A Self-Powered, Real-Time, NRF24L01 IoT Based-Cloud Enabled Service For Smart Agriculture Decision-Making System

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Research Article

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A Self-Powered, Real-Time, NRF24L01 IoT Based-Cloud Enabled Service for Smart Agriculture Decision-Making System

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Abstract:

Internet of Things (IoT) based automation has provided sophisticated research and developments in the field of agriculture. In agriculture field production, using environmental and deployment sensors like DHT11, soil moisture, soil temperature, and so on, IoT has been utilised to monitor field conditions and automation in precision agriculture. The environmental parameters, field evaluation, deployment parameters, and shortage of water has become an unresolved task for agriculture monitoring. All of this leads to insufficient production of the agricultural crop. To eradicate the above-mentioned problems, we proposed a system in the using an architectural manner. This system uses an NRF24L01 module with in-built power and low noise amplifiers to enable a long-distance communication for transmission of the field information about the current crop situation to the farmers. This work is investigating an appropriate, reasonable, and applied IoT technology for precision agriculture by considering various applications of agriculture and experiments. The proposed system reduces power consumption, and improves operational efficiency. The proposed system reduces human efforts and also evaluates heat index measurement to monitor the environment. Based on the experiments, the current consumption and life expectancy of the AWMU are determined to be 0.02819 A and 3 days 20 hours 13 minutes and 47 seconds, respectively. Furthermore, the maximum transmission of AWMU is in an environmental location is 200 meters line of sight from the router.

Keywords: Internet of Things, ThingSpeak cloud platform, NRF24L01 modules, Sensors, Actuators, Agriculture applications

1. Introduction

In recent years, the Internet of Things (IoT) and Wireless Sensor Networks (WSN) have become increasingly essential [1] in agriculture. IoT is having abundant applications like agriculture, healthcare, smart cities, commerce, home automation, education, and the environment. These applications [2] are developed by the IoT sensor cloud-enabled, edge computing, cloud computing, and WSN.

Agriculture and soil monitoring is based on environment and soil parameters. These have come from animal health, crop health, plant health, soil health, soil ecosystem, climate balance, and human health. We came to know about animal health by tracking movement. For proper irrigation, there should be nutrients, fertilizers, and water requirements that lead to better crop health, soil health, and plant [3] health. Weather assessment comes under the climate balance and the soil ecosystem is associated with soil fertility and quality. Human health also plays a major role in the agriculture workplace as shown in Fig. 1.

A. Smart Agriculture Monitoring (SAM)

IoT can provide automation in agriculture monitoring systems with help of sensors, actuators embedded hardware platforms, and cloud-enabled technologies like big data and cloud computing. Generally, the IoT role in agriculture has been transformed [4] to different domains such as water and soil management, crop monitoring, etc. WSN also enables automation in the field of agriculture with energy harvested [5] nodes, hardware cost-effectiveness, and scalability.

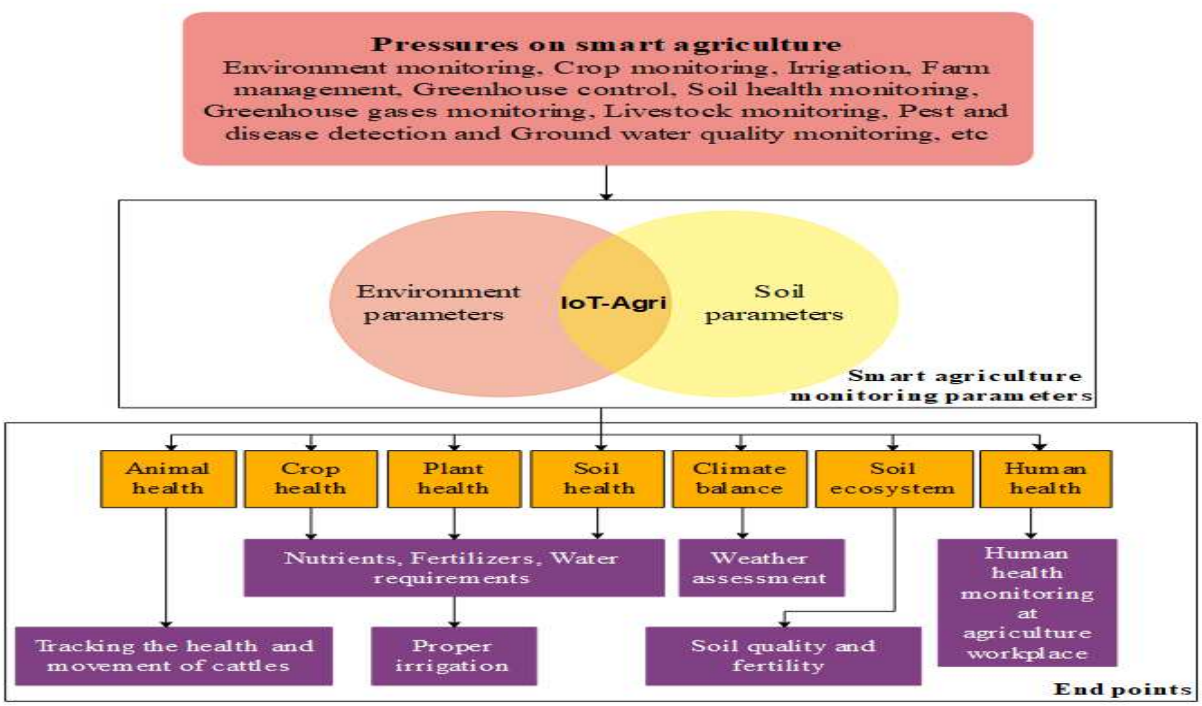

Fig. 1 Overview of the smart agriculture parameters

B. Remote Monitoring Systems using IoT

The Internet of Things (IoT) is a promising approach for remote monitoring and interconnectivity of the proposed system in this scenario, thanks to communication protocols, an open-source cloud platform for experiment results based on Application Programming Interface (API), visualization dashboards, and [6] web development tools.

2. Related Work

Emerging technologies are playing a crucial role in smart agricultural monitoring systems, precision agriculture, and smart irrigation with complete automation and design implementations in the current scenario. Some of the existing works are discussed below.

Nestor Michael Tiglao et al. [7] proposed an Agrinex system, which is used for smart irrigation with a low-cost design and has a mesh-based topology framework. It consists of hardware like RF module (NRF24L01), sensors (Temperature and Humidity, soil moisture), actuator (servo motor), and embedded boards (Arduino and raspberry pi). Sensor's data processed and transmitted through the ATMEGA328P microcontroller and then via a gateway (sink node) to the server or cloud with the help of internet connectivity. The user can able to access the sensor data from the cloud and also developed a web application for remote accessing and visualizing the sensor data in online mode.

Raul Morais et al. [8] explained the mySense concept which means that data handling of environment for developing the agriculture practices. In this article, four-layered architecture shows the systematic data collection towards the precision agriculture issues is discussed. This architecture is made of four important components such as input components (sensors) and input components (actuators), gateway (Arduino Uno, Raspberry pi) and wireless sensor network, web and cloud services, and applications of end-user. It enables the hardware platforms with cost-effective design end products to monitor the agriculture applications.

Uélison Jean L. dos Santos et al. [9] represented the agriculture prediction model which gives insight on anticipate problems and improves the production of crops. This model has three major components like LoRa module, the Time series model, and ARIMA predictive model. With the help of this model, to eradicate the crop defects and notifications are sent to the farmers regarding their filed information. In this model, sensors data acquisition with time series to provide accurate results in agriculture production to the farmers.

Shadi AlZu’bi et al. [10] proposed an internet of multimedia things in smart agriculture applications. This article, mainly focussed on smart farming for the optimized process of irrigation. Internet of multimedia things having three important components like image processing, IoT sensors, and machine learning techniques, these techniques are used in the decision-making system for proposed irrigation. In this project deep learning is also state of the art for achieving the optimal decision-making smart irrigation system.

Khalid Haseeb et al. [11] demonstrated an IoT and WSN based energy efficient framework for smart agriculture applications. In this paper, IoT and WSN are used to perceive the crop conditions and precision agriculture automation by using different IoT sensors and these IoT sensors deployed in the field of agriculture. To improve crop yield production over the smart farming decision-making system and acquire sensor data about the crops and plant. This proposed system concentrated on few important metrics like communication range, SNR, system throughput, power consumption, and packet drop ratio.

Sanjeevi et al. [12] focussed on smart farming and agriculture monitoring using cloud computing, the Internet of Things, and wireless sensor network. In this article, the proposed methodology gives insight into network efficiency, low latency, high SNR, MSE, and more coverage area. Based on the sensor data, the receiver module has performed the action regarding motor on/off operations for proper water usage to agriculture monitoring. Different types of sensors and other components have been used in the hardware implementations for the smart agriculture monitoring system.

Table 1 shows the IoT and WSN based smart agriculture monitoring systems with various wireless communication technologies and different metrics considered. These systems ensure cost-effectiveness, high flexibility, and fast deployment based on mesh topology configuration in the agriculture field. Most of the existing systems are used Wi-Fi and ZigBee technologies for transmitting the sensor data of the agriculture field to the farmer.

Table 1 Shows the IoT and WSN based smart agriculture monitoring systems with the proposed system

Ref. & Year	**Soil parameters**	**Environment parameters**	**Wireless technology**	**Topology based**	**Type of network**	**Energy harvesting**	**Data Storage**	**Data Visualization**
[13], 2010	No	Temperature, Humidity	RFID	No	WPAN	No	Yes	No
[14], 2011	No	Temperature, Humidity	GPRS	No	WLAN	No	Yes	No
[15], 2012	Temperature, Moisture, EC	No	6LoWPAN	Mesh	WPAN	No	Yes	No
[16], 2013	No	Temperature	GPRS	Star	WLAN	No	Yes	No
[17], 2014	Moisture	Temperature, Humidity	ZigBee	Star or Mesh	WLAN	No	No	No

[18], 2 015	CO_2	No	ZigBee	No	WLAN	No	Yes	No
[19], 2016	pH level, Electric Conductivity (EC)	Atmospheric temperature, Humidity, Luminance	Wi-Fi	No	WLAN	No	Yes	Yes
[20], 2017	Soil temperature	Temperature, Humidity, Pressure, Wind Speed, Leaf wetness	Wi-Fi	No	WLAN	Yes	No	Yes
[21], 2018	Soil moisture	Temperature, Humidity	LoRa	No	WWAN	Yes	No	Yes
[22], 2019	Soil Moisture	Air temperature, Air humidity	Wi-Fi	No	WLAN	No	No	Yes
[23], 2020	Temperature, Humidity	Air temperature, Air humidity	LoRaWAN	Star	WWAN	No	Yes	Yes
Proposed system	Soil temperature, Soil moisture	Air temperature, Air humidity	NRF24L01	Mesh	WLAN	Yes	Yes	Yes

A. Overview of wireless communication technologies

In many of the applications, wireless communication technologies have been used. Based on the transmission distance the wireless technologies are divided into 3 categories. They are short-range communication [24] for the distance of <10m, medium-range communication for the distance of 10m to 100m, and long-range communication for the distance of distance >100m. The short-range communication includes Radio-frequency identification, Bluetooth, ultra-wideband, and so on. Wi-Fi and ZigBee are used for medium-range communication [25] technology. In long-range communication, cellular networks are used. Additionally, the cellular networks like 2G/3G/4G, LPWA is new technology and is used in many applications as shown in Fig. 2. The LPWA features include low power consumption, low data rate, large coverage area, etc. LPWA technology cannot be used for audio/video streaming due to its low data rate. This technology is suitable in situations where there is a need to transmit the distance over more distances with smaller data rates. The LPWA offers a more than 15km communication range with a power consumption of 100mW.

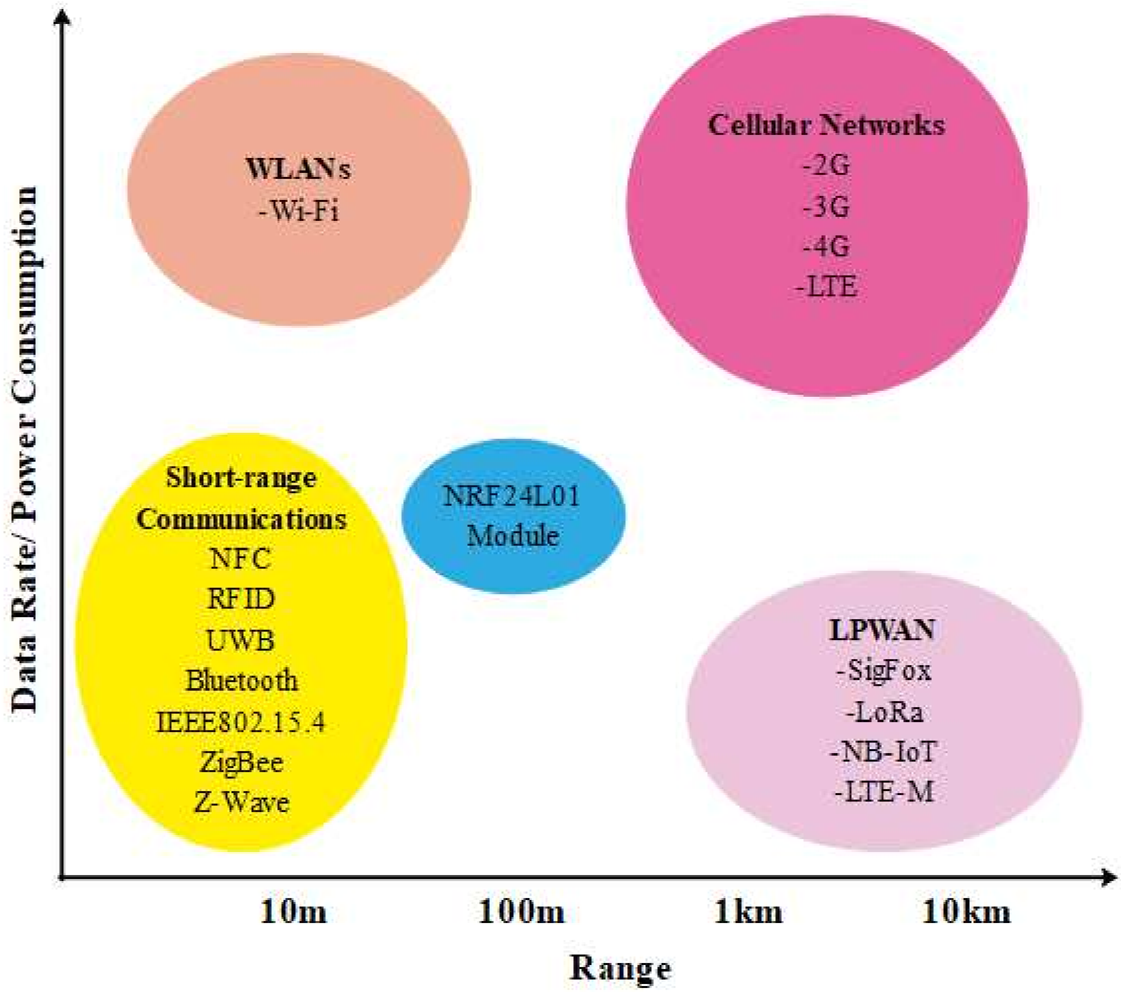

Fig. 2 Various wireless communication technologies for range and data rate comparisons

B. Sensor Node Architecture (SNA)

Sensor Node Architecture (SNA) consists of four [26] units such as a transmission unit, a sensing unit, a processing unit, and a power source as shown in Fig. 3.

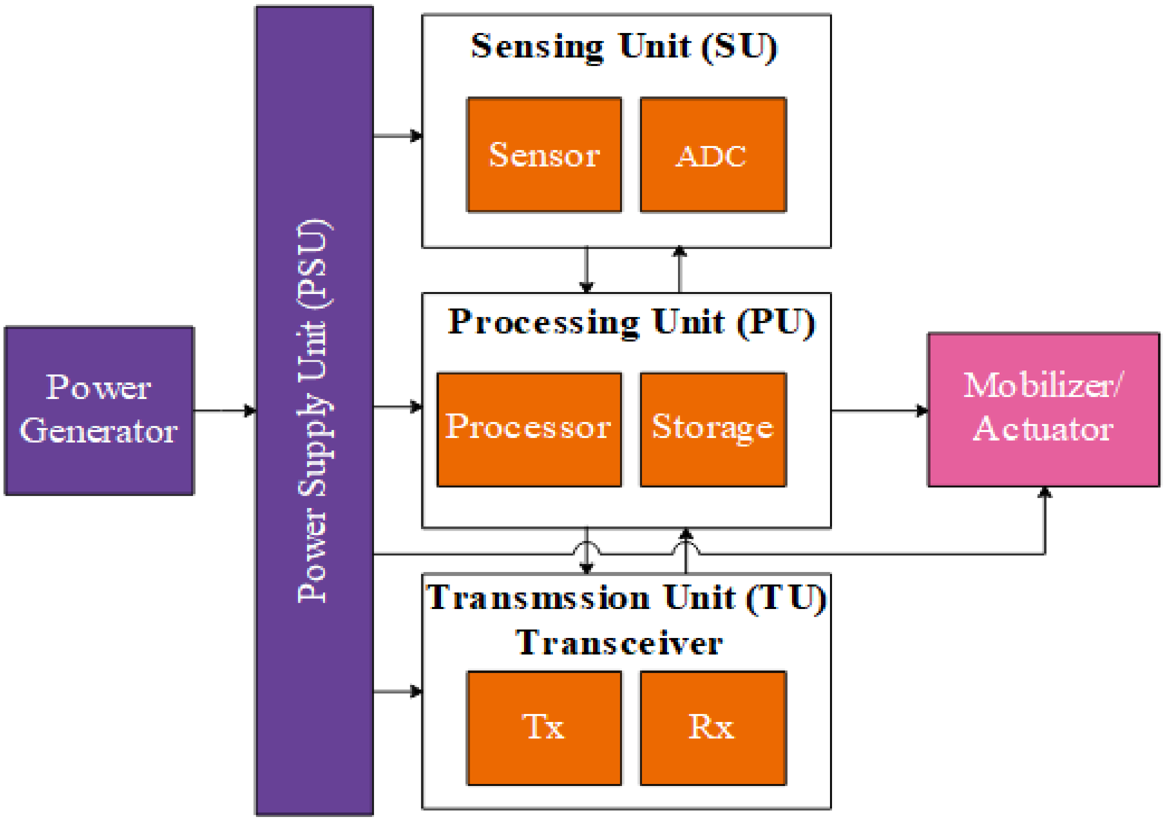

Fig. 3 Sensor node architecture

- **Sensing Unit (SU)**

It is the most important element of a sensor node. It consists of two sub-units, they are:

a) A sensor: It is a device that responds to a physical stimulus and transmits a resulting impulse.

b) An analog-to-digital converter (ADC): It is a system that converts an analog signal into a digital signal.

- **Power Unit (PU)**

It is an important element of the sensor node, which supplies the power to all the node components.

- **Power Generator**

It is a device that is capable of generating energy.

- **Processing Unit (PU)**

It enables to perform certain tasks by offering cooperation with other nodes. It has two components such as

a) Computer or Processor unit: It executes the information.

b) Storage or memory unit: It is the unit where all the information given to a system is stored.

- **Transmission Unit (TU)**

It helps in data transmission and reception by establishing a connection between the sensor node and the WSN. In this unit, we are having a transceiver.

- **Transceiver**

It is a device that is capable of transmitting and receiving information through a transmission medium.

- **Location finding system**

It is an external device that is used to automatically identify and track the location of objects or people in real-time.

- **Mobilizer**

It is used to move the sensor nodes when it is required to carry out the assigned tasks.

3. Development of experimental setup

In this section, the description of the proposed system development for agriculture applications with the help of different required hardware components [27] for making the system efficient and intelligent. The hardware components are classified into five types:

3.1 Field sensors

In various applications of agriculture, the environment sensors (DHT11 [28] means air temperature and air humidity) and deployment sensors (soil temperature and soil moisture) are plays a very significant role. Here, few important sensors [29] have been discussed in table 2.

Table 2 Shows the various sensors used in agriculture applications

S. No	Sensor image	Sensor name	Technical details	Applications
1.		DHT11: Temperature and Humidity	Input voltage: 3.3V-5.5V, Range of humidity: 20%-90%, Range of temperature -0^0C-50^0C, Accurateness- ±2, Persistence -1, and Exchangeability.	Environment and Smart agriculture
2.		FC-28: Soil moisture	Operating supply:3.3-5v, Voltage (Output):0-4.2v, Current(Input):35mA, Signal (Output): Analog and Digital	Smart gardening and Smart agriculture monitoring
3.		DS18B20: Soil temperature	Power supply: 3.3V-5.5V, 4.7k resistor, Operating temperature range: -55°C to +125°C, Stainless steel shell 6*50mm, Cable length: 50 cm, working directly with One Wire data protocol	Soil health monitoring and Smart agriculture monitoring

3.2 Microcontroller

In the view of an implementation of proposed architecture consists hardware microcontroller board (Arduino Uno) and it is an open-source hardware platform having few important specifications mentioned in table 3.

Table 3 Shows the Arduino Uno hardware microcontroller specifications

S. No	Technical specifications
1.	Microcontroller type: Atmel-ATmega328P
2.	Operating DC voltage: 5 V
3.	Digital I/O pins: 14, Analog input pins: 06
4.	Quartz crystal oscillator: 16 MHz
5.	USB port: 01
6.	Flash Memory: 32 kB

7.	EEPROM: 1 kB, SRAM: 2 kB
8.	Programming: Arduino IDE (Install on PC)
9.	Supported languages: Wiring, C++

3.3 Wireless communication technologies and Protocols

In this study, wireless communication technologies and protocols are used for data transmission for short and long-range distances. IoT is having many wireless communication technologies as well as protocols. Apart from that some of them have been discussed for sending the data to a cloud server. The wireless communication technologies like Wi-Fi, NRF24L01 are used to network connectivity to a range of about 100 m and 200m through a router (wireless access point) respectively, and as well as protocols like MQTT, CoAP for providing the communication between the machine to machine (M2M) and messages are sent to cloud.

3.4 NRF24L01 module

NRF24L01 Module consists of two libraries like RF24 and RF24Network for providing all packages into the Arduino sketch. It acts as both transmitter and receiver to send the data over the network at a 200m distance. It has operated at 2.4GHz and the data rate ranges from 250 Kbps, 1-2 Mbps. The wireless transceiver NRF24L01 module is having an in-built Wi-Fi SoC antenna and a total of 8 input and output pins.

3.5 Field actuators

In the field of agriculture applications, field actuators have been provided the controlling functions of devices. In this scenario, filed actuators are like the Reay module, Motor module, and LED indicator module. Based on sensor data, the action will be performed by a particular actuator with an LED indicator. Field actuators are having few important specifications discussed in table 4.

Table 4 Shows the different types of actuators specifications

S. No	Relay module	Motor module	LED's indicator module
1.	Operating DC voltage: 5V, Single channel: 6 Pins, 3-pins are connected to load side and other connected to microcontroller side. Load side pins are NC (Normally Close), COM (Common), and NO (Normally Open)	Operating DC voltage: 5V-9V; Two operations: ON/OFF, It has 3 parts like Outlet, Inlet and DC input, Material: Plastic	When motor is ON then Green LED glow otherwise Red LED glow.

4. Proposed Architecture

The proposed architecture of a self-powered, real-time, nrf24l01 IoT based-cloud enabled service for smart agriculture decision-making system consists of two sections such as Transmitter section (Tx) and Receiver section (Rx) as shown in below Fig. 4 and the wireless connection between AWMU to WAMU as shown in below Fig. 5.

The transmitter section (Tx) is responsible for monitoring the agriculture field to get information (agriculture parameters) from environmental sensors and deployment sensors (agriculture sensors). So the physical layer comes into the picture and it senses all agriculture parameters through sensors like temperature, humidity, moisture, and so on. It sends the digital signal to another above level. Data acquisition is a collection of data from sensors deployed in the agriculture field. Once got completion of the data collection process and will be processed the data, the term is called data processing which comes under hardware embedded platforms (IoT gateway) along with wireless communication technologies for IoT, based on the conceptual and communication layers. Through communication protocols like MQTT and CoAP, only the messages are transmitted from client to server based on a set of rules for data in formats such as XML, JSON, CSV, and so forth. These things have happened while the Internet is available at farmers' place and it comes under the Internet layer.

The receiver section (Rx) is to take care of the agriculture field information which is stored in the cloud server repository (IoT-cloud) with the help of IoT security like API key (Application Programming Interface). So that data access from the cloud repository through preconfigured devices like mobile phones, laptops, and so forth. The accessing layer is responsible for access the data from the cloud through a farmer's mobile phone regarding agriculture data. The application layer is built to do completely automatic visualization through graphical representation, monitoring for real-time applications, and statistical analysis for data. IoT cloud itself data storage and data analysis is done in it. By using some of the machine learning algorithms are used in IoT applications for data analysis. Finally, IoT cloud platforms are providing cloud services for data storage and analysis. These cloud platforms are associated with the architecture of IoT for providing cloud services.

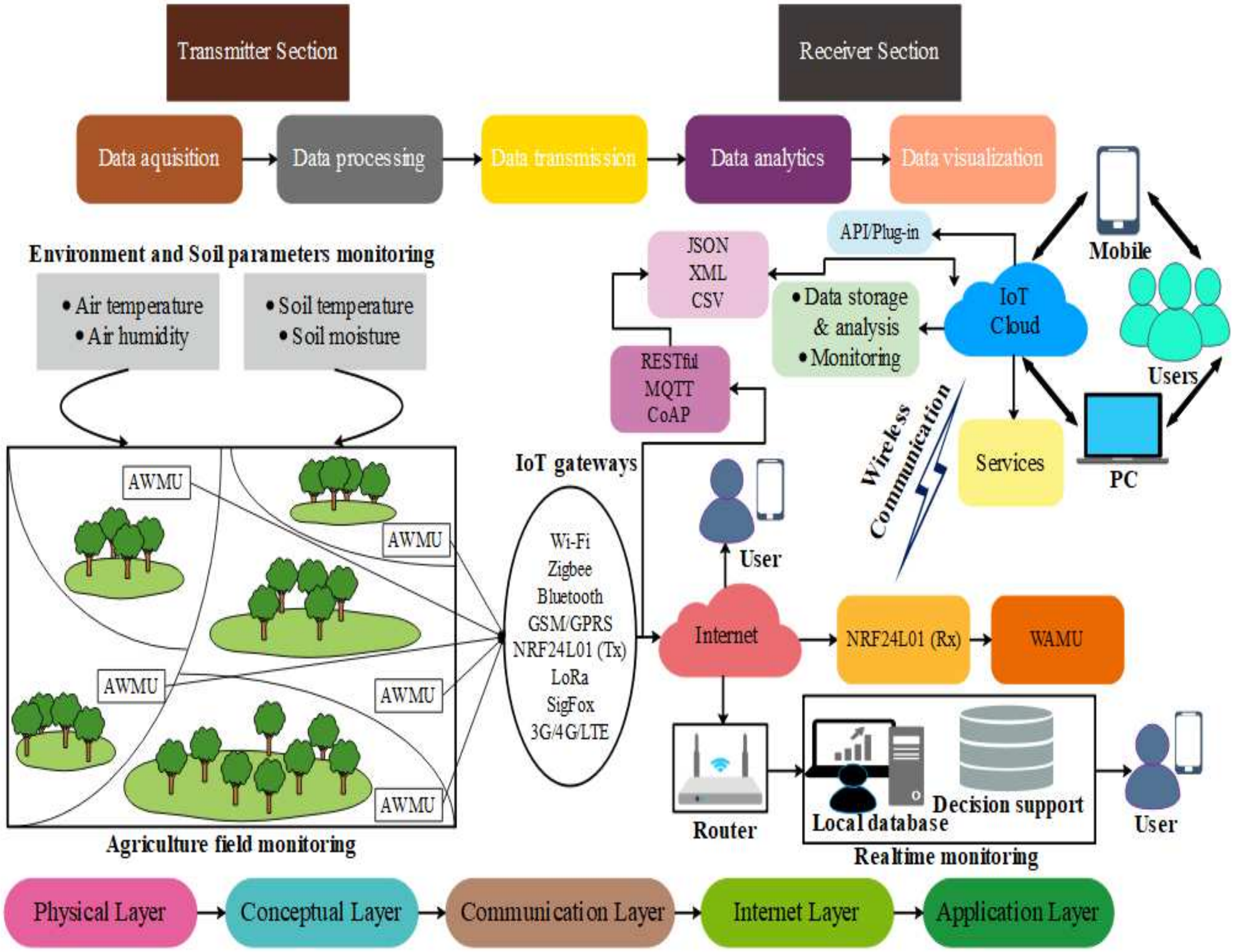

Fig. 4 Proposed architecture for the smart agriculture decision-making system

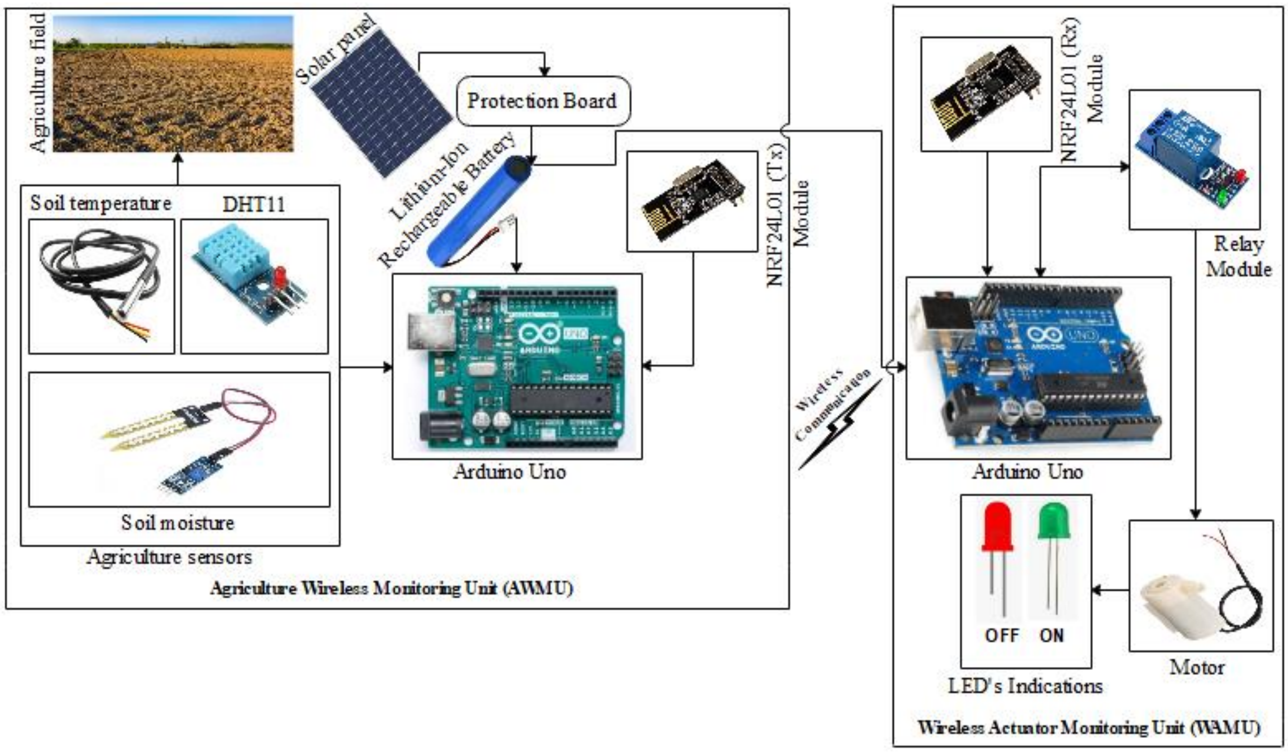

Fig. 5 Wireless connection between AWMU to WAMU architecture

4.1 Agriculture Wireless Monitoring Unit (AWMU)

Agriculture Wireless Monitoring Unit (AWMU) is deployed in the field of agriculture. It consists of environment sensors, agriculture sensors, hardware platform (Arduino), energy harvesting capability circuit for power supply, and wireless transmitter module (NRF24L01). The sensors like DHT11 (temperature and humidity sensor), soil temperature, soil moisture sensors, and NRF24L01-Tx module are connected to the microcontroller. The AWMU has transmitted the information to other devices through wireless communication over a network with good internet connectivity. In the agriculture field, each AWMU is communicated through Wi-Fi connectivity. Finally, the filed information is sent through the IoT gateway from AWMU to the receiver module.

4.2 Wireless Actuator Monitoring Unit (WAMU)

Wireless Actuator Monitoring Unit (WAMU) is deployed in the field of agriculture. It has 4 modules such as 1. Relay module 2. Motor module 3. LED’s indicator module 4. NRF24L01-Rx module and hardware platform (Arduino Uno), energy harvesting capability circuit for power supply. Based on sensor data, which is coming from the AWMU then actuators are responded accordingly through wireless communication over a network. Once it reaches the field information to WAMU and it again sends to the server or cloud. In the agriculture field, the WAMU is communicated through wireless communication connectivity to the cloud.

4.3 Field Estimation for Deployment Sensors

The proposed system consists of environment and deployment sensors that are employing in the agriculture field and each sensor covers the different coverage area. To achieve [30] the better connectivity means more coverage area (above 1 acre) with no data loss and long-range communication as shown in Fig. 6 and Fig. 7. And also if the length (L) of the sub-field is low then received sensor data is more accurate, which means rises monitoring of agriculture field and reducing the cost-effective of sensor deployment. So total agriculture field is dividing into five sub-fields based on wireless connectivity of sensors in Eq. 1 and each sub-field is having three Agriculture Wireless Monitoring Nodes (AWMN). And also each AWMN contains 4 sensors that are deployed in the agriculture field. So that number of sensors selected in a particular agriculture sub-field for coverage connectivity in Eq. 2.

$$\text{Total agriculture field (above 1 acre)} = 5 \times \text{Subfields} \tag{1}$$

$$S_N = \frac{6a}{\pi r^2} \tag{2}$$

Where S_N = Number of selected sensors, a = Field area, r = Sensor radius for transmission

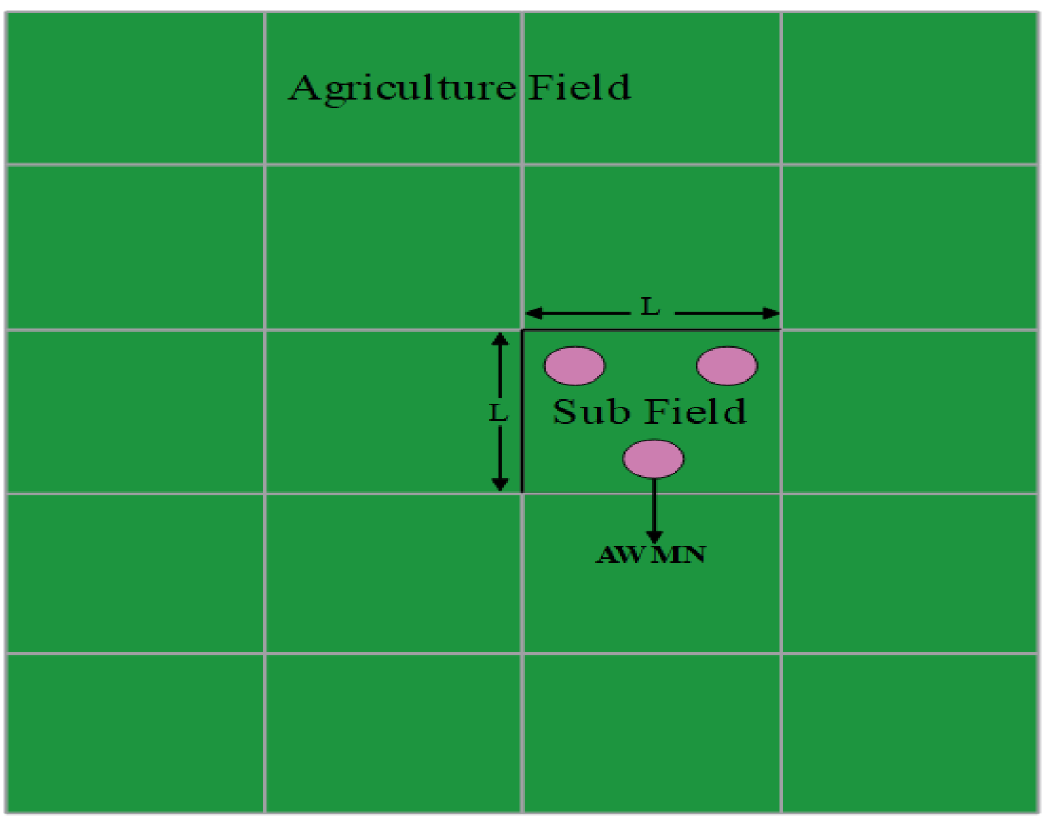

Fig. 6 Field estimation and dividing sub-fields for coverage area

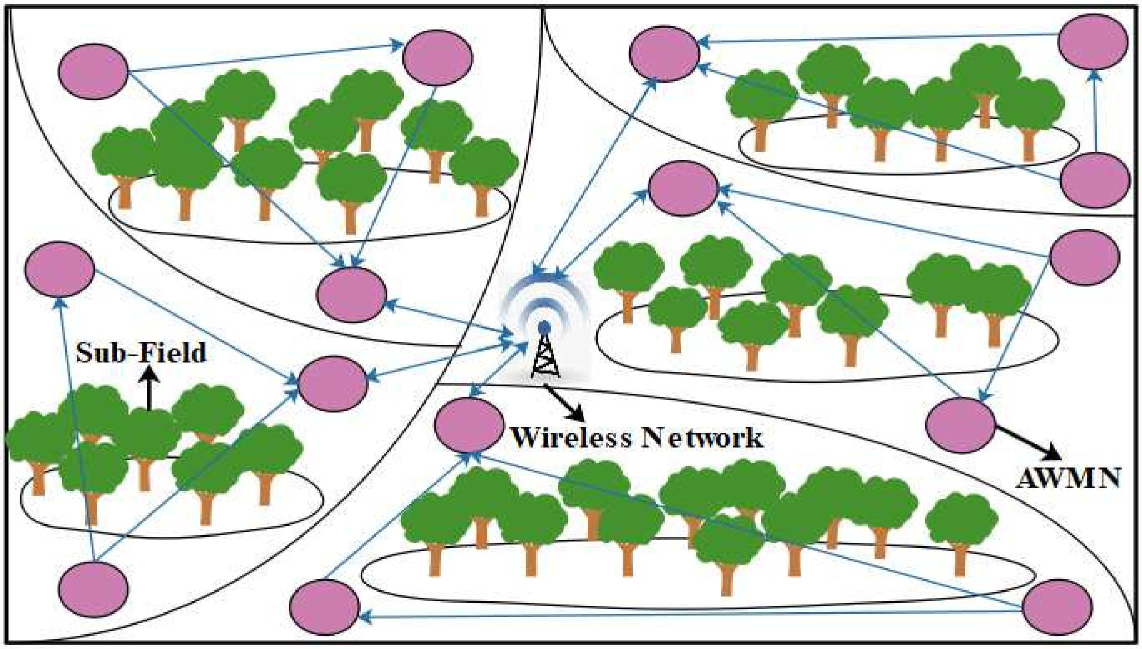

Fig. 7 The agriculture field divided into five sub-fields, together with 15 Agriculture Wireless Monitoring Nodes (AWMN)

5. Heat Index (HI) measurement

Heat Index (HI) is defined as the combination of air temperature (T) and air humidity (H) values to regulate the equivalent temperature experienced by plants or crops. In this process, the DHT11 sensor is connected to a microcontroller (Arduino Uno) and it gives the sensors values like temperature and humidity (Environment parameters). Based on the sensor values, heat index measurement [31] is calculated from Eq. 3 and it is used to good environmental conditions for agriculture monitoring.

$$HI = C_1 + C_2T + C_3H + C_4TH + C_5T_2 + C_6H_2 + C_7T_2H + C_8TH_2 + C_9T_2H_2 \quad (3)$$

Where HI is the heat index in Degree Celsius (^{0}C) and C_1, C_2……… C_9 are called standard constants.

6. Workflow of the proposed smart agriculture system

Figure 8 shows the complete workflow of the proposed system for smart agriculture monitoring.

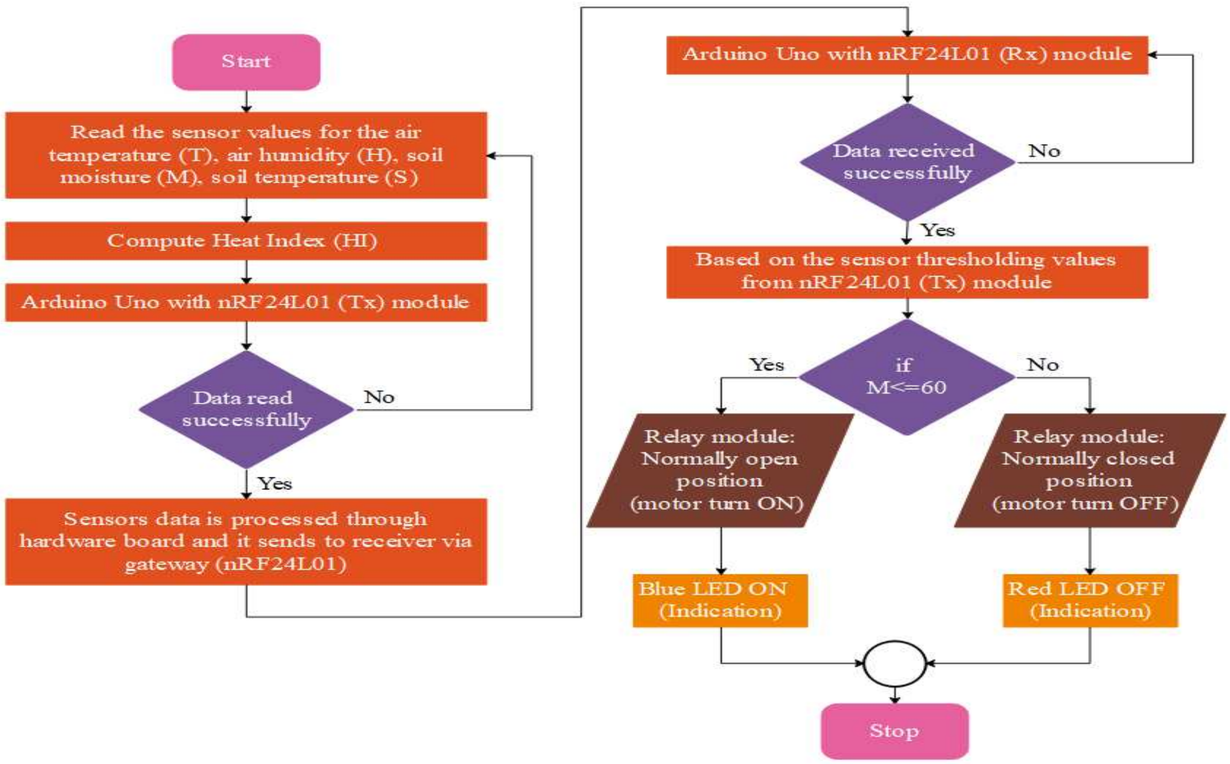

Fig. 8 Workflow of the proposed smart agriculture system

7. Heat Index (HI) algorithm

HI algorithm

Step1: Input: Temperature and humidity sensor (DHT11), Soil moisture sensor (FC-28), Soil temperature (DS18B20) sensors data.

Step2: Output: ThingSpeak cloud platform along with the heat index value and notifications for agriculture monitoring through ThingView mobile application.

Step3: Initialization of variables;

$T, H, M, S, C_1, C_2 \ldots\ldots\ldots C_9, HI;$

Step4: if ((T! =0) || (H! =0)) || ((M! =0) || (S! =0))

Step5: Read $T, H, M, S, C_1, C_2 \ldots\ldots\ldots C_9$;

Step6: By using the Heat Index formula based on the sensor's data for agriculture monitoring.

$$HI = C_1 + C_2T + C_3H + C_4TH + C_5T_2 + C_6H_2 + C_7T_2H + C_8TH_2 + C_9T_2H_2;$$

Step7: conditions for motor turning ON/OFF operations.

if (M (in percentages) <= 60) then

Relay Module: Normally open position // motor turn ON // Blue LED ON (indication)

else if (M (in percentages) > 60) then

Relay Module: Normally closed position // motor turn OFF // Red LED OFF (indication)

End

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8. Hardware implementations

In this section, hardware implementation is discussed. The proposed system consists of two parts one is the transmitter part and the other one is the receiver part. The transmitter and Receiver circuits are connected wirelessly. NRF24L01 module is used for wireless communication. The DHT11 sensor, soil moisture sensor, soil temperature sensors, and NRF24L01 Transmitter module are connected to the Arduino board at the Transmitter section. The receiver circuit consists of an NRF24L01 receiver module and a submersible pump (motor) that is connected to Arduino Uno. The soil moisture and soil temperature sensors are deployed in the soil. The data collected by this DHT11 sensor, soil moisture, and soil temperature sensors are transmitted to the receiver side circuit. Some Threshold value is set at the receiver side microcontroller. If the sensor received is below the threshold value then the motor will be in OFF condition and if the received sensor is above the threshold value then the motor will be turned ON and automatically irrigates the field. So, Depending on the data received and threshold values, the submersible pump (motor) will ON/OFF operations accordingly as shown in Fig. 9, Fig. 10, and Fig. 11.

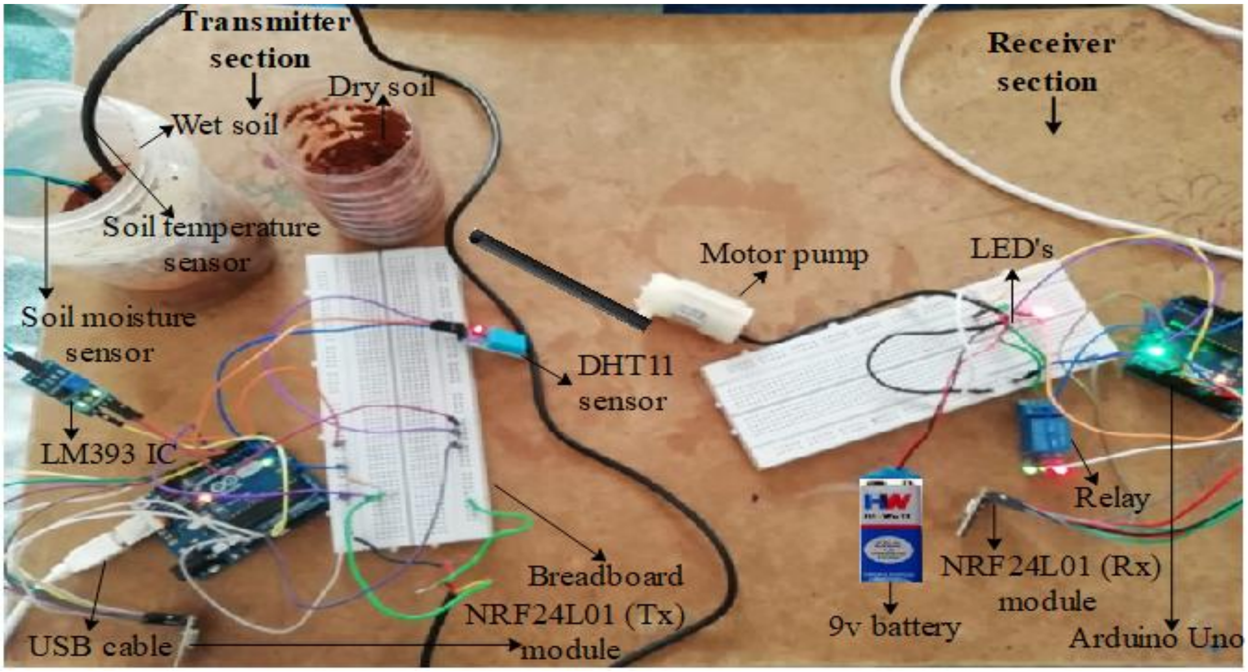

Fig. 9 a demonstration of the proposed system

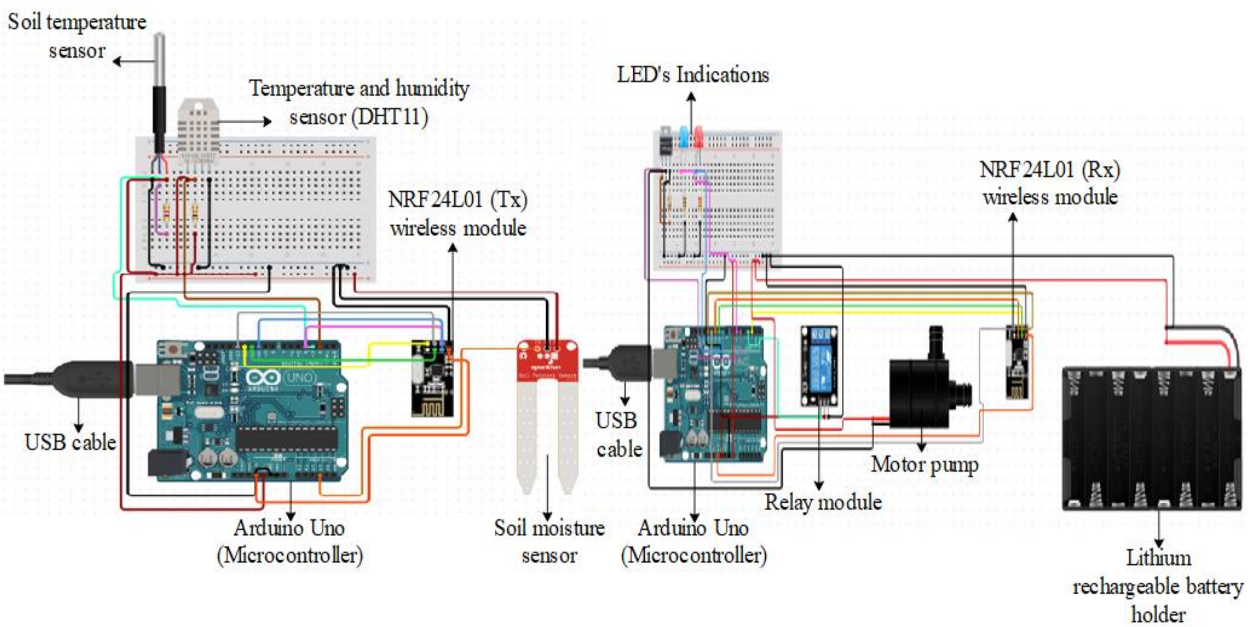

Fig. 10 Schematic diagram for connecting the necessary components of the transmitter and receiver sections

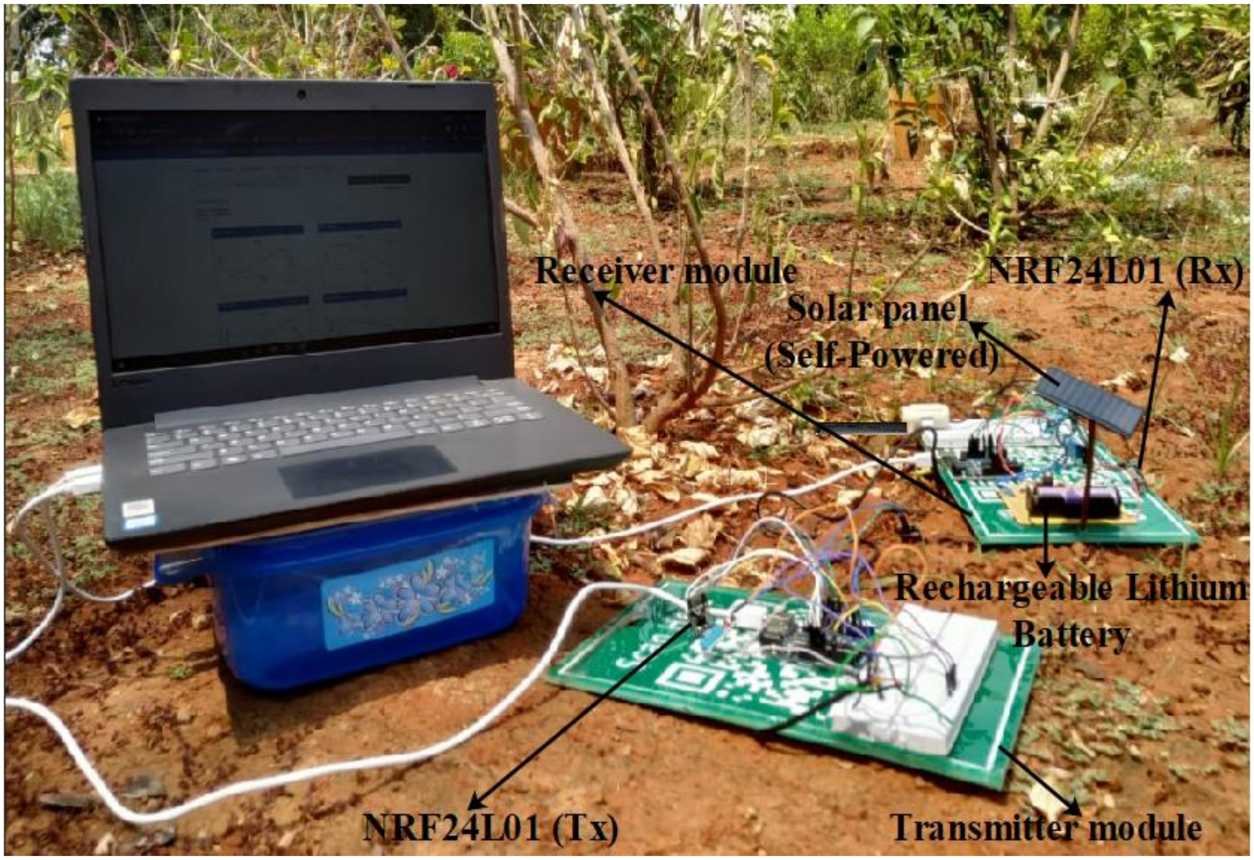

Fig. 11 Practical hardware implementation of the proposed agriculture monitoring system

4.1 Results and Discussion

The results are categorized in five ways 1. Network metrics 2. Serial monitoring output 3. ThingSpeak output 4. ThingView mobile application 5. Comparative analysis. These are explained with graphical representations are given below.

9.1 Evaluation of current consumption of AWMU

In this section, the AWMU has primarily two modes of operation in the proposed agriculture monitoring system. There are 2 modes: active and low power. The sensor data will be delivered to the monitoring system through remotely (WAMU) in the agriculture field once every second. For each reading consists of sixty four samples, which are sent as packets to the ThingSpeak cloud platform. The data must be transmitted in 567.6 x10^{-6} seconds. So, for the time being, the AWMU will be in a power-saving mode (idle). Because the device operates on batteries, this will improve power efficiency. Eq. 4, 5, and 6 are used to calculate the average current consumption of AWMU.

A. Sleep mode current contribution of AWMU

$$= (\text{Sensors idle current} + \text{NRF24L01 idle current}) \times (\text{Transmission period} - \text{Execution time}) \tag{4}$$

$$= (16.9 \times 10^{-3}\text{A} + 11.3 \times 10^{-3}\text{A}) \times (1\text{s} - 567.6 \times 10^{-6}\text{s})$$

$$= (16.9 \times 10^{-3}\text{A} + 11.3 \times 10^{-3}\text{A}) \times (1\text{s} - 567.6 \times 10^{-6}\text{s})$$

$$= 0.02818\ \text{A} * \text{s}$$

B. Active mode current contribution of AWMU

$$= (\text{Sensors event current consumption} \times \text{Execution time}) + (\text{NRF24L01 event current consumption} \times \text{Execution time}) \tag{5}$$

$$= (16.8 \times 10^{-3}\text{A} \times 567.6 \times 10^{-6}\text{s}) + (13.5 \times 10^{-3}\text{A} \times 567.6 \times 10^{-6}\text{s})$$

$$= 1.71982 \times 10^{-5}\ \text{A} *$$

C. Average current consumption of AWMU

$$\frac{\text{Sleep mode current contribution of AWMU} + \text{Active mode current contribution of AWMU}}{\text{Transmission period}} \tag{6}$$

$$= \frac{0.02818\ \text{A} * \text{s} + 1.71982 \times 10^{-5}\ \text{A} * \text{s}}{1\text{s}}$$

$$= 0.02819\ \text{A}$$

9.2 Life expectancy of AWMU

The proposed system uses a 2.6 A*h battery capacity. The theoretical conditions of the battery in Eq. 7 can be used to calculate the life expectancy of AWMU.

Total days of AWMU operation

$$= \frac{\text{Battery current rating}}{\text{Average current consumption}} \qquad (7)$$

$$= \frac{2.6\ A * hrs}{0.02819\ A}$$

= 92.23 hrs

= 3 days 20 hrs 13 mins and 47 secs

9.3 Maximum transmission between AWMU and Router

An experiment is carried out to determine the maximum range between AWMU and the network router, in which the network router (wireless access point) is kept fixed and AWMU is displaced at various distances. One thousand five hundred packets are sent to the server from a particular distance to achieve the maximum practical distance between AWMU and the router. The packet loss rate vs distance plot is shown in Fig. 12. It is noticed from the plot that if the farmer is within 200 meters of the plot, the PLR (Packet Loss Rate) is minimal, and it is below 2 percent.

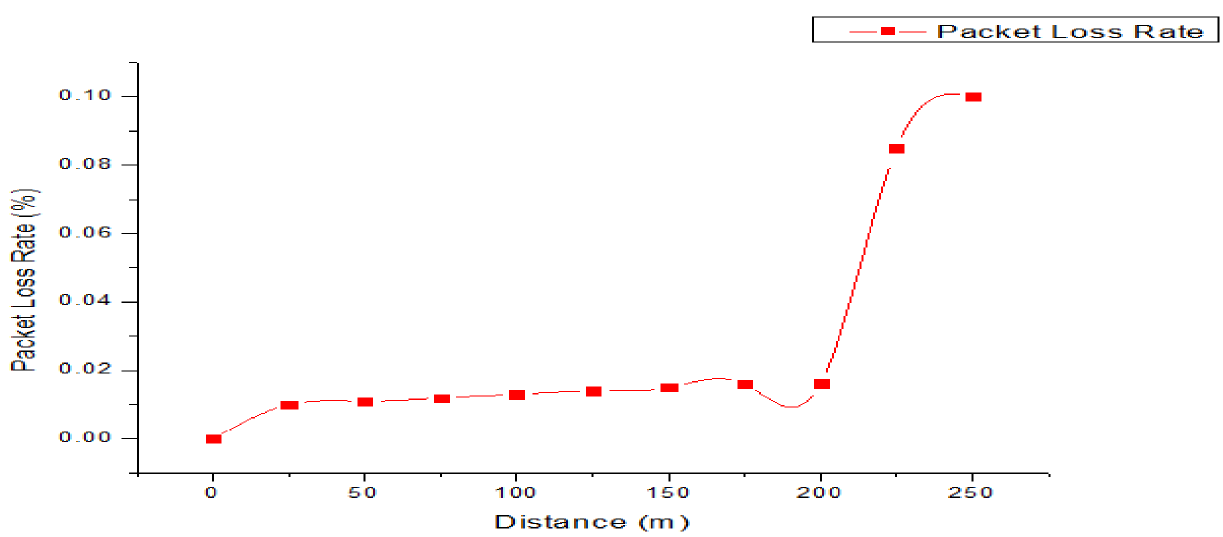

Fig.12 Packet loss rate Vs distance

9.4 Serial monitoring output

In this process, the result has been observed by the user through serial monitor using communication port or serial port COM11 at the transmitter section and COM3 at the receiver section as shown in Fig. 13 and Fig. 14 respectively. Fig. 15 shows the circuit implementation through Proteus software for simulation.

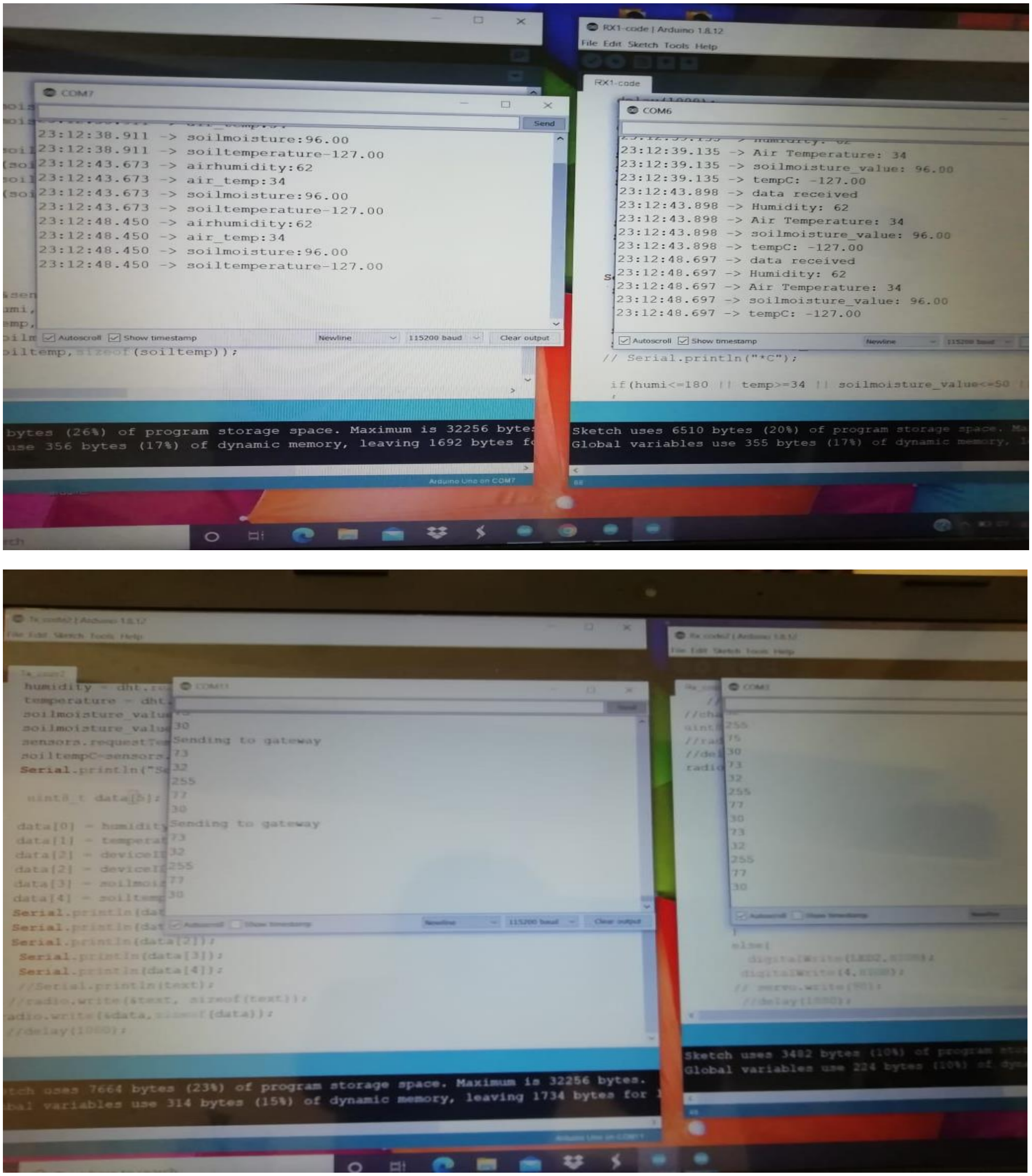

Fig. 13 Serial monitoring results from Arduino IDE for both the transmitter and receiver sections

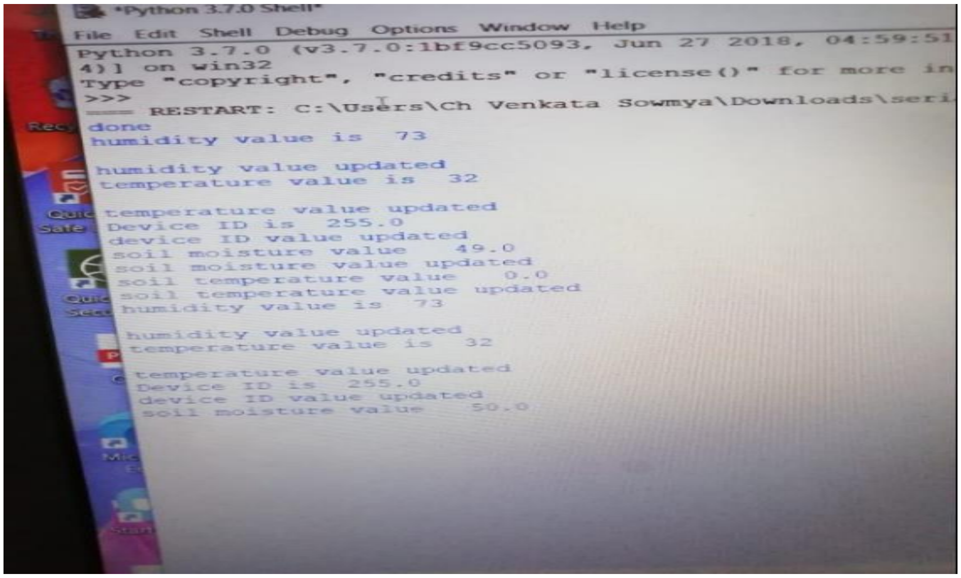

Fig. 14 Serial monitoring results from Python IDE

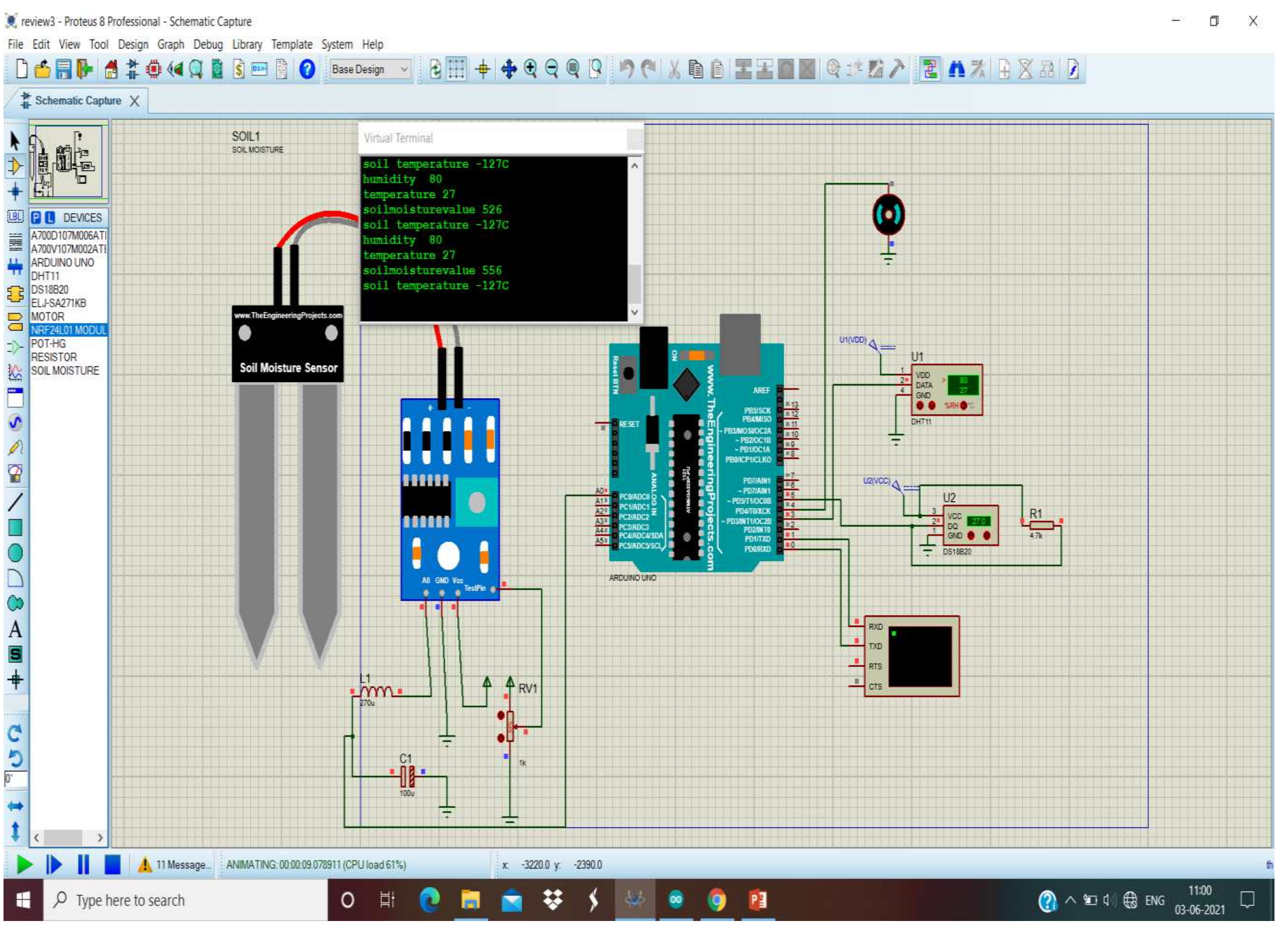

Fig. 15 Circuit implementation in Proteus software

9.5 ThingSpeak cloud platform output

In this section, the result has been observed through the ThingSpeak cloud platform using the ThingSpeak cloud API (Application Programming Interface) Key. Various ThingSpeak fields as shown in Fig. 16.

Fig. 16 Implementation results from the ThinkSpeak cloud platform

9.6 ThingView mobile application

ThingView is a mobile application for IoT devices. It enables the ThingSpeak cloud platform to visualize and display the received sensor information through the ThingSpeak channels as shown in Fig. 17.

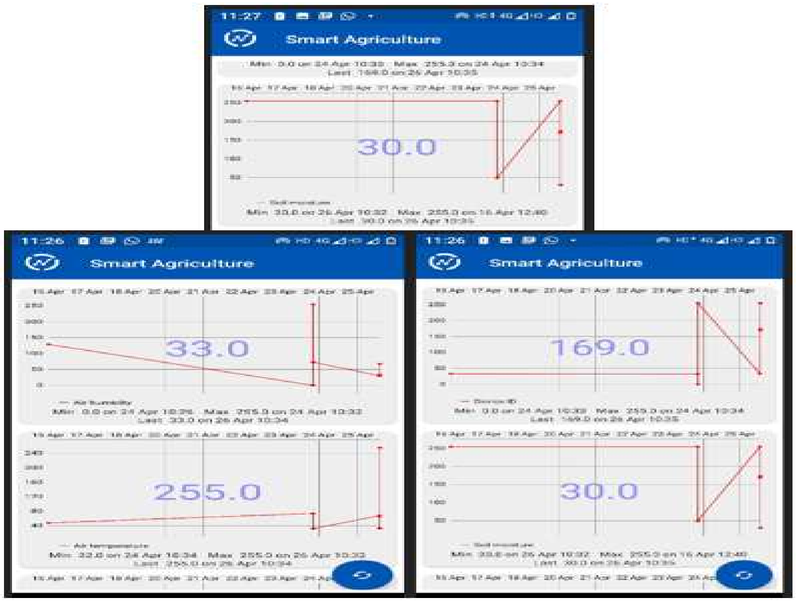

Fig. 17 Implementation results from the ThingView mobile app

9.7 Comparative analysis

The proposed system gives better results when compared to existing systems in terms of wireless link quality, cost development, architecture implementation, a distance of communication and cloud storage services as shown in table 5, and the various wireless networks with link quality versus distance as shown in Fig. 18.

Table 5 shows the comparison of the parameters between the proposed system and existing systems

S. No	Architecture	Wireless connectivity module	Distance	Cloud Storage	Cost	Simulation tool	Applications
1	No	No	20 m	No	High	NS2	Agriculture
2	No	LTE (2G)	50 m	No	High	MATLAB	Agriculture
3	No	Wi-Fi	100 m	No	High	Arduino IDE	Agriculture
4 (Proposed)	Yes	NRF24L01	200 m	Yes	Low	Arduino IDE, Python IDE	Agriculture and Environment

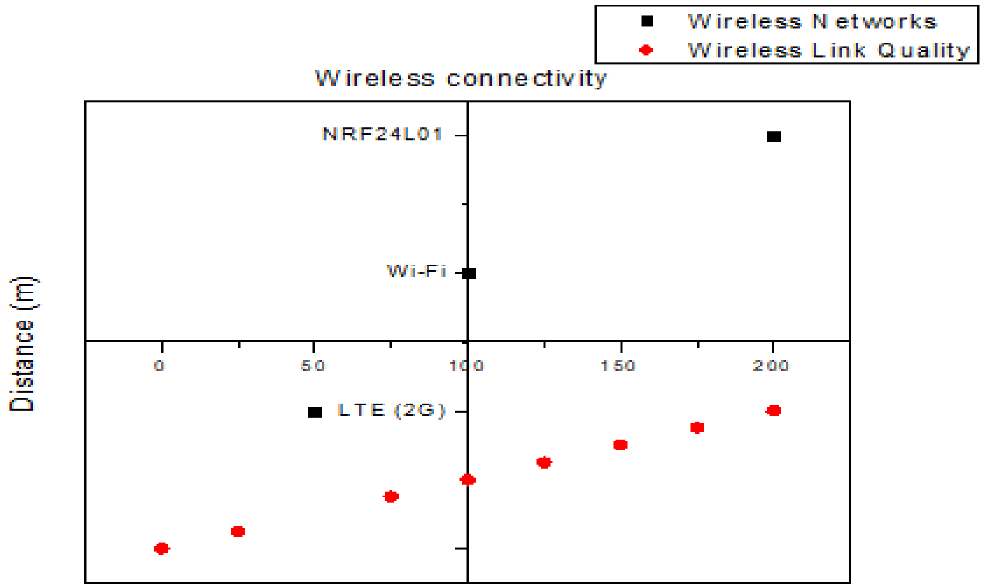

Fig. 18 Wireless Networks and Link Quality Vs distance

Conclusion

IoT investigates the agricultural field's quality to increase the crop yields, boost efficiency, and lower the costs. The proposed Self-Powered, Real-Time, NRF24L01 IoT based-cloud enabled service for smart agriculture decision-making system contributes to agricultural technology by enhancing the monitoring and irrigation management schedules on a time-to-time basis. Since it is based on IoT, field conditions can be monitored in real-time through remote location. Additionally, the system has some flaws, such as a limited coverage area. Incompetence and data loss are caused by the surface area of sensors inserted into the device. The proposed system is supposed to solve the issues of existing systems. As a result analysis, farmers can choose the best strategy for healthy agriculture practices with cost-effective hardware is used. The proposed approach increases accuracy and reduces data loss with enabling of long-distance monitoring option, low power consumption, wireless connectivity, and link quality between the AWMU to WAMU over a 200 meters line of sight are the other advantages.

Declarations

Funding: In this work, no funding is involved of any agency or organizations.

Conflicts of interest: There is no conflicts of interest with any person or body regarding this work.

Availability of data and material: Related to the work, every data has been provided in the manuscript.

Code availability: Not required for this work.

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