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A Secure, Low-Cost Cloud-Based Data Storage, Retrieval, and Analytics System for IIoT Agriculture Application

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Abstract

With the Internet of Things being widely adopted, it led to rise of millions of devices which produce enormous data in various formats. IoT is now being used in many Agriculture applications, with large-scale deployment of leading to industrial IOT in agriculture. The management of devices, secure storage, and data processing poses challenges due to limited energy, storage, and vulnerability to threats that can impact data integrity. To address these challenges a comprehensive framework tailored to cater to agriculture IIoT is proposed. This framework is based on cloud computing and integrates data processing, secure and efficient storage, and dynamic data collection while ensuring secure and controlled access to the system. The hardware compromises of node MCU which interfaces with the sensors and actuators and processes and sends their data to the cloud service i.e., firebase via Wi-Fi. the sensors used are the DHT11 temperature and humidity sensor, LDR light sensor, and soil moisture sensor and actuators namely the water pump, light, and humidifier represented by LED lights. The received data in the firebase cloud can be accessed by our website after crypto. the website features a login page, real-time sensor data, actuator control, and real time line chart on the home page. The owner and supervisor are given full access to read data and control actuators whereas the workers are given read-only access to data ensuring system integrity. This proposed system optimizes storage by reducing load on end devices is cost effective occupies minimal storage and ensures security, efficiency, and compliance.

Keywords: *IIoT, Node MCU, water pump, light, humidifier, actuators, sensors, real-time, website, DHT 11, LDR, firebase, WIFI, website development, security, compliance*

1. Introduction

IoT is the means of connecting various physical devices to the internet. The devices usually sensors, actuators, devices, and machines can now collect data from surroundings, exchange and process it. These IoT-enabled devices can be programmed and automated to function autonomously. IoT when enriched with the latest cloud technology further solves problems that arise with using IoT like storage and processing of data generated by devices, allowing real-time access to data to be easily tackled. The cloud can process terabytes of data which is cost effective and economical eliminating the need for owning physical servers. With the added benefit of serverless cloud computing IoT has found increased adoption in agriculture, homes, healthcare and wearables, etc.

With IoT being adopted at an incredibly fast pace by many industries, this led to IoT being implemented on a very large scale with some industries whose application requires

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

millions of devices to be integrated into the system. With IoT implemented on this large scale, it gave way to a new term Industrial Internet of Things also being widely known as Industrie 4.0. IIoT can be utilized to integrate a wide array of technologies ranging from machine learning, data analytics, and automation to robotics and machine-to-machine communication(M2M).

While the IIoT might look promising it also comes with its fair bit of challenges. Now that more numbers of devices are connected to the internet, these devices can also serve as vulnerable entry points into the IIoT system. With various different manufacturers of these devices in the market with their own different non-standard security systems and standards it complicates the entire process of complete system-wide protection. There is a lack of standardization in the complete IoT ecosystem with some devices on older security standards and some on legacy systems. There are severe consequences of poor security implementation in IIoT with system downtime, data breaches, data tampering, and DDoS bot attacks, hence the need for a robust secure IIoT system arises.

In order to maximize the protection and integrity of data in an IIoT system with need to implement security parameters namely Confidentiality, Integrity, authentication, authorization, encryption, and timely system updates and patching of known vulnerabilities. For additional security in IIoT system utilization of secure communication channels, end-to-end security, real-time system monitoring and response, and network segmentation can be implemented, it is necessary to first study the requirement of the application before implementing these additional security measures as they can increase computational overload leading to higher cost of operation.

The aim of the proposed IIoT system is

- To design a low-cost, secure, and efficient data storage, retrieval, and analytics system using cloud technology for IIoT agriculture applications.
- The system proposed should transmit data efficiently while utilizing the minimal network bandwidth and shall occupy minimal storage space in the cloud.
- To develop a Full stack website that provides real-time sensor data, actuator control, real-time line charts, and Role-based access to the proposed system.

2. Literature Survey

Table 1 contains information regarding the previous works done on data storage, retrieval, and analytics based on the computing technique alongside similar existing agriculture IoT frameworks with relevant remarks.

S.No	Paper	Technique	Remarks
1	[2]	Cloud Computing	Improved data compression and security utilizing algorithms
2	[3]	Hybrid cloud computing with role segregated access	There is high computational overload and limited scalability
3	[4]	Fog and Edge Computing	Edge computing increases edge device load

4	[5]	Cloud Computing and block chain technology	High Security but higher cost and power draw
S.No	**Paper**	**Technique**	**Remarks**
5	[6]	Cloud computing with PIR algorithm	High latency, a tradeoff between security and efficiency
6	[7]	Simple IoT device architecture using legacy physical server	Low security and integrity of data, no access controls provided
7	[8]	Simple IoT architecture-based intrusion detection system	Store data locally, on-device data processing, high energy consumption
8	[9]	Cloud ARM 11 based Public IP and RDBMS system for agriculture IoT	Not power efficient, missing role-based access and actuators controls, no encryption mechanism

3. Block Diagram

This section briefly outlines the proposed system architecture. The entire system can be subdivided into three sections with each part portraying a necessary function.

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ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

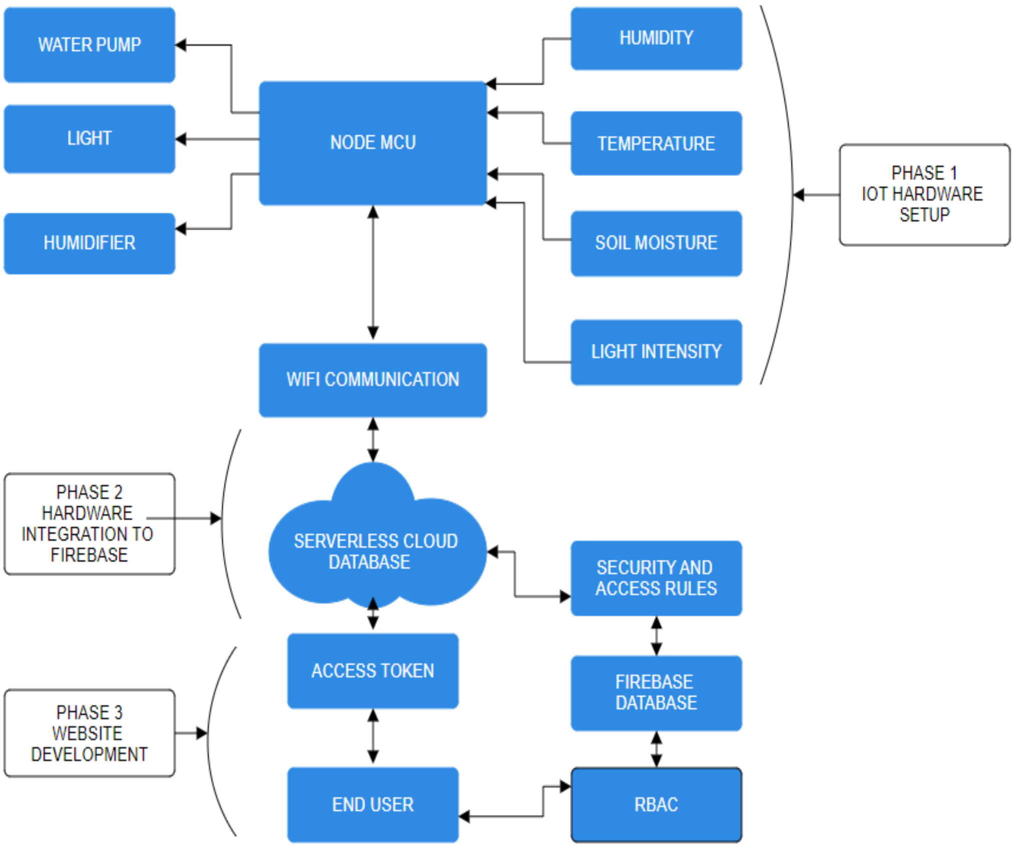

Figure 1 Block diagram of secure data storage and retrieval system

3.1 IoT Hardware Setup

Selection and interfacing of hardware is the first step in achieving our proposed system. The sensors utilized are a DHT 11 Temperature and Humidity sensor, LDR based Light sensor, resistive soil moisture sensor, the actuators are represented by blue, green, and red LED light and finally, the microcontroller used is ESP8266-based NodeMCU.

NodeMCUv1.0: it is an open-source IoT platform that is built on top of an ESP8266 Wi-Fi microcontroller. NodeMCU provides us with a comprehensive framework in order to develop applications easily. It works by the combination of Lua scripting language and hardware functionalities of ESP8266.

NodeMCU comes with built-in Wi-Fi capabilities in order to connect to the network or internet additionally it has GPIO pins for interfacing with other devices and Arduino compatibility. It works on the standard IEEE 802.11 b/g/n standard in the 2.4ghz frequency range. It is low-cost, easy to use, and promotes fast IoT prototyping.

Software tools: Arduino IDE

Programming language: Embedded C

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www.ijasem.org
Vol 18, Issue 4, 2024

Figure 2 NodeMCU v1.0

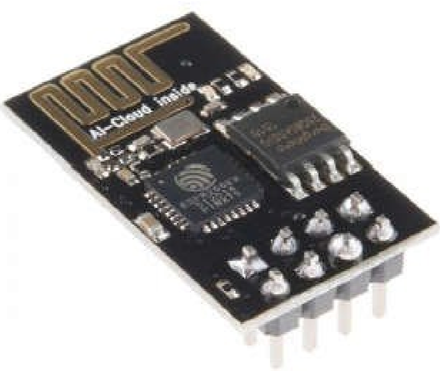


Figure 3 ESP8266 Wi-Fi Module

DHT11: it is a low-cost sensor that can measure both temperature and humidity values. It provides an output signal which is calibrated for use in various applications where there is a need of environmental monitoring of these parameters. It consumes very less power usually under 2.5mA, which makes it very desirable for applications that utilize limited-capacity batteries.

With its digital output signal, it makes the process of integration with other devices like microcontrollers and development boards easier. It uses a single wire for data communication and is very compact making it desirable for simpler low-cost embedded systems.

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

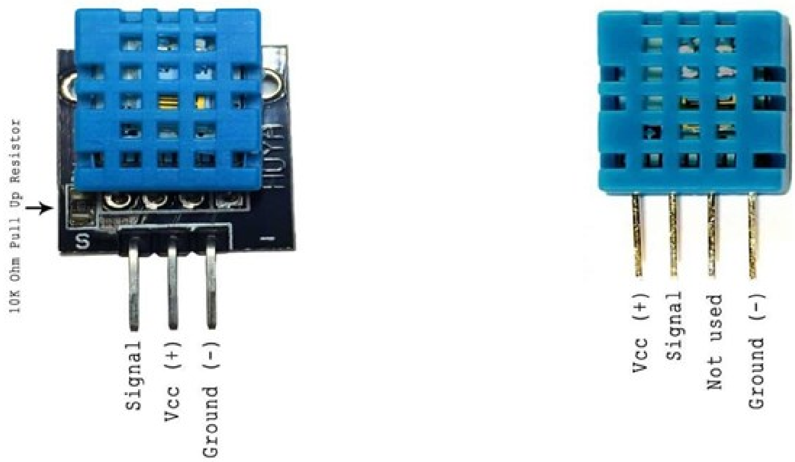


Figure 4 DHT 11 Sensor

Soil Moisture Sensor: it is a low-cost and simple sensor that is used for the purpose of measuring the content of moisture in the soil. It consists of two conducting probes that are placed in the soil. It works by detecting the amount of electricity that is passing through the probes. When there is more moisture in the soil the resistivity of the conductive probes decreases and when there is less moisture i.e., when the soil is dry the resistivity is higher, the changes in resistivity determine the moisture content in the soil.

it consists of two outputs digital and analog any one can be utilized as there is only one analog pin in nodeMCU hence the digital mode is utilized. This sensor is simple to interface and can be used with many popular microcontrollers and development platforms.

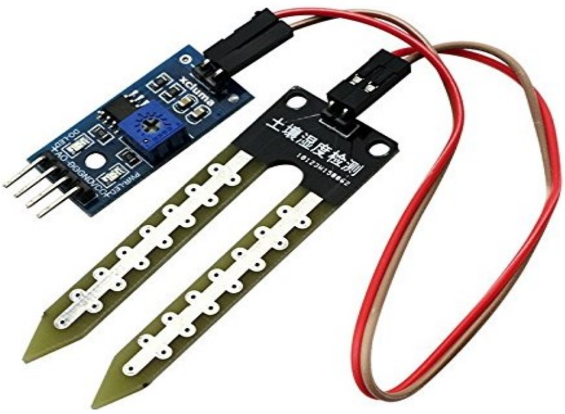


Figure 5 Soil Moistire sensor

LDR Light Sensor: LDR is Light light-dependent resistor it is also called a photoresistor. This sensor is used for measuring the intensity of light. It consists of a photoresistor whose resistance increases when the darkness increases and its resistance decreases when it is in bright light. Hence by the changes in resistivity, the intensity of the light is calculated.

This sensor provides an analog output only hence we interface it to the analog pin on the nodeMCU. The cost of this sensor is less and is easy to interface with microcontrollers and other development boards requiring minimal interfacing. Its response is typically slower but is widely used for non-precision applications.

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

Figure 6 LDR Light Sensor

3.2 Google Firebase Cloud Development Platform

Firebase was developed and introduced by Google as a cloud platform that offers a wide range of tools and services that can be used for developing different types of mobile and web applications. It provides backend development services like data management, authentication, analytics, and hosting services.[1]

The code to integrate Firebase with NodeMCU is done by utilizing the cryptographic API (Application Programming Interface) key provided by Firebase. Once the key which is based on a scrypt algorithm with AES (Advanced Encryption Standard) 256 bit is integrated and Firebase authenticates it then the NodeMCU can communicate with the Firebase cloud and real-time database and send and receive data. It offers a real-time database, firestore, and various other cloud functions such as serverless architecture, event-driven execution, security, and monitoring.

Programming language: JavaScript/Typescript, Kotlin/Java, Swift/objective-C and Dart.

Software tools: Firebase web platform

3.3 Website Development

This is the last stage of the proposed scheme. Here a full stack website is proposed which can be accessed by all the authorized employees. Here each employee is provided with an email ID and password that can be used to log on to the website. once an employee logs into the website, he can get access to all sensor values like temperature, humidity, light intensity, and soil moisture status. Based on the role assigned to the employee in the Firebase platform if he is the owner or supervisor, he has an additional option to control the actuators. New users can be assigned to the Firebase platform.

The website structure consists of 6 pages that are as follows:

- Role Selection Page
- Owner/Supervisor Sign-in Page
- Worker Sign-in Page
- Authentication (on Backend)
- Worker Home Page
- Owner or Supervisor Home Page

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

The programming language and web development software tools used are mentioned below:

- **Software Tool:** Visual Studio Code 1.94.1
- **Programming Language:** HTML, CSS, and JavaScript
- **Framework:** Bootstrap Framework
- **Backend:** Firebase BaaS (backend as a service)
- **Targeted platforms:** All platforms with modern browser support

4. Consideration in designing the framework

There are many challenges and considerations encountered during the time of designing the framework. The main aim was to store data securely occupying minimal space in the cloud, easy to retrieve the stored data some challenges and considerations are as follows:

- In general, the end devices of IIoT are redundantly deployed and they may collect redundant, heterogeneous, dynamic, one-sided, and inaccurate data [13]. As a consequence, the raw data are not suitable for being stored and retrieved.

- The main aim of utilizing cloud storage is to reuse the data stored in the near future with the aim of searching and querying the data efficiently and retrieving it again.

- To ensure that the proposed system has robust security, it is essential to protect and maintain the integrity of data. while making it still reliable for use. This necessitates the design for implementation of various privacy protection and preserving schemes in the data storage system.

- To prevent unauthorized access, we assign roles based on the specific access each user needs, limiting their privileges accordingly, in order to interpret the data basic line charts are to be implemented for analytics. Data in the cloud should we organized dynamically to let new data storage and old data being indexed for efficient retrieval.

- Considering the ease of access, as a website can be used on any device with an active internet connection, we decided to pursue the development of a website instead of a device-specific application.

5. Hardware Implementation of the Proposed System

The hardware implementation consists of hardware components that are used in the system namely NodeMCU, DHT11 sensor, soil moisture sensor, LDR light sensor, and 3 LEDs (Blue LED for Humidifier, Green LED for water pump, and red LED for Light source) and female connecting pins.

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

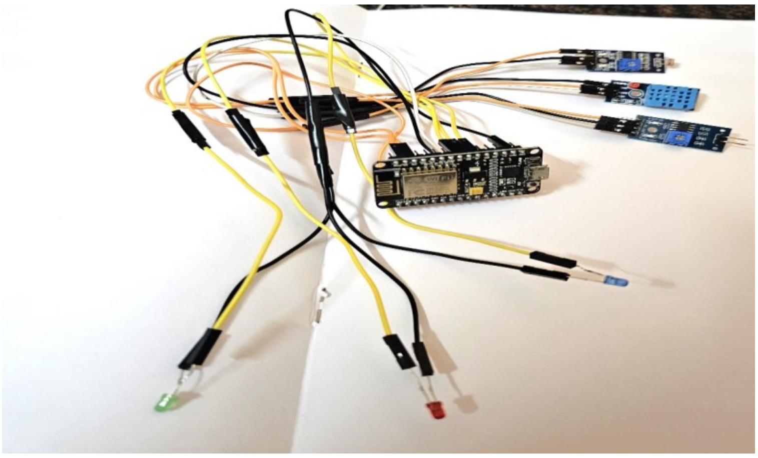


Figure 7 Prototype Hardware implementation of the proposed system

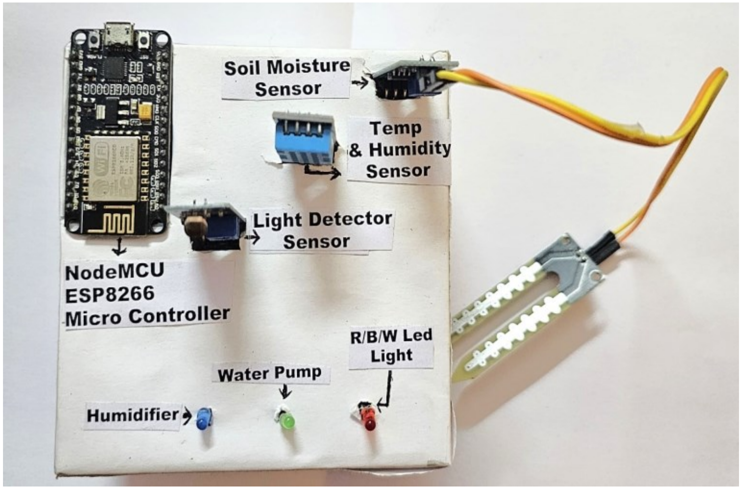


Figure 7 Final Hardware implementation of the proposed system

6 Implementation Results and Analysis:

This section discusses the results obtained from the proposed system and its analysis.

6.1 Hardware Implementation Results:

Figure 8 gives the result when the humidity is greater than the lower limit and less than the upper limit, then the blue LED representing the humidifier is switched turned ON whereas the soil status is “Wet” and the light intensity is above the threshold hence only humidifier is turned on whereas water pump and light is turned OFF. (Here all the parameters are measured in a room environment and the soil moisture sensor is dipped in water to get Wet Status)

ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

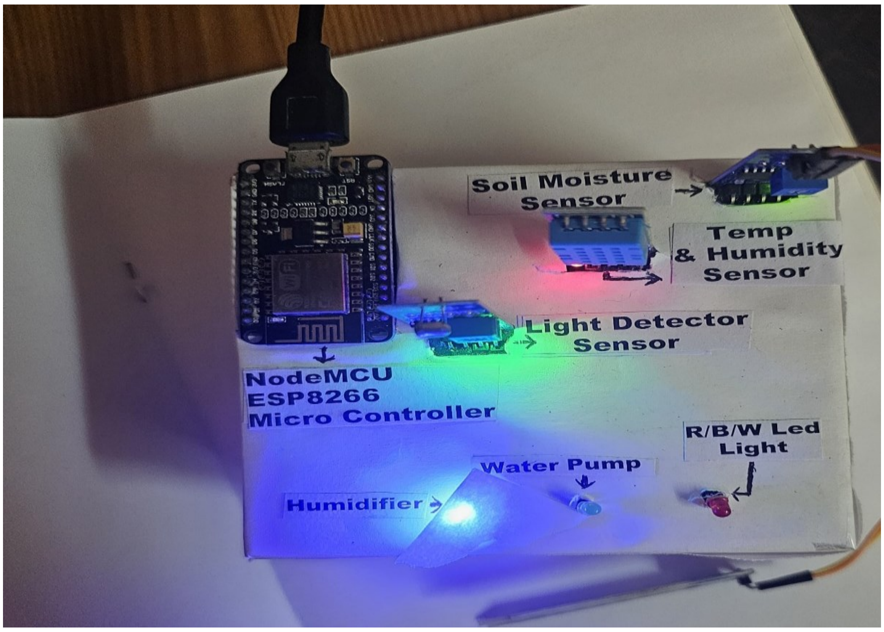


Figure 8 Humidifier ON, Water Pump and Light OFF

Figure 9 gives the result when the water pump is turned ON manually or if it's set to AUTO mode where the water pump only turns ON when it detects that the soil is dry. Hence here soil is wet and humidity is higher than the threshold and the light intensity is above the set intensity threshold thereby Water pump is ON and the rest humidifier and light are OFF

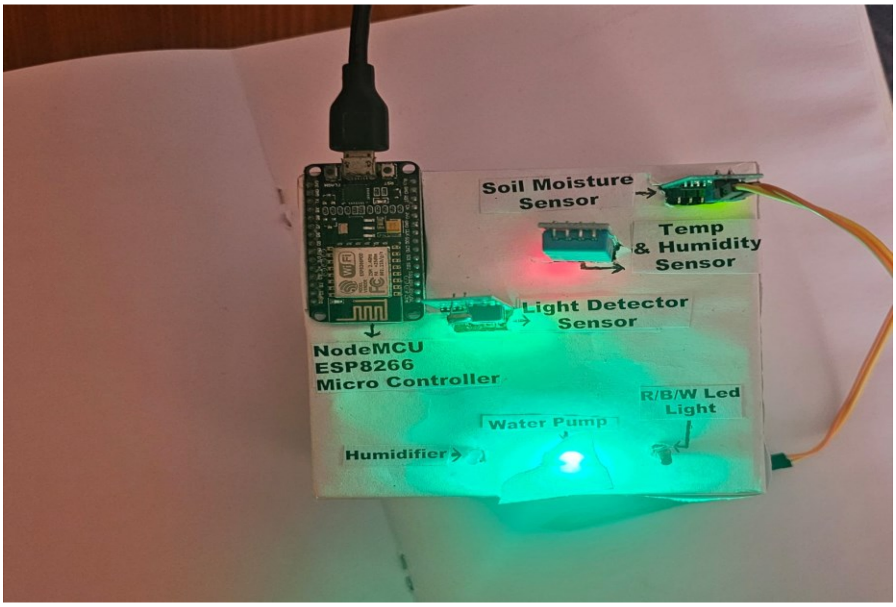


Figure 9 Water Pump ON, Humidifier and Light OFF

Figure 10 gives the result when the light intensity is detected to be lower than the set threshold value. The Light is turned ON when the light intensity goes below the threshold value and turns off once it's above the threshold. The humidifier and water pump are at OFF status due to humidity higher than set values and the soil status being wet.

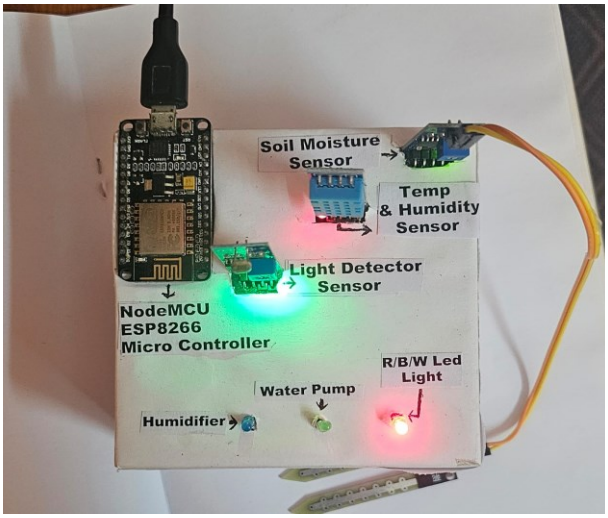
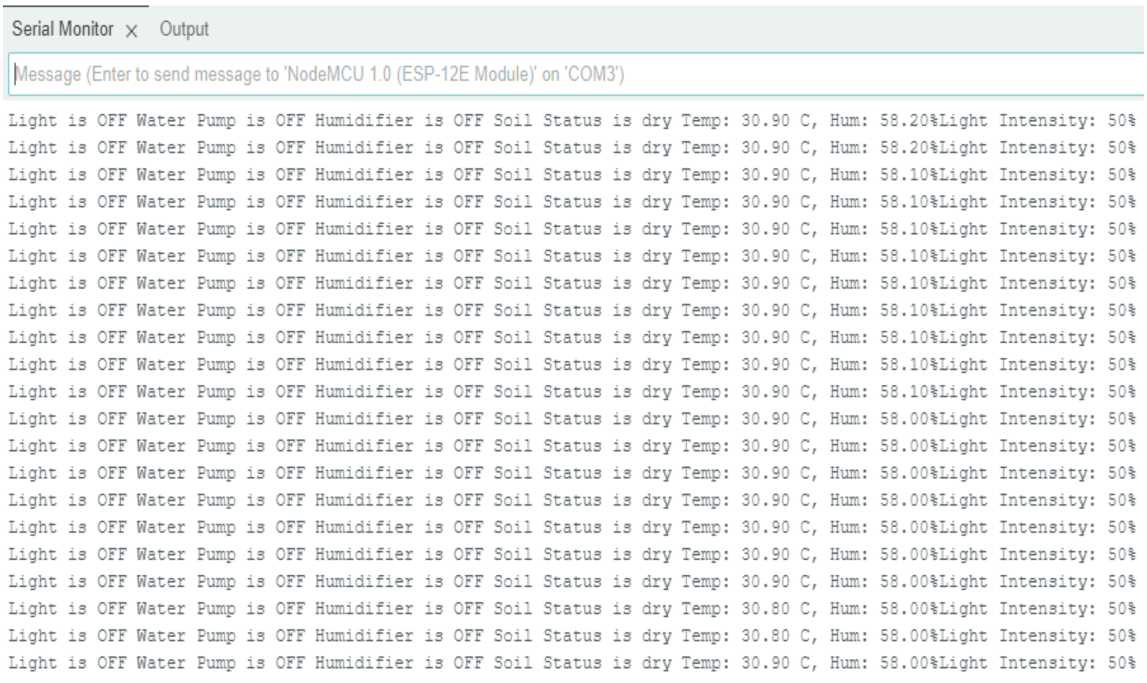


Figure 10 Light ON, Humidifier and Water Pump OFF



Serial Monitor × Output

Message (Enter to send message to 'NodeMCU 1.0 (ESP-12E Module)' on 'COM3')

```
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.20%Light Intensity: 50%
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.20%Light Intensity: 50%
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.10%Light Intensity: 50%
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.10%Light Intensity: 50%
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.10%Light Intensity: 50%
Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.10%Light Intensity: 50%
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Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.00%Light Intensity: 50%
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Light is OFF Water Pump is OFF Humidifier is OFF Soil Status is dry Temp: 30.90 C, Hum: 58.00%Light Intensity: 50%
```

Figure 11 shows sensor and actuator values on the serial monitor of the Arduino IDE

6.2 Firebase Web Platform Results:

Firebase provides a free spark plan which we can utilize for upto 1 GB of firestore stored data in real time database and 10GB of Downloads. The proposed system occupied only 498 Bytes of data and 14.5MB downloads.

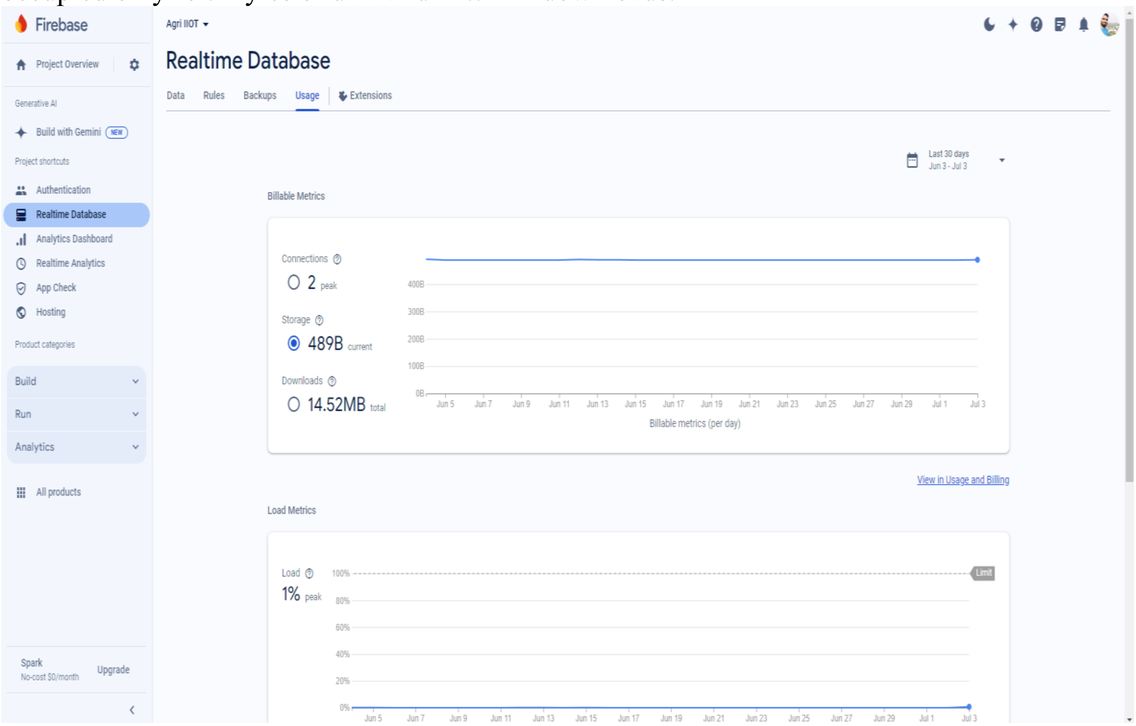

Figure 12 Storage Space Occupied and Data Downloads

6.3 Website Development Results

The website can be accessed on any device by opening the browser and visiting the URL: www.agri-iiot.web.app as shown in Figure 13.

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www.ijasem.org
Vol 18, Issue 4, 2024

Figure 13 URL and Login Page

After the user selects the role then he is redirect to the respective login page of Admin for owner or supervisor and worker page for worker.Figure 15 shows If the user enter wrong email or password then a popup with Login Failed please try again appears.if correct login details are entered they are redirected to respective home pages.

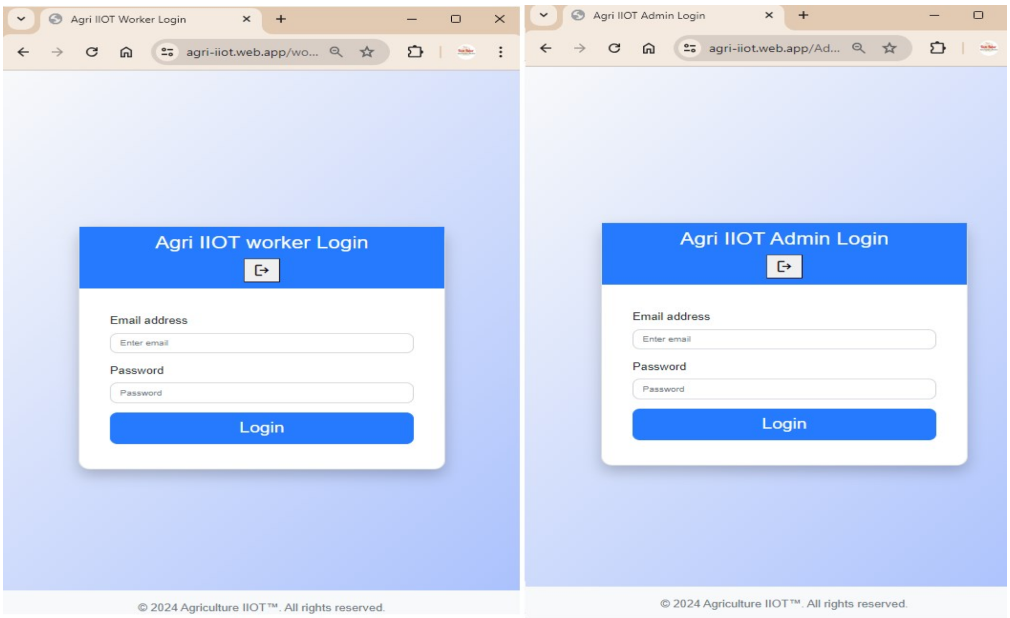

Figure 14 Worker or Admin Login Page

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ISSN 2454-9940
www.ijasem.org
Vol 18, Issue 4, 2024

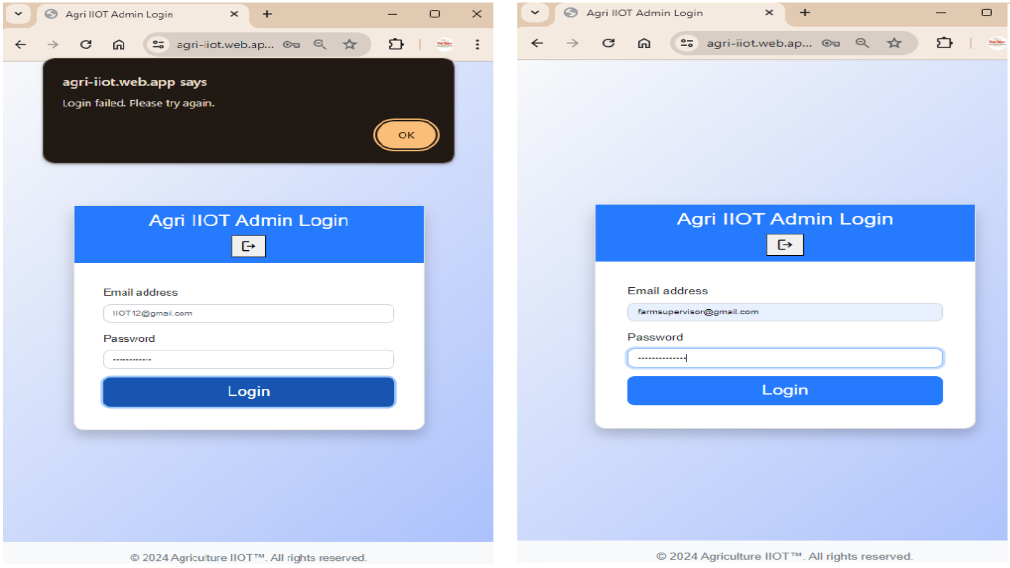

Figure 15 incorrect login details vs correct login

When owner or supervisor is logged into the website the home page contains sensor data updated every 10 minutes,real time line charts and the control of actuators by setting their threshold values as shown in Figure 16 and finally the worker home page is similar to that of Admin page except it doesn't have access to control of actuators as shown in figure 17.The real time line charts are indentical for both admin and worker page. The thresholds can be set and it applies when clicked on submit button.

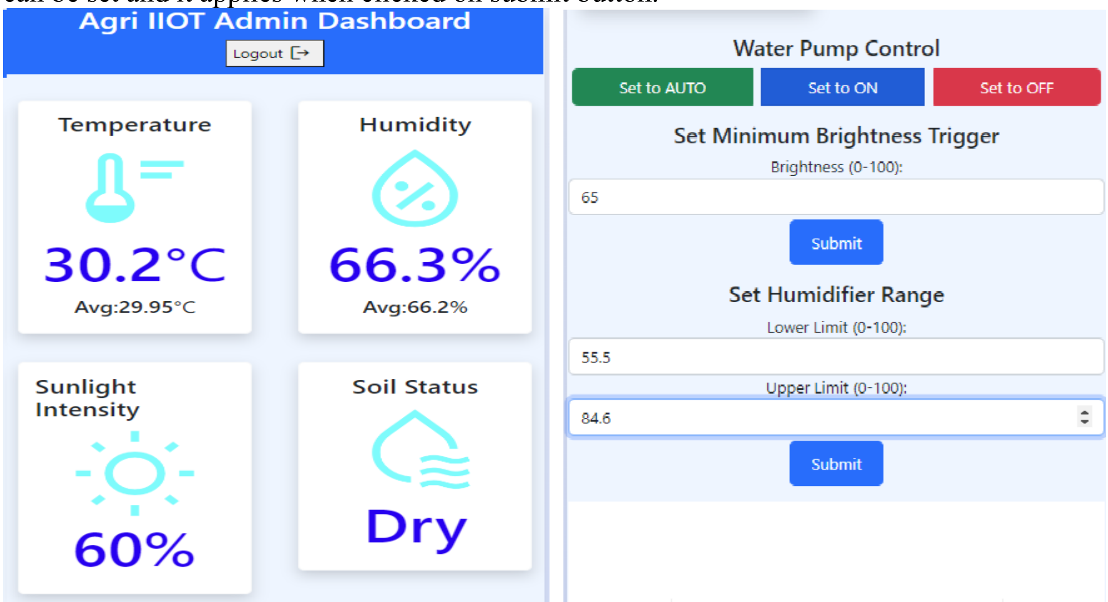

Figure 16 Admin Home Page with Actuator Control

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN 2454-9940

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Vol 18, Issue 4, 2024

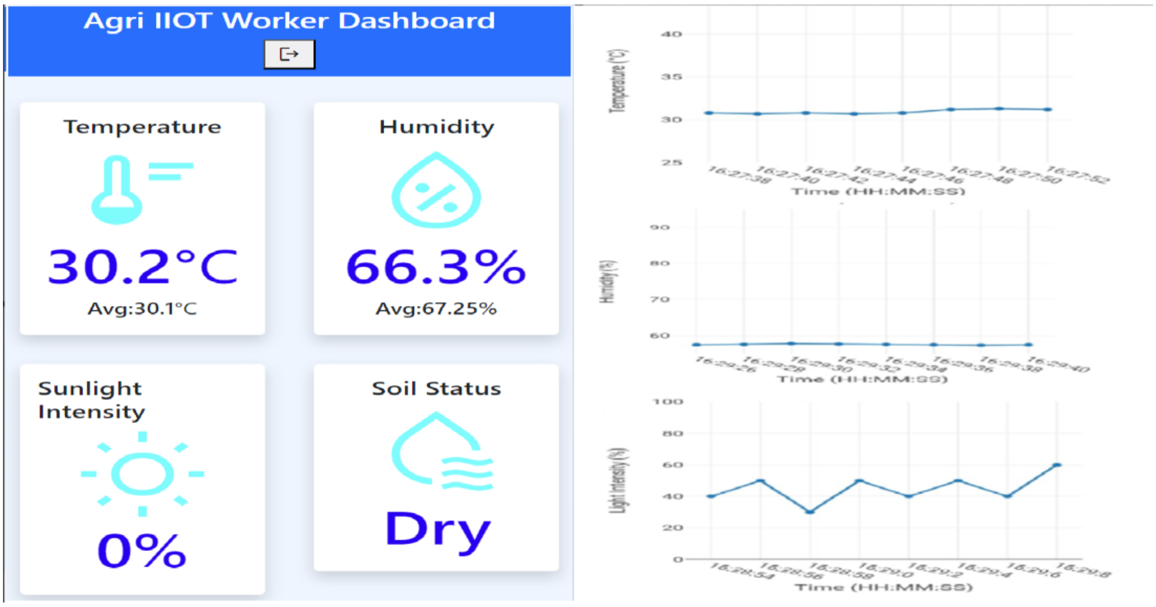

Figure 17 Worker Home Page with Real Time Line Charts

7. Conclusion

The system developed is very secure with Role-based access to the system, it is efficient and occupies very less space which in turn contributes to lower cloud operation costs, in addition to this all the hardware utilized in the system is very economical. The proposed system is faster and in comparison, to all the existing techniques as discussed in the literature survey. This system does not use physical servers thereby reducing associated costs and improving security. The website developed was made for in-house use for authorized workers, owners, and supervisors in agriculture. This system can be integrated with other industry-specific applications. The role-based access to the system promotes data integrity and identity management eliminating problems arising with giving unrestricted access to non-authorized users. This system was successfully designed and tested and a prototype was made to demonstrate its working.

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ISSN 2454-9940
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Vol 18, Issue 4, 2024

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