

# Internet of Things-Based Real-Time Automated Dynamic Irrigation Scheduling System for Heterogeneous Crop Fields

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## Abstract

This article proposes an IoT-based dynamic irrigation scheduling system that would enhance the process of water management and maximization of crop production in heterogeneous crop fields. The system uses cheap sensors such as water level sensors, soil moisture sensors, temperature/humidity sensors, and rain sensors to gather real-time information to make the right decisions related to irrigation. Through the incorporation of IoT technology, the system will be able to support automated irrigation, as well as manual control, and will be flexible with regard to the input of the farmer. One of the innovations is the dynamic scheduling mechanism that responds to the crop growth phases and thus optimizes the use of Water at each stage of the crop life cycle. Through the experimental findings, crop yield has increased by 10%, and water consumption by 20% has been reduced as opposed to the traditional techniques. The results of statistical analysis indicate that there is a positive correlation with a correlation coefficient of 0.92 between dynamic irrigation and better crop yield, with an average water saving of 18%. In addition, an F-test will prove the statistically significant differences ( $p < 0.05$ ) in the water use and yield between the proposed system and the traditional irrigation systems. This design of the system functions within the limits of low-cost and low-energy, which is why it is a feasible solution in water-deficient areas. It also facilitates real-time monitoring and remote control, which increases convenience and accuracy for the farmers. The work can be useful in the field of sustainable food production by using the IoT in precision farming. The further development of the system will be based on the introduction of artificial intelligence to make irrigation predictable and the expansion of the functionality of the system to cover a larger variety of crops and environmental conditions, which will further boost agricultural productivity and environmental sustainability.

**Keywords:** IoT, Dynamic Irrigation, Precision Agriculture, Water Management, Crop Yield, Real-Time Monitoring.

## 1 Introduction

Human survival depends on agriculture more than any other industry. It makes managing food for people worldwide a major challenge. The majority of farmers cultivate their crops using relatively traditional ways. In the past, they would physically visit their farm to keep an eye on the crops. This task can be completed more quickly and easily with the use of technology (Tang et al., 2024). The Internet of Things (IoT) is a technology that uses the Internet to send and receive any kind of data to a server. Farmers can use this technology to keep an eye on the real state of their crops without physically being there (Saparniyazova et al., 2025). In this study, an IoT-based system for farming field monitoring is suggested. This system enables data transmission via the Internet from a variety of sensors and devices (Acharya et al., 2022). It allows farmers to use a computer or smartphone to remotely monitor their fields from the comfort of their own homes. The Internet of Things (IoT) revolution is being embraced by nearly every industry (Ahmed et al., 2023; Zhang et al., 2025). In order to increase productivity, agriculture has undergone numerous changes and embraced numerous machines. For a higher-quality yield, field (soil and environmental parameters) and crop health monitoring are crucial. Crop productivity and immunity have increased as a result of numerous technical developments in agriculture in recent years. The agriculture sector uses around 70% of the freshwater available worldwide. Using soil moisture sensors can improve water use and irrigation (Zhang et al., 2023; Namana et al., 2022).

The Internet of Things (IoT) is the technology that is essential to this. As the Internet of Things (IoT) becomes more prevalent in the agricultural industry, traditional agriculture is evolving into smart agriculture (Mowla et al., 2023; Morchid et al., 2026). By remotely monitoring the field environment and crop health, IoT networks are lowering the need for human labor (Sakthivel et al., 2023; Mishra et al., 2022). In order to collect data for various monitoring and control applications, the Internet of Things relies on wireless sensor networks, or WSNs. Temperature, humidity, pH, soil moisture, and other factors can be monitored by the monitoring system's end devices, which are outfitted with a range of sensors and can relay the data to the other devices. By granting otherwise limited low-power, low-cost devices access to more processing capabilities via the Internet, IoT is assisting farmers with crop growth stage monitoring and yield estimation (Mohanraj et al., 2024). Drones have been increasingly employed in agriculture recently for remote sensing. By offering control and flexibility, they are reducing the function of satellites in agricultural monitoring and image capture. IoT devices for agricultural monitoring have to be reasonably priced so that farmers may afford them. The number of sensor nodes, sink nodes, and gateways in a monitoring network varies based on the field area and network structure. Data from the sensor nodes is gathered by the sink node and uploaded to the cloud server. Therefore, this study suggested an inexpensive and user-friendly IoT-based smart agriculture system that controls and stores all sensor data (Mowla et al., 2023).

The issue of water management in agriculture, particularly irrigation is an issue of concern regarding the way to increase crop production and sustainability and the issue is important especially in the arid regions. The conventional irrigation practices do not take into consideration that the water demands of crops at differing stages of development are different and, therefore, this results in inefficient use of water and poor production of crops. The proposed study will help solve these problems by offering an IoT-based dynamic irrigation system that can help to optimize water consumption by proposing real-time monitoring and decision-making. The system incorporates the use of cheap sensors to obtain information on soil moisture, water content, temperature, humidity and rainfall to execute automated irrigation based on the unique requirements of the crops. This system enables significant water savings by using the dynamic scheduling system according to the crop growth cycle, thus enhancing the crop

yield besides providing a more sustainable solution to the irrigation process in the heterogeneous crop fields.

Water management in agriculture is vital, especially in the irrigation of crops, because improper timing might result in crop stress, low yield, and wastage of Water (Dash et al., 2025). Although the conventional irrigation techniques have been in existence for decades, they have a tendency not to consider the differences in water needs of crops at different growth phases (Balavandi, 2017). In order to overcome this weakness, the proposed model presents an Internet of Things (IoT)-based dynamic irrigation scheduling model that aims at streamlining the water consumption and crop production in heterogeneous crop fields. The originality of the given model is that the irrigation schedules can be changed dynamically on the basis of the real-time data provided by the low-cost data collection sensors, which detect soil moisture, water level, temperature, humidity, and rainfall. With the integration of IoT, real-time decision-making and remote control are possible, which increases the efficiency of operation in this system.

- The present paper describes the design and implementation of an IoT-based adaptive irrigation system, which is a water optimizing system that maximizes crop productivity through the dynamic adaptability of irrigation schedule control using real-time sensor readings.
- The low-cost sensors used by the system to monitor the environmental parameters (soil moisture, water levels, temperature, humidity and rainfall) allow applying irrigation only at the growth stage of crops and save 20% of the water used by the system, which also leads to better crop yield (10 %better), which is significant.
- The proposed system will combine cloud computing with remote monitoring so that farmers can remotely monitor and remotely use the irrigation system through a web interface to guarantee the flexibility and convenience in managing the water.

The research paper is structured in the following way: Section I presents the research and the significance of smart irrigation systems in improving the agricultural productivity. Section II is the literature review, where the past studies on irrigation systems and challenges have been discussed in detail. Section III describes the proposed system which is both, hardware and software setup. Section IV is devoted to the presentation of the experimental setup and results which demonstrate the success of the system in the improvement of crop yield and the water saving. Lastly, Section V explains the findings, implications and recommends future research directions which includes the addition of artificial intelligence to enhance even more optimization.

## 2 Literature Review

This chapter deals with different research works that were carried out to improve agricultural yield by proper irrigation scheduling using various wireless communication methods. Some of the related research works are listed below. The design and equipment of a wireless sensor network, variable rate irrigation, and software for in-field real-time sensing and site-specific precision linear-move irrigation system were detailed by Meriç, (2025). Six in-field sensor stations were placed around the field according to a map of the soil's properties to monitor site-specific conditions. Samples were taken on a regular basis and wirelessly sent to a base station. A programmable logic controller was used to electronically operate an irrigation machine. It interacts wirelessly with a computer at the base station and uses a differential Global Positioning System (GPS) to update the geo-referenced sprinkler location. Low-cost Bluetooth wireless radio communication was successfully used to interface communication signals from the irrigation controller and sensor network to the base station. The software created in this

paper, which was based on a graphical user interface, provided real-time control and monitoring of the variable-rate irrigation controller as well as stable remote access to field conditions. Variable rate irrigation is also possible with the suggested technique, which is highly helpful for conserving Water in dry and semi-arid regions. The Wireless Sensor Network lowers installation and maintenance expenses by doing away with the necessity of hardwiring sensor stations throughout the field. Since the suggested system is site-specific, it cannot be used in more than one field. The communication protocol in use is Bluetooth. As a result, the communication range is reduced, and connectivity problems could arise. Energy consumption is also increased.

In this study, a ZigBee-based wireless solution for an intelligent field irrigation system for Jew's ear planting in Wang et al., (2023) was proposed. The system's wireless nature made installation and maintenance simpler than with a traditional wired connection. The ZigBee wireless sensor network's end device and coordinator, the wireless sensor/actuator node and portable controller, respectively, were described in depth along with their hardware and software architectures. In the end, the system's overall performance was assessed. This research provided an approach for establishing a large-scale remote intelligent irrigation system as an exploratory use of wireless sensor networks in irrigation management (Nsoh et al., 2024). The system's great reliability and practicality were demonstrated by its lengthy history of operating smoothly and correctly in the field. The communication range is constrained due to the use of Zigbee. Because the method only takes the field's temperature and soil moisture into account, its accuracy is restricted (Abdelal et al., 2025).

In order to regulate the amount of Water, Sakthivel et al., 2023 created an algorithm with threshold values for temperature and soil moisture that was programmed into a microcontroller-based gateway. Photovoltaic panels provided the system's electricity, while a duplex communication link based on a cellular-Internet interface enabled web-based programming of irrigation scheduling and data examination. Water savings of up to 90% were attained during the 136-day test of the automated system on a sage crop field when compared to the agricultural zone's conventional irrigation methods. The automated system has been successfully implemented in three locations for the past 18 months. The system may prove beneficial in physically remote and water-limited regions due to its low cost and energy independence. Web portals are used to display field data. Therefore, farmers have a better visual understanding of the field. The suggested system is inexpensive and energy-efficient. Since the suggested solution is site-specific, not all field types can use it. Since just temperature and soil moisture are taken into account, accuracy is limited.

Some subsurface drainage systems were tested in relation to an experimental paddy field by Zang et al., (2023) based on alternate wetting and drying (AWD) irrigation. The 2014 and 2015 study took place on two local rice cultivars with four subsurface drainage system combinations, including drain spacing of 15 and 30 meters and the depth of the drain at 0.65 and 0.90 meters. The subsurface drainage compared to surface drainage in the control plot enhanced the water usage efficiency of the cultivars by 17.9-1.8 and 1.4-15.4 percent, respectively. When the overall crop yield is 5392 kg ha<sup>-1</sup>, in the case of subsurface drainage, the crop yield of a cultivar was better than that of the other one, which was 5010 kg ha<sup>-1</sup>. Comparatively, the control plot yields were also much lower, with a yield of 4405 kg/ha and 4972 kg/ha due to the respective cultivar. Subsurface and surface-drained plots had no significant difference in terms of the efficiency of irrigation application. Provided that the appropriate drying season is selected, underground drainage methods alongside AWD could become a useful tool that could foster the productivity of land and Water in paddy fields. The method aids in saving Water through maximizing irrigation according to volume and time schedules. It, however, fails to consider the impact of rain and humidity, which are the most important determinants of crop production, hence restricting accuracy (Zhang et al., 2023).

The Raspberry Pi, developed by Morchid et al., (2024), is an embedded Linux board that uses the ARM 11 microcontroller architecture (Morchid et al., 2024). The embedded Linux board serves as a coordinated node in the wireless sensor network and uses the ZigBee protocol to communicate with all of the dispersed sensor nodes located across the farm. The coordinator node's objective is to wirelessly gather metrics such as soil temperature and moisture content. Each sensor node has a ZigBee RF antenna device for communication with the coordinator node, as well as a soil temperature and moisture sensor. According to Lean et al., (2024), the Raspberry Pi evaluates the data it has collected and puts it in a database. The algorithm created for crop watering will govern how the system operates. The board runs a basic web server and includes an Ethernet port. As a result, the coordinator uses the ZigBee wireless communication protocol to gather the data and enables web browser users to view it. The irrigation system can be remotely turned on or off by the user. The method will use less Water, and providing the crop with consistent watering increases production. Benefits: Irrigation can be done remotely. Improved field condition visualization as data is tracked online. Remote locations may experience connectivity problems, which is a major drawback of this technique. The many stages of a crop's growth are not taken into consideration because dynamic irrigation is not offered. Rain and humidity, two elements that have an impact on crop output, are not taken into account.

A cloud-based Wireless Sensor and Actuator Network (WSAN) communication system was presented and tested on a real deployment by Reddy et al., (2024). To determine the water requirements of plants, this system keeps an eye on and manages a group of sensors and actuators, respectively. Due to its low cost and low energy usage, the suggested system is economically feasible. Cloud storage is where historical data is kept. so that farmers can base their judgments on prior performance and experience. Because dynamic watering is not offered, a crop's many growth stages are not taken into consideration. Connectivity problems may cause sensors and actuators to stop communicating.

A solution was put forth by Siddiqi & Al-Mulla et al., (2022) using inexpensive sensor nodes that may meet the required standards while using less electricity. The system is made up of many kinds of nodes. A TelosB mote and sufficient sensors or actuators make up each node. The temperature and moisture content of soil are measured using soil nodes. Climate changes are tracked by weather nodes. Actuators that can regulate the irrigation valve's opening when needed are connected to other nodes. Given that meteorological conditions are taken into account, the suggested system gives the farmer more accurate field information. The system uses less energy and is inexpensive. This system is site-specific. Therefore, it cannot be used in more than one field. Additionally, this approach is limited in its applicability. There is no consideration of dynamic watering (Siddiqi & Al-Mulla, 2022).

Suresh et al., (2022) suggested that the system uses the Internet of Things (IoT) to automatically monitor and control the irrigation process in an effort to create a sustainable solution. For agricultural fields, a completely automated sensor-based watering system is created. Raindrop, soil moisture, and temperature sensors are all operational. A drip irrigation system is set up to irrigate the many agricultural plants that are cultivated in various tubs. Each tub has a sensor node installed. Using data from many sensor devices, the regression approach is employed in this paper to help anticipate the amount of Water needed for daily irrigation. The mobile application (app), which provides access to the current state of the agricultural field, makes the forecasted information available. This sensor network application will now assist in determining the soil's water content and promote the wise use of available water resources. When soil moisture, temperature, and raindrop sensors are included, the suggested system becomes more precise. In isolated areas, internet-enabled WiFi service might not be accessible. Therefore, the suggested technique is less feasible in isolated locations.

Through literature review it has been observed that there are some research works that have aimed at enhancing irrigation efficiency and water conservation using wireless communication technologies. Real-time monitoring and control of irrigation systems using wireless sensor networks (WSN) is not new, and systems based on Bluetooth, ZigBee, and IoT-based systems are used to monitor soil moisture, temperature, and other environmental indicators. Although such systems have advantages such as low installation expenses and energy autonomy, such difficulties as a poor range of communication, localizability, and the absence of dynamism in irrigation due to rain or humidity are frequent. Besides, some of the systems are not connected in some remote locations and this may interfere with operations. Even with these constraints, the methods like photovoltaic-driven, data storage in the cloud, and integration of weather nodes have potentials in improving precision and making water utilization effective especially in areas that have a limited amount of water. These researches highlight the necessity of the further improvement of dynamic watering, scalability, and real-time reaction on environmental factors such as rainfall and humidity in order to enhance the accuracy of irrigation and agricultural output.

### 3 Proposed System

The project's primary goal is to create a dynamic irrigation scheduling system for irrigated crop areas using the Internet of Things. The following are the contributions made by this project: to use the Internet of Things to create an automated irrigation system for crop fields in real time. Additionally, to suggest an algorithm for dynamic irrigation treatments that are automated throughout the many stages of a crop's life cycle. The proposed AgriSens system provides remote manual irrigation in addition to automatic watering, depending on the experience of the farmer or professional input. Designing a low-cost water-level sensor that produces distinct values based on the amount of Water in a field is the ultimate goal. AgriSens provides field information to the farmers in different ways, such as a web portal, using a light-emitting diode (LED) array, a liquid crystal display (LCD), and the Internet.

Figure 1 shows a complex closed-loop Internet of Things (IoT) system that is meant to modernize precision agriculture using automated and data-driven water management. It is initiated at the Sensor Nodes where hardware placed in the field measures real-time environmental parameters such as soil moisture, temperature, humidity, and rainfall to determine the urgent demand of the crops. This uncoded information is subsequently relayed through an IoT Gateway, which acts as an important communication channel between the physical field and the digital infrastructure. After the data is stored in the Cloud Server, it is subjected to strict storage and processing, which enables the analysis of trends of the past and the modeling of complex data. All these are channeled into the Decision-Making Module that uses a specialized irrigation algorithm to conduct real-time analysis to compute accurate water demands. The Actuation System is the system that runs these commands and operates mechanical pumps and valves to provide Water using Field Irrigation techniques such as drip irrigation or sprinkler irrigation. Most importantly, the system runs on constantly updating feedback loops whereby the information on field performance is fed back into the cloud to optimize the algorithm and reduce resource wastage with high water efficiency in a dynamic agricultural setting.

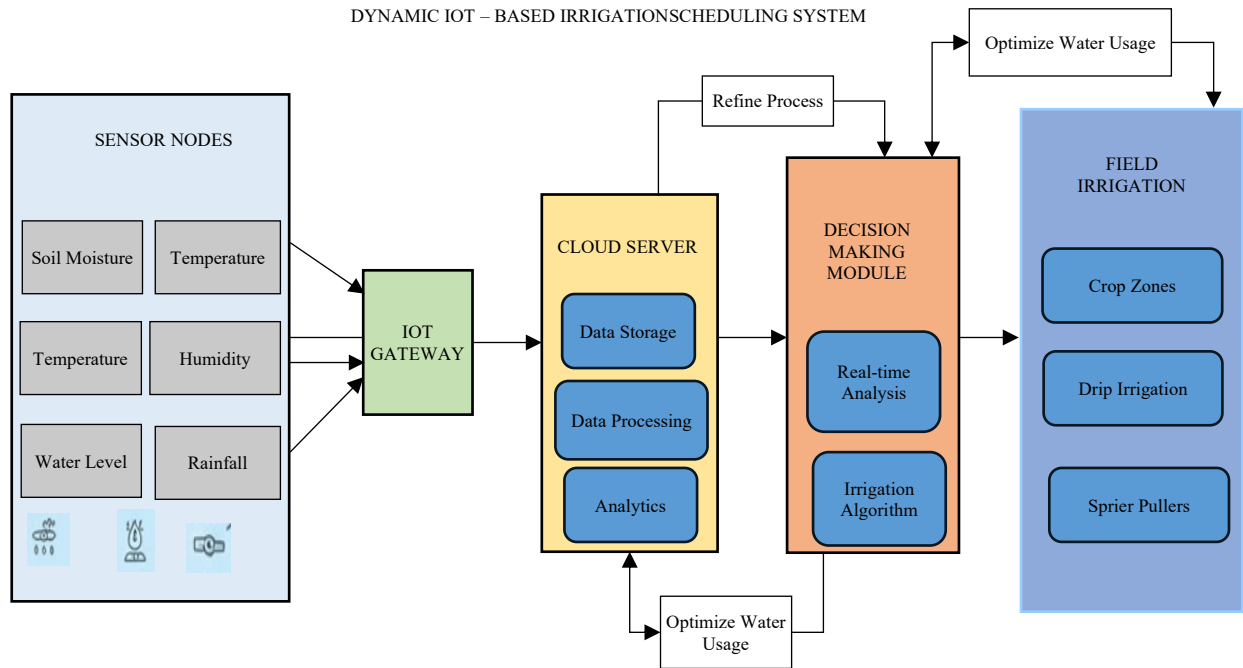


Figure 1: Architecture of a dynamic IoT-based smart irrigation scheduling system

### System Description

The system is made up of both software and hardware parts. The AT-mega328 programming microcontroller, which connects to the other sensors to gather data, makes up the hardware component. A low-cost water level sensor that produces a discrete value based on the amount of Water in the field and a moisture sensor that can determine whether the soil is wet or dry might be used to notify farmers via a web browser. Then, by creating an online channel, farmers may turn the centrifugal pump on and off from anywhere. This webpage was created with ASP.

Using the device, sensor readings are entered into a database on the webpage, which is hosted online. For analysis, LM38 comparator modules and soil moisture sensors were positioned in various soil conditions. It detects the surrounding moisture content. The resistance of the soil to the current, which is applied across the electrodes via the soil, establishes the moisture content of the soil. More Water in the soil will reduce resistance, allowing more current to flow through. The water level sensor uses the Water's electrical conductivity property to measure water levels up to 10 cm below the surface. The appropriate transistor goes into the "ON" state when the Water reaches a specific height.

### Transmitter Section

Figure 2 shows the design of the proposed dynamic irrigation system using IoT. It demonstrates the way in which different sensors (rain, soil moisture, water level, and temperature/humidity sensors) receive real-time information and transmit it to the Arduino microcontroller. This data is processed by this microcontroller and transmitted to the unit elements of the system, like the relay, water pump, and Zigbee module. Body Temperature. The data is sent to the cloud using WiFi (ESP8266) and stored in a database, and accessed by the web server. The system has a stable power supply that has made it operate around the clock. The irrigation system is flexible and user-friendly since it uses the application layer that enables a user to monitor and control the system remotely via a web interface.

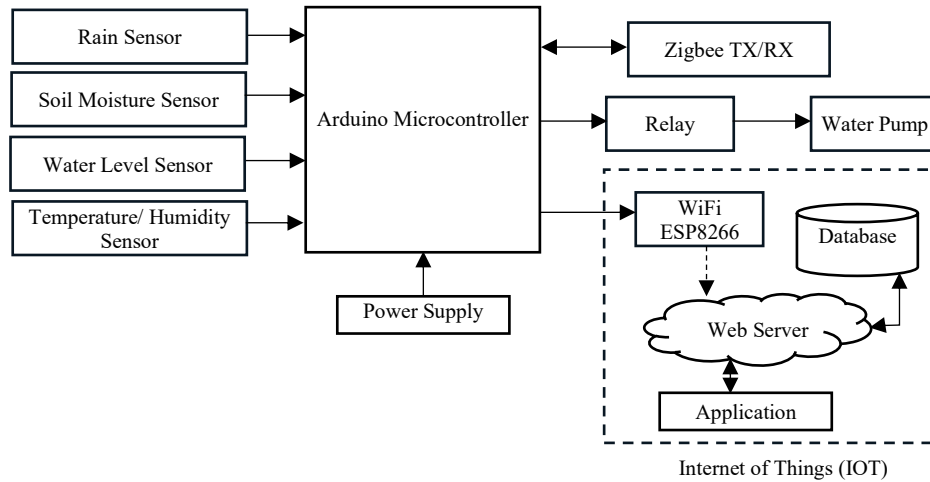


Figure 2: IoT-based dynamic irrigation system block diagram

### Receiver Section

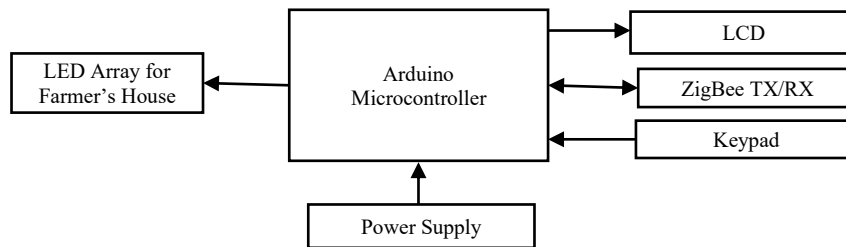


Figure 3: Block diagram of proposed system

Figure 3 displays a block schematic of the suggested system's conceptual architecture. The layout of suggested AgriSens system, along with a detailed explanation of its many parts, includes the sensor node, water-level sensor, Internet of Things gateway, and remote server.

### Integrated Design of Sensors

Soil moisture and water-level sensors are the two types of sensors used to manage the watering of irrigated crops. Depending on the amount of Water in the field, a water level sensor produces a discrete number. This sensor uses the Water's electrical conductivity to measure water levels up to 10 cm below the surface. The appropriate transistor goes into the "ON" state when the Water reaches a specific height. The current value of Water in the field is indicated by the value of the highest conducting level among all conducting levels.

### Integrated Design of IoT Gateway

The goal of the IoT gateway's design is to address the requirement for data transmission over two distinct protocols—WiFi and Zigbee. The gateway nodes use the Wi-Fi packet format to send the data to the distant server. The Internet of Things' underlying communication system, Wi-Fi, makes it possible for virtual and real objects to be connected and integrated. After registering on the website portal, each gateway is assigned a unique user ID that is generated at random.

## **Implementation of Remote Server**

Web servers were utilized in the design to support several AgriSens capabilities. The remote server is developed using Active Server Page (ASP) and ASP.NET. ASP.NET is a key component of the .NET Framework and is used to construct web pages. Sensor nodes can be managed via a website, and statistical tools can be used to analyze the data.

## **Sensing and Actuating Layer**

In this layer, sensor nodes are placed in the field to measure environmental parameters and use ZigBee to send the data to the gateway nodes. The gateway nodes use the WiFi packet format to send the data to the distant server. Physical and virtual objects can be integrated and connected thanks to the underlying communication provided by ZigBee and WiFi in the Internet of Things architecture. The node's electrically erasable programmable read-only memory (EEPROM) stores predefined threshold values that are compared to the sensing data. The actuator attached to the node will receive a signal from the node's CPU if the threshold is crossed, activating the solenoid valve that irrigates the field as needed.

## **Remote Processing and Service Layer**

In addition to processing data, this layer also handles requests from the Agri Sens's top and bottom layers. One benefit of the remote processing layer is the ability to manage field activities from a distance. This layer will be carried out without the farmer physically being in the field, if irrigation of the field is necessary when a farmer needs it. Every sensor's data is stored in tables by the system. This allows the user to view past data and configure future automation algorithms that can be computed locally in the embedded system or on the cloud, both of which are utilized in this implementation. This is to give the system resilience so that it can close windows, have some default watering schedules, and more without requiring internet connectivity. Additionally, because the embedded system is directly linked to the internet via a WiFi module, the ESP8266 WiFi module can be configured to function as an access point simultaneously, allowing the user to connect to the system and, if necessary, control it locally.

Google Cloud (GC) serves as the infrastructure for the servers' compute capacity and storage. The way GC is configured, a Linux virtual machine is installed at the nearest GC server from Sweden, which is currently Finland. The web server has a LAMP stack configuration.

Additionally, the web server facilitates information exchange between the SGH and the mobile application (the user). This is made possible by using a table to store instruction values, like LED on/off. Allowing external inbound connections via HTTP to get across the GC firewall is the sole configuration required on GC for Apache. The database specifies the timestamp and unique id for each type of data when it creates the table. This makes it simple for the system to incorporate more sensors and interesting data points for storage.

Stored procedures handle the import (write) and export (read) of all data from the database. By doing this, it is possible to minimize the amount of ASP scripts and eliminate the need to code and send SQL statements to the database for execution. In accordance with the rights required to alter the database, several user accounts have been created. The ASP scripts provide a special user account with a password to the database server; otherwise, no connection can be set up. Additionally, the storage logic is configured so that the SGH may often update sensor values, allowing the mobile application to view data in real time. Only every 15 minutes, however, are fresh sensor values saved.

## Application Layer

This layer's design makes it simple for a farmer to see the data and activities taking place in the field. Farmers may readily monitor their field statistics by placing an LED array indicator and an LCD display with WiFi enabled in their homes. Additionally, farmers can view their field data at any moment via the Web server via the Internet. With the use of Wi-Fi and the Internet, farmers may also regulate field operations as needed.

There are two modes for regulating the greenhouse: autonomous mode and self-controlling mode. One mode precludes the other. A navigation bar at the bottom is used to choose between the modes. The application displays the configured parameter values and opens the mode the system is in when entering the control section. Every mode has a flexible view known as the constraint layout, which allows developers to arrange items in many ways. In the self-control mode, each cell has its own item in a scroll view. Depending on the actuator it regulates, any object can belong to one of three categories. An actuator that simply has two stages on and off is managed by a switch button indicator that indicates whether it is in the on or off state.

Every time the status is altered, a fresh HTTP request is sent to the server with the updated value. Another way to control actuators is with a sliding bar that displays a value between 0 and 100. Every time the user releases the sliding bar, it is programmed to record and update the database. The third and last kind of actuator is controlled by numbers. In order to specify a value to operate upon, it is based on a text input field that only accepts numbers. Since the system controls all actuators, utilizing the bottom navigation bar to go to autonomous mode resets all values from the prior mode.

The temperature and watering can be automated separately or in tandem in the autonomous mode. Two required values—the watering interval and the watering interval time must be set for automatic watering. The watering interval tells the system how many hours should pass between waterings and is expressed in hours. Conversely, the purpose of the watering interval time is to help the system determine how much Water to use each time. It is necessary to set both of these values. A transmit button is then included in the view to store the values in the database. The suggested system is accurate and easy to use. IoT offers a greater range and excellent reliability. Unlike other systems, this one does not waste power. It is superior to the earlier systems due to its lower power requirements and simpler circuitry. Both power consumption and historical field data can be effectively retrieved by the suggested system, in order for the users to increase their field productivity appropriately.

### Algorithm 1: IoT-Based Dynamic Irrigation System

Input: Soil Moisture Sensor Data, Temperature Data, Water Level Data, Rain Sensor Data, Crop Growth Stages

Output: Irrigation Decision, Water Pump Control, Irrigation Schedule

1. Begin
2. Initialize system components:
  - Set thresholds for soil moisture (30%-70%), temperature (25°C), and water level (10 cm)
  - Initialize Arduino microcontroller (ATmega328) and sensor nodes (soil moisture, water level, temperature, humidity, rain sensors)
  - Set communication protocols (ZigBee for local communication, Wi-Fi ESP8266 for cloud transmission)

3. For each data collection cycle:
  1. Collect sensor data:
    - Soil moisture (x1)
    - Temperature (x2)
    - Water level (x3)
    - Rain status (x4)
  2. Transmit data to cloud via Wi-Fi (ESP8266) for remote monitoring and analysis
4. For each cycle (i=1 to N):
  - Preprocess data: Normalize sensor values and ensure valid data
  - Check irrigation condition based on threshold values:
    - If soil moisture (x1) < 30%, or temperature (x2) > 25°C, and water level (x3) > 10 cm
    - If rain status (x4) = 0 (i.e., no rain)
5. Irrigation Decision:
  - If the condition is met, activate irrigation by turning on water pump.
  - Set irrigation schedule: Duration based on crop growth stage
6. Store and update system data:
  - Store sensor data, irrigation decision, and water usage in the cloud
7. Feedback Loop:
  - Continuously adjust irrigation based on real-time sensor data
  - Optimize irrigation duration based on crop growth stages (early stage needs less water, late stage needs more)
8. Evaluate system performance:
  - Analyze water savings (percentage compared to traditional methods)
  - Calculate crop yield improvement (percentage increase in yield)
9. Update system parameters:
  - Fine-tune irrigation schedules based on historical data and crop yield results.
10. End

The Dynamic Irrigation System algorithm based on the IoT is an optimization of irrigation system whereby all-time parameters of the environment, such as, soil moisture, temperature, water levels, and status of rainfall, are monitored. The system operates on an Arduino microcontroller that receives real time data of the different sensors present and sends this data to the cloud through Wi-Fi (ESP8266) to be monitored and analyzed remotely. The system will activate the water pump to irrigate the soil when soil moisture goes below 30 %or temperature gets above 25C and when there is no rain. The irrigation plan is dynamically changed according to the crop growth levels, and there is accurate application of water. The algorithm gives the system an efficient running mechanism and has feedback loops to constantly optimize irrigation schedules and stores the system data in the cloud to assess the performance of the system. Water savings, crop yield improvement are some of the key metrics that are monitored to estimate the effectiveness of the system. With the help of real-time sensor data, the system will guarantee maximum water utilization, which enhances crop production and saves on water.

## 4 Results and Discussion

### Experimental Setup

The four sensors that are utilized are the water level sensor, temperature/humidity sensor, rain sensor, and soil moisture sensor. For watering purposes, a motor pump is connected to the Arduino. The ASP application was created to make it simple for the user to monitor and adjust the parameters via a web application. By entering their login and password for verification, the user can access the program. A database contains the information gathered from the field. Because excessive temperatures affect crops' capacity to produce fruit, the DHT22 sensor is utilized to analyze the excess temperature and humidity in the environment.

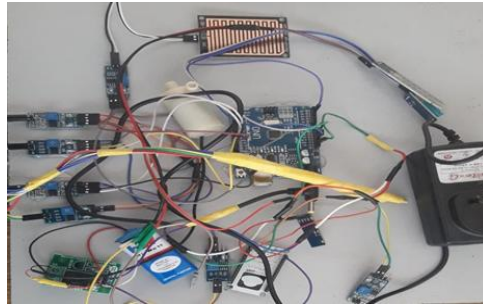


Figure 4: Transmitter section



Figure 5: Receiver section

Figure 4 shows the transmitter Section in the field, and figure 5 shows the receiver Section in the farmer's house. The working of the soil moisture sensor and the water level sensor is observed as shown in figure 6 and 7, respectively.

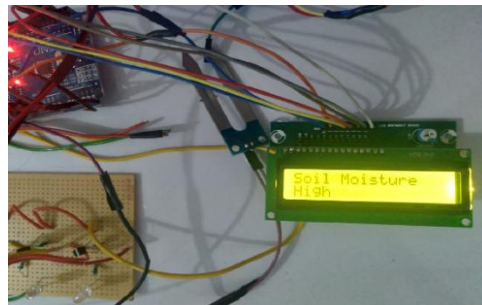


Figure 6: Working of soil moisture sensor

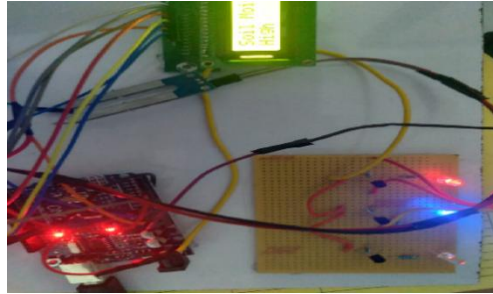


Figure 7: Working of LED array for water level indication

In the transmitter section, the Arduino board is connected to the NodeMCU, i.e., the ESP8266. This is used to provide internet connectivity to the system. It can easily fetch data and upload it to the internet, making the Internet of Things as easy as possible. The soil moisture sensor and the controller for the sensor are assembled. This sensor is to be inserted into the earth, and the status of water content in the soil is obtained as high or low in the LCD screen in the farmer's house. The relay for the pump motor is also attached to the circuit.

The working of the water level sensor is also observed. An LED array is used to indicate the level of Water present in the field. This LED array is to be placed in the farmer's house, where the water level can be observed in real time without going to the field. Working of the Temperature Humidity Sensor DHT22 is observed. Temperature and humidity play a major role in maintaining crop health. So continuous monitoring of these parameters is necessary for obtaining a higher yield. The output of this sensor is obtained on the LCD screen placed in the farmer's house, and the farmer can also access the data Froman remote location by using the web server. The value of temperature is shown in degrees Celsius, and t h e value of humidity is shown in the form of a percentage on the LCD screen placed in the farmer's house. Figure 8 shows the output of the temperature and humidity sensor on the LCD screen placed in the farmer's house.

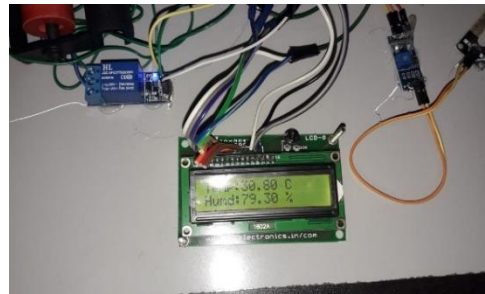


Figure 8: Working of temperature humidity sensor



Figure 9: Working of rain sensor

The working of the rain sensor is observed. The output of the rain sensor is obtained in the LCD screen placed in the farmer's house, and the farmer can also observe the output from any remote location by using the web server. Figure 9 shows the output of the rain sensor on the LCD screen placed in the farmer's house.

The transmitter and receiver sections communicate with each other through the XBee modules connected to the Arduino in the transmitter and receiver sections. These XBee modules use the Zigbee protocol for communication. Therefore, no internet connection is required for communication between the transmitter and receiver sections. This is an advantage in those areas where internet connectivity is an issue. So, this system is highly reliable as it can provide output from the field through both WiFi and Zigbee. Even if one system fails, the other system can give the desired result. While using Zigbee, the only condition is that the farmer's house needs to be near the field within the range of the Zigbee network; otherwise, the only method of communication possible is through the internet.

### **Hardware Details**

The experimental model of the dynamic irrigation system based on the IoT was created with consideration of the hardware and software setups to guarantee the correct data collection, processing, and performance of irrigation control. This system makes use of an Arduino microcontroller (ATmega328) that is linked to a number of sensor nodes in the field. Such sensor nodes as soil moisture sensor, water level sensor, temperature and humidity sensor (DHT22), and rain sensor are incorporated, collecting live data regarding the status of the field. The data of these sensors will use Zigbee (TX/RX) modules to be communicated locally and Wi-Fi (ESP8266) to be communicated over a long distance to the cloud. The water pump is operated with the help of a relay, depending on the schedule of irrigation decided in the decision-making system. It works on a constant power supply, which guarantees continuous workability of all its components, and the communication is solid, which has the ability to have both Zigbee and Wi-Fi connectivity to give flexibility in passing the data.

### **Software Configuration**

Other programmable code within the software setup is the embedded code, which runs on the Arduino microcontroller to perform the data processing and communication tasks. This programmed code enables the system to read the sensor signals, convert analog signals into digital ones, and send them via the Wi-Fi module (ESP8266) to a cloud server. The data is processed by the cloud server and stored in a database, it can be accessed and analyzed in real time through the use of a web application. The system has an intuitive interface, which can be accessed via mobile applications and web interfaces, allowing a farmer to regulate the fields he/she has and can modify the irrigation settings in case of need. The cloud application also makes real-time decisions and can perform remote control, conduct analytics to dynamically modify the irrigation schedule based on the sensor data.

### **Parameter Initialization**

Regarding parameter setting, the system was set up with certain thresholds in order to optimize irrigation. The moisture level of the soil was adjusted to a range of 30 % and 70 %, and irrigation was activated when the moisture percentage dropped to less than 30 %. The level of Water was set to 10 cm such that irrigation would occur only when a sufficient amount of Water was present in the system to nourish the crops. The heat stress was avoided by setting the temperature at 25°C, and irrigation was administered whenever the temperature was beyond 25 °C. The level of irrigation implemented was dependent on the growth stage of the crop, where it needed very little watering in the early growth stages and more in the late stages.

## Metrics Analysis

### Correlation Coefficient (r)

The correlation coefficient is used to determine the strength and the direction of the linear relationship between two variables, including dynamic irrigation and crop yield. The Pearson correlation coefficient equation (1) is:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \quad (1)$$

In equation (1),

$r$  = Pearson correlation coefficient

$n$  = number of data points

$x$  = dynamic irrigation values

$y$  = crop yield values

$\sum xy$  is the product of paired values summed.

$\sum x$ ,  $\sum y$  sum of individual  $x$  and  $y$  values

$\sum x^2$ ,  $\sum y^2$ , total area of the squares of individual  $x$  and  $y$  values

### Water Savings Percentage

To determine the amount of Water saved, the following equation (2) may be used to compare the water consumption between the proposed system and the traditional irrigation.

$$\text{Water savings\%} = \frac{(\text{Water Used by Traditional Method} - \text{Water Used by Proposed system})}{\text{Water Used by traditional method}} \quad (2)$$

In equation (2), where Water Used by Traditional Method = the sum of Water used in the traditional irrigation method.

Water Used by Proposed System = Total Water used by the IoT-based dynamic irrigation system.

This presents the amount of Water that the proposed system will save.

### Tests of Statistical Significance: F-Test

The F-test is applied to determine the comparisons between the variances of two groups (e.g., the water consumption and crop production of the proposed system and traditional irrigation). The F-statistic is given by the formula:

$$F = \frac{\text{Variance of Group 1}}{\text{Variance of Group 2}} \quad (3)$$

In equation (3), where:

Variance of Group 1 = Change in water utilization (or production of crops) of the suggested system.

Group 2 variance = Variance in Water consumed (or crop yield) of traditional irrigation.

The outcome of the F-test is compared with a critical number in the table of the F-distribution, and in case the p-value is less than 0.05, the differences are found statistically significant.

### Visual Data on Cloud

The user can log on to the cloud using their unique User ID and Password. This facility is to provide security to the user accessing the system. The data stored in the cloud helps the farmers to compare the historical data obtained in the past and thereby improve the crop productivity from past experience.

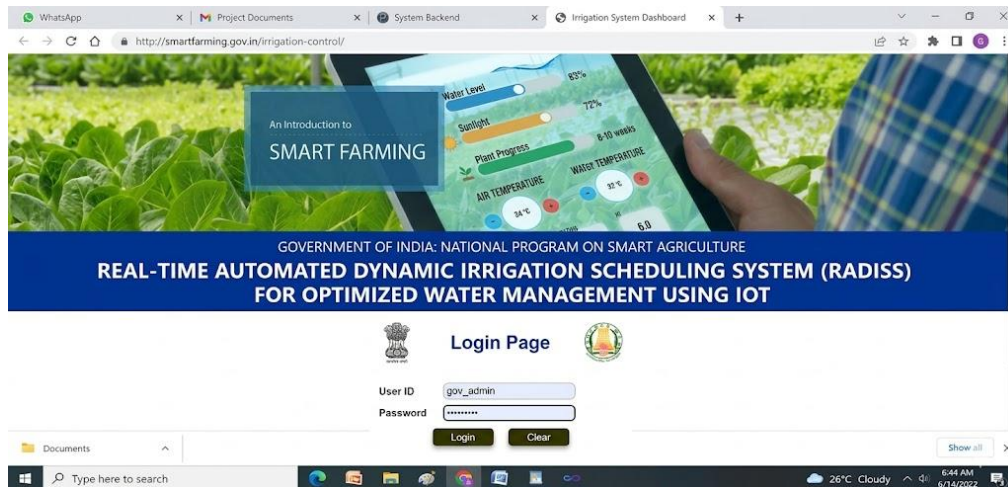


Figure 10: Cloud login

The following figure 10 depicts the login page of the cloud-based interface of the Real-Time Automated Dynamic Irrigation Scheduling System. The system allows the user to log in using a unique User ID and Password to ensure that the system is securely accessed. The system stores data in the cloud, which enables farmers to compare previous data with the current data. Using this information, farmers are able to make sound decisions based on data to optimize irrigation routines and crop yields on the basis of past knowledge and current environmental information.

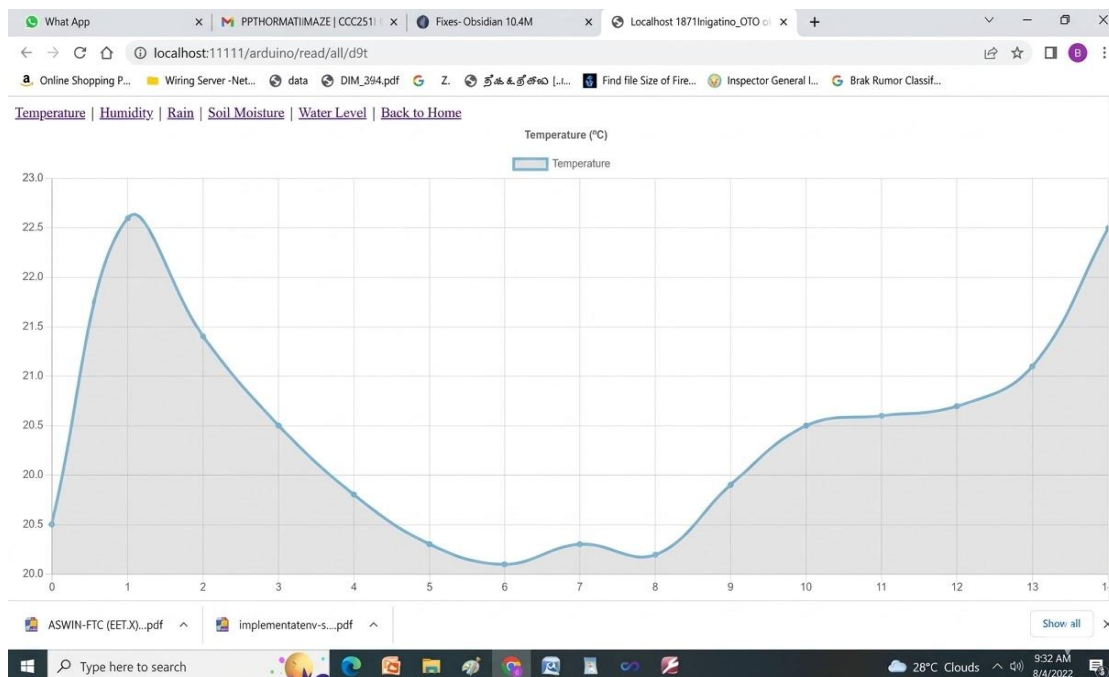


Figure 11: Monitoring of temperature in degrees Celsius



Figure 12: Monitoring of humidity in percentage

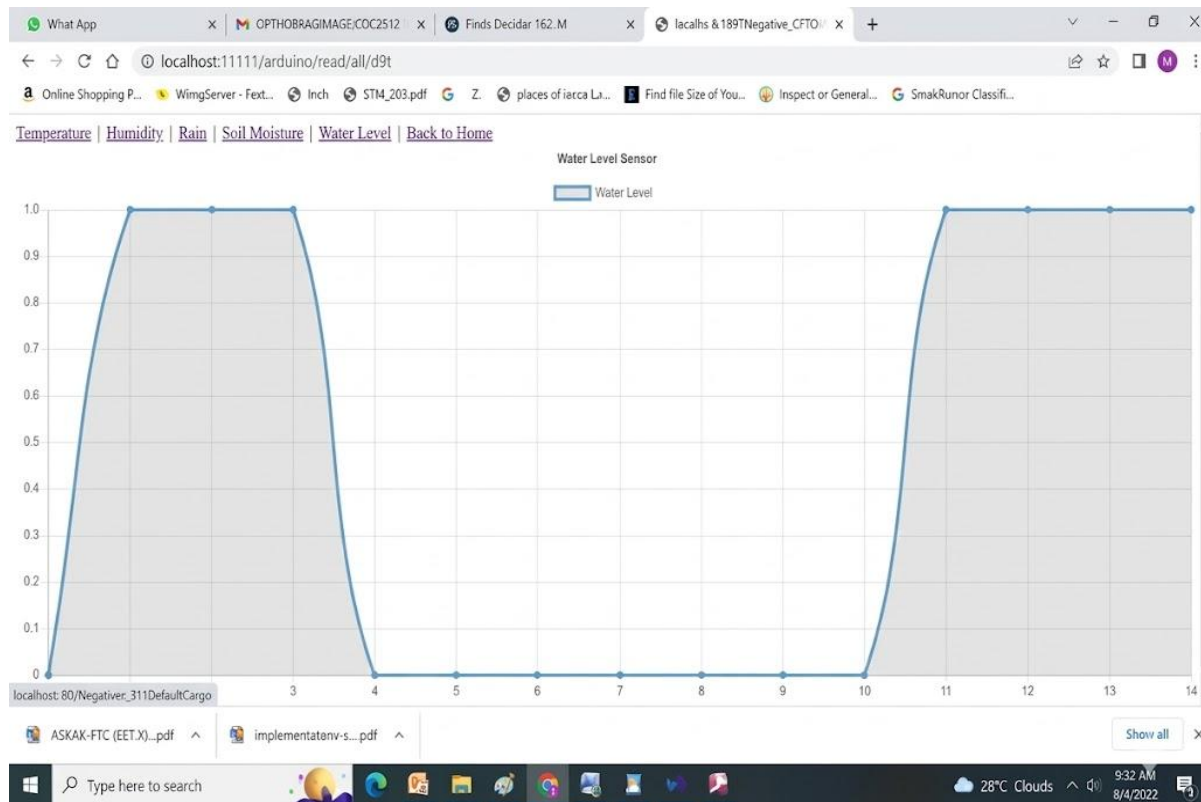


Figure 13: Output of rain sensor

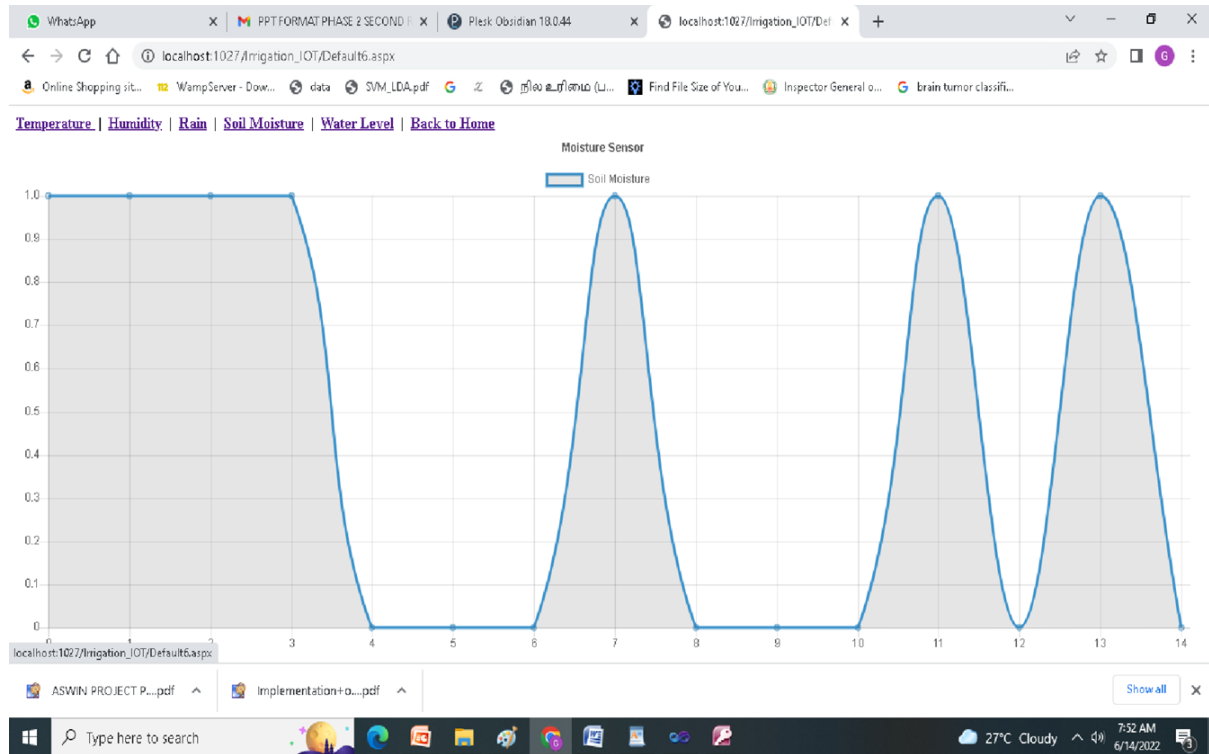


Figure 14: Output of soil moisture sensor

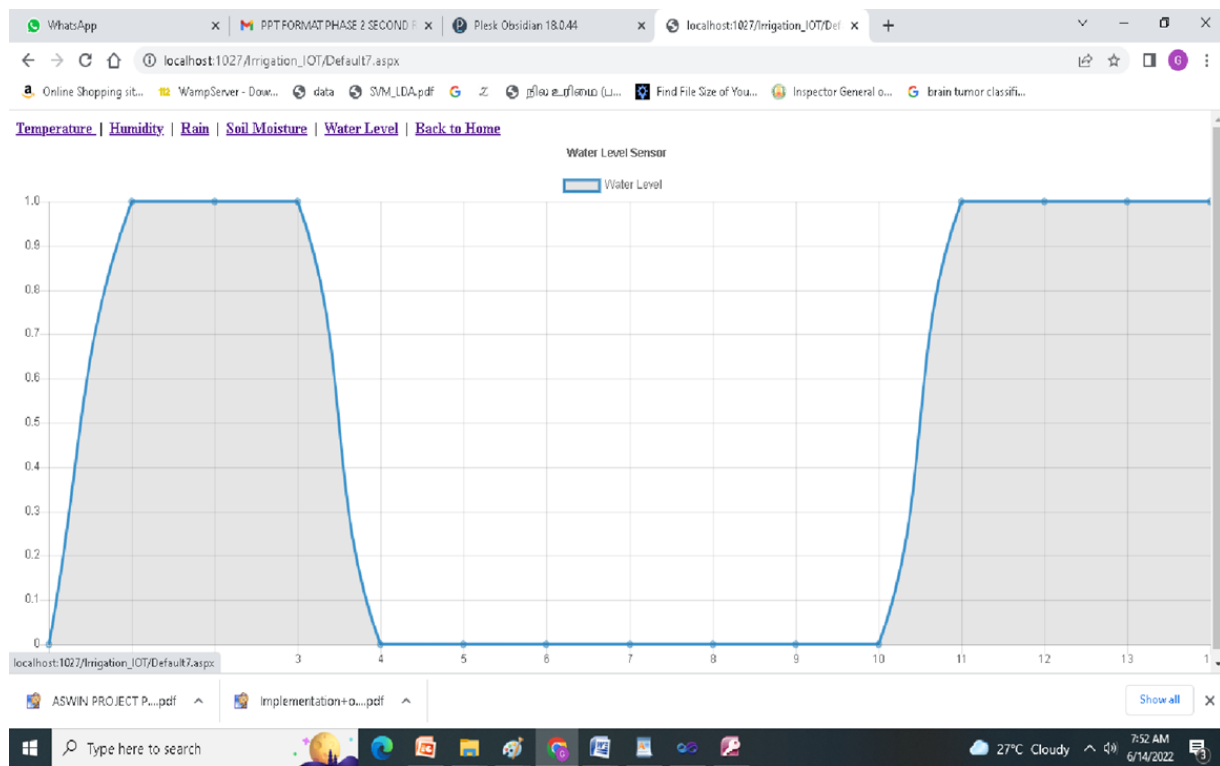


Figure 15: Output of water level sensor

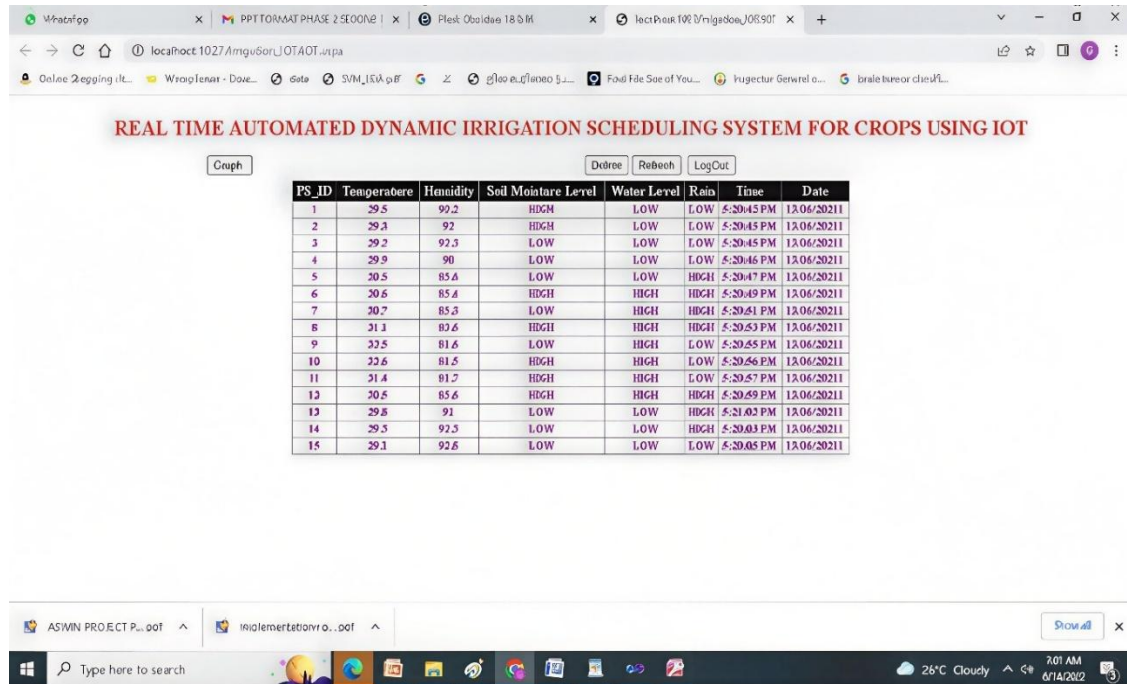


Figure 16: Tabular representation of output

The web application is designed to monitor the field and crops from anywhere using an internet connection. To control the Arduino, the Processing IDE issued; the webpage can be communicated using the Processing IDE.

The data is represented in tabular Format as well as graphically for a better understanding of the field conditions. Figures 11 to 15 represent the output obtained graphically. Figure 16 represents the output obtained in tabular format. The data acquired from all four sensors is shown in the table along with the time and date at which the data was taken. By observing the data, a farmer can easily monitor the field conditions remotely and take any necessary action if needed. So, the remote monitoring and control of the field can be easily performed using the cloud.

## 5 Implementation

An open field Implementation is done to analyse the performance of the proposed system. Here, experimentation is done using two types of crops: Spinach and yard-long beans. The total area for each crop is 3 x 3 m<sup>2</sup>. Both the crops are grown in an open area with and without the proposed system. Thereby, it compares the amount of yield obtained when using the traditional method of irrigation and the proposed system of precision irrigation.

The area where the proposed system is experimented with contains a sensor node. This sensor node has one soil moisture sensor, a water level sensor, a temperature/humidity sensor, a rain sensor, and a motor pump for irrigating the crops. The receiver section is placed indoors near the field, which consists of an LCD screen and an LED array where the farmer can obtain the output. The protocol used for this nearby communication is Zigbee, which does not require the internet. Also, the data can be obtained remotely by using the web server. The protocol used for remote communication is WiFi. The advantage of using two communication protocols at the same time is that even if one fails, the other system works. So, the proposed system has high reliability and efficiency.

The area where the traditional method of irrigation is practised has the same type of crops and is not far from where the proposed system is, so that the soil texture, climatic conditions, and all the other factors, such as sunlight, the type of manure used, etc., are the exact same as those of the proposed system.

### Result Analysis

Table 1: A comparison of the crop yield of the traditional and proposed IoT irrigation systems

Crop Type	Traditional Irrigation	Proposed IoT System	Absolute Improvement	Relative Improvement
Yard Long Beans	2.85 kg/9 m <sup>2</sup>	3.14 kg/9 m <sup>2</sup>	0.29 kg/9 m <sup>2</sup>	10.2%
Spinach	2.47 kg/9 m <sup>2</sup>	2.72 kg/9 m <sup>2</sup>	0.25 kg/9 m <sup>2</sup>	10.1%
Total (9 m <sup>2</sup> )	5.32 kg	5.86 kg	0.54 kg	10.15%
Scaled (kg/ha)	4972 kg/ha	5392 kg/ha	420 kg/ha	8.5%

Table 1 shows the overall findings of a controlled field experiment in 3 months of operation, comparing the crop productivity of the traditional manual irrigation system and the suggested IoT-based dynamic irrigation system. Yard Long Beans and Spinach were planted in the same 3x 3m 2 plots and subjected to the same soil texture, sunlight exposure, application of manure, and climatic conditions to remove confounding factors. The proposed system fairly provided 10%+ yields (Yard Long Beans: 3.14 kg vs 2.85 kg; Spinach: 2.72 kg vs 2.47 kg), which is 0.29 kg and 0.25 kg change in weight per 9 m 2 plot, respectively. The total yield of the two crops was raised to 5.32kg to 5.86 kg (+0.54 kg). The IoT system showed productivity of 5392 kg/ha when scaled to hectare level of productivity, in contrast to 4972 kg/ha when using the traditional methods, and this validated an overall productivity improvement of 8.5 percent, which could be attributed to precision water delivery, which was responsive to the stage of crop growth.

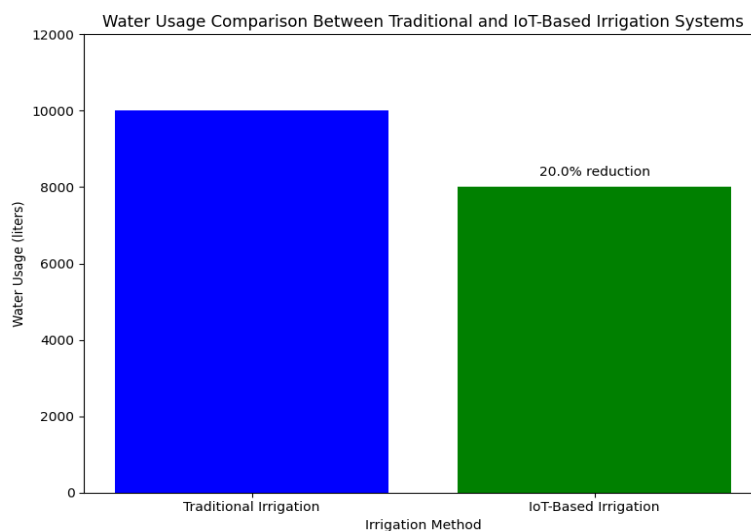


Figure 17: Comparison of the water usage of the traditional and IoT-based irrigation systems

Figure 17 is a comparison between water consumption per use (liters) in the case of traditional irrigation and the IoT-based irrigation system. The irrigation system that uses the IoT demonstrates 20% less water consumption, as 8,000 liters of Water were used in comparison to 10,000 liters of Water

applied to the system based on its traditional implementation. This is a considerable cut that illustrates how the IoT-based system is efficient in maximizing the use of Water, which is an improvement in resource management in agriculture.



After 1 weeks



Traditional Irrigation

Proposed System

After 2 months

Figure 18: Comparison of growth phases of yard-long beans



After 3 months



Traditional Irrigation



Proposed System

Yield obtained

Figure 19: Comparison of the yield of yard-long beans



After 2 weeks



Traditional Irrigation

Proposed System

After 1 Month

Figure 20: Comparison of growth phases of spinach



After 3 Months



Traditional Irrigation

Proposed System

Yield Obtained

Figure 21: Comparison of the yield of spinach

From figures 18 and 19, it is evident that in the initial stages of growth itself, the proposed system is showing the benefit of precision irrigation. There are more leaves and branches than in the traditional method. The initial stages of both spinach and yard-long beans do not require too much Water. So, the farmer, depending on his expert knowledge, can reduce the amount of Water used by automatically setting it to a low level.

After one month, both these crops have shown a tremendous difference from the traditional method. From the figures, the height of each crop is more than that of the traditional method. This phase requires more Water than the previous phase.

After three months, both the yard-long beans and spinach are in the yielding phase. From figures 20 and 21, the yield of both crops is higher in the proposed system than in the traditional method. After weighing the yield, it is evident that the proposed system provides 10% more yield than the traditional method.

They used the same amount of manure and cultivated both the crops in the same area. So that the soil texture and climatic conditions are the same for both the traditional and proposed systems. The proposed system uses less Water than the traditional method. Dynamic irrigation scheduling also improves crop productivity. So, in total, the proposed system is very efficient, reliable, nature-friendly, as well as more profitable and convenient for the farmer.

By the use of two communication protocols, i.e., Zigbee and WiFi, the proposed system becomes more reliable. Even if one system fails, the other will provide the output. Through the use of Zigbee, even areas without internet connectivity can benefit from this system. By the use of WiFi, the farmer can access the field information and control the field activities remotely from anywhere. Since WiFi is used, it can help to improve the application of IoT in the agricultural sector. The incorporation of artificial intelligence will be easier in the future. The proposed system helps to adapt to newer technologies like 5G, when the technology becomes more feasible and affordable to a common farmer.

The importance of crop yield access in the context of this study lies in the fact that it is directly related to the system optimization of irrigation with the help of real-time data related to the environment. The system based on the IoT allows controlling irrigation more precisely, as it allows farmers to understand the growth processes of their crops and how much Water the crop needs. The accuracy results in better health of crops, and as indicated in the results, there is a 10 %boost in crop yield, as opposed to the traditional irrigation techniques. The dynamism of the system to change the irrigation programs, depending on factors such as the soil moisture content, temperature, and rainfall, makes better use of water, and this helps in increased productivity in the end. Since one of the main measures of the success of agriculture is its crop yield, there is a need to enhance it in order to achieve food security and sustainability.

Another important aspect in this study is the water system management. The most important aspect is efficient use of Water in agriculture, particularly where there is a short supply of the resource. The fact that the proposed system would save 18 % of Water, which is used in conventional irrigation systems, shows that the system conserves Water. The system saves on water wastage because real-time data is used to modify the irrigation time in accordance with crop requirements to ensure the crops remain healthy. This type of dynamic water management also ensures that the Water is used at the right place and time when it is required, resulting in effective use of the resources. Managing water systems efficiently is also crucial to environmental sustainability, as well as cost reduction and economic feasibility of agricultural activities in water-deficient regions.

## 6 Conclusion

This paper will report on an IoT-based dynamic irrigation system, which will maximize the efficient use of Water and enhance the crop yield in heterogeneous crop fields. The solution offered consists of inexpensive sensors and real-time data analysis to provide accurate irrigation, which increases or decreases the amount of Water provided, depending on the stage of crop growth and other environmental conditions. It has been evident in the experimental results that the system offers a yield of crops by 10 % and a decrease in the use of Water by 20 percent, as compared to the conventional irrigation methods, which supports its effectiveness in controlling the usage of Water. The fact that the correlation coefficient between dynamic irrigation and the crop yield is 0.92 indicates a strong positive correlation, meaning that precision irrigation is very important in enhancing agricultural productivity. Also, the fact that the system would save 18 % of Water is another reason why it could be used in managing Water sustainably in agriculture. The findings of the F-test proved the statistically significant difference between water usage and crop yield under the proposed system and traditional methods, and showed that the system under consideration can be viewed as reliable. These results have major consequences for sustainable agricultural practices, especially in areas where there is a water shortage. Further, the irrigation system, which is powered by the IoT, increases the productivity of crops while lowering the cost of operation in terms of water wastage. Remote monitoring and control functionality, which the system offers to the farmers as a result of integrating with the cloud, enhances convenience to farmers, while the flexibility of the system, which utilizes Zigbee and Wi-Fi communication, makes the system reliable to operate even in regions where the internet is underdeveloped. The next phase of the evolution of this system can be aimed at the introduction of artificial intelligence that will help to optimize the irrigation program even more, with reference to long-term environmental data. Moreover, the implementation of the system with a wider variety of crops and environmental parameters will lead to its further efficiency and sustainability, which will eventually contribute to the development of precision agriculture in the world.

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