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

Lova Raju K.¹ · V. Vijayaraghavan¹

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Abstract

Agriculture has been benefited by advanced research and development due to Internet of Things (IoT)-based automation. Environmental and deployment sensors such as DHT11, soil moisture, soil temperature and others are used in agriculture field production and IoT technology is being employed to assess field environment in smart agriculture. Most of the existing systems work only on the air temperature and humidity sensing, for agriculture health monitoring. These systems have limitations to send sensing data from long distances. The approximate range of data communication for these systems is below 100 m which is quite less for agriculture field coverage, in general. As a result of this, agricultural crop production is not up to the mark. We propose an architecture framework to address the above-mentioned shortcomings. This proposed architecture can be applied for long range communications with no data loss and no interference in the information. The system employs an NRF24L01 transceiver module, which works at 2.4 GHz for long-distance communications towards monitoring of agriculture parameters. This research is aimed into a suitable, feasible, and integrated Internet of Things (IoT) technique for smart agriculture. The proposed system saves energy and boosts productivity. This method reduces human effort while evaluating heat index measurement parameters in order to monitor the environment for optimal agriculture growth. The current consumption and life expectancy of the Agriculture Wireless Monitoring Unit (AWMU) are 0.02819 Amperes and 3 days 20 hours 13 minutes and 47 seconds, respectively, according to the experimental analysis. In an open environmental area, the maximum transmission distance for AWMU is up to 200 meters from the wireless access point.

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

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1 Introduction

In recent years, Internet of Things (IoT) and Wireless Sensor Networks (WSN) has become more essential [1] in agriculture. IoT has 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 are 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 a 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. In the agricultural workplace, human health is also vital as shown in Fig. 1.

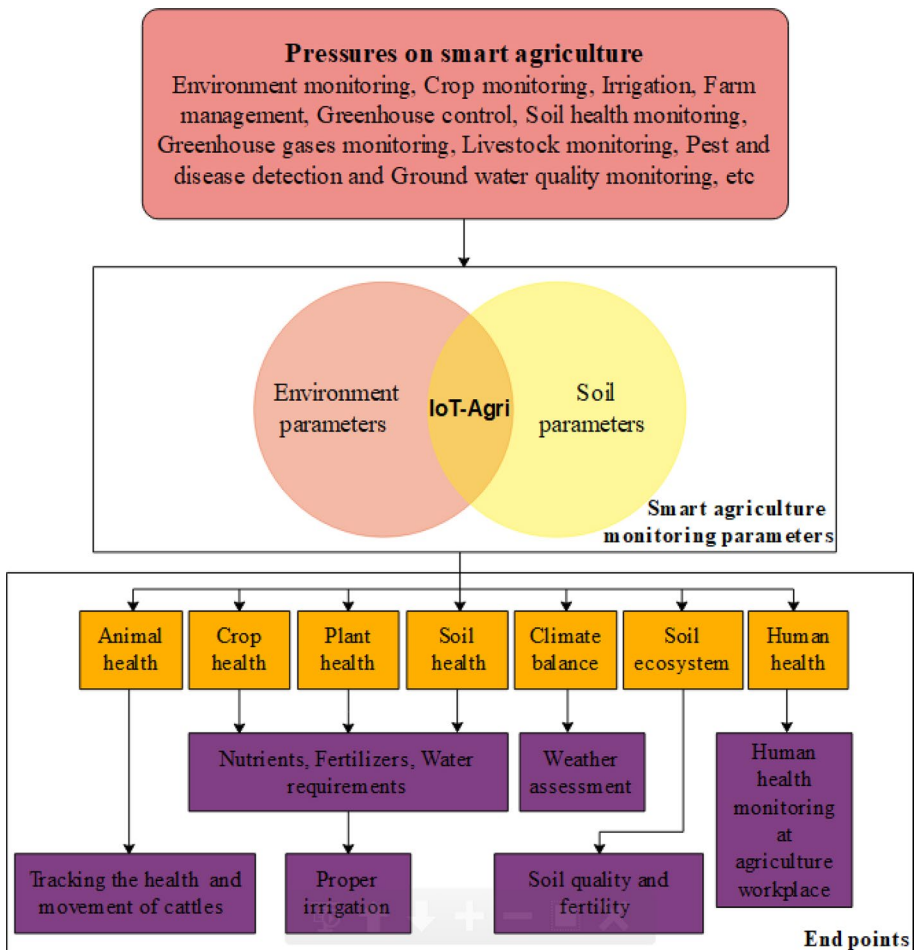


Fig. 1 Overview of the smart agriculture parameters

Consideration of soil moisture content, as well as air temperature and humidity parameters, can help to increase field productivity through smart agriculture. So that monitoring of smart agriculture. This real-time monitoring of both the environment and agriculture aids, by making an appropriate and accurate [4] decisions, which improve the productivity of the field, saves money, time, and resources. IoT devices or sensors can keep monitoring the parameters of an agricultural area as well as the environment around it. All of the information gathered by these devices is uploaded to a database over the internet. This collected data can be accessed by the user in a remote manner for monitoring of the field in real time or for further analysis.

1.1 Smart Agriculture Monitoring (SAM)

IoT can provide automation in agriculture monitoring systems with the 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 [5] to different domains such as water and soil management, crop monitoring, etc. WSN also enables automation in the field of agriculture with energy harvested [6] nodes, hardware cost-effectiveness and scalability.

1.2 Remote Monitoring Systems Using IoT

The Internet of Things (IoT) is a promising approach for remote monitoring and interconnectivity through lightweight communication protocols, an open-source cloud platform for experiment results based on Application Programming Interface (API), visualization dashboards and [7] web development tools. The architecture, deployment, and validation of an IoT system to monitor soil parameters in real-time and facilitate data collecting in remote field locations are presented in this research.

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 Tiglaio et al. [8] 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 Uno and Raspberry pi). Sensor's data is 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. Users can access sensor data via the cloud, and a web application has been built for remote monitoring and visualising sensor data in an online mode.

Raul Morais et al. [9] explained the mySense concept which means data handling of the environment in developing the agriculture practices. In this article, four-layered architecture shows the systematic data collection towards the precision agriculture issues which was discussed earlier. 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. [10] 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. By this model, we can eradicate, the crop defects and the notifications are sent to the farmers regarding their field 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. [11] proposed a smart agriculture applications are using the internet of multimedia things. This article, mainly focussed on smart farming, for optimizing irrigation process. Internet of multimedia things has 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 a state of art, for achieving the optimal decision-making smart irrigation system.

Khalid Haseeb et al. [12] 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 to acquire sensor data about the crops and plants. This proposed system concentrates on few important metrics like communication range, SNR, system throughput, power consumption, and packet drop ratio.

Sanjeevi et al. [13] 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 areas. 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 use Wi-Fi and ZigBee technologies, for transmitting the sensors data of the agriculture field to the farmer.

2.1 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 (SRC) [25] for the distance of < 10 m, medium-range communication (MRC) for the distance of $(10\text{--}100)$ m, and long-range communication (LRC) for the distance > 100 m. SRC includes RFID (Radio-frequency identification), BLE (Bluetooth), UWB (ultra-wideband), and so on. Wi-Fi and ZigBee are used for MRC [26] technology. In LRC, cellular networks are used. Additionally, cellular networks like 2G/3G/4G, LPWA are new technologies and are 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 over large distances

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

Ref. and Year	Soil parameters	Environment parameters	Wireless technology	Topology based	Type of network	Energy harvesting	Data Storage	Data Visualization
[14], (2010)	No	Temperature, Humidity	RFID	No	WPAN	No	Yes	No
[15], (2011)	No	Temperature, Humidity	GPRS	No	WLAN	No	Yes	No
[16], (2012)	No	Temperature, Humidity	ZigBee	Mesh	WPAN	No	No	No
[17], (2013)	No	Temperature	GPRS	Star	WLAN	No	Yes	No
[18], (2014)	Moisture	Temperature, Humidity	ZigBee	Star or Mesh	WLAN	No	No	No
[19], (2015)	CO ₂	No	ZigBee	No	WLAN	No	Yes	No
[20], (2016)	pH level, Electric Conductivity (EC)	Atmospheric temperature, Humidity, Luminance	Wi-Fi	No	WLAN	No	Yes	Yes
[21], (2017)	Soil temperature	Temperature, Humidity, Pressure, Wind Speed, Leaf wetness	Wi-Fi	No	WLAN	Yes	No	Yes
[22], (2018)	Soil moisture	Temperature, Humidity	LoRa	No	WWAN	Yes	No	Yes
[23], (2019)	Soil moisture	Air temperature, Air humidity	Wi-Fi	No	WLAN	No	No	Yes
[24], (2020)	Temperature, Humidity	Air temperature, Air humidity	LoRa WAN	Star	WWAN	No	Yes	Yes
Proposed system	Soil temperature, Soil moisture	Air temperature, Air humidity	NRF24L01	Mesh	WLAN	Yes	Yes	Yes

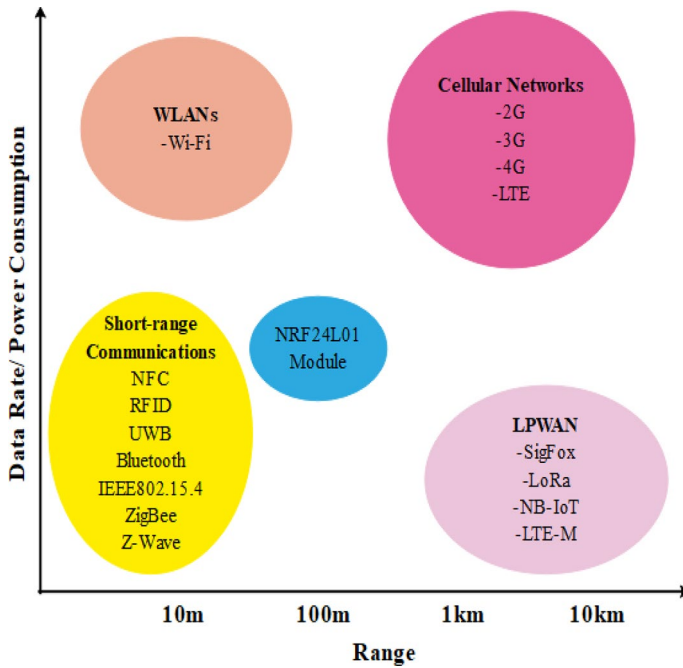


Fig. 2 Various wireless communication technologies for range and data rate comparisons

with smaller data rates. The LPWA offers more than 15 km communication range with a power consumption of 100 Mw.

2.2 Sensor Node Architecture (SNA)

Sensor Node Architecture (SNA) consists of four [27] units such as a transmission unit, a sensing unit, a processing unit, and a power source as shown in Fig. 3.

2.2.1 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.

2.2.2 Power Unit (PU)

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

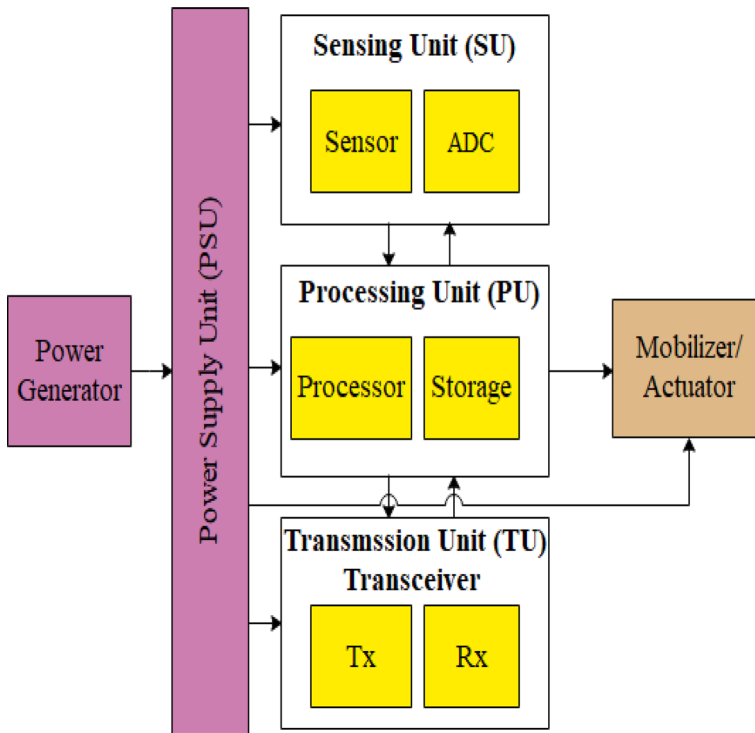


Fig. 3 Sensor node architecture

2.2.3 Power Generator

It is a device that is capable of generating energy.

2.2.4 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.

2.2.5 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.

2.2.6 Transceiver

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

2.2.7 Location Finding System

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

2.2.8 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, which helps in the development of agricultural applications, with the help of different required hardware components, [28] 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 [29] means air temperature and air humidity) and deployment sensors (soil temperature and soil moisture) play a very significant role. Here, few important sensors [30] have been discussed in Table 2.


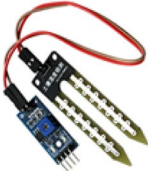

3.2 Microcontroller

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

3.3 Wireless Communication Technologies and Protocols

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

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: 3.3 V-5.5 V, Range of humidity: 20–90%, Range of temperature: 0–50 °C, Accuracy: ±2, Persistence: 1 and Exchangeability	Weather stations, Environment and Smart agriculture monitoring
2		FC-28: Soil moisture	Operating supply: 3.3 V-5.5 V, Voltage (Output): 0 V-4.2 V, Current(Input):35 mA, Signal (Output): Analog and Digital	Smart gardening and Smart agriculture monitoring
3		DS18B20: Soil temperature	Power supply: 3.3 V–5.5 V, 4.7 k resistor, Operating temperature range: −55 °C to +125 °C, Stainless steel shell 6*50 mm, Cable length: 50 cm, working directly with One Wire data protocol	Soil health monitoring and Smart agriculture monitoring

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 200 m distance. It has operated at 2.4 GHz 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. NRF24L01 module employs the Serial Peripheral Interface (SPI) protocol.

3.5 Field Actuators

In the field of agriculture applications, field actuators have provided the controlling functions of devices. In this scenario, field actuators are like the Relay 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.

4 Proposed Architecture

The proposed architecture is 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 is established between AWMU (TX) to WAMU (RX) as shown in Fig. 5. This proposed architecture is included which six layers discussed below.

The transmitter section (TX) is responsible for monitoring the agriculture field to get data from the environment 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 the above level, i.e., the conceptual layer. Data passing tasks received from the conceptual layer are handled by the communication layer. Internet layer is the most among the three layers which form the system backbone. ThingSpeak cloud works in the internet layer. The application layer supports the network of IoT development in large scale. All the applications, services, and research activities connected to a network of IoT have come under the business layer. Data acquisition is a collection of data from sensors deployed in the agriculture field. Once the completion of the data has been completed, then it gets processed and this processed data 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 lightweight communication protocols like MQTT and CoAP, 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 will be happened while the Internet is available at farmer's place and it comes under the Internet layer.

The receiver section (RX) aim 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 gets access from the cloud

repository through preconfigured devices like mobile phones, laptops and so forth. The application layer is responsible to access the data from the cloud through a farmer's mobile phone regarding agriculture data. The application layer is built in order to undergo complete automatic visualization through graphical representation, monitoring for real-time applications, and statistical analysis for data. Data storage and data analysis is done in IoT cloud itself. Finally, IoT cloud platforms are providing cloud services for data storage and analysis. These cloud platforms are associated with architecture, of IoT for providing cloud services such as Software-as-a-Service (SaaS), Platforms-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS).

The absence of soil moisture content, as well as the discrete collection of data from sensors, is a cause of concern with the existing systems. However, most of the conventional systems which work entirely on temperature and humidity parameters for monitoring agriculture health metrics are inefficient and inaccurate in nature.

The main motto of the proposed architecture is to provide a system which can be employed for proper agriculture practices. Here, we consider two sections viz. 1). Transmitter containing Agriculture Wireless Monitoring Unit (AWMU) and 2). Receiver containing Wireless Actuator Monitoring Unit (WAMU). While transmission of the data between transmitter and receiver, few important advantages can be observed such as long range communication, low power consumption, good wireless link quality and wider field coverage area.

The technical novelty of this work is, the proposed system is having no data loss for long distance communication. It has low power consumption, and the life expectancy of sensor node is high. Also, there is cost-effectiveness as compared to previous reported systems for agriculture monitoring. We have also calculated the heat index (HI) measurement parameter as a part of environmental conditions towards smart agriculture monitoring.

4.1 Agriculture Wireless Monitoring Unit (AWMU)

Agriculture Wireless Monitoring Unit (AWMU) is deployed in the field of agriculture. It consists of environmental sensors, agricultural sensors, hardware platform (Arduino Uno), 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 transmits 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 field 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 four modules such as:

- Relay module
- Motor module
- LED's indicator module
- NRF24L01-RX module

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 + +

And also hardware platform (Arduino Uno), energy harvesting capability circuit for power supply. Based on sensor data, which is coming from AWMU, then actuators responds accordingly through wireless communication over a network. Once it reaches field information to WAMU, then 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 different coverage areas (each sensor has a 30 to 35 m range of coverage). To achieve better connectivity (which means more coverage area i.e., 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 the agriculture field and reducing the cost-effectiveness 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).

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



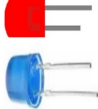
$$S_N = \frac{6a}{\pi r^2} \quad (2)$$

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

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

Table 4 Shows the different types of actuators specifications

S. No	Actuator images	Name of the actuators	Specifications
1		Relay module	Operating DC voltage: 5 V, 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)
2		Motor module	Operating DC voltage: 5 V-9 V, Two operations: ON/OFF, It has 3 parts like Outlet, Inlet and DC input, Material: Plastic
3		LED's indicator module	When motor is ON then Green LED glow otherwise Red LED glow

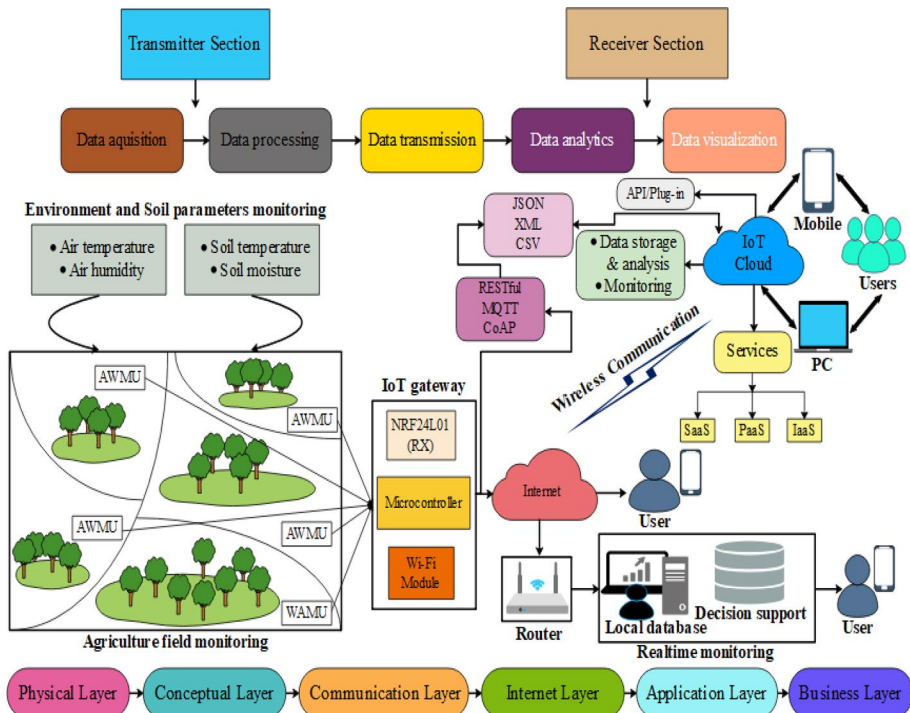


Fig. 4 Proposed architecture for the smart agriculture decision-making system

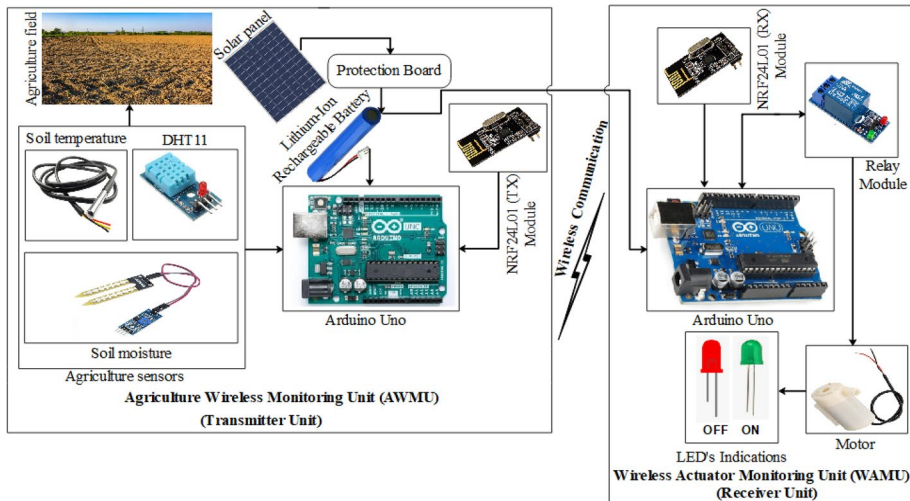


Fig. 5 Wireless connection is established between AWMU (TX) to WAMU (RX) architecture

sensor 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 in good environmental conditions for agriculture monitoring.

The HI value obtained is 33, which has been calculated by taking into consideration the temperature and humidity parameters, as shown in Eq. (3) given below. This value can be used as a reference for optimum environment monitoring of agriculture crop health.

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

where HI is the heat index in Degree Celsius ($^{\circ}\text{C}$) and C_1, C_2, \dots, 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.

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;

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

Step4: if $((T! = 0) \parallel (H! = 0)) \parallel ((M! = 0) \parallel (S! = 0))$

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

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 $(M \text{ (in percentages)} \leq 60)$ then

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

else if $(M \text{ (in percentages)} > 60)$ then

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

End

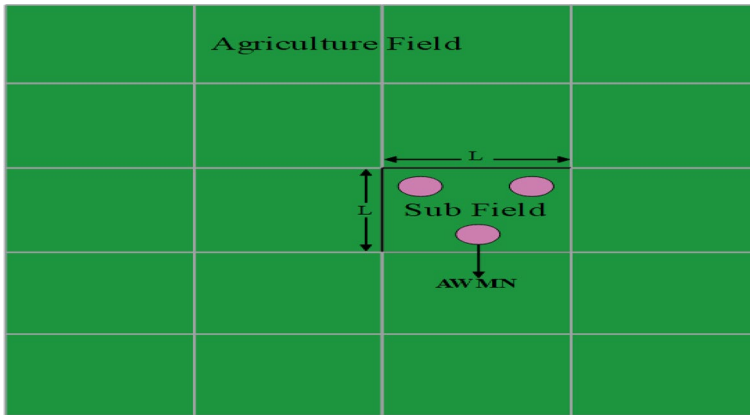


Fig. 6 Field estimation and dividing sub-fields for coverage area

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 in 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 be doing ON/OFF operations accordingly as shown in Figs. 9, 10, and 11.

9 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 remote access (WAMU) in the agriculture field once

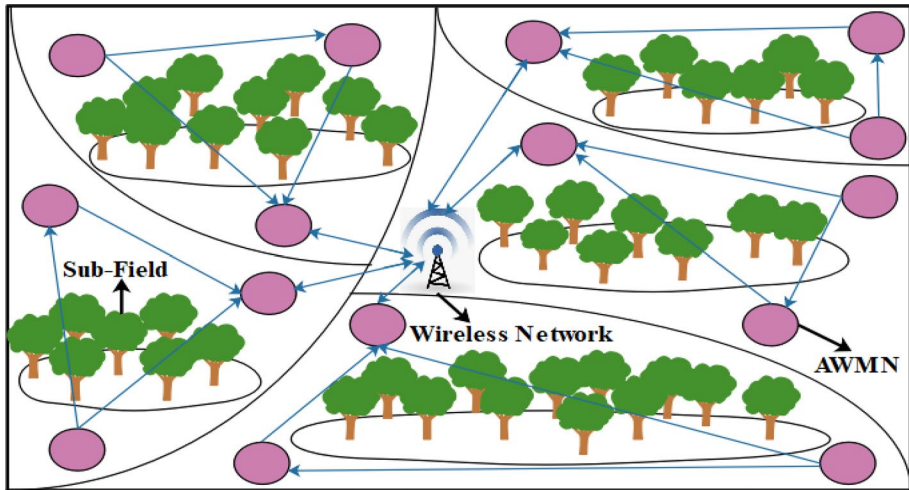


Fig. 7 The agriculture field divided into five sub-fields, together with 15 Agriculture Wireless Monitoring Nodes (AWMN)

every second. Each reading consists of sixty-four samples, which are sent as packets to the ThingSpeak cloud platform. The data must be transmitted in 567.6×10^{-6} s. So, for the time being, the AWMU will be in a power-saving mode (idle), because the device is operated on batteries. This will improve power efficiency. Equation (4), (5), and (6) which are used to calculate the average current consumption of AWMU.

9.1.1 Sleep Mode Current Contribution of AWMU

$$\begin{aligned}
 & (\text{Sensors idle current} + \text{NRF24L01 idle current}) \times (\text{Transmission period} - \text{Execution time}) \\
 &= (16.9 \times 10^{-3} \text{ A} + 11.3 \times 10^{-3} \text{ A}) \times (1 \text{ s} - 567.6 \times 10^{-6} \text{ s}) \\
 &= (16.9 \times 10^{-3} \text{ A} + 11.3 \times 10^{-3} \text{ A}) \times (1 \text{ s} - 567.6 \times 10^{-6} \text{ s}) \\
 &= 0.02818 \text{ A} \cdot \text{s}
 \end{aligned} \tag{4}$$

9.1.2 Active Mode Current Contribution of AWMU

$$\begin{aligned}
 & \text{Active mode current contribution of AWMU} \\
 &= (\text{Sensors event current consumption} \times \text{Execution time}) \\
 &+ (\text{NRF24L01 event current consumption} \times \text{Execution time}) \\
 &= (16.8 \times 10^{-3} \text{ A} \times 567.6 \times 10^{-6} \text{ s}) + (13.5 \times 10^{-3} \text{ A} \times 567.6 \times 10^{-6} \text{ s}) \\
 &= 1.71982 \times 10^{-5} \text{ A} \cdot \text{s}
 \end{aligned} \tag{5}$$

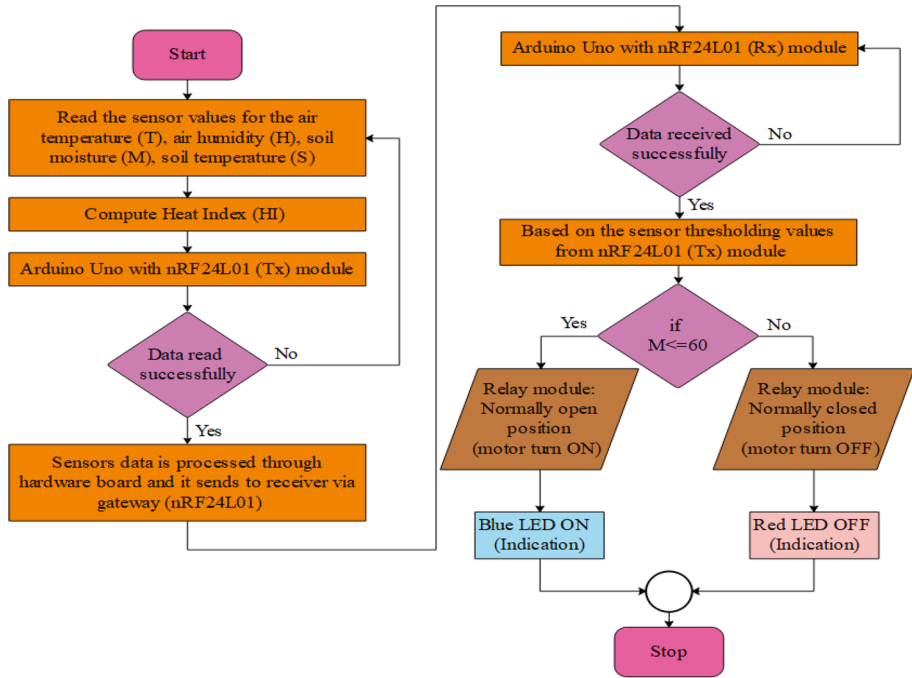


Fig. 8 Workflow of the proposed smart agriculture system

9.1.3 Average Current Consumption of AWMU

Average current consumption of AWMU

$$= \frac{(\text{Sleep mode current contribution of AWMU}) + (\text{Active mode current contribution of AWMU})}{(\text{Transmission period})} \quad (6)$$

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

$$= 0.02819\text{A}$$

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.

$$\text{Total days of AWMU opeartion} = \frac{\text{Battery current rating}}{\text{Average current consumption}} \quad (7)$$

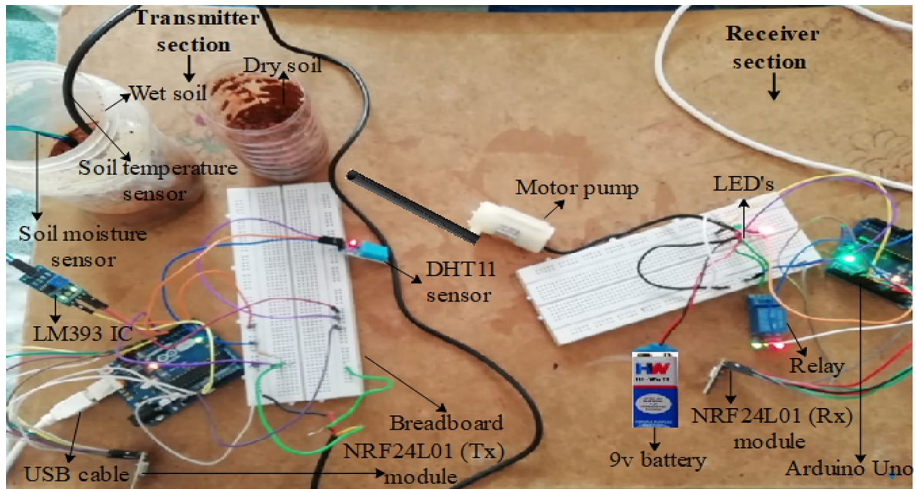


Fig. 9 A demonstration of the proposed system

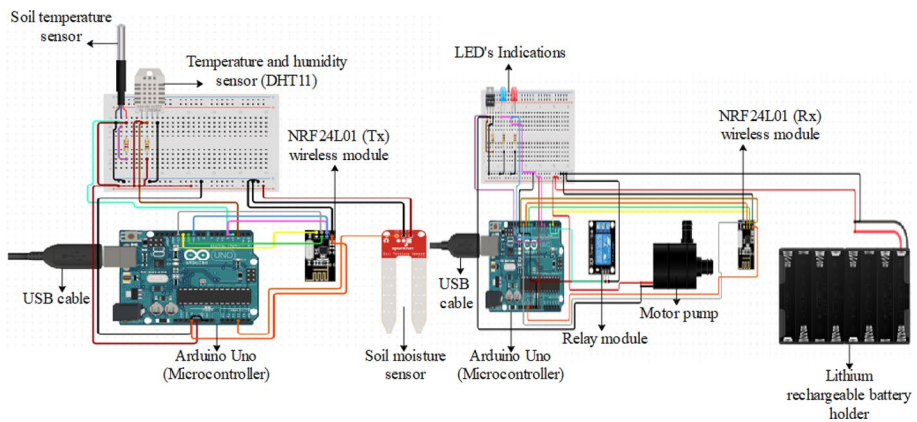


Fig. 10 Schematic diagram for connecting the necessary components of the transmitter and receiver sections

$$\begin{aligned}
 &= \frac{2.6 \text{ A*hrs}}{0.02819 \text{ A}} \\
 &= 92.23\text{hrs} \\
 &= 3 \text{ days } 20 \text{ hrs } 13 \text{ mins and } 47 \text{ secs}
 \end{aligned}$$

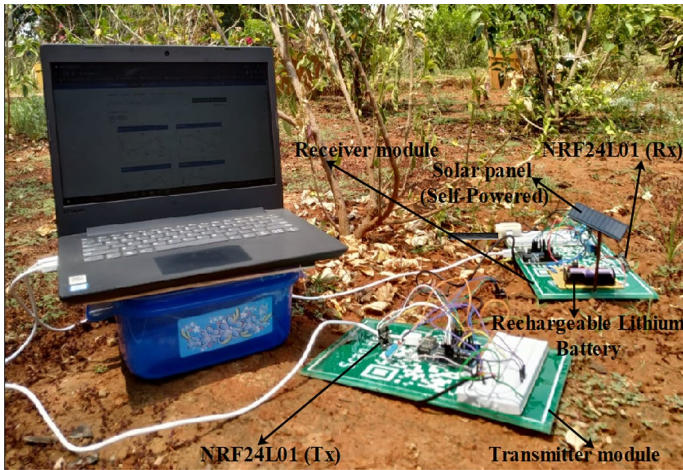


Fig. 11 Practical hardware implementation of the proposed agriculture monitoring system

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 m of the plot, the PLR (Packet Loss Rate) is minimal, and it is below 2 percent.

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 Figs. 13 and 14 respectively. Figure 15 shows the circuit implementation through Proteus software for simulation.

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.

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.

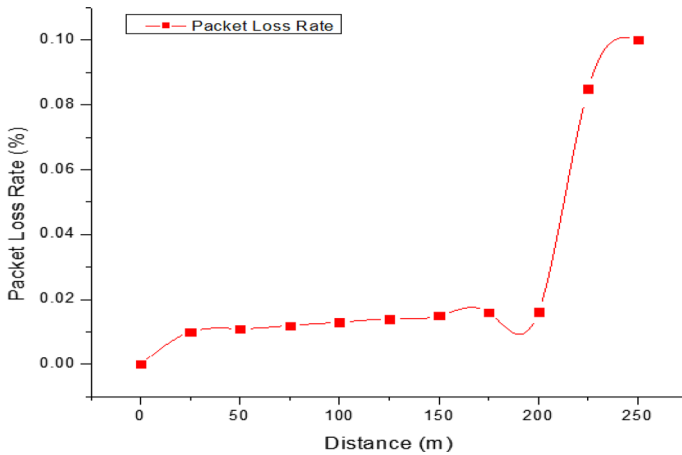


Fig.12 Packet loss rate versus distance

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 various wireless networks with link quality versus distance as shown in Fig. 18. Table 6 provides information on the parameters related to the proposed architecture as well as existing systems. Figure 19 illustrates the field coverage area versus distance.

10 Conclusion

IoT investigates the agricultural field's quality to increase crop yield, boost efficiency, and lower costs. Here, 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 a remote location. Additionally, the system has some flaws, such as limited coverage area and high data loss. The proposed system is supposed to solve the issues of existing systems. As a result, farmers can choose the best strategy for healthy agriculture practices with cost-effective hardware. The proposed approach increases accuracy and reduces data loss by enabling long-distance monitoring options. There is low power consumption, more field coverage area. Also, there is good wireless connectivity and the link quality is increased up to 200 m in open environment.

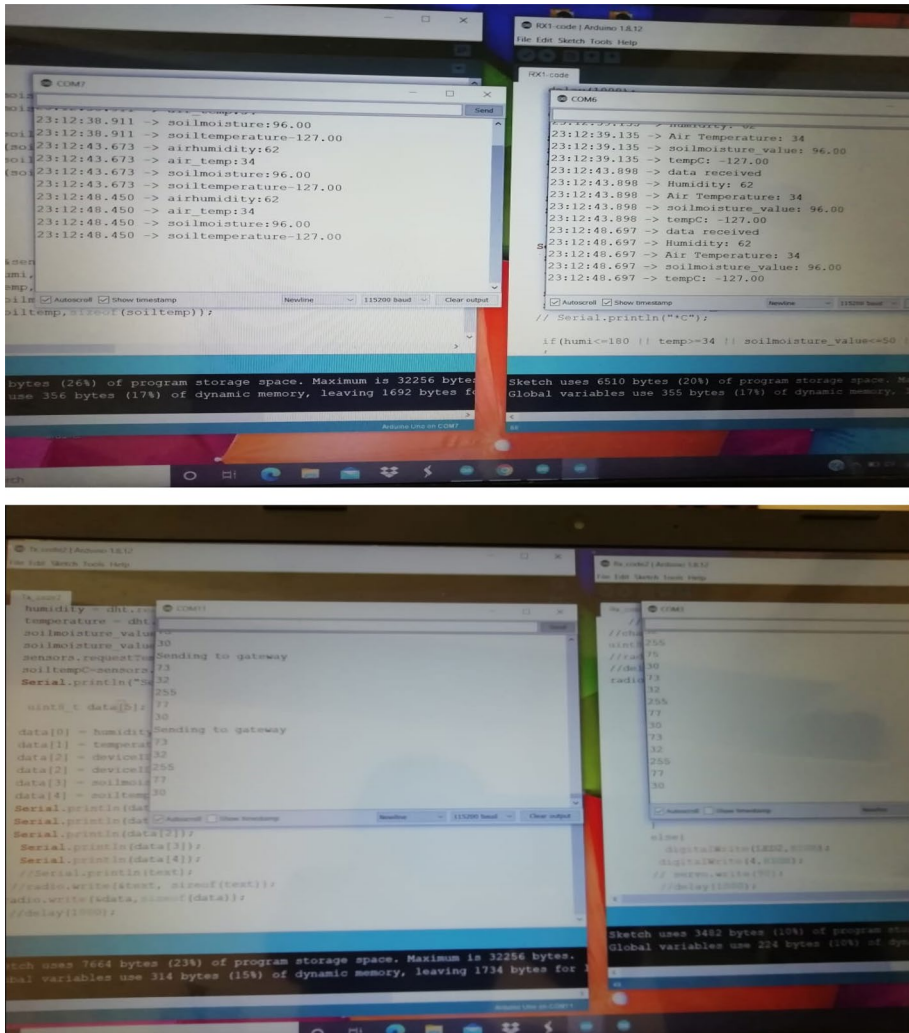


Fig. 13 Serial monitoring results from Arduino IDE for both the transmitter and receiver sections

```

Python 3.7.0 Shell
File Edit Shell Debug Options Window Help
Python 3.7.0 (v3.7.0:1bf9cc5093, Jun 27 2018, 04:59:51)
4) | on win32
Type "copyright", "credits" or "license()" for more in
>>>
===== RESTART: C:\Users\Ch Venkata Sowmya\Downloads\seri
done
humidity value is 73
humidity value updated
temperature value is 32
temperature value updated
Device ID is 255.0
device ID value updated
soil moisture value updated
soil moisture value updated
soil temperature value updated
soil humidity value is 73
humidity value updated
temperature value is 32
temperature value updated
Device ID is 255.0
device ID value updated
soil moisture value 50.0
    
```

Fig. 14 Serial monitoring results from Python IDE

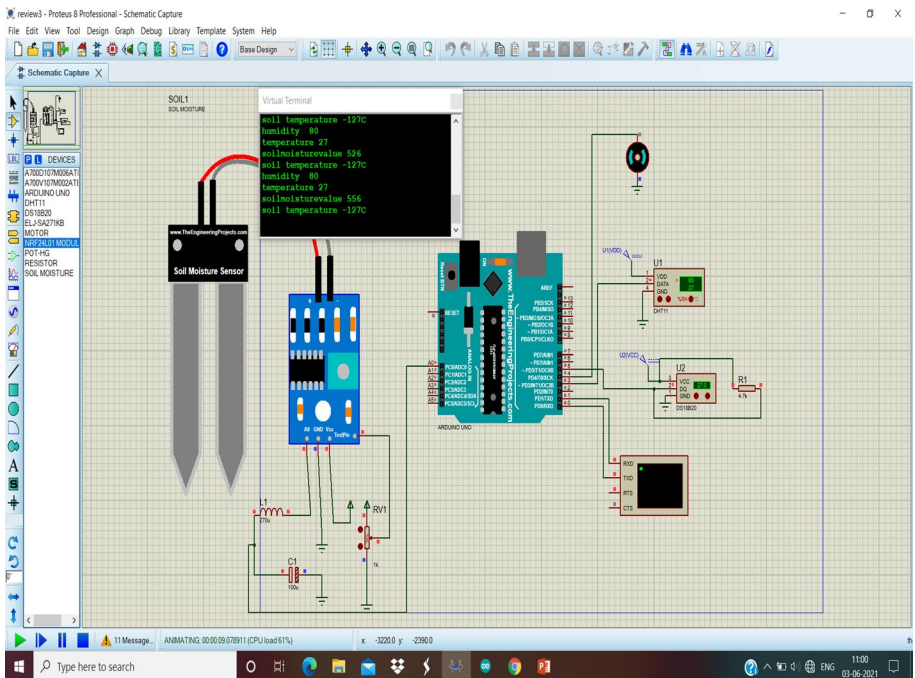


Fig. 15 Circuit implementation in Proteus software



Fig. 16 Implementation results from the ThinkSpeak cloud platform

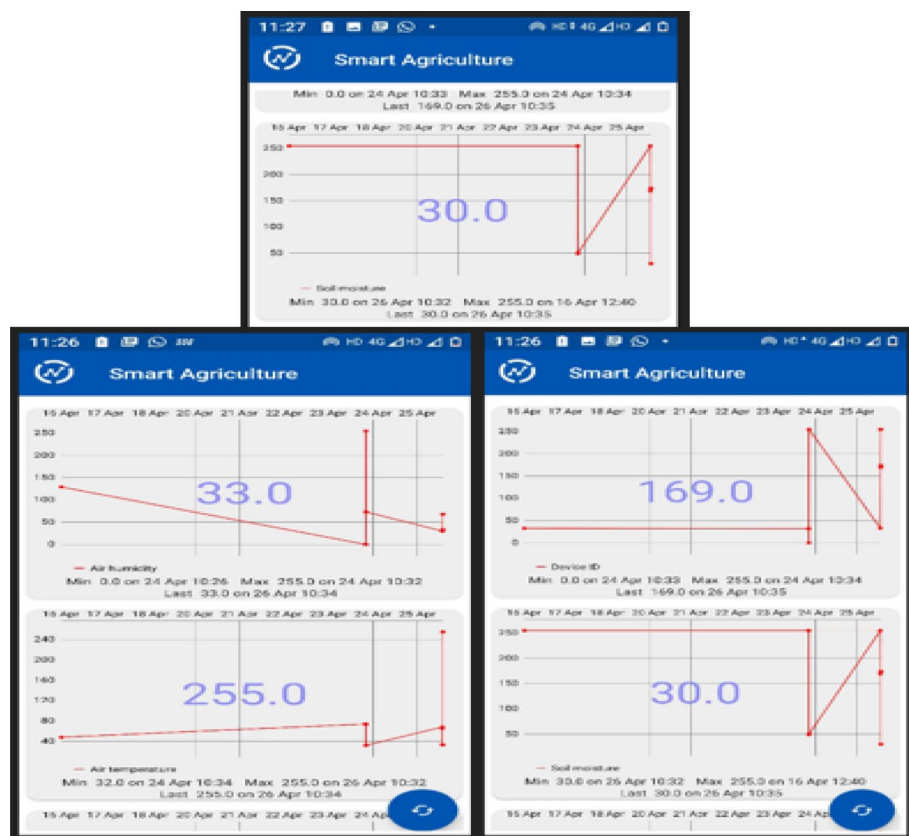


Fig. 17 Implementation results from the ThingView mobile app

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

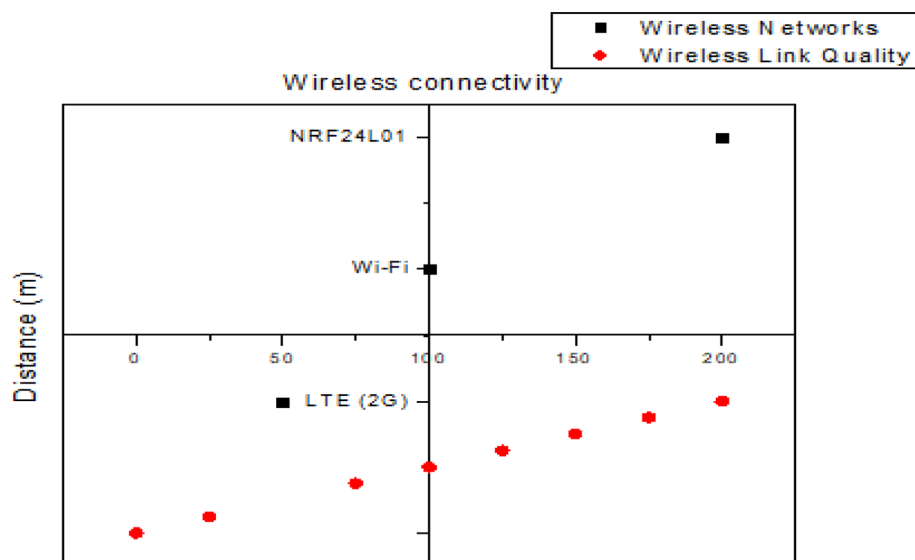


Fig. 18 Wireless Networks and Link Quality versus distance

Table 6 Proposed architecture Vs existing systems

S. No	Implementation of architecture	No. of sensors used	Wired/Wireless connectivity module	Field coverage area (Acre)
1	Yes	2	Ethernet shield	1.05
2	Yes	3	Wi-Fi (ESP8266 Chip)	1.15
3 (Proposed)	Yes	4	NRF24L01	1.25

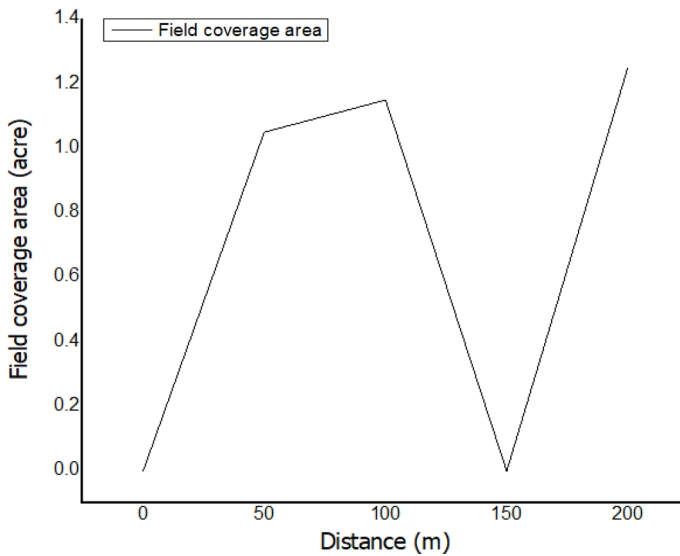


Fig. 19 Field coverage area Vs distance

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Data Availability Related to the work, every data has been provided in the manuscript.

Code availability Not required for this work.

Declarations

Conflict of interest There is no conflict of interest with any person or body regarding this work.

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