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Original Article

Smart Irrigation System

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Abstract - *Smart irrigation systems powered by IoT technology are vital in agriculture. Traditional methods often harm plant health and wastewater. Conversely, IoT-driven smart irrigation enhances water management, boosts crop yield, and supports sustainable farming. It uses sensors, data analysis, and automation to gather and analyse real-time data for informed decisions and real-time control. The hardware comprises a central unit using Raspberry Pi and sensors measuring Temperature, Humidity, and soil moisture. Node-red manages data flow and decision-making by incorporating sensor data and external weather information. It links with the Favoriot platform for seamless data streaming, offering cloud storage and analysis. A predefined set of thresholds for soil moisture, humidity, and Temperature guides irrigation decisions. This system provides precise irrigation assessments, customization, and secure cloud storage. By optimizing water usage, enhancing crop health, and enabling remote monitoring and control, it promotes sustainable water management in agriculture.*

Keywords - *Agriculture, Favoriot platform, IoT, Node-red, Raspberry Pi.*

1. Introduction

The Internet of Things (IoT) is an intelligent technology that can be used for various industry applications, including monitoring transport systems, the environment, and other commercial sectors [1]. An embedded communication program enables industrial equipment to be connected to the Internet, or industrial applications may be monitored and controlled from an application on a mobile device using the Internet of Things. IoT makes connecting physical items like sensors and actuators to the Internet possible [2].

The lack of water and the requirement for effective water management in agriculture has emerged as significant global challenges [3]. Due to poor planning and resource utilisation, traditional irrigation techniques frequently use wastewater. Smart irrigation systems have become creative responses to these problems, utilising contemporary technologies to optimise water management, improve crop output, and support sustainable agriculture. Global food security and agricultural production are both seriously threatened by water scarcity [4].

Overwatering or incorrect scheduling are examples of inefficient irrigation techniques that drain water supplies and result in financial losses and environmental damage [5]. To optimise irrigation practices and increase water use efficiency, smart irrigation systems integrate sensors, data analytics, and automation [6]. These sensors offer essential information for planning and decision-making on irrigation systems [7].

Actuators and control valves are examples of automation technologies used to manage water flow and deliver the correct amount of water required by crops [8]. Remote monitoring and management of irrigation systems are made possible through communication system integration [9]. Smart irrigation systems provide precise irrigation scheduling based on plant water requirements compared to conventional irrigation techniques [10].

By conserving water, we can reduce the effects of water scarcity and promote sustainability. A promising approach to overcoming water scarcity, increasing agricultural production, and supporting sustainable water management practices is innovative irrigation systems [11,12]. These systems optimise water use, enhance crop health, and lessen environmental consequences using sensors, data analytics, and automation. To overcome obstacles and progress the application of smart irrigation systems in various agricultural contexts, ongoing research and development activities are required [13].

Traditional irrigation methods could be more efficient and labour-intensive, leading to water waste and poor crop yield [14]. Additionally, manual irrigation systems are based on the experience of farmers and may need to be more accurate, leading to overwatering or underwatering [15]. Therefore, there is a need for a smart irrigation system that can optimise irrigation and reduce water usage while improving crop yield [16]. The smart irrigation system should be able to monitor soil moisture, weather conditions, and crop water requirements to make accurate decisions on irrigation scheduling and quantity [11,17]. The system should also be easy to use and affordable for small and large-scale farmers [18].

2. Materials and Methods

Our method involves connecting humidity, temperature, and soil moisture sensors to the Raspberry Pi, which serves as the main control device. Node-RED is the platform for flow management and decision-making, incorporating readings from multiple sensors, including the humidity, temperature, and soil moisture sensors [19]. In addition, we integrate the Open Weather Forecast API to access weather data, including the prediction of rainfall [20].

This data is incorporated into the decision-making process within Node-RED to optimise irrigation schedules based on weather conditions. Furthermore, the Favoriot Platform is integrated into the system using the MQTT broker, enabling seamless data streaming and analysis, ensuring efficient communication and data management for our smart irrigation system.

Node-RED is a powerful tool used for building the Internet of Things (IoT) applications by simplifying wiring and code blocks to carry out tasks [21]. It uses a visual programming approach that allows developers to connect 'ideas' to do a study [22]. The connected nodes, generally input, processing, and output nodes, make up a flow.

FAVORIOT Platform: It provides an IoT platform that may be used for any IoT project [23]. Data from sensors and actuators may be integrated into the platform over the Internet. As IoT devices grow more ubiquitous, data collection and storage become less of a challenge [24]. Developers may build vertical apps without worrying about hosting them on the platform [25].

The methodology encompasses the following steps: identifying system requirements and integrating sensors, installing and setting up Node-RED, designing the system flow visually within Node-RED, acquiring real-time data from the connected sensors, processing the received data and making decisions based on predefined thresholds, implementing control mechanisms to adjust the irrigation system, testing and refining the system flow, deploying it to the target hardware platform, and monitoring the system's performance for further optimisations. This approach enables the efficient utilisation of Node-RED's visual interface to read sensor values in real-time and automate irrigation processes for improved water management and crop yield, as illustrated in Figure 1.

To illustrate the smart irrigation system's flow, Figure 2 depicts the flow chart that outlines the sequence of operations and data flow within the system. This flow chart visually represents how components interact and work together to optimise irrigation processes, conserve water, and enhance crop yield.

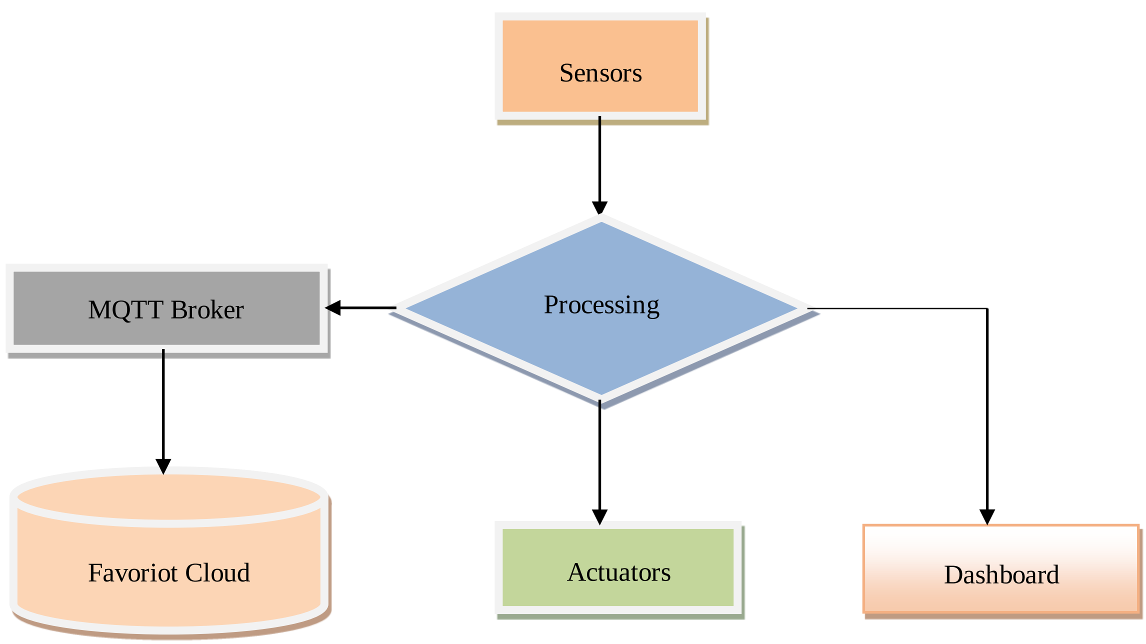

Fig. 1 Node-red system view

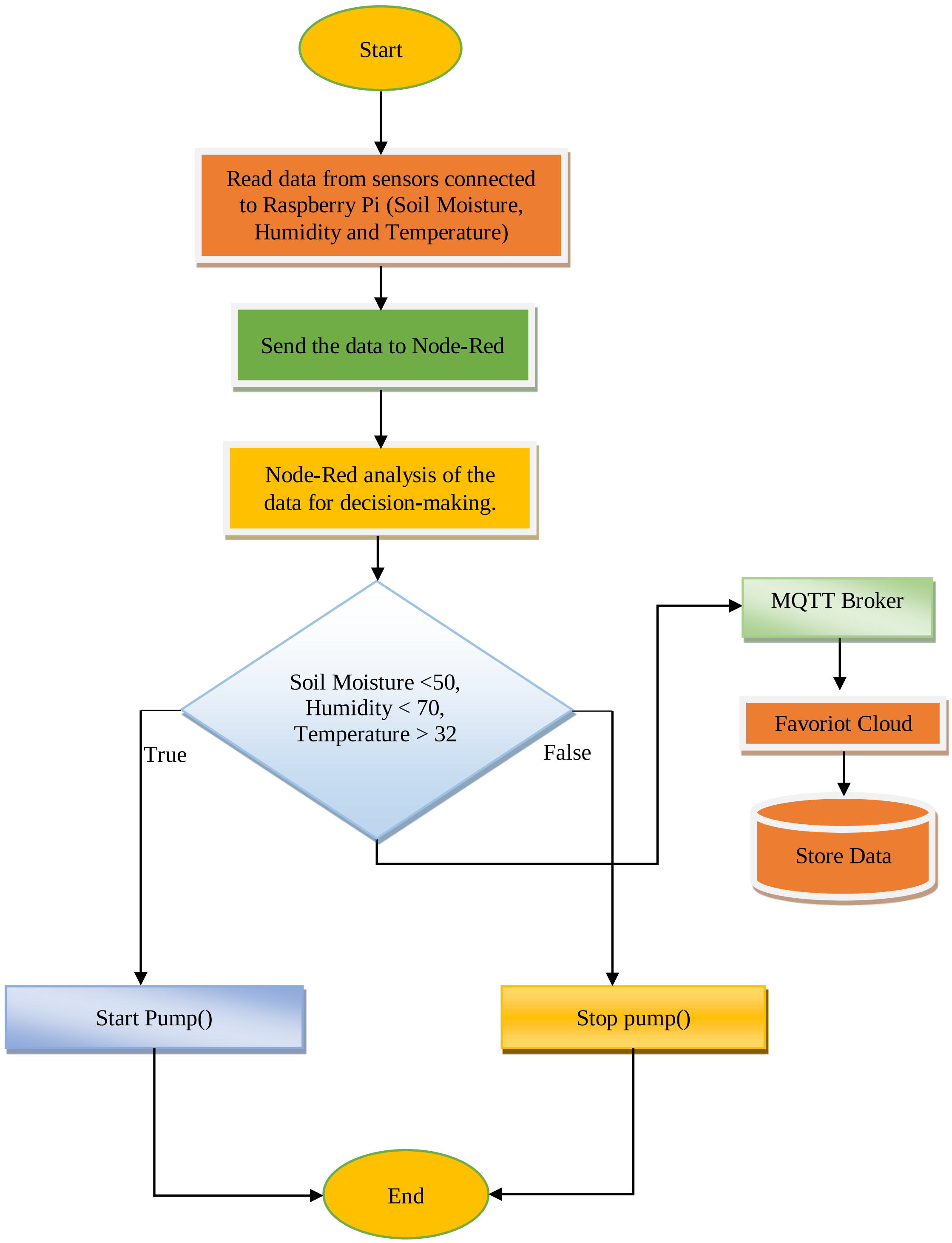

Fig. 2 System flowchart

2.1. Raspberry Pi 4.0

In our project, we employed the Raspberry Pi 4.0 as the hardware platform for our smart irrigation system. The Raspberry Pi 4.0, a powerful single-board computer, offered ample computing power and various connectivity options, making it an ideal choice for IoT applications [26]. By utilising Raspberry Pi 4.0, we were able to run Node-RED and other necessary software components to handle data acquisition, processing, decision-making, and irrigation system control. Its compatibility with various operating systems and software libraries gave us flexibility, while GPIO pins allowed us to integrate sensors, actuators, and other essential components easily. The Raspberry Pi 4.0 also provided various connectivity options, such as Wi-Fi, Ethernet, and Bluetooth [27]. We connected an Ethernet cable to enable internet connectivity, allowing us to remotely monitor and control the smart irrigation system for increased convenience and flexibility. Overall, the Raspberry Pi 4.0 was a reliable and versatile foundation, enabling our smart irrigation system's seamless integration of software, sensor interfaces, and connectivity.

2.2. Temperature and Humidity Sensor

Our project utilised the DHT11 module, which combines temperature and humidity sensors into a single unit [28]. This module streamlined the integration process, allowing us to easily incorporate temperature and humidity sensing capabilities into our smart irrigation system. We could read real-time Temperature and humidity data by connecting the module to our Raspberry Pi and implementing specific nodes in our Node-RED flow. These readings were then utilised for further processing and decision-making within the system, enabling us to optimise irrigation based on accurate sensor information. Integrating the DHT11 module enhanced our smart irrigation system's ability to monitor environmental conditions and make informed decisions, improving water efficiency and crop yield.

2.3. Soil Moisture

We utilised the Soil Moisture Sensor v2.0 in our smart irrigation system project. This sensor is specifically designed to measure the moisture content in the soil, providing crucial information for effective irrigation management [29]. The Soil Moisture Sensor v2.0 integrates into our system by connecting it to the appropriate pins of the Raspberry Pi. By incorporating this sensor, we could accurately monitor the soil's moisture levels in real-time.

The data obtained from the Soil Moisture Sensor v2.0 was then utilised in our system's logic to determine the plants' irrigation needs. This integration allowed us to optimise water usage by ensuring the plants received adequate moisture levels while avoiding overwatering. Ultimately, the Soil Moisture Sensor v2.0 played a vital role in our smart irrigation system's efficient and precise irrigation.

2.4. Relay Module and Water Pump

Our smart irrigation system project incorporated a relay module and water pump as actuators. The Relay Module was a switch, enabling us to control the water pump operation based on our system's commands [30]. Using the relay module, we established a safe and efficient interface between the Raspberry Pi and the water pump, allowing for precise control of water delivery to the plants. With this integration, our smart irrigation system could automate the irrigation process, activating or deactivating the water pump as needed based on sensor readings and system logic. This combination of the relay module and water pump as actuators enhanced the functionality of our system, enabling optimised water usage and efficient irrigation management [31].

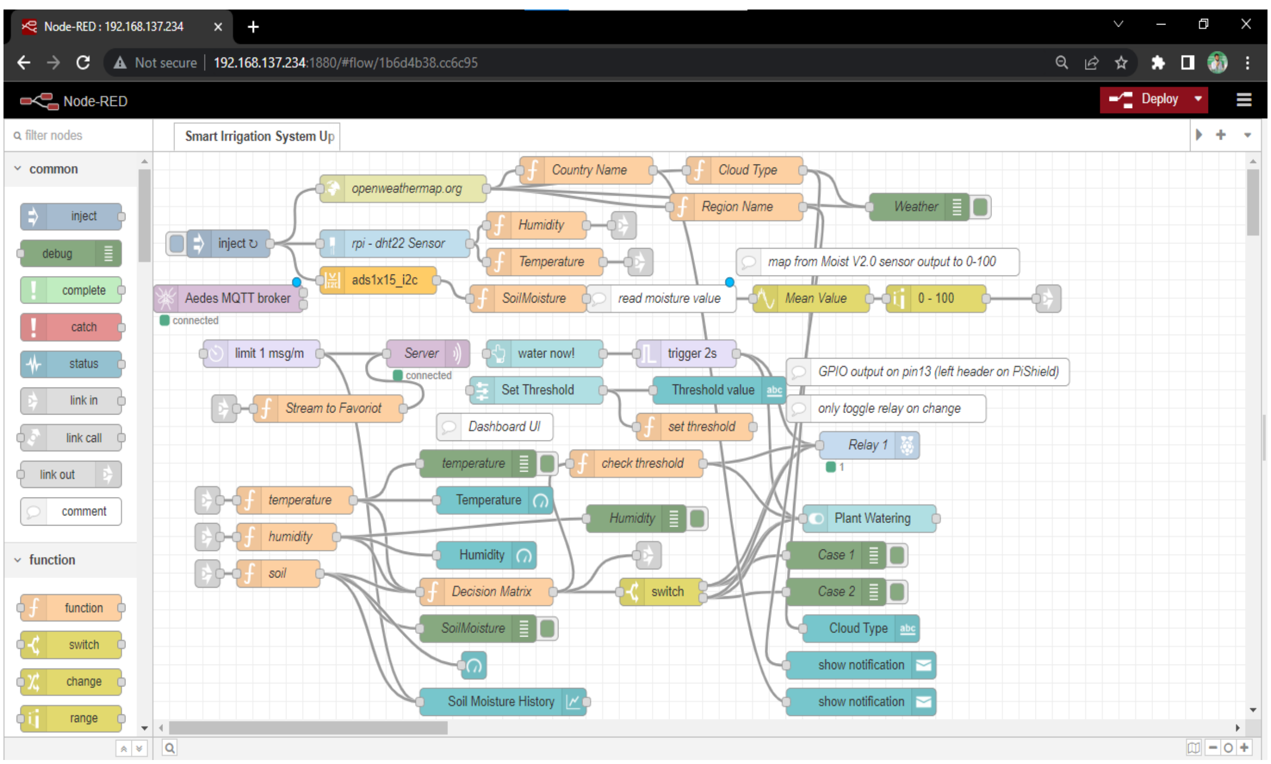

Fig. 3 Node-red flows

2.5. Software Description

In our smart irrigation system, we utilised Node-RED flows for decision-making and sending data to the Favoriot platform, as shown in Figure 3. To connect the DHT11 temperature and humidity sensor, we leveraged the appropriate library within Node-RED, which allowed us to interface with the sensor and retrieve real-time Temperature and humidity data. The sensor data was then processed and analysed within the Node-RED flows to make informed decisions about irrigation requirements.

Similarly, for the soil moisture sensor, we connected it to an ADC (Analog-to-Digital Converter), the library within Node-RED. This library facilitated the conversion of analogue readings from the soil moisture sensor into digital data that could be processed and utilised within the system.

The moisture readings were then incorporated into the decision-making process to determine the irrigation needs based on the moisture levels in the soil.

Additionally, we incorporated the Open Weather Forecast API within Node-RED to access weather data, precisely predicting the chance of rain. This data was integrated into the decision-making flow to determine if irrigation should be adjusted based on weather conditions.

Considering the weather forecast, the system could avoid unnecessary irrigation during periods of expected rainfall, conserving water resources and optimising irrigation schedules [32].

Once the decision-making process was complete, Node-RED flows were used to send the relevant data, including Temperature, Humidity, soil moisture, and irrigation decisions, to the Favoriot platform. This allowed for centralised data management and remote access to the system's information, enabling monitoring and control from the Favoriot interface.

2.6. System Connection

In our system connection, we have the Soil Moisture sensor, Temperature Sensor, and Humidity Sensor all connected to the Raspberry Pi, as revealed in Figure 4. These sensors provide real-time data on soil moisture levels, Temperature, and Humidity, respectively [33, 34]. The Raspberry Pi is the central control unit, collecting data from these sensors [35, 36].

Next, we utilise Node-RED as flow management and the decision-making platform. Node-RED receives the data from the sensors connected to the Raspberry Pi and processes it accordingly. The flow in Node-RED incorporates the readings from all three sensors, allowing for comprehensive analysis and decision-making based on the combined data. Furthermore, we connect the Raspberry Pi and the Node-RED flows to the Internet. This enables the system to have internet connectivity for remote access, monitoring, and control. With internet connectivity, the system can access external services and APIs.

One such external service is the open weather forecast API. By integrating the Open Weather Forecast API into our system, we can retrieve weather data, including rainfall predictions, which is crucial for optimising irrigation schedules [37]. This data is incorporated into the decision-making process within Node-RED to make informed irrigation decisions based on the combined sensor data and weather forecasts. Finally, we forward the data collected from the sensors and the decisions made by Node-RED to the Favoriot Platform for storage and further analysis. The data is transmitted using the MQTT broker, ensuring seamless and efficient data streaming to the Favoriot Platform.

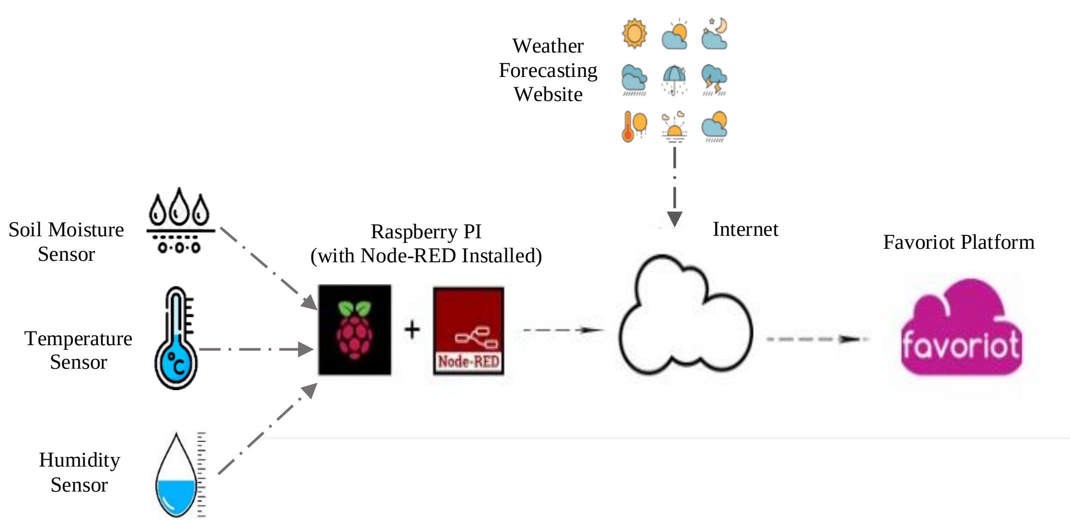

Fig. 4 System connection

We have established a system connection to develop a comprehensive smart irrigation system. This system collects data from various sensors and processes it using Node-RED. It also combines weather forecasts and securely stores the processed data on the Favoriot Platform. This integration enables efficient monitoring, control, and analysis of the irrigation system, improving water management and optimising crop yield [38].

2.7. System Truth Table

As shown in Table 1, we can observe the decision-making process based on the combinations of Soil Moisture, Humidity, and Temperature values. Here are the key insights from the truth table analysis:

When Soil Moisture is low (<50), humidity is high (>70), and Temperature is high (>32), the decision is "No irrigation." This suggests that when the soil moisture is low. Still, Humidity and Temperature are high, so irrigation may not be required as environmental conditions are already conducive to plant growth. Similarly, when Soil Moisture is high (>50), humidity is high (>70), and Temperature is high (>32), the decision is also "No irrigation." This implies that when the soil moisture, Humidity, and Temperature are high, additional irrigation may not be necessary as the moisture levels are already sufficient.

On the other hand, when Soil Moisture is low (<50), humidity is low (<70), and Temperature is high (>32), the decision is "Irrigation required." In this case, even though the soil moisture is low, the low humidity indicates a potential need for irrigation to ensure adequate moisture levels for plant growth.

Lastly, when Soil Moisture is low (<50), humidity is low (<70), and Temperature is low (<32), the decision is also "Irrigation required." This suggests that irrigation is needed when all three factors indicate lower levels, such as low soil moisture, low Humidity, and low Temperature, may hold back plant growth.

Overall, the truth table analysis provides a logical framework for decision-making based on the specified threshold values for Soil Moisture, Humidity, and Temperature. It helps determine when irrigation is required and can be avoided, considering the interplay between these factors in the context of plant growth and irrigation needs.

Table 1. Truth table

Soil Moisture	Humidity	Temperature	Decision
Low (<50)	High (> 70)	High (>32)	Low (No irrigation)
High (>50)	High (> 70)	High (>32)	Low (No irrigation)
Low (<50)	Low (< 70)	High (>32)	High (Irrigation required)
Low (<50)	Low (< 70)	Low (<32)	High (Irrigation required)

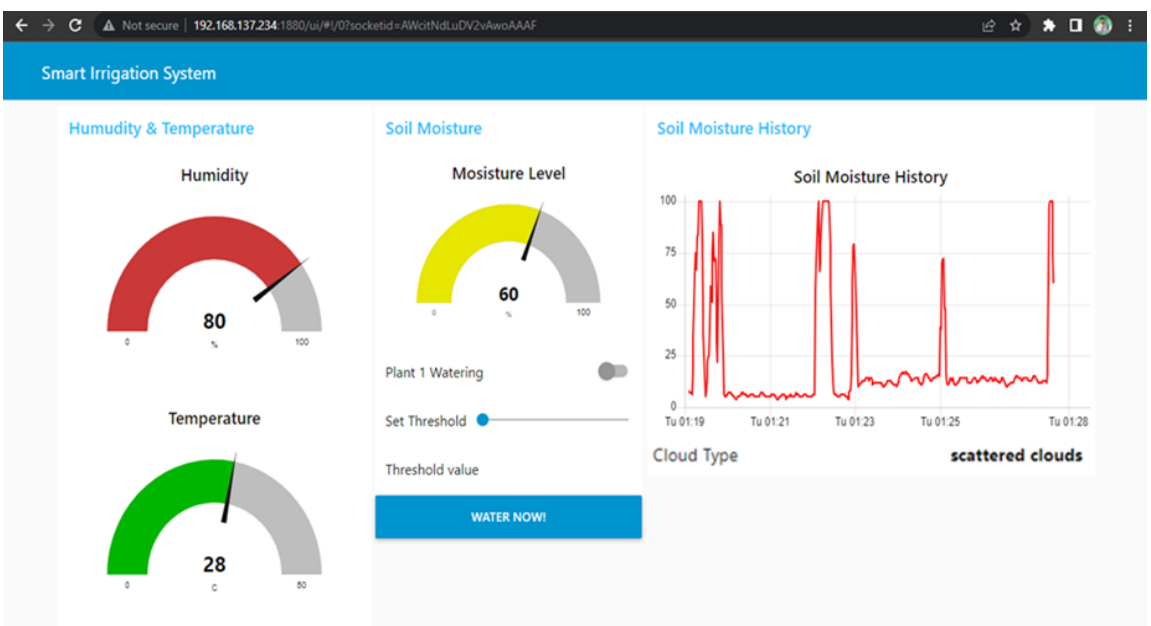

Fig. 5 No irrigation needed

3. Results and Discussion

Based on Figure 5, which provides readings of humidity (80%), Temperature (28°C), and Soil moisture level (60%), our system determines that no irrigation is needed. This decision aligns with the threshold values set by the system, indicating that the current environmental conditions are suitable for plant growth without additional watering. Moreover, our design records soil moisture history, providing valuable reference data for monitoring and analysing moisture levels over time. This historical information can aid in understanding patterns and trends and optimising irrigation schedules for optimal plant health and water conservation.

Regarding weather conditions, our system virtualizes the type of cloud as scattered clouds. This information can be beneficial for considering the impact of weather on irrigation needs and adjusting the watering schedule accordingly.

Flexibility and contingency: Our system incorporates a manual irrigation option. In the case of a system outage or malfunction, users can utilise the manual irrigation feature by accessing the options button labelled "Water Now." This allows direct control and intervention in watering the plants as a backup measure.

In addition to the provided features, our smart irrigation system offers the flexibility to customise the threshold values for different plants. This allows users to set specific thresholds based on the unique requirements of each plant species or variety. By enabling users to define their thresholds, our system ensures that irrigation decisions are tailored to the specific needs of different plants in the garden or field. This flexibility accommodates plant species, growth stages, and environmental preference variations. For example, some plants may require higher soil moisture levels to thrive, while others may prefer drier conditions. By allowing users to adjust the threshold values, our system ensures that irrigation decisions align with the individual requirements of each plant, optimising water usage and promoting healthy growth.

This customisation feature empowers users to create a personalised intelligent irrigation system that best suits their gardening or agricultural needs. It provides the freedom to fine-tune and adapt irrigation settings as needed, promoting efficient water management and maximising the potential of diverse plant species in the system. Our smart irrigation system evaluates current environmental parameters and makes informed decisions based on predefined or desired thresholds. Including Soil moisture history, virtualization of weather conditions, and the availability of a manual irrigation option contribute to a comprehensive and adaptable system that optimises water usage while ensuring the health and vitality of the plants.

Based on Figure 6, the current Temperature is 26 degrees Celsius, the humidity is 44%, and the soil moisture is 68%. The previous threshold for soil moisture was less than 50% but has been manually adjusted to 77%, as we can see from the threshold value. Since the current soil moisture level is 68% and the new threshold is 77%, the soil moisture is still below the desired threshold. Therefore, irrigation is indeed required to provide water to the plants.

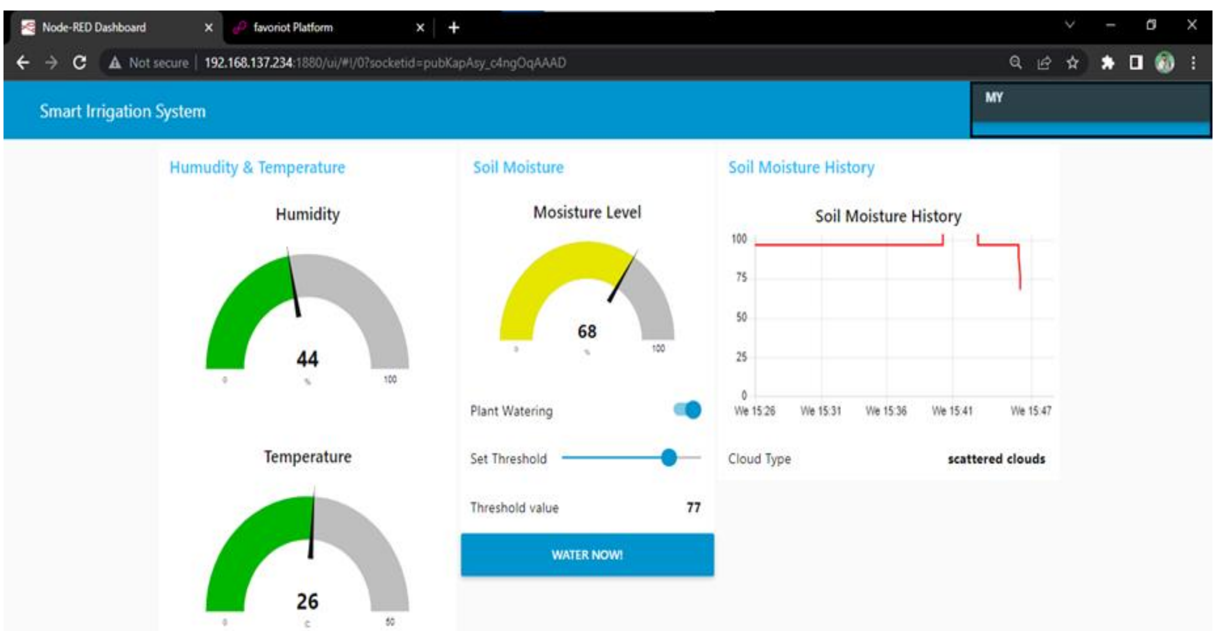

Fig. 6 Irrigation needed

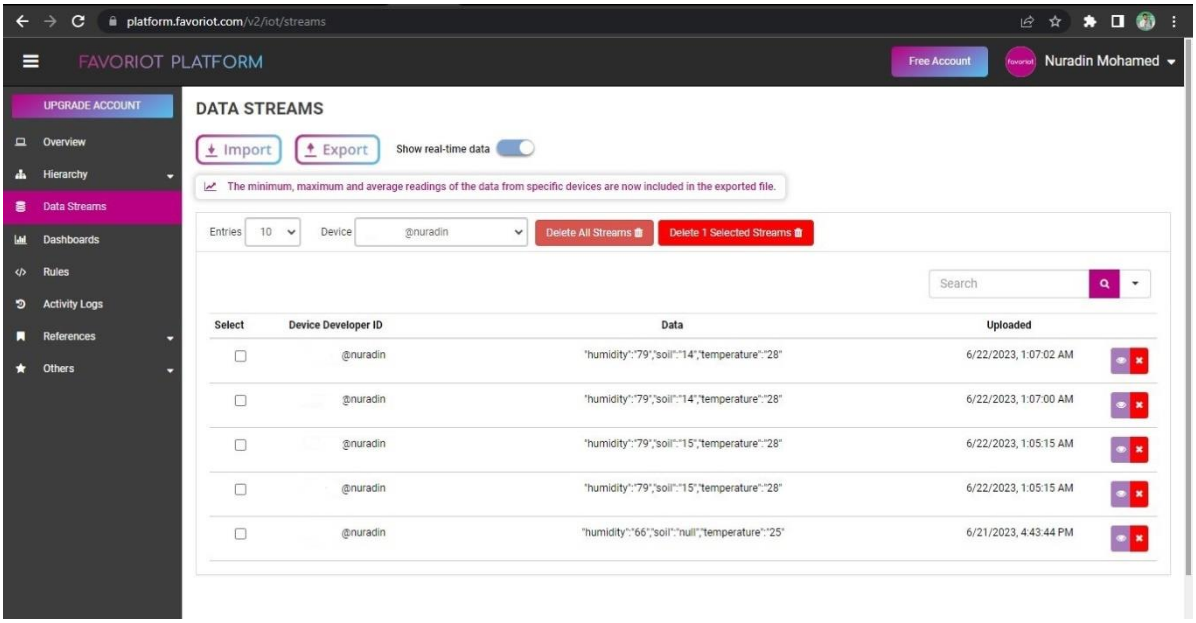

Fig. 7 Stream to favoriot platform

Irrigation artificially supplies plants with insufficient natural rainfall or soil moisture. Watering the plants through irrigation helps maintain the soil moisture at an optimal level, promoting healthy plant growth and preventing water stress.

In this case, with a soil moisture level of 68% below the desired threshold of 77%, the plants may need more water for their growth and development. To rectify this situation, irrigation should be initiated to supplement the existing moisture in the soil. The specific method and amount of irrigation required would depend on various factors, including the plant species, soil type, local climate, and irrigation system available. It is essential to consider these factors to ensure efficient water usage and avoid overwatering, which can harm plant health.

Providing adequate irrigation ensures that the plants receive the necessary water for optimal growth and productivity. Based on Figure 7, we stored the data streams on the Favoriot platform every second. Our smart irrigation system ensures that real-time data is collected and securely stored in the cloud. This continuous data recording frequency allows for highly accurate and up-to-date information about environmental conditions and irrigation activities. Storing data in the cloud offers several benefits.

First and foremost, it provides a reliable and secure storage solution. The Favoriot platform ensures the integrity and safety of the data, protecting it from loss or damage that could occur while using local storage methods. Additionally, cloud storage eliminates the need for physical storage infrastructure, reducing costs and simplifying data management. Access to the data stored on the Favoriot platform is simple from any location with an internet connection. This allows for remote monitoring, analysis, and control of the smart irrigation system. Users can easily access stored data and view it in real-time or review historical trends and patterns for in-depth analysis.

The availability of continuous data in the cloud enables future analysis and research. By leveraging this data, users can gain valuable insights into irrigation patterns, plant health, and water usage trends. This information can help optimise irrigation schedules, identify areas for improvement, and make data-driven decisions for enhanced water management and crop yield.

4. Conclusion

Implementing a smart irrigation system driven by IoT technologies presents a revolutionary approach to addressing several critical aspects of modern agriculture, including water management, crop productivity, and sustainability. This advanced system controls cutting-edge components and data-driven intelligence to transform traditional irrigation practices.

At its core, the smart irrigation system is a paradigm shift in water management. Through the seamless integration of sensors, data analytics, and automation, it becomes possible to precisely tailor irrigation schedules to meet the real-time water requirements of plants. The system's ability to make dynamic decisions based on these requirements conserves water and fosters healthier crop growth while reducing the environmental impacts of excess water use.

The heart of this project is a robust IoT infrastructure, with a Raspberry Pi serving as the central control unit. This powerful microcomputer orchestrates the entire system's operation. Connected to it are sensors that provide crucial environmental data: Temperature, Humidity, and soil moisture. These sensors work harmoniously to collect essential information about the conditions that plants are experiencing.

Node-RED, a powerful flow management and decision-making tool, ensures effective decision-making. It processes real-time data from the sensors, constantly assessing the state of crops and the surrounding environment. It then makes informed decisions about when and how much to irrigate based on predefined threshold values for soil moisture, Humidity, and Temperature. One of the standout features of this smart irrigation system is its adaptability. By allowing users to adjust these threshold values, the system can be tailored to meet the specific needs of various types of plants. Whether it is optimising water delivery for delicate flowers or robust crops, this system can be customised to ensure optimal results.

Integrating the Favoriot platform for data storage is a critical element in the system's functionality. By storing data in the cloud at a high frequency (every second), the system guarantees that information is accurate and up to date. This data repository is not just for record-keeping; it is a treasure trove of insights into irrigation patterns, plant health, and water usage trends.

The ability to access this data remotely is a game changer. Farmers and agricultural practitioners can monitor and control the system from anywhere, giving them unprecedented flexibility and convenience. Furthermore, the data collected over time can be analysed to fine-tune irrigation schedules, leading to more efficient water use and increased crop productivity. In conclusion, the smart irrigation system outlined in this project represents a pivotal advancement in agriculture. It tackles the inefficiencies and challenges that have long plagued traditional irrigation methods. By harnessing the potential of IoT technologies, it offers automated, precise irrigation management, leading to tangible benefits such as water conservation, enhanced crop yields, and environmentally responsible water management practices.

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