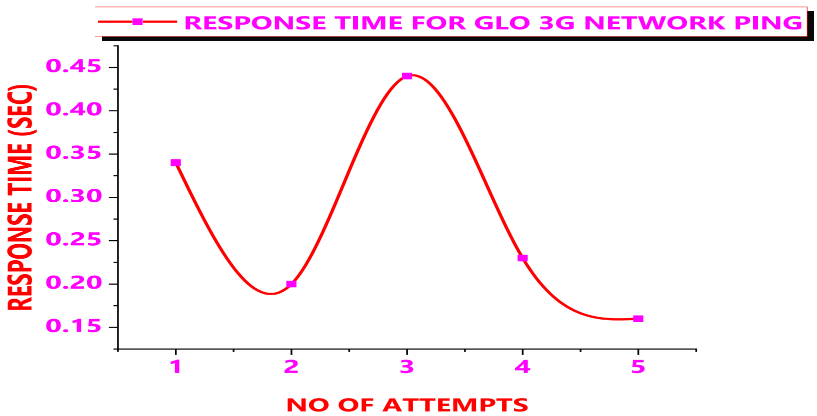

Fig. 14. Response Time of the System Using 3G Network

Figure 14 depicts the system's response time in five different attempts when using the 3G Glo service option. When studying and testing the system, the reaction time is critical. It determines the system's efficiency and effectiveness in responding to control

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

and data flow changes. The 3G outcome is comparable to the 4G result. Both are, without a doubt, excellent services. These tests are performed to guarantee that the system is reliable under various service scenarios. Human error and a minor service lag are to blame for the variations in response time. The system is projected to produce the results of easy operation, reduced labor, minimal water waste, and efficient irrigation management based on the results of this test. Figure 15 depicts the application's response time when using a 2G network service. Five such attempts were performed, and the system's response time was measured accordingly. The quickest response time was 0.34 seconds, and the slowest was 0.75 seconds. This is the amount of time it takes the system to respond to each event that occurs in the application interface at any given time. When viewed through the eyes of a person, this may go unnoticed. Even though the reaction time on the 2G network is not up to 1 second, it is still fast when compared to the other network types employed. A response time of less than 1 second for all three network service types suggests that the system is efficient and effective. Figure 16 depicts the system's response time after five distinct trials using three different Glo network configurations. The reaction time on the 4G network was the fastest, while the response time on the 2G network was the slowest, implying that the 2G network has a longer delay. Despite this, the fastest response time is less than a second. As a result, the system is long-lasting in terms of speed. Irrigation becomes more precise, simple, and stress-free. This irrigation concept might be applied to large-scale farming in Nigeria, boosting the country's agricultural economy to the next level. The technology is expected to provide low-cost maintenance, ease of operation, reduced complexity, and efficient irrigation management in farming.

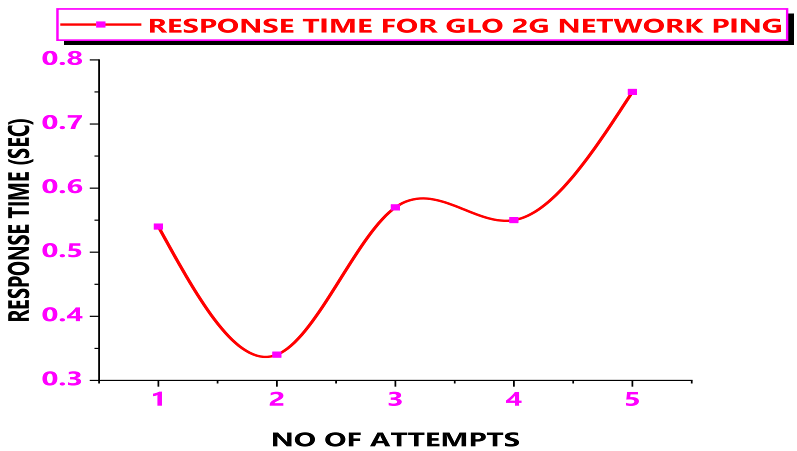

Fig. 15. The Response Time of the System using 2G Network

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

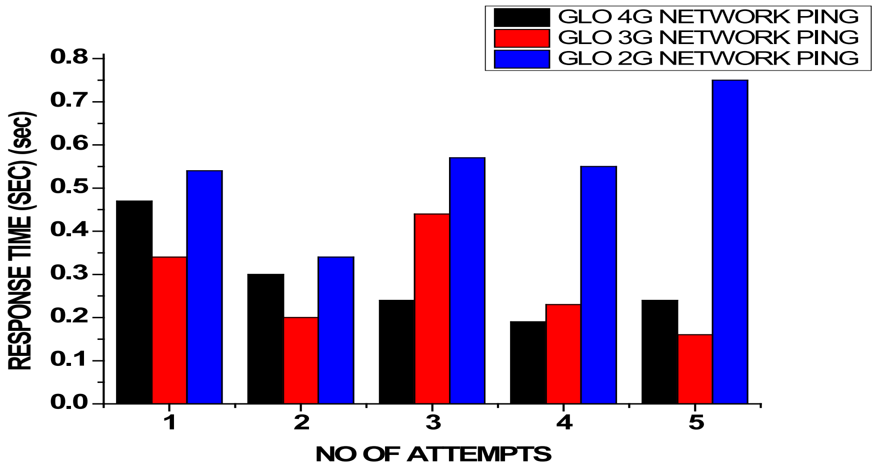

Fig. 16. The Response Time of the System using 2G, 3G and 4G Network

Different readings on the three soil types were taken in an inquiry to evaluate the system's performance. Figure 17 shows ten readings for sandy, ten for loamy, and ten for clayey soils, in that order. It should be noted that the clayey soil takes longer to reach saturation than the other soil types. It takes longer to saturate the soil due to its qualities, which allow it to absorb more water due to the proximity of the soil particle pack.It is also worth noting that, due to the absorbing rate of sandy soil, the sandy soil saturation period is short in comparison to others. A range of soil types, including sandy, loamy, and clayey, were used to evaluate the automated approach. The fastest average response time was 0.8 seconds, which was less than one second. As a result, the system is effective in terms of response time. According to the saturation calculation, sandy soil has a lower water retention capacity than loamy and clayey soil. The soil moisture content is maintained at 60% to obtain the water applied to the soil in cubic millimeters. The test is carried out using a manual irrigation approach, but the results reveal that the improved method is more efficient.

ISSN 2709-4529

Table 1. Soil Moisture content, water applied to Loamy soil, sandy soil, and clayey soil, Saturation time, and Response Time (sec)

S/N	Moisture Content %	Water Applied mm^3	Saturation time (sec)	Response Time (sec)
Sandy soil				
1	3	500	8.00	0.67
2	6	474	5.50	0.70
3	9	448	4.72	0.80
4	12	422	4.42	0.75
5	15	396	4.34	0.69
6	18	370	4.12	0.78
7	21	344	3.00	0.70
8	24	318	3.22	0.72
9	27	292	3.45	0.76
10	30	266	2.52	0.82
Loamy soil				
1	8	450	6.00	0.99
2	16	391	4.70	0.76
3	24	318	4.02	0.80
4	32	253	3.00	0.84
5	36	252	3.20	0.76
6	39	250	3.42	0.80
7	40	175	3.56	0.78
8	48	110	1.70	0.81
9	56	45	1.00	0.78
10	57	32	0.9	0.78
Clay soil				
1	16	383	7.6	0.74
2	32	253	6.5	0.82
3	36	250	6.3	0.72
4	39	248	6.1	0.78
5	42	178	6.0	0.79
6	45	102	5.5	0.77
7	48	110	5.0	0.75
8	51	100	4.8	0.76
9	54	80	4.7	0.75

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

10	57	40	4.5	0.81

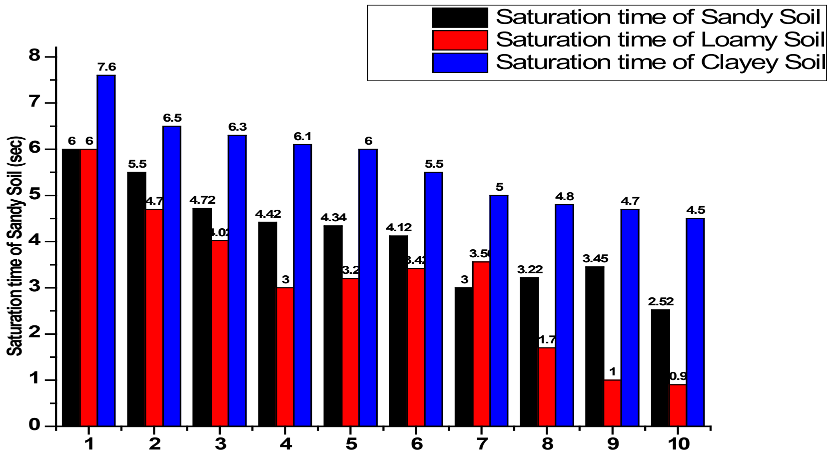

Fig. 17. Graph showing the comparison between various types of soil.

Average response time for loamy Soil = $\frac{0.67+0.70+0.80}{3}$ = 0.72sec; average saturation time for loamy soil = $\frac{8.00+5.50+4.72}{3}$ = 6.073sec; while average response time for sandy soil = $\frac{0.99+0.76+0.80}{3}$ = 0.85sec; average saturation time for sandy soil = $\frac{6.00+4.70+4.02}{3}$ = 4.906sec; and average response time for Clay soil = $\frac{0.74+0.82+0.75}{3}$ = 0.77sec; average saturation time for Clay soil = $\frac{7.6+6.5+5.0}{3}$ = 6.366 sec.

The many integrated units carry out their tasks following the set goals. Water is discharged to the soil according to the need at the time. Because the voltage recorded in a dry condition surpassed 3 volts, corresponding to a 3 percent soil moisture level, the soil is watered until the voltage detected in a moist state is 1 volt, corresponding to a soil moisture level of less than 60%. This is used to determine the amount of watering required. The graph displays the distinctions and comparisons between the various soil types. There is a certain sort of plantation that should or can be cultivated on each soil. Therefore, the soil for a particular plantation is chosen based on the specifications or requirements of the plant that would grow best on it. As illustrated in Figure 12, the value presented is refreshed every one second, as indicated previously. The user can also utilize this panel to manually turn on/off the system if necessary. This project's irrigation approach can be applied to large-scale farming, bringing Nigeria's agricultural sector to the next level. The technology is expected to provide low-cost maintenance, ease of operation, reduced complexity, and efficient irrigation management in farming.

5 Conclusion

One of the backbones of agricultural technology has been the automated irrigation system. Many techniques of providing water to fields were developed over time. IoTs have been used to increase agricultural yields, improve quality, and lower expenses in agriculture. This research proposed an Arduino-based smart irrigation system using a wireless sensor network to overcome the problem of overwatering, underwatering, and efficient time utilization in farming. This system is implemented and evaluated using Arduino IDE, Proteus Simulation Tools, and the Blynk Platform. The effect of the four-mobile network: MTN, GLO, Airtel, and 9mobile on response time for Gidan- Kwano area was evaluated. Testing carried out on the system resulted in a response time of 0.75 seconds for the Glo 2G network and 0.45 seconds for the Glo 4G network. Less than 1sec in the worst-case scenario. Compared with the already existing irrigation systems, this system design emerged to be simple to use by the farmer, smart, efficient in terms of portability, and affordable compared with other systems. Also, the appropriate soil moisture content is maintained, whether it rains or not. This reduces excesses and ensures healthy plant growth, increasing agricultural productivity, and cultivating crops are made possible throughout the year. The system will also help power and drive agricultural innovation through the use of IoT.

6 References

[1] Y. Shekhar, E. Dagur, S. Mishra, R. J. Tom, M. Veeramanikandan, and S. Sankaranarayanan, "Intelligent IoT based automated irrigation system," *Int. J. Appl. Eng. Res.*, vol. 12, no. 18, pp. 7306–7320, 2017.

[2] A. Nasiakou, M. Vavalis, and D. Zimeris, "Smart energy for smart irrigation," *Comput. Electron. Agric.*, vol. 129, pp. 74–83, 2016, DOI: 10.1016/j.compag.2016.09.008.

[3] R. Koech and P. Langlat, "Improving irrigation water use efficiency: A review of advances, challenges and opportunities in the Australian context," *mdpi.com*, 2018, Accessed: Sep. 08, 2021.

[4] A. Muhammad, B. Haider, and Z. Ahmad, "IoT Enabled Analysis of Irrigation Rosters in the Indus Basin Irrigation System," *Procedia Eng.*, vol. 154, pp. 229–235, 2016, DOI: 10.1016/j.proeng.2016.07.457.

[5] M. S. Munir, I. S. Bajwa, M. A. Naeem, and B. Ramzan, "Design and implementation of an

IoT system for smart energy consumption and smart irrigation in tunnel farming," *Energies*, vol. 11, no. 12, 2018, DOI: 10.3390/en11123427.

[6] H. Navarro-Hellín, J. Martínez-del-Rincon, R. Domingo-Miguel, F. Soto-Valles, and R. Torres-Sánchez, "A decision support system for managing irrigation in agriculture," *Comput. Electron. Agric.*, vol. 124, pp. 121–131, 2016, doi: 10.1016/j.compag.2016.04.003.

[7] H. Biabi, S. Abdanan Mehdizadeh, and M. Salehi Salmi, "Design and implementation of a smart system for water management of lilium flower using image processing," *Comput. Electron. Agric.*, vol. 160, pp. 131–143, 2019, DOI: 10.1016/j.compag.2019.03.019.

[8] N. K. Nawandar and V. R. Satpute, "IoT based low cost and intelligent module for smart irrigation system," *Comput. Electron. Agric.*, vol. 162, pp. 979–990, 2019, DOI: 10.1016/j.compag.2019.05.027.

[9] D. Kandris, C. Nakas, D. Vomvas, and G. Koulouras, "Applications of wireless sensor networks: An up-to-date survey," *Appl. Syst. Innov.*, vol. 3, no. 1, pp. 1–24, 2020, DOI: 10.3390/asi3010014.

[10] S. R. Jondhale, R. Maheswar, and J. Lloret, "Fundamentals of Wireless Sensor Networks," *EAI/Springer Innov. Commun. Comput.*, pp. 1–19, 2022, DOI: 10.1007/978-3-030-74061-0_1.

[11] R. Priyadarshi, B. Gupta, and A. Anurag, "Wireless Sensor Networks Deployment: A Result Oriented Analysis," *Wirel. Pers. Commun.*, vol. 113, no. 2, pp. 843–866, 2020, DOI: 10.1007/s11277-020-07255-9.

[12] R. Kashyap, *Applications of Wireless Sensor Networks in Healthcare*. 2019.

[13] H. Landaluce, L. Arjona, A. Perallos, F. Falcone, I. Angulo, and F. Muralter, "A review of iot sensing applications and challenges using RFID and wireless sensor networks," *Sensors (Switzerland)*, vol. 20, no. 9, pp. 1–18, 2020, DOI: 10.3390/s20092495.

[14] L. Hamami and B. Nassereddine, "Towards a smart irrigation system based on wireless sensor networks (WSNs)," *Proc. 1st Int. Conf. Comput. Sci. Renew. Energies, ICCSRE 2018*, no. Iccsre 2018, pp. 433–442, 2018, DOI: 10.5220/0009776004330442.

[15] N. M. Tiglao, M. Alipio, J. V. Balanay, E. Saldivar, and J. L. Tiston, "Agrinex: A low-cost wireless mesh-based smart irrigation system," *Meas. J. Int. Meas. Confed.*, vol. 161, p. 107874, 2020, DOI: 10.1016/j.measurement.2020.107874.

[16] C. J. H. Pornillos *et al.*, "Smart Irrigation Control System Using Wireless Sensor Network Via Internet-of-Things," *2020 IEEE 12th Int. Conf. Humanoid, Nanotechnology, Inf. Technol. Commun. Control. Environ. Manag. HNICEM 2020*, 2020, DOI: 10.1109/HNICEM51456.2020.9399995.

[17] Meeradevi, M. A. Supreetha, M. R. Mundada, and J. N. Pooja, "Design of a smart water-saving irrigation system for agriculture based on a wireless sensor network for better crop yield," *Lect. Notes Electr. Eng.*, vol. 500, pp. 93–104, 2019, DOI: 10.1007/978-981-13-0212-1_11.

[18] A. C. Bartlett, A. A. Andales, M. Arabi, and T. A. Bauder, "A smartphone app to extend use of a cloud-based irrigation scheduling tool," *Comput. Electron. Agric.*, vol. 111, pp. 127–130, 2015, DOI: 10.1016/j.compag.2014.12.021.

[19] K. Chartzoulakis and M. Bertaki, "Sustainable Water Management in Agriculture under Climate Change," *Agric. Agric. Sci. Procedia*, vol. 4, pp. 88–98, 2015, doi:

10.1016/j.aaspro.2015.03.011.

[20] R. B. Venkatapur and S. Nikitha, "Review on Closed Loop Automated Irrigation System," *The Asian Review of Civil Engineering*, 2017. www.trp.org.in (accessed Sep. 08, 2021).

[21] A. Susmitha, T. Alakananda, M. L. Apoorva, and T. K. Ramesh, "Automated Irrigation System using Weather Prediction for Efficient Usage of Water Resources," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 225, no. 1, 2017, DOI: 10.1088/1757-899X/225/1/012232.

[22] L. Kamelia, M. A. Ramdhani, A. Faroqi, and V. Rifadiapriyana, "Implementation of Automation System for Humidity Monitoring and Irrigation System," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 288, no. 1, 2018, DOI: 10.1088/1757-899X/288/1/012092.

[23] A. Rajendran, S. Ezhilnirai Kavinila, J. Harini, and V. O. Sangeethaa, "Automatic irrigation on sensing soil moisture content," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 6, pp. 798–803, 2019, Accessed: Sep. 08, 2021. [Online]. Available: https://www.academia.edu/download/54646882/IRJET-V3I340.pdf.

[24] J. Patel, E. Patel, and P. Pati, "Sensor and Cloud-Based Smart Irrigation System With Arduino: a Technical Review," *Int. J. Eng. Appl. Sci. Technol.*, vol. 03, no. 11, pp. 25–29, 2019, DOI: 10.33564/ijeast.2019.v03i11.005.

[25] V. Vinoth Kumar, R. Ramasamy, S. Janarthanan, and M. VasimBabu, "Implementation of iot in smart irrigation system using arduino processor," *Int. J. Civ. Eng. Technol.*, vol. 8, no. 10, pp. 1304–1314, 2017.

[26] A. Chitransh, A. Sagar, and A. Kumar, "Automated Solar Powered Irrigation System A Technical Review," *Int. Res. J. Eng. Technol.*, pp. 3–5, 2016, Accessed: Sep. 08, 2021.

[27] O. BingöL, Burcin Özkaya, and M. Bayram, "Wireless Sensor Network Based Remote Drip Irrigation System," *J. Eng. Sci. Des.*, vol. 6, no. 4, 2018.

[28] A. A. Felix and O. H. E, "Design and implementation of an automatic irrigation system based on monitoring soil moisture," *Electr. Inf. Eng. Dep. Covenant Univ. Niger.*, no. April 2017, pp. 540–544, 2016, DOI: 10.1109/ICICI.2017.8365190.

[29] S. Adamala, "Traditional to Smart Irrigation methods in India," *Am. J. Agric. Res.*, vol. 1, no. 1, p. 1, 2016, doi: 10.28933/AJAR-08-1002.

[30] J. Kumar, S. Mishra, A. Hansdah, and R. Mahato, "Design of Automated Irrigation System based on Field Sensing and Forecasting," *Int. J. Comput. Appl.*, vol. 146, no. 15, pp. 975–8887, 2016, DOI: 10.5120/ijca2016910938.

[31] M. Gupta, P. Srivastava, and T. Islam, "Integrative use of near-surface satellite soil moisture and precipitation for estimation of improved irrigation scheduling parameters," in *Satellite Soil Moisture Retrieval*: Elsevier, 2016, pp. 271-288.

[32] J. Gutierrez, J. F. Villa-Medina, A. Nieto-Garibay, and M. A. Porta-Gandara, "Automated irrigation system using a wireless sensor network and GPRS module," *IEEE Trans. Instrum. Meas.*, vol. 63, no. 1, pp. 166–176, 2014, DOI: 10.1109/TIM.2013.2276487.

Journal of Digital Food, Energy & Water Systems, 2 (2): 121-147, 2021
ISSN 2709-4529

7 Author

Engr. Buhari Ugbede Umar is a Lecturer in the Department of Computer Engineering, Federal University of Technology, Minna, Niger State, Nigeria. He obtained his B.Eng. in 2008 and M. Eng in 2015 in Electrical and Computer Engineering and Computer Engineering respectively. He is currently a PhD student at the Department of Computer Engineering, Federal University of Technology, Minna, Niger State, Nigeria. He has published in reputable journals and learned conferences. His areas of research include Information and Computer security, Intelligent systems, Embedded systems, Digital System Design, Biomedical Signal Processing, Artificial Intelligence and Image Processing.

Eustace Dogo holds a PhD degree from the Department of Electrical and Electronic Engineering Science, University of Johannesburg, South Africa. He obtained both BSc and MEng degrees in Electrical Engineering from Saint Petersburg State Technical University, Russia. He lectures at the Department of Computer Engineering, Federal University of Technology Minna, Nigeria. His research interest is in theoretical and applied Machine Learning, Artificial Intelligence, IoT and Cloud Computing.

Nuhu Bello Kontagora is a Lecturer II in the Department of Computer Engineering at the Federal University of Technology, Minna, Niger State, Nigeria. He obtained his B.Eng. in Electrical/Computer Engineering from the Federal University of Technology, Minna and MTech. in Computer Science from the Ladoke Akintola University of Technology, Ogbomosho, Oyo State, Nigeria. He is a third-year PhD student of Computer Engineering at Ahmadu Bello University, Zaria, Nigeria. He has published in reputable journals and learned conferences. His areas of research include Computer and information security, intelligent/embedded systems, Wireless and computer networks, Internet of things. He can be reached at nuhubk@futinna.edu.ng.

Engr Arifa Khatoon Haq is pursuing her PhD study in the field of Computer engineering at the Federal University of Technology, Minna in Nigeria. She has a master in Computer Engineering. Her research interest includes Data management, Computer Network Security, Bio-Inspired algorithm and Combinatorial Optimization in Engineering.

Paul Tobi Olaleye received his B.Eng. in 2020 from the Computer Engineering Department, Federal University of Technology, Minna. His research interests are in Blockchain, Data management and Computer Network Security.