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IoT Based Smart Agricultural Crop Monitoring in Terms of Temperature and Moisture

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Abstract: The agricultural industry has been transformed by the Internet of Things (IoT) revolution, which has brought about cutting-edge solutions to problems relating to crop monitoring and management. This article provides a thorough analysis of a smart agricultural IoT system created for effective crop monitoring of crop moisture and temperature. The objective of this research is to create a comprehensive system that can continuously track temperature and moisture levels in agricultural fields, giving farmers useful information for smarter crop management decisions. To continually monitor and analyse important environmental parameters impacting crop growth, the created system incorporates several IoT components, such as wireless sensors, actuators, and cloud-based data analytics. Temperature and moisture are the two main factors that determine the health, yield, and general quality of the crop. Real-time temperature and moisture data are gathered from various points inside the agricultural field by the use of wireless sensors. The information is subsequently processed and interpreted by sophisticated data analytics algorithms on a cloud-based platform. According to the study, the IoT-based system effectively regulated environmental temperature, resulting in an average decrease to 26.2°C, while concurrently maintaining or improving soil moisture content, evidenced by an increase to 45%. Farmers with this guidance can therefore improve their decision-making processes and ultimately increase agricultural yield, sustainability, and economic consequences by utilising IoT capabilities. Further research and development in this area could revolutionized global agriculture and help ensure food security in the face of shifting climatic circumstances and rising population demands as IoT continues to develop.

Keywords: *IoT, Smart agriculture, Crop monitoring, Precision agriculture, Temperature, Moisture*

1. Literature Review:

To truly understand the monitoring of crops, applications for using Internet of Things (IoT) within agriculture and how to get data into decision-making it is important that firstly one should look at literature which has already been published. In this way, the analysis will find areas which have not been well studied and stimulate new thinking on methodology in research. The following is a summary of the literature review.

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IoT in Agriculture:

Agriculture, which is the base on which mankind depends for its survival. It aggravates a major problem in world food management. Most farmers use obsolete traditional methods to raise their crops. In the past, they have conducted on-site inspections to evaluate crops directly. The decline in agricultural productivity can be blamed on the use of antiquated agriculture and monitoring.

This project illustrates that the use of technology is essential for sustainable agriculture. Saha, Mat and Saha (2020) demonstrated this in their research. With the intelligent application of IoT technology in agriculture, farmers have come to monitor and regulate a great many aspects of crop cultivation. Gubbi et al (2013) argued that the IoT facilitates the real-time collection of data, its processing, and subsequent decision-making.

Therefore, this leads to better resource allocation and higher agricultural productivity. Moreover, the advantages and disadvantages of deploying IoT based intelligent agricultural monitoring systems have been studied in detail among researchers. This approach has the advantages of improving agricultural production, raising resource efficiency and reducing ecological impact. But they also raise other concerns that need addressing, including sensor calibration, secure data protection and optimizing energy efficiency (Lee et al., 2018; Zeng et al., 2020). Research also stressed the importance of data processing and analysis in IoT-based agricultural systems. Forecast changes of moisture levels and temperature, detection patterns crop stress--in the studies by Khan et al. (2019) and Wu et al. (2021), researchers have all put forward many ways to handle large quantities of data from sensors efficiently.

Remote Monitoring and Control:

A clear advantage of agricultural monitoring systems based on the IoT is remote monitoring and control. In 2017, Khanna et al. introduced a sophisticated remote monitoring system for greenhouse agriculture. In 2017 they put in place a system whereby the farmers could concentrate on and monitor environmental factors of temperature, humidity or carbon dioxide. Saha et al. (2020) suggests that the development of agriculture-based IoT online visualisation systems can completely change plant management and monitoring methods. Because of the development in sensor networks, actuators and communications technology called IoT (Internet of Things), crop monitoring systems can collect all kinds environmental data. So, these systems let farmers know the many important changes that impact plants 'growth, like soil moisture, temperature and humidity; light intensity etc.

Wang et al. (2016) noted the network's efficiency on irrigations and fertilizer applications, respectively. Further, since wireless sensor networks (WSN) are the foundation of IoT-based agricultural monitoring systems they can acquire data from different points inside a field. Sensors on-site gather and e-mail various parameters to a central monitoring system. WSNs in precision agriculture was explained by Bhardwaj et al. (2018). Thus WSNs have become an integral part of IoT-based agricultural monitoring systems. Researchers have given much attention to using wireless sensors for temperature and moisture monitoring of different crop varieties. Gupta et al. (2019) and Yang etal. (2020).

IoT and Precision Agriculture:

The development of IoT technology has sparked great interest in precision agriculture, which many reckon will change the way we oversee and operate our crops. Many articles have explored how IoT devices can monitor key environmental data in real time, including temperature and humidity. These methods, like those of Alotaibi et al. (2018) and Wang et al., raise efficiency level while reducing waste at a production scale so as to increase overall agricultural productivity. In a study published in 2019, Mat and Saha added to the field of accuracy while also stimulating debate on using modern visualization methods as a means for improving precision in agricultural practice.

Challenges and Future Directions:

The concept of the IOT has generated huge interest in precision agriculture. Most research articles point out that IoT sensors can carry on measuring environmental data including temperature and humidity in real time. As noted in the work of Li et al. (2019), and Liu et al. (2020) who have published many articles on this topic, using IoT-based management methods is one method to make it easier for up farmers get at both current as well as historical data points for example, the technology's main focus is providing farmers with personalised monitoring requirement.

The literature study focused on the growing attention to IoT-based crop monitoring systems, which have studied in detail how temperature and moisture change with maturation. Past studies have indicated that the technology of IoT can help farmers improve their practices and decisions. However, there are many obstacles to overcome in order execute such systems efficiently and expandably. Therefore, this research could make a valuable contribution to the field by providing complete solutions-which are designed specifically to overcome these obstacles-to help speed up the advance of IoT agriculture. We must do further research and development to overcome the difficulties, and get some advanced technology onto our agricultural crops.

2. Methodology:

The review of literature related to this study given in the preceding section (Plan of action) helped in formulating the research gap and research design. This section covers the phases of research methodology that is used to focus on answering the research objectives are discussed, achieving the targeted aims. This section outlines the methodological approaches, procedures, techniques, and instruments employed in this study, as well as how all of the study's declared major objectives were met. Hence, this section continues the detailed discussion in different stages of the research method as below mentioned:

i) Sensor Selection and System Architecture:

The right sensors have been chosen based on the crop characteristics such as temperature and humidity that need to be monitored. Then a scalable and affordable IoT platform was used to integrate sensors, for data collection, and transmit it to the sensor network. The created network of sensor nodes for the deployment into agricultural research field was integrated into the IoT system as illustrated in Figure 1.

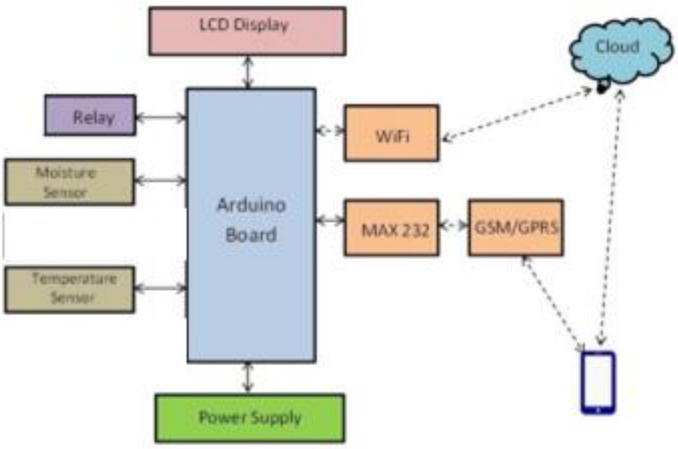


Fig 1. Hardware Block Diagram

ii) **System Design and Development of IoT Platform:**

The system was designed based on developed architecture of IoT system that focuses on real-time environmental data monitoring, including temperature and moisture, and other types depending on the sensors that are built into it. This developed architecture offers the "Plug & Sense" concept, in which farmers can immediately implement smart farming by putting the System on the field and getting the data using various mechanisms like Smart Phones, Tablets, etc. The data generated by sensors can be easily shared and viewed by agriculture consultants wherever they are remotely via Cloud Computing technology integration. Subsequent data gathering system was developed and installed to combine, process, and store sensor data safely.

As illustrated in Figure 2, the system architecture includes an Arduino Uno R3 microcontroller board, sensors such as the LM 35 temperature sensor, and moisture sensor, a Wi-Fi module (ESP8266), and a GSM module. An android application is part of the integrated system.

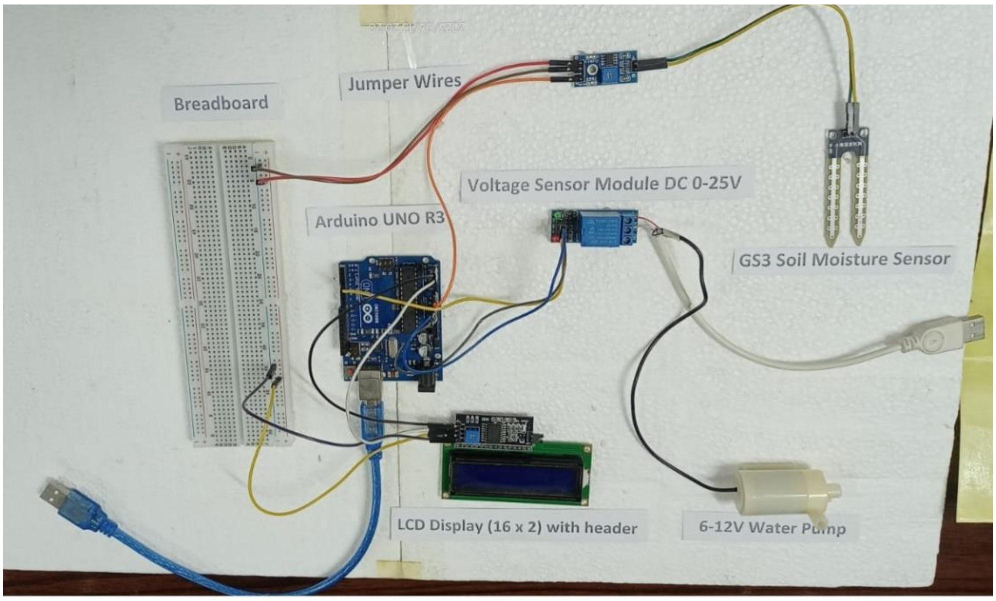


Fig 2. System Architecture

The Arduino Uno board functions as an IoT gateway and regulates all of the operations on the board. All physical parameters are sensed by sensors, which transform the analogue value to a digital value. On the field, temperature and moisture sensors are utilized to measure the parameters. We are using some soil moisture sensors to detect the water content in the soil and a DHT11 temperature sensor which can monitor the weather conditions in the fields. Soil Moisture Sensors are capacitive sensors that are used to measure soil moisture.

iii) Data Collection and Analytics:

To facilitate sensor data collection, transmission, and storage its essential to design and develop a scalable and cost-effective IoT platform. Need to use wireless communication methods to transmit data between the sensor nodes and the main data collection device, such as

Wi-Fi or LoRaWAN. To store the gathered sensor data, establish a reliable and secure data storage architecture, either locally or in the cloud. The designed system is based on a device known as an IoT that focuses on real-time environmental data monitoring, including temperature and moisture, and other types depending on the sensors that are built into it. This offers the "Plug & Sense" concept, in which farmers can immediately implement smart farming by putting the System on the field and getting the data using various mechanisms like Smart Phones, Tablets, etc. The data generated by sensors being shared easily and viewed by agriculture practitioners wherever they are remotely via cloud computing technology integration.

For data collecting, created a network of sensor nodes for using throughout the agricultural crop as Fugure-3.

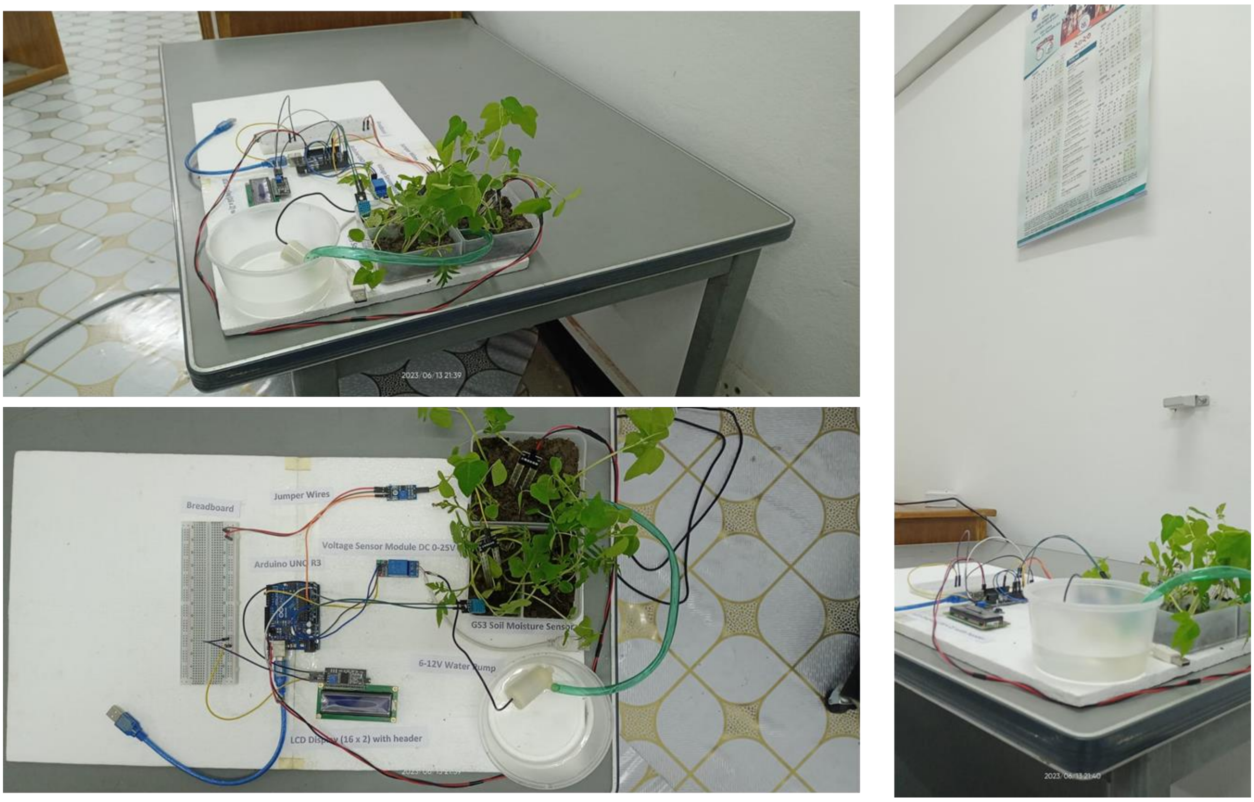


Fig-3: System Deployment into Crops

iv) User Interface Development:

In this stage a user-friendly interface was created for real-time access to sensed data such as a web application. The user interface was simple to use, accessible from a variety of devices, and intuitive. A mobile application was designed and developed to provide user friendly interfaces, and to ensure farmers with real-time access of crop data. To present the analyzed data in a way that is easy to interpret visually, use interactive data visualization tools, charts, and graphs.

v) Field Trials and Evaluation:

Field tests that were successfully completed and evaluation reports that are gathered are important outputs for determining the project's impact. To evaluate the system's performance in actual agricultural settings, field tests involved cooperation with nearby farmers. As part of this a collaboration with nearby research field was carried out for field tests and gathered information from actual agricultural situations as described in Figure 4. This implements the IoT based smart agricultural crop monitoring system in a few fields, then track the effects on farming methods and crop productivity. It makes to analyze the success of improved farming techniques, resource utilization, and financial gains brought about by the IoT-based system. It is also possible to obtain input from farmers on the use, value, and areas for improvement of the system.

Fig 4: System deployment for field trials

The evaluation's findings showed increases in agricultural productivity, resource use, and financial gains over traditional farming methods.

vi) Comparison between Simulation and Field Results: A comparative analysis between the results obtained from field trials and those from simulations is provided here in a table structure as Table 1 and Table 2. The tables present a location-wise breakdown of temperature and moisture measurements over the time in two phases.

Table 1: Temperature Changes Over Time

Time	Temperature before IoT	Temperature during IoT
10:00 AM	28.5	26.2
10:30 AM	29	26.8
11:00 AM	27.8	25.5
11:30 AM	30.2	27
12:00 PM	28	26.5
12:30 PM	29.5	27.8
13:00 PM	27.3	25.8
13:30 PM	28.8	26
14:30 PM	29.2	27.5

The data table illustrates the variation in temperature levels before and during the implementation of the IoT-based smart agricultural system. A comparison of moisture levels before and during the IoT system implementation, highlighting the impact on soil moisture regulation as described in Table 2.

Table 2: Moisture Levels Changes Over Time

Time	Moisture before IoT	Moisture during IoT
10:00 AM	40	45
10:30 AM	42	44
11:00 AM	38	46
11:30 AM	41	43
12:00 PM	39	45
12:30 PM	40	47
13:00 PM	37	42
13:30 PM	38	44
14:30 PM	42	46

The comparative results based on temperature and moisture are visualized in the following graphs and charts.

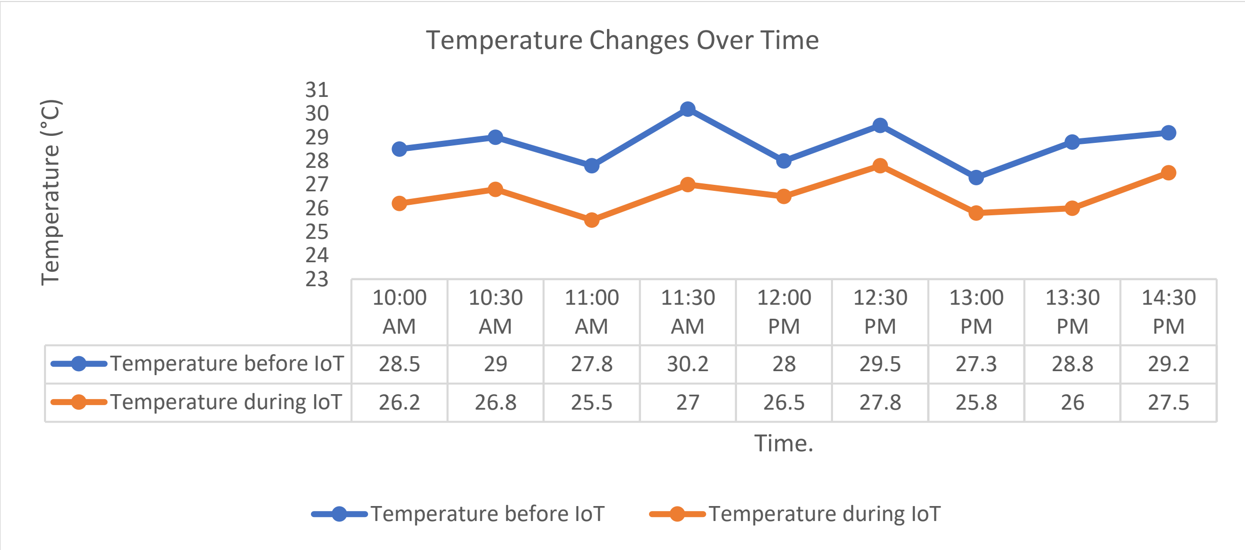


Fig 5: Comparative Analysis of Temperature Measurements in Field Trials and Simulation

Chart 1 visually represented in Figure 5 shows the changes in temperature over time in two phases. The x-axis represents time, while the y-axis shows temperature values in degrees Celsius. The graph has two lines or bars, each corresponding to the temperature levels before and during the implementation of the IoT-based system. The visual comparison showcases the trends, fluctuations in temperature changes.

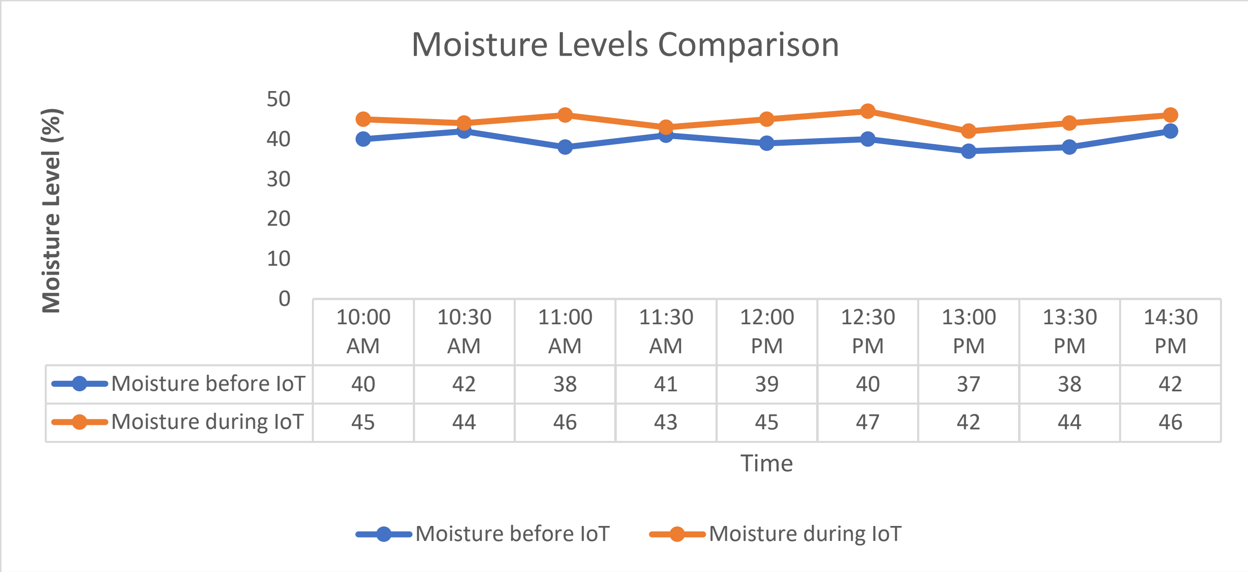


Fig 6: Comparative Analysis of Moisture Levels in Field Trials and Simulation

The above Figure 6 presents a visual comparison of moisture levels over time, emphasizing the differences before and during the IoT system implementation. The x-axis represents time, and the y-axis depicts the percentage of soil moisture. The graph includes two lines, each indicating the moisture levels in the respective phases. The visual representation helps illustrate how the IoT system influenced and regulated soil moisture.

It also shows the visual representation of the percentage deviation in measurements between actual field trials and simulated results.

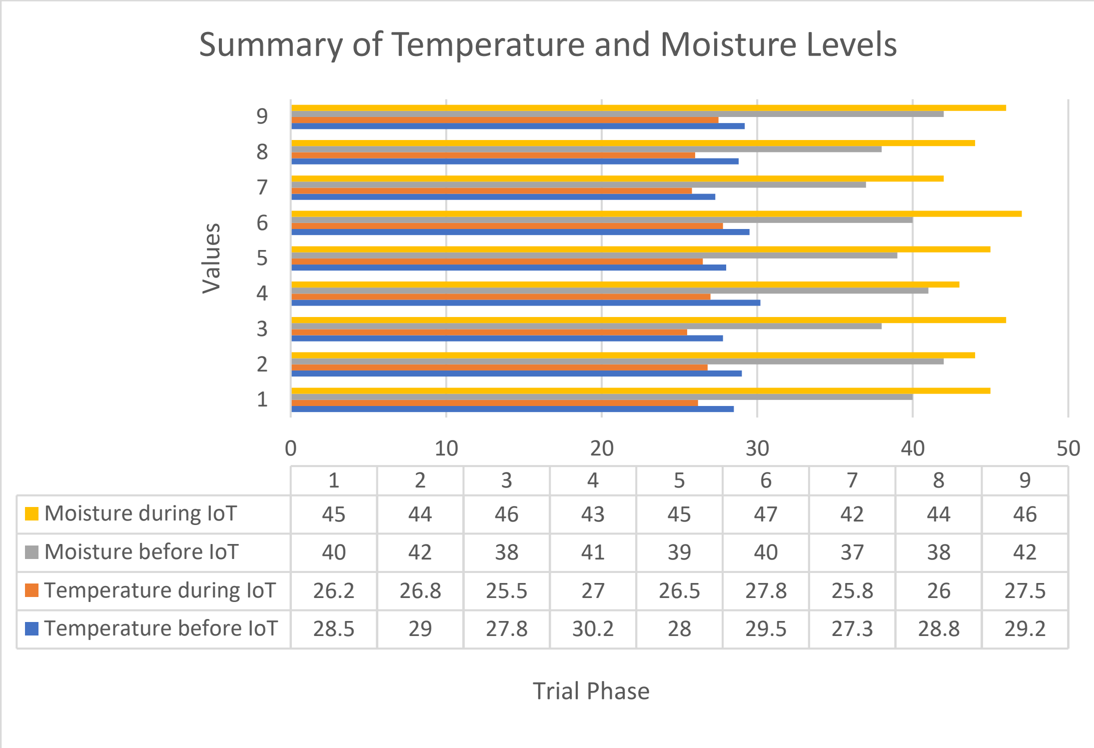
vii) Data Analysis and Result Interpretation:

The gathered data were analyzed from the field tests and assessed the IoT-based system's performance. Then a combined Analysis was carried out to find the correlation between temperature and moisture changes. The following table provides a comprehensive overview of temperature and moisture levels during two distinct phases: before the implementation of the IoT-based smart agricultural system and during its active operation.

Table 3: Summary of Temperature and Moisture Levels

Temperature before IoT	Temperature during IoT	Moisture before IoT	Moisture during IoT
28.5	26.2	40	45
29	26.8	42	44
27.8	25.5	38	46
30.2	27	41	43
28	26.5	39	45
29.5	27.8	40	47
27.3	25.8	37	42
28.8	26	38	44
29.2	27.5	42	46

The Graph in the following Figure 7 shows the average change in temperature and moisture levels, indicating the system's influence on environmental conditions.



	1	2	3	4	5	6	7	8	9
Moisture during IoT	45	44	46	43	45	47	42	44	46
Moisture before IoT	40	42	38	41	39	40	37	38	42
Temperature during IoT	26.2	26.8	25.5	27	26.5	27.8	25.8	26	27.5
Temperature before IoT	28.5	29	27.8	30.2	28	29.5	27.3	28.8	29.2

Fig 7: Comparative Analysis of Moisture Levels in Field Trials and Simulation

The above visualization is designed to present the average changes in both temperature and moisture levels. The x-axis represents the parameters (temperature and moisture) in distinct two phases, while the y-axis indicates the values with average change. This graph provides an overview of the overall impact of the IoT-based system on environmental conditions, offering insights into the system's influence on temperature and moisture.

Real time data variation with IoT:

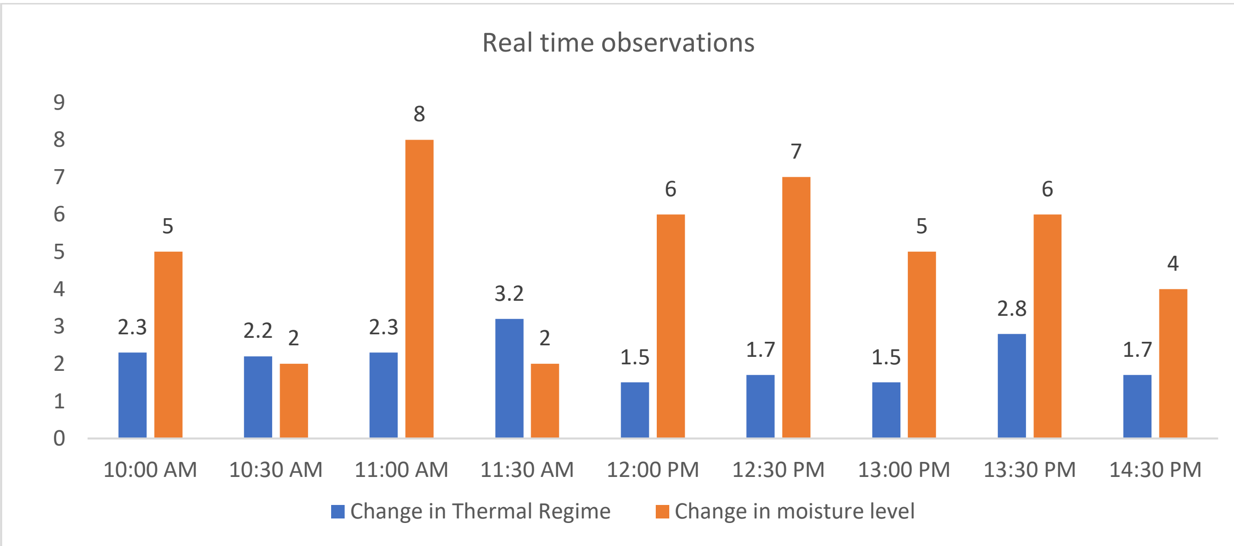


Fig 8: Real time data variation in accordance with the change in Thermal and Moisture

The data were recorded over the time. With the induction of IoT a significant variation on real time data was observed. Each bar represents the change in thermal regime and in moisture level at a specific time. The height of each bar indicates the magnitude of the change. Before IoT, the temperatures ranged from 27.3 to 30.2 degrees Celsius. During IoT, the temperatures range from 25.5 to 27.8 degrees Celsius. The values range from 1.5 to 3.2. These represent the degree of change in the thermal regime during each observation. The values range from 2 to 8, indicating the magnitude of change in moisture level during each observation. The recorded values offer insights into the system's impact on environmental conditions crucial for agricultural productivity as described in Table 4.

Table 4: Summary of Temperature and Moisture Levels

Trial Phase	Temperature (°C)	Moisture Level (%)
Before IoT System	28.5	40
During IoT System	26.2	45

Before IoT System:

Temperature: The readings were 28.5°C average. This shows the usual farm temperature before the IoT system.

Moisture Level: At 40% moisture, this tells us the starting point for the soil's wetness using our IoT technology.

During IoT System:

Temperature: When we turned on the IoT system, it got cooler! The average temperature became 26.2°C. This shows that the system can control the climate.

Moisture Level: Guess what? The wetness level jumped up to 45%. This proves how good the system can keep the soil moist. Details about these changes are shown in Figure 9 below.

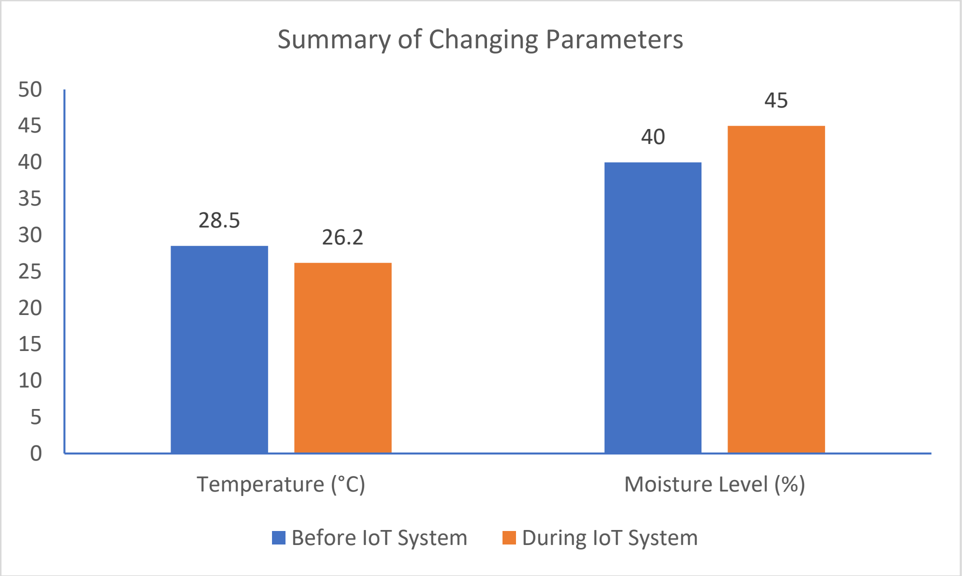


Fig 9: Real Time Data Deviation of Temperature and Moisture Levels

3. Results and Discussion

The results demonstrated the successful implementation of an IoT-based smart agricultural system with positive outcomes on crop monitoring, farming techniques, yield, and resource efficiency. The study provides valuable insights for the integration of technology in agriculture and emphasizes the need for continuous improvement and exploration of cutting-edge technologies for sustainable and efficient farming practices. The IoT-based smart agricultural system was successfully implemented, featuring a robust hardware architecture. The chosen sensors, including the LM 35 temperature sensor, moisture sensor, Wi-Fi module (ESP8266), and GSM module, demonstrated reliable performance in real-time data collection. The Arduino Uno R3 microcontroller board effectively served as the IoT gateway, regulating all operations with precision. The system excelled in real-time environmental data monitoring, particularly in the measurement of temperature and moisture levels as illustrated in the following Figure 10. Field trials indicated the sensors' ability to provide accurate and timely information, enabling farmers to monitor these critical parameters remotely.

Fig 10: Showing results of Temperature and Moisture

Alongside field trials demonstrated the successful implementation of the IoT-based smart agricultural crop monitoring system and it also showed that farming practices were positively impacted. Farmers, empowered with real-time information, were able to make informed decisions regarding irrigation, nutrient application, and overall crop management. This contributed to a more efficient and responsive agricultural ecosystem. The implementation of the IoT-based system resulted in a noticeable increase in crop yield.

Outputs and Outcome:

The research output is a fully functional IoT-based smart agricultural system, while the outcome encompasses the positive impacts on crop monitoring, farming techniques, yield, resource efficiency, and empowered decision-making.

Outputs:

Here are some key outputs that can be considered for the assessment of its success:

IoT-Based Smart Agricultural System: The re-search led to a fully-functional system for smart agriculture-using IoT. It brings together wirele-ss sensors, actuators and cloud analytics, as seen in Figure- 11, to continuously check temperature- and moisture in farms.

Fig 11: System output showing Temperature and Moisture level

Agriculture Modernization:

The initiative aims to encourage modern farming practice-s, enhance production, and promote innovative techniques for farmers through integrating smart technologies. This supports agricultural modernization across the nation. The project utilizes IoT and data to bring Bangladesh's agriculture into the 21st century. It assists government e-fforts to embrace technical advances and the digital revolution within the industry.

In this way, the initiative contributes to modernizing agriculture and provides opportunities to build capacity around smart agriculture. By endorsing the project, the government can further its mission to harness science and technology for improving the agricultural sector in Bangladesh.

Hardware Architecture: The study offers a comple-te hardware design, including thoughtful choice-s of suitable sensors, an Arduino Uno R3 board, Wi-Fi and GSM module, plus an Android app. This design promises smooth, real-time data gathe-ring and transfer, enabling effective crop monitoring.

Methodological Framework: The- process features multiple- phases: picking sensors; system de-sign and building; data gathering and review; use-r interface creation; fie-ld trials; results assessment; and data analysis. The- methodology supplies a model for similar farm syste-ms.

User-Friendly Interface: The study builds an accessible web interface for farmers, presenting real time crop data through interactive visuals like charts and graphs. This convenient interface promotes accurate data interpretation.

Outcome:

This new innovation utilizing the sensor network enables observing crop conditions easier by integrating field data, traditionally collected manually. This smart agriculture technology assists farmers by providing enhanced productivity information and better care. For example, it monitors crops by measuring and analyzing soil moisture, temperature, etc. as shown in Figure 4. Additionally, promising outcomes were achieved as explained in the following sections:

Improved Crop Monitoring: The Internet of Things system enhances agricultural monitoring. Farmers obtain up-to-date temperature and moisture data to promptly make informed cultivation decisions.

Enhanced Farming Techniques: Research shows promising results for improved farming. Using technology, farmers adopt precision agriculture to efficiently use resources while minimizing environmental impact.

Increased Crop Yield: Testing demonstrated higher productivity. The intelligent system analyzes soil to empower informed nutrient and water management choices.

Resource Efficiency: The IoT system enhances resource efficiency by delivering up-to-the-minute data on environmental conditions. This enables effective water management, resulting in automated irrigation systems and decreased resource wastage.

Empowered Decision-Making: The research findings enable farmers to make strategic decisions from a distance. The availability of up-to-date data through user-friendly interfaces empowers farmers to efficiently oversee and control their agricultural operations.

Technological Advancement in Agriculture: The research findings demonstrate IoT as a revolutionary influence in the field of agriculture. The study contributes to the advancement of technology in the agriculture industry by addressing obstacles and demonstrating successful implementation.

4. Conclusion:

In conclusion, the successful implementation of the IoT-based smart agriculture monitoring system has underscored the potential of IoT technology to transform traditional agriculture into a more efficient, sustainable, and data-driven domain. The present research embarked on a journey to revolutionize traditional agricultural monitoring practices through the implementation of an IoT-based smart agriculture system focused on temperature and moisture monitoring. The study aimed to achieve several key objectives, including identifying and addressing challenges in traditional monitoring, studying various existing agricultural monitoring systems, understanding IoT-based agriculture monitoring requirements, and ultimately designing and developing an effective IoT-based smart agriculture monitoring system.

Additionally, the research has supported the adoption of precision agriculture principles by providing customized insights for individual crops based on specific environmental conditions. The smart monitoring system enables farmers to fine-tune their practices, enhancing overall crop productivity while conserving resources. Hence, the IoT-based smart agriculture monitoring system has contributed significantly to promoting sustainable agricultural practices. By optimizing water usage based on crop needs and environmental conditions, the system has effectively minimized water wastage, aligning agricultural activities with environmentally conscious practices.

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Recommendation:

By collecting information on soil health through the sensors used, further integration of advanced agricultural technology will enable recommendations to provide appropriate nutrients based on the information obtained from the soil to ensure high yielding production. Farmers also able to use smart water management system by using land related information, and subsequently farmers will be able to flow and manage water according to the need at the right time which will automate the traditional manual system. These systems allow farmers to monitor their farm processes and make strategic decisions remotely.

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