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High-technology agriculture system to enhance food security: A concept of smart irrigation system using Internet of Things and cloud computing

Abdennabi Morchid [a], Ishaq G. Muhammad Alblushi [b], Haris M. Khalid [c,d,*], Rachid El Alami [a], Surendar Rama Sitaramanan [e], S.M. Muyeen [f]

[a] *Department of Physics, Laboratory of Informatics, Signals, Automation and Cognitivism (LISAC), Faculty of Sciences Dhar El Mahraz, Sidi Mohamed Ben Abdellah University, BP 1796 Fes-Atlas, 30003 Fez, Morocco*
[b] *Department of Electrical and Electronics Engineering, Higher Colleges of Technology, Sharjah 7947, United Arab Emirates*
[c] *College of Engineering and Information Technology, University of Dubai, Academic City, 14143 Dubai, United Arab Emirates*
[d] *Department of Electrical and Electronic Engineering Science, University of Johannesburg, Aukland Park 2006, South Africa*
[e] *Samsung Austin Research and Development Centre (SARC), Advanced Computing Lab (ACL), San Jose, CA, USA*
[f] *Department of Electrical Engineering, Qatar University, Doha 2713, Qatar*

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ABSTRACT

Context: Food security is highly reliant on agricultural activity to drive the world economy. However, this activity is in great danger due to climatic changes and improper use of irrigation techniques. Consequently, the lives of numerous individuals worldwide are in jeopardy. In light, this paper investigates the promise of smart irrigation systems based on new technology.
Objective: To meet the growing demand for water in agriculture, this study presents an intelligent irrigation system that uses cutting-edge technologies of (1) cloud computing, (2) embedded systems, and (3) Internet-of-Things (IoT). The main objective is to demonstrate how this innovative strategy can effectively manage water resources, supporting food security through cutting-edge agricultural technology.
Methods: This paper proposes a smart irrigation system based on cutting-edge technologies like the embedded system, Internet of Things (IoT), and cloud computing as a groundbreaking strategy to improve food security through the implementation of advanced agricultural technology. This system supervises real-time monitoring of crucial environmental factors such as (1) moisture, (2) humidity, (3) temperature, and (4) water levels, in smart agriculture practices. In addition, this system employs the latest sensors, including the module (DHT22), water level sensor, and moisture sensors, which are connected to the widely used embedded system (ESP32). The system uses the ThingSpeak cloud and ThingView app to enable wireless communication between the device and the farm owner, enhancing their interaction. The automated control of the two water pumps is based on the readings of various environmental factors. Moreover, this will also present a mathematical-driven function known as linear interpolation to calibrate the water level sensor in percentage. This system was created using the V-model software development approach.
Results and conclusion: Farmers can access comprehensive farm data from anywhere in the world as the sensor data is transmitted in real-time to both the ThingSpeak cloud and the ThingView. This capability allows for more precise crop irrigation and increased production. The study's findings demonstrate a striking 70% reduction in water consumption for soil irrigation when utilizing the proposed smart irrigation system. This paper underscores the significant promise of smart irrigation systems, driven by IoT, embedded systems, and cloud computing, to conserve water resources and advance food security.
Significance: This article proposes an innovative solution that reduces soil irrigation water consumption by 70% compared to traditional methods. It explores how smart irrigation can improve the sustainability of agriculture and positively influence food security.

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* Corresponding author.
E-mail address: mkhalid@ud.ac.ae (H.M. Khalid).

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Nomenclature

Acronyms

AI	Artificial Intelligence
CPU	Central Processing Unit
DHT22	Digital Humidity & Temperature
GDP	Gross Domestic Product
Hs	Humidity Sensor
ID	Identity
I2C	Inter Integrated Circuit
IoT	Internet of Things
LED	Light Emitting Diode
LCD	Liquid Crystal Display
MCU	Marvel Cinematic Universe
MQTT	Message Queuing Telemetry Transport
Ms	Moisture Sensor
PC	Personal Computer
s	Seconds
SDIO	Secure Digital Input Output
SPI	Serial Peripheral Interface
T-Pump	Tank Pump
Ts	Temperature Sensor
ToffTP	Turning Off Tank Pump
ToddWP	Turning Off Watering Pump
TonTP	Turning On Tank Pump
TonWP	Turning On Watering Pump
HC-SR04	Ultrasonic Distance Sensor
UART	Universal Asynchronous Receiver/Transmitter
Ws	Water Level Sensor
W-Pump	Watering Pump
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network

1. Introduction

1.1. *Agriculture – food security, gross domestic product, world population, and climate change*

Agriculture plays a crucial role in ensuring food security and has a significant impact Gross Domestic Product (GDP) of the country. With the projected increase the global population, there will be a greater need for agricultural production (FAO et al., 2022). The need for food will in-fact rise significantly as the world's population continues to grow. Also, it is expected that the world population will surpass 10 billion by 2050. To fulfil the increased demand caused by population growth, food production must increase by almost 70 % (Giller et al., 2021). For agriculture to satisfy this need, it must adapt and expand. However, due to additional difficulties brought about by climate change and water constraints, existing agricultural methods are no longer enough to supply this expanding need (Elijah et al., 2018).

1.2. *Smart agriculture – sustainability, production, and resources*

Smart agriculture is rapidly implementing contemporary technology to address these issues and boost production and sustainability (Ahmed et al., 2018; Lindgren et al., 2018). For instance, a recent scientific field called "smart irrigation" employs data-intensive techniques to maximize water consumption and boost agricultural production. Farmers may gain useful information from sensors and data analytics in agriculture to better understand how their actions affect the soil. Farmers may use data gleaned from environmental parameter monitoring and analysis to improve practices, make well-informed decisions about resource use, and identify crop problems early on. This improves sustainability and creates a deeper comprehension of the link between farming and land (Idoje et al., 2021; Ojha et al., 2015). Technology in agriculture is essential for resource conservation, reducing the environmental effect of farming operations, and feeding the world's population. With the advent of the digital age, sophisticated technologies are replacing old farming techniques. These systems provide enormous quantities of data that may be used to optimize resources used and boost agricultural output. Hence, the use of technology and data-driven decision-making in agriculture will boost productivity, decrease waste, and protect the planet's natural resources (Weersink et al., 2018; Khan et al., 2021). Agriculture, not only plays a crucial part in providing food security and sustainability, but it also significantly contributes to a nation's economic development (Beckman and Countryman, 2021). As was already established, agriculture has a big influence on a country's GDP.

1.3. *Agriculture, economic, innovative technology, scope, and possible potential of the paper*

In reality, throughout history, agriculture has been a key factor in the economic success of numerous nations. In rural regions, especially agriculture, not only produces food but also, opens doors to employment. For farmers and those who work in the agricultural value chain, such as processors, marketers, and exporters, it is a significant source of revenue. As a result, agriculture has the ability to promote economic expansion, reduce poverty, and improve living conditions. Investments in innovative agriculture technology have the potential to accelerate economic growth. Farmers can boost their earnings, produce more food with fewer resources, and open new markets for their goods with the aid of modern agricultural systems and smart technology (Bathaei and Štreimikienė, 2023; Blakeney, 2022). In light of the economic considerations and the imperative to optimize the use of this vital resource, the implementation of computerized smart systems in North Africa and worldwide has become crucial (Assouli et al., 2018). The proposed paper presents an advanced smart irrigation system that aims to revolutionize agricultural efficiency and increase yields. With a broad scope that includes innovative irrigation technologies and cutting-edge technological applications such as the Internet of Things, cloud computing, and embedded system, the paper focuses on improving food security. Through potential stability and the promotion of sustainable agricultural practices, the study also envisages a future in agriculture contributing to the promotion of global food stability.

1.4. *Intelligent irrigation – internet, deep Learning, Machine Learning, and motivation of this work*

The intelligent irrigation, utilizing state-of-the-art technology like Internet-integrated systems, plays a pivotal role in collecting precise data (such as temperature, humidity, and soil moisture), this helps in demonstrating its effectiveness in practical applications, and facilitating remote control (Rahman et al., 2020; Pramanik et al., 2022; Abba et al., 2019; Munir et al., 2021). Consequently, the utilization of the Internet in recent years reflects significant advancements in integrated systems, particularly in developed nations, leading to remarkable improvements in water conservation and production efficiency (Abi Saab et al., 2019; Pasika and Gandla, 2020). Additionally, the emergence of cutting-edge technologies such as deep learning, machine learning, and artificial intelligence in agriculture contributes further to the maintenance and boost of the outcome (Talaviya et al., 2020; Saleem et al., 2021; Subeesh and Mehta, 2021). Motivated by global food security concerns, this research focuses on irrigation. Meeting the food needs of a growing population while preserving water resources is of paramount importance. Current traditional irrigation practices affect yields and food security. The study proposes an intelligent irrigation system that integrates IoT and cloud technologies. This innovation makes it possible to conserve water efficiently, increase yields, and feed crops well. With broad global application, this approach advances smart farming, helping to improve food security and sustainability.

1.5. *Smart irrigation, Internet of Things, ThingSpeak, and focus of this work*

Numerous cutting-edge technologies, including the IoT, have broad applications. It is hard for farmers to personally visit and monitor every part of the farms they oversee, which might result in inconsistent watering. Losses in money and poor crop quality are consequently a result of this. In order to solve this problem and streamline the agricultural process, the research papers (Ayaz et al., 2019; Habib et al., 2023), suggest an intelligent irrigation system that makes use of cutting-edge IoT technology. These studies (Kamienski et al., 2019; García et al., 2020), also introduce the concept of "smart agriculture," which makes use of data technology to increase agricultural output and raise the overall quality. Furthermore, the mentioned works (Pathak et al., 2019; Ndunagu et al., 2022), make use of the ThingSpeak platform, which provides a complete solution for gathering and storing data acquired from agricultural sensors and controllers, to meet the needs of farm operators. This portal is a useful resource for collecting and preserving important agricultural data. Wireless sensor networks are utilized by these papers while creating autonomous plants. By using a smart irrigation system, irrigation settings may be managed automatically (Tiglao et al., 2020; Lloret et al., 2021; Zervopoulos et al., 2020; Morchid et al., 2022; Morchid et al., 2021). In these studies (Olisa et al., 2021; Hussen Hajjaj et al., 2020; Hanan et al., 2019; Tham et al., 2022), a water level sensor was utilized. Specifically, The HC-SR04 device of the real-time water level monitoring system is used to accurately measure the water level as a key component. Further, this study presented a review of applications of IoT and sensor technology to increase food security and agricultural sustainability (Morchid et al., 2024). The focus of this study is to provide a smart irrigation system that that would use cloud computing and embedded IoT technologies to optimize water utilization and make sure plants get the right quantity of water. The research shows how this method might increase agricultural yields, decrease water waste, and assist offset the problem of food security. The system's feasibility for application in many places around the world is also emphasized in this paper, supporting the progress of smart agriculture.

1.6. *Main contribution of this work*

The main contribution of this paper is expressed as follows. Fig. 1 also shows the graphical abstract of the proposed scheme based on these contributions.

- A smart irrigation system is proposed using new technologies like the IoT, embedded systems, and cloud computing as a groundbreaking strategy to improve food security through the implementation of advanced agricultural technology.
- The proposed system supervises real-time monitoring of crucial environmental factors such as moisture, temperature, humidity, and water levels in smart agriculture practices.
- The proposed system also employs state-of-the-art sensors which includes the (1) humidity and temperature sensor module (DHT22), (2) water level sensor, and (3) moisture sensors. All these sensors are connected to the widely-used embedded system (ESP32). The system uses the ThingSpeak cloud to enable wireless communication between the device and the farm owner, enhancing their interaction.
- Farmers can access comprehensive farm data from anywhere in the world as the sensor data is transmitted in real-time to both the ThingSpeak cloud and the ThingView application. This capability allows for more precise crop irrigation and increased production.
- The proposed scheme also presents a mathematical-driven function known as linear interpolation to calibrate the water level sensor in percentage. This smart irrigation system was created using the V model software development approach.
- The suggested solution in this paper uses 70 % less water for soil irrigation compared to traditional techniques. It is more efficient and environmentally friendly since it prevents drowning crops and draining water beds.
- The proposed article also examines the effects of smart irrigation on agricultural sustainability and its impact on food security.

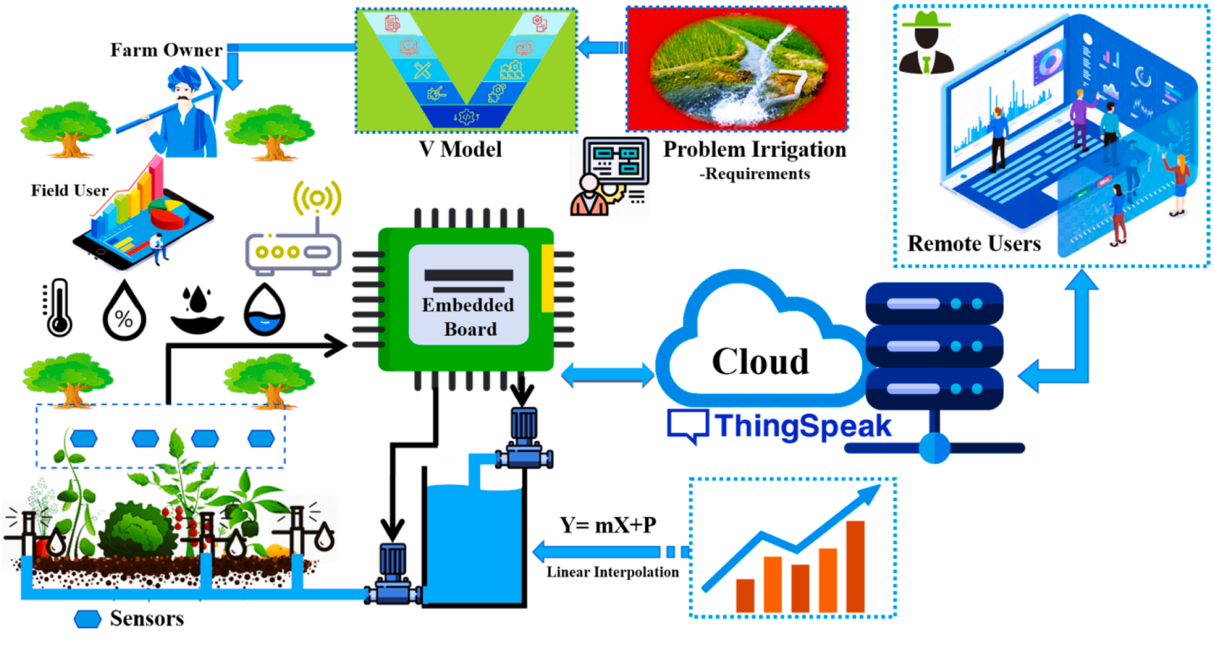


Fig. 1. Graphical abstract of the proposed paper.

1.7. *Formation of the remaining paper*

The formation of the remaining paper is structured as follows: The architecture of the proposed scheme is described in Section 2. Section 3 discusses the algorithm of the proposed system. Section 4 discusses the results and discussion of the proposed system. Finally, the conclusions and future work are presented in the last Section 5. The framework of the paper can also be seen in Fig. 2.

2. Architecture of the proposed scheme

Smart irrigation systems gather information on soil moisture and other parameters using several IoT devices and sensors. These sensors can detect the moisture content of the soil, temperature, humidity, and even water level. They can also capture images of the crops to track their development and general health. Remote control of an irrigation system using data obtained from sensors and wireless communication with a cloud-based platform for analysis. The data is processed and analyzed on a cloud-based platform which makes use of models and algorithms to find the best watering plan depending on the information gathered. The irrigation system is connected to a small computer called an embedded board which can regulate the irrigation system's water flow depending on instructions.

Through a mobile application, farmers can access and monitor the system, which gives them real-time information on the soil moisture, weather, and irrigation schedule. Through the app, they may manually operate the irrigation system or modify the watering schedule. Farmers can increase agricultural yields and optimize irrigation thanks to this. As it only supplies the crops with the water they require, this technology also conserves water resources and lowers expenses. Furthermore, crop planning and research may be done using the data gathered by the smart irrigation system. Farmers, for instance, might spot trends in crop growth and pinpoint the perfect circumstances for a certain crop by examining data collected over time. Future agricultural yield optimization and crop planting schedule decisions may both be made using this knowledge. In the context of smart irrigation, wireless sensor networks (WSNs) enable autonomous plant management through functions such as environmental monitoring, nutrient management, disease detection, automated irrigation, and communications. Wireless sensor networks provide real-time data on factors such as temperature, humidity, soil moisture, water level, and nutrient levels. They support adaptive control systems, use low-power nodes for greater energy efficiency, and enable remote monitoring and control through cloud integration. Overall, WSNs contribute to the creation of autonomous plants by facilitating data-driven decision-making and optimizing plant conditions to improve crop productivity and sustainability. On the other hand, the integration of various sensors into WSNs is essential for plant autonomy. The most common sensors are those measuring temperature, humidity, soil moisture, light, nutrients, pests, water levels, and wind. Collectively, these sensors help improve plant-related processes. The integration of various sensors improves the accuracy and efficiency of autonomous plant management systems, enabling informed decisions to be made to improve crop productivity and sustainability.

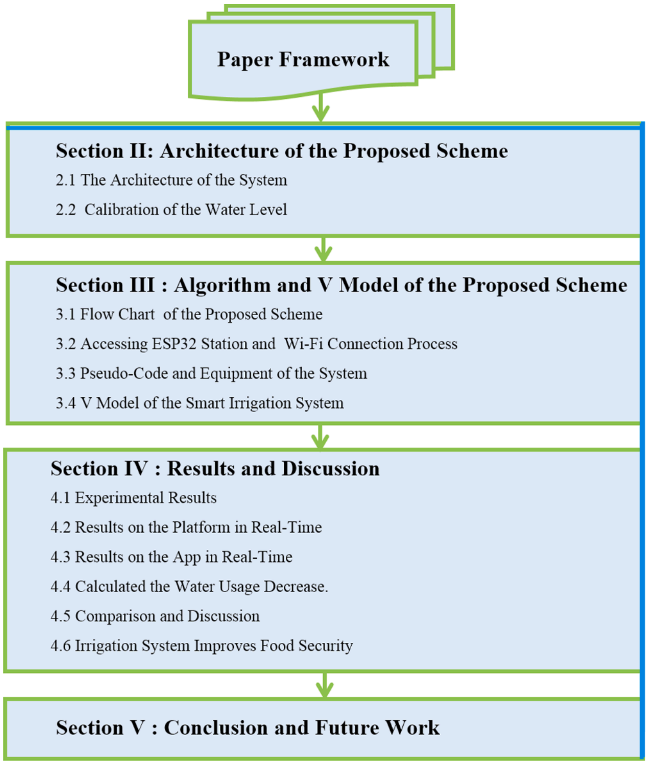


Fig. 2. Paper framework of the paper.

2.1. *The architecture of the system*

This section describes the structure of the smart irrigation system shown in Fig. 3. The system is made up of three essential parts: IoT devices, cloud computing, and application interface. Internet connectivity enables consumers from all around the world to view and track their farm data.

The irrigation system is an automated electronic system that is intended to efficiently manage irrigation scheduling. Its primary goal is to accommodate the changing needs of plants as they develop. Through the analysis of soil moisture content, the system determines the precise percentage of water necessary for irrigation, ensuring accurate scheduling for various agricultural seasons and crop varieties. The key aims of smart irrigation encompass optimizing water consumption to reduce costs, enhancing agricultural productivity, benefiting farms, fostering energy efficiency, and ensuring food security through utilizing new technologies like the IoT, cloud computing, embedded systems, and sensors.

The IoT architecture of the proposed system, shown in Fig. 3, comprises three fundamental components: (1) IoT devices, (2) cloud computing, and (3) the application interface. The components of IoT devices include sensors, actuators, a control unit, and a gateway, among others. These sensors are in charge of monitoring critical environmental factors including air humidity, air temperature, soil moisture, and water level within the smart farm. The soil moisture sensor is used to measure the soil moisture content. In addition, the DHT22 device, which is famous for its accuracy, was used, which is a two-in-one combined sensor to measure humidity and temperature. In addition, the HC-SR04 ultrasonic distance sensor is used to detect water levels. The ESP32 microcontroller-powered control unit receives sensor readings and coordinates the actuators to make sure that the plants are watered on schedule. The ESP32 microcontroller is appropriate for larger-scale applications since it has adequate memory capacity and improved processing capability. The smart irrigation system's actuators are essential for carrying out instructions from the ESP32 controller. In our system, a water sprinkler is used to water the plants, and a water pump is used to fill the tank.

The next development in the IoT device architecture is the addition of a gateway. The gateway gathers sensed data from the control unit and carries out critical data processing operations to enable intelligent aggregation, optimize network traffic, and lower energy consumption. It effectively bundles the essential components of the particular process model and sends them to the cloud, leading to appreciable decreases in latency and costs at higher levels. The data is continually processed by conventional cloud computing systems when it is received from the gateway.

Cloud computing is the focus of our system architecture's second

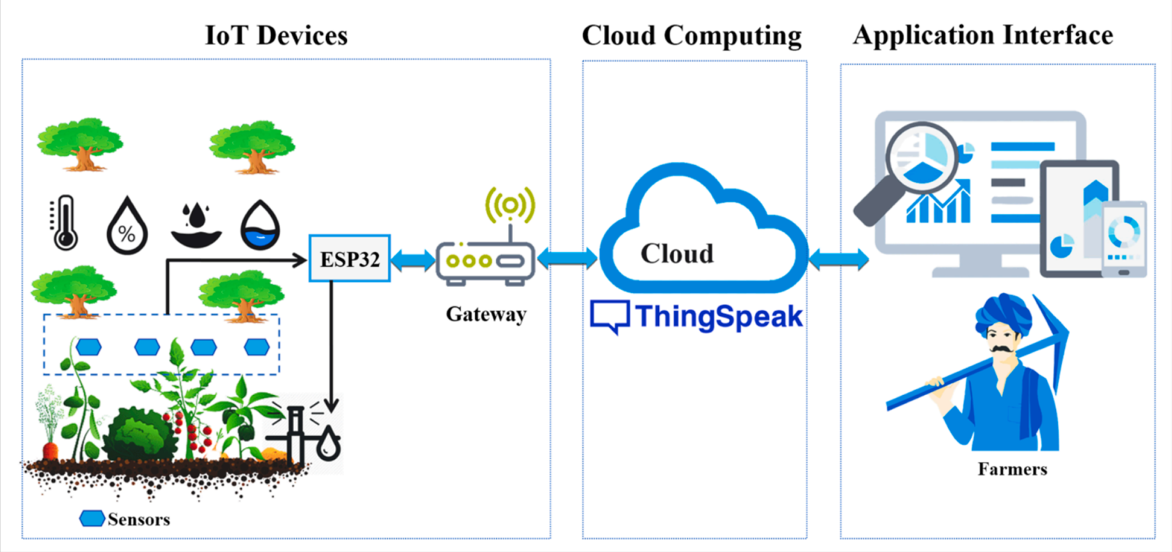


Fig. 3. The smart irrigation system's IoT architecture.

component. Farmers now have access to a huge variety of data that was gathered through the control unit and delivered over the gateway console, thanks to this layer. Farmers may gather, view, and analyze real-time data streams by utilizing the cloud-based IoT analytics platform ThingSpeak. ThingSpeak is a complete data management platform that enables farmers to design unique data visualizations using their own technology. The platform allows for the collection, visualization, analysis, and derivation of useful insights from live data streams. Using the ThingSpeak platform to post data or the ThingView app to retrieve data, farmers may communicate with the system.

The irrigation system architecture is completed by the application interface, often known as the front layer. Results of data processing, such as soil moisture, humidity, temperature, and water level, are shown in this user-facing component. Farmers may get real-time data visualizations using ThingSpeak and use the knowledge to guide their decisions. This interface makes it possible for the farmer and the system to communicate seamlessly, which makes it easier to monitor and manage the irrigation systems.

2.2. Calibration of the water level

In this section, the sensor calibration method is employed in the proposed work. The HC SR04 device was utilized to measure the water level. Several studies (Olisa et al., 2021; Hussen Hajjaj et al., 2020; Hanan et al., 2019; Tham et al., 2022), have employed an ultrasonic sensor to determine the water level. However, these papers did not provide a mathematical calculation for the calibration procedure of the ultrasonic sensor used to measure the water level. In the proposed study,

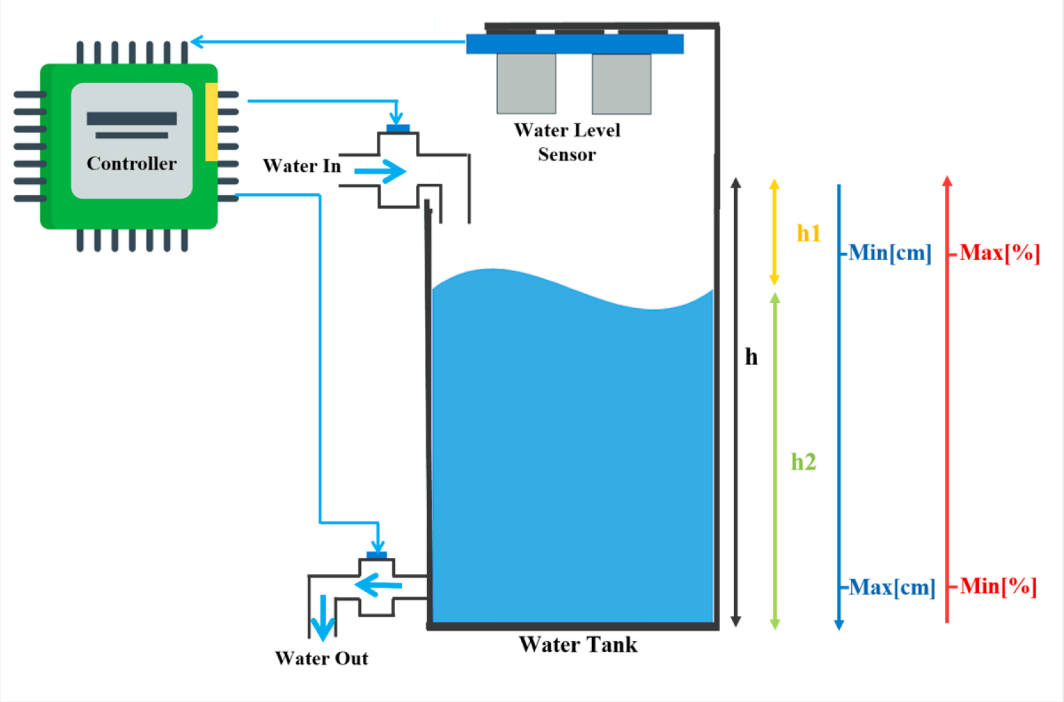


Fig. 4. Architecture of the water level calibration.

a calibration technique is utilized to study the water level sensor. This technique involves a linear interpolation function, referred to as the water level sensor calibration, which establishes a relationship between the sensor's values and the corresponding water level. (1) expresses this relationship in a linear formula. Specifically, when the maximum value of the sensor is represented in centimeters, the minimum value corresponds to the %, and vice versa. Fig. 4 visually illustrates this relationship between the sensor's values and the water level in %.

The calibration process was used to accurately adjust the input of the ultrasonic sensor. The sensor is connected to the ESP32 Microcontroller for seamless integration and data processing. During the system startup, we obtain synchronized sensor data for a duration of 2 sec. Subsequently, we conduct a thorough analysis of the system, focusing on the highest and lowest values of the sensor readings. The HC-SR04 device is capable of measuring distances ranging from 2 cm to 400 cm. Equation (1) represents the mathematical interpolation function used to detect the water level in percentages, such as 5 %, 30 %, etc. This linear interpolation representation of our proposed system is as follows:

$$\mathrm{Y} = \mathrm{mX} + \mathrm{P} \tag{1}$$

In the given linear interpolation (1), the variables used are defined as follows:

Y: Output of the water level in %.
X: Input of the water level in cm.
m: Coefficient.
P: Zero adjustment.

The coefficient may be computed as in equation (2) if we assume that the difference between the highest and minimum values is equal to the h_2 described in equation (3). Consequently, level Y is equal to 1 when X is equal to the maximum value (Max). Further context or computation can be used to calculate the value of P, which represents zero adjustments as flow in equation (4).

$$m = -99/h2 \tag{2}$$

$$\mathrm{h2} = \mathrm{Max} - \mathrm{Min} \tag{3}$$

$$\mathrm{P} = 1 - \mathrm{m\,x\,Max} = 1 + 99\,\mathrm{x\,Max}/20 \tag{4}$$

In the proposed paper, it has been determined that the maximum distance in the water tank is 25 cm, and the minimum reading is $h_1 = 5$ cm. Therefore, based equation (3) the difference between the maximum and minimum values (h_2) is calculated as h_2 = Max - Min = 25 cm − 5 cm = 20 cm. Using this information, the coefficient (m) can be calculated as m = -99/h_2 = −99/20 = −4.95. (4) is obtained as follows:

$$\mathrm{Y} = -4.95\mathrm{X} + 1 + 99\,\mathrm{x\,Max}/20 \tag{4}$$

For instance, if X = Min = h_1 = 5 cm, the value of the water level (Y) will be 99 %. On the other hand, if X = Max = 25 cm, the water level value will be 0 %.

The discussion of this study towards the linear interpolation has important implications for sustainable agriculture, smart irrigation systems, and food security. This representation permits precise detection of water levels at various places in a tank or reservoir by creating a link between the values of the water level sensor and corresponding percentages. This interpolation may be used by smart irrigation systems to optimize water use and enhance agricultural operations. Farmers and system controllers can plan irrigation and manage water resources more effectively by continually monitoring the water levels. The system can deliver the proper quantity of water to crops using this real-time data, preventing over- or under-irrigation. This strategy offers two advantages. Firstly, it promotes sustainability and ensures that just the appropriate amount of water is delivered, therefore conserving water resources. Secondly, the representation helps to preserve crop health and production, enhancing food security, by precisely determining water levels.

According to the mathematical calibration technique presented in this article, integrating linear interpolation into the smart irrigation system offers significant advantages. The accuracy of the water level sensor is significantly increased by this mathematical calibration technique, providing reliable information for making informed irrigation decisions. By enabling the system to accurately assess soil moisture levels, thereby reducing the risks associated with over- or under-watering, the use of linear interpolation improves overall irrigation planning. In particular, by reducing water wastage and complying with sustainable farming methods, this strategy improves resource efficiency. Linearization also improves accuracy. In addition, the approach increases the reliability of data-driven decision-making of the smart irrigation system, which in turn fosters stakeholder confidence in the accuracy of the system to make well-informed and effective management decisions. Linear interpolation effectively optimizes agricultural operations by precisely calibrating the sensors, particularly water level sensors, in the smart irrigation system presented in this paper. This enhancement enables better irrigation scheduling, guaranteeing accurate soil moisture measurements and reducing water wastage. The result is greater resource efficiency, in line with sustainable practices. What's more, improved precision has a positive impact on crop productivity, promoting plant health and increasing overall agricultural output.

This section includes a method for calibrating the water level sensor that will provide farmers with accurate results. This calibration technique optimizes the possibilities of seamless and secure soil irrigation management by facilitating effective process control. This strategy differs noticeably from the approaches put forward by authors (Olisa et al., 2021; Hussen Hajjaj et al., 2020).

3. Algorithm and V-model of the proposed scheme

The algorithmic aspect of the proposed approach comprises three essential elements. It begins with a visual flowchart illustrating how the method works. Next, it explains the process of accessing the ESP32 station and establishing a Wi-Fi connection. Finally, it presents the pseudo-code, details of the system equipment, and V Model. This combination of algorithmic representation and equipment information is a valuable resource for researchers, developers, and enthusiasts who want to understand how the system works.

3.1. *Flow chart of the proposed scheme*

The smart irrigation system algorithm created particularly for smart agriculture is shown in detail in Fig. 5. The algorithm encompasses all stages of the software code, beginning with the initialization of the sensors and ending with the display of sensors data on both the ThingSpeak platform and the ThingView application.

The initialization of the temperature, humidity, moisture, and water level sensors is the first step in our system's flow chart in order to get correct values from these sensors. The sensor parameters are adjusted as needed after initialization to ensure accurate readings. Next, the system checks if the ESP32 microcontroller, the ESP32 used in the system, is connected to the ThingSpeak cloud. If not, the system tries connection with the cloud. Additionally, the sensor data is printed on the console for monitoring purposes. For the moisture sensor, if the reading falls below 40 %, indicating a low moisture level in the soil, the watering pump (W-Pump) is activated, and the green LED indicator is turned on. Conversely, if the reading exceeds 40 %, the pump remains switched off. The DHT22 sensor, responsible for measuring air temperature and humidity, continuously reads the values every 2 s while checking for any potential errors. If the temperature reading exceeds 45 °C, indicating a high temperature, the yellow LED is illuminated; otherwise, the yellow LED remains off. In the case of the water level sensor, if the reading indicates a level below 10 %, indicating a low water level in the tank, the tank pump (T-Pump) is activated, and the red LED is turned on. Conversely, if the reading is above 10 %, the tank pump remains off, and the red LED remains unlit. Every 2 s, the suggested smart irrigation

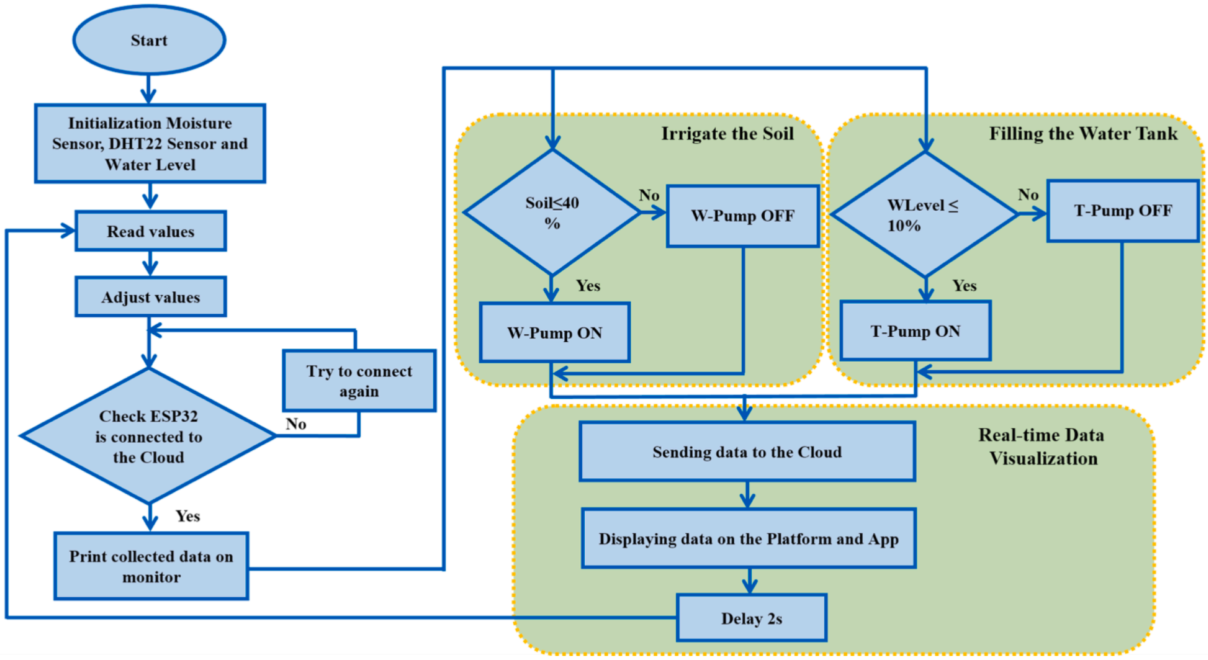


Fig. 5. Flow chart of the proposed smart irrigation system.

system's data is updated (2S). On the LCD, the sensors' whole output is shown in real time. The system also instantly transmits all sensor data to the ThingSpeak cloud and ThingView app. In order to provide accurate and current information on the system's performance, the data is updated every 2 s. Overall, this Smart Irrigation System makes sure that plants and crops receive enough water, and it runs well with little assistance from humans. In addition, this flow chart makes sure that the sensors are working properly, checks their readings, and initiates the required actions in response to predetermined thresholds, as shown by the activation of pumps and indicators.

3.2. Accessing ESP32 station and Wi-Fi connection process

3.2.1. Accessing ESP32 station

The embedded system (ESP32) is typically linked to a wireless router, which acts as an access point for the ESP32 to connect to the local network in these situations. In most cases, the ESP32 is set up as a station, enabling it to connect to the router and access the network. In this setup, we would need toc be connected to the same local network as the ESP32 in order to control it. This implies that we may operate the ESP32 from any device that is also linked to the same network, such as IoT embedded systems (including other ESP32 devices), IoT gateways (which may include routers), and IoT terminals like PCs or smartphones as illustrated in Fig. 6. Our system can access and manage the ESP32 from anywhere in the range of that network as long as these devices are

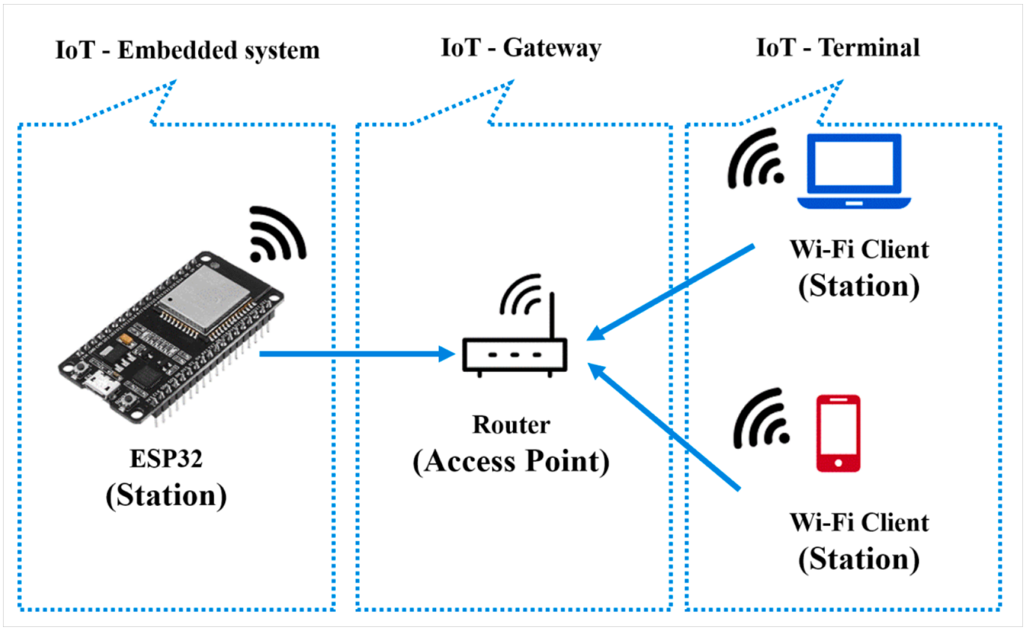


Fig. 6. Accessing the ESP32 station from anywhere.

linked to it.

3.2.1.1. Wi-Fi connection process. The accompanying flow chart serves as an illustration of the methodical flow that the design process for creating a Wi-Fi connection adheres to. The ESP32 microcontroller is initially initialized to guarantee good operation. The system then confirms that the microcontroller is effectively linked to a Wi-Fi network. The information is swiftly and in real-time delivered to the ThingSpeak cloud platform after the connection has been verified. As shown in Fig. 7, this guarantees that all sensor-generated data is easily accessed and shown on the ThingSpeak platform and the associated ThingView application.

3.3. Pseudo-code and equipment of the system

In order to program, develop, and visualize the algorithm's structure, the pseudo-code is supplied below. The algorithm for the suggested irrigation system is shown in Table 1. This pseudo-code defines the simulation of intelligent irrigation based on an embedded system that monitors environmental conditions, controls pumps, and communicates with the cloud (The ThingSpeak platform and the ThingView application). It starts by defining constants for the different thresholds in lines 1–2. The program uses variables to represent sensor readings, pump states, and connection status in lines 3–11. Initialise built-in devices such as ESP32 and sensors in lines 12–13.

The main loop (While true) is executed continuously, simulating the real-time behavior of the system on lines 14–40. Within the loop: Sensor values (temperature, humidity, moisture, water level) are (1) simulated, although actual sensor data is used in practice. (2) The humidity sensor reading is calibrated on a percentage scale. (3) The water level is calculated by linear interpolation. (4) The simulated data is sent to the cloud platforms (ThingSpeak and ThingView) for visualization and analysis. (5) The state of the connection to the cloud is simulated. (6) Control logic evaluates humidity and water levels to determine pump conditions. (7) Pump control flags (TonWP, ToffWP, TonTP, ToffTP) are set based on the control logic conditions. (8) A simulation delay has been introduced between iterations.

The code uses placeholder functions to read sensors, set values, and check connectivity to the cloud. These functions need to be implemented to interact with real devices and services. In general, this pseudo-code demonstrates the logic of the system that collects sensor data, communicates with the cloud (ThingSpeak and ThingView), and controls pumps according to predefined thresholds.

Table 2 briefly gives the hardware components used in this design, and explains the particular uses for which it was used. It includes the controllers, sensors, pumps, and other devices used in this system.

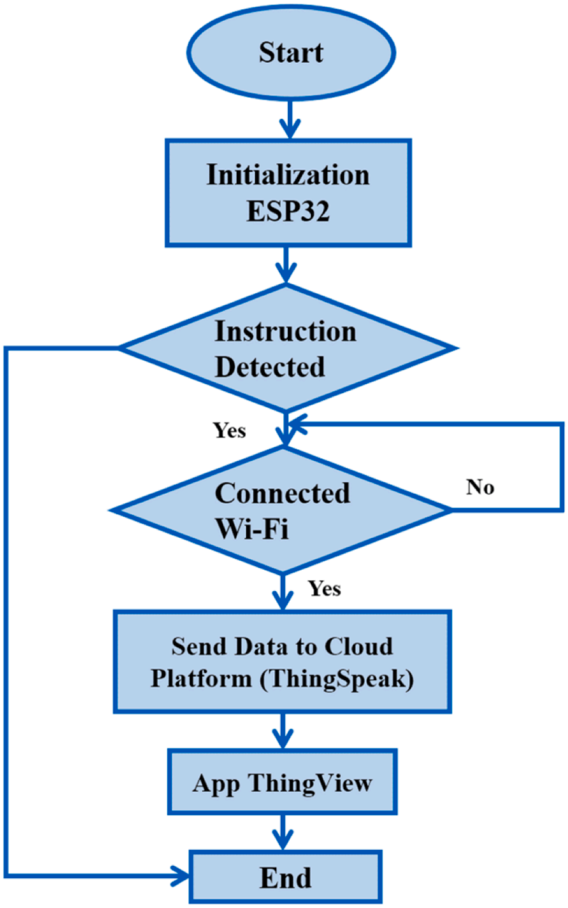


Fig. 7. Flow chart of ESP32 Wi-Fi connection process.

3.4. V Model of the smart irrigation system

A crucial element of our approach is the integration of sensor and control system data into the V model, which guides the development of the best irrigation program. Within the framework of the V model, which is a software development methodology, we have created an intelligent irrigation system exploiting the IoT and an integrated board such as the ESP32. This board transmits data to the cloud, including platforms such as ThingSpeak, and enables remote monitoring via the ThingView application.

As shown in Fig. 8 the exact ways to apply the V model, in this case, are as follows:

1. *Requirements Gathering and Analysis:* The requirements for the system are gathered and examined at this stage of the V Model. This involves identifying the system's users, such as farmers and agricultural engineers, their requirements and goals (such as automating irrigation based on weather and soil conditions and sending data to the cloud for remote monitoring and analysis), as well as any limitations that must be taken into account (such as cost, and compatibility with existing equipment).
2. *System Design:* The system architecture and general design are developed at this stage. This entails a choice of sensors to track soil moisture, temperature, and water level, an embedded board such as ESP32 to collect and process sensor data, and a wireless communication module such as Wi-Fi to transmit sensor data to a remote server or a cloud-based platform such as ThingSpeak. Designing the control system that will be used to create the ideal irrigation schedule is also part of this phase.
3. *Implementation:* The integration of sensor and control system data into the Model V is a crucial step in the implementation of our intelligent irrigation system. At this stage, the system is activated, the control system is configured and the integrated board, such as the ESP32, is programmed. A connection to the cloud is established, enabling the irrigation system to be monitored and operated remotely. It's important to note that this phase also includes the integration of sensor data into the control system, enabling the best irrigation program to be determined. The code practice for sending sensor data to the ThingSpeak cloud platform is also implemented during this stage. This seamless integration of components guarantees optimum system efficiency, enabling precise, responsive management of the irrigation program according to environmental conditions and specific crop needs.
4. *Verification:* To make sure the system satisfies the criteria established in step one, this stage entails testing it. Functional testing, performance testing, and integration testing are all part of this. The communication between the embedded board and the ThingSpeak cloud platform as well as the communication

Table 1
Algorithm 1.

Pseudo-code of the proposed schemes

```
//Define constants:
Min_Moisture_Thereshold = 40
Min_Water_Level_Thereshold = 10
//Variables:
Ts ← Temperature
Hs ← Humidity
Ms ← Moisture
Ws ← Water level
TonWP = false ← Watering pump state
TonTP = false ← Tank pump state
ToffWP = false ← Watering pump state
ToffTP = false ← Tank pump state
Max = 20 ← Maximum distance between ultrasonic sensor and water surface
Initialize ESP32 ← Embedded board
Initialize sensors ← Initialization of the (Ts, Hs, Ms, Ws)
While true:
// Simulate sensor readings:
  Ts = GetTemperature() ← read value (Ts)
  Hs = GetHumidity() ← read value (Hs)
  Ms = GetMoisture() ← read value (Ms)
  Ws = GetWaterLevel() ← read value (Ws)
// Perform two-point calibration on moisture sensor:
  Moisture = map(Ms, 4095, 2413, 0, 100) ← Calibration using function map()
// Calculate water level using linear interpolation:
  WaterLevel = -4.95 * Ws + 1 + (99 * Max) / 20 ← Based equation Y = mX + P
// Simulate ThingSpeak and ThingView communication:
  if (ESP32 is connected with ThingSpeak Cloud):
    Print collected data on the monitor
    Send data to ThingSpeak platform
    Send data to ThingView app
  else:
    Try to connect again
// Control watering pump based on moisture level:
  if (Moisture <= Min_Moisture_Thereshold):
    TonWP = true
    ToffWP = false
  else:
    TonWP = false
    ToffWP = true
// Control tank pump based on water level:
  if (WaterLevel <= Min_Water_Level_Thereshold):
    TonTP = true
    ToffTP = false
  else:
    TonTP = false
    ToffTP = true
Delay (2 s) ← Repeat for each period of 2S
End While
```

between the embedded board and the remote server or cloud-based platform are both tested at this stage.

(5) *Maintenance:* The deployment of the system and any required upkeep and upgrades are done in this final phase of the V Model. This stage also entails keeping an eye on the system's operation and making any required modifications. Additionally, it entails testing the connectivity, upgrading the firmware, and making sure that new software versions are compatible. This stage also entails keeping an eye on the information transmitted to ThingSpeak and resolving any transmission problems.

Using an ESP32 microcontroller with large memory capacity and enhanced processing capability confers several advantages, especially in the area of our smart irrigation system. The selection of an ESP32 microcontroller with robust memory capacity and processing capability improves the efficiency, responsiveness, and adaptability of our smart irrigation system, supporting the optimization of irrigation of crops and promoting sustainable agricultural practices.

4. Results and discussion

In this section, we provide a detailed analysis of the proposed Smart Irrigation System, including its results and efficiency compared to existing scientific papers. We also look at how the system affects agricultural sustainability and how it helps provide food security. The innovation of this study lies in its integration of cutting-edge technology like embedded system cloud computing and the IoT. The system makes it possible to monitor and manage irrigation operations in real-time by leveraging IoT devices, sensors, and actuators. Utilizing cloud computing enables data storage, analysis, and decision-making, which results in enhanced irrigation control and optimum water utilization. This novel strategy transforms conventional approaches by improving irrigation operations' accuracy, efficacy, and sustainability. Efficiently sent to ThingSpeak platforms and the ThingView app, data from simulated sensors represent environmental parameters such as temperature and humidity. Data is provided securely regularly, simulating sensor updates in real-time, using the MQTT protocol for communication. Cloud platforms can be configured to accurately visualize data using graphs and charts, enabling real-time monitoring and analysis, just like with field data.

Table 2
The equipment of the system.

Sr. no	Hardware	Functions
1.	ESP32 Microcontroller	The ESP32 is a flexible microcontroller with a variety of features and capabilities. It may be used in combination with a host MCU as a secondary device or as an independent system. Reduced communication stack overhead on the main application processor is one of its main benefits. The ESP32 can also communicate with other systems, allowing the inclusion of Bluetooth and Wi-Fi features via SPI/SDIO or I2C/UART interfaces. Because of its adaptability, the ESP32 is a potent tool for several applications.
2.	DHT22 (AM2302)	It is a two-in-one combination sensor for measuring ambient air humidity and temperature, all with high accuracy.
3.	Soil Moisture Sensor	A device used to detect moisture or water content in the soil. Farmers and gardeners use the information to make informed decisions about watering and watering schedules by gaining vital insight into soil moisture content.
4.	HC-SR04 – Ultrasonic Distance Sensor	The device is used to measure and monitor the water level within a tank, giving vital data for effective water management.
5.	Tank Pump	The tank pump was employed to recharge the tank when it became empty. This device contributes to the system's continued operating effectiveness and offers a dependable water source for irrigation needs.
6.	Watering Pump	The watering pump is responsible for irrigating the soil by delivering water to the plants
7.	Relay_1	A relay was utilized to activate the tank pump for tank refilling when it becomes empty.
8.	Relay_2	A relay was used to control the watering pump responsible for soil irrigation.
9.	Power Supply	Powering all of the system's components with electrical energy is the power source's main duty. This power source acts as the system's main energy source, supplying each component with the energy it needs to operate properly, including the sensors, actuators, controllers, and communication modules. By providing dependable power, the system can function without interruption, making it possible to complete activities like data gathering, processing, and communication successfully.

4.1. Experimental results

The experimental results of the proposed irrigation system are presented in Table 3. The table provides continuous measurements of various parameters including soil moisture, temperature, and humidity, as well as outputs from the water level sensor in centimeters and the water level in percentages. These measurements were recorded over a period of seven days. Additionally, Table 3 includes information on the status of data transmission to the platform and app, indicating whether the data was successfully sent, and the response time of 2 s. It should be noted that the weather conditions during the data collection period were normal, with no rainfall. These comprehensive measurements provide valuable insights into the performance of the smart system, showcasing the variations in soil moisture, temperature, humidity, and water level over the seven-day period. Such data is critical for optimizing irrigation strategies and ensuring efficient water management in agricultural practices. Cloud computing, in particular the integration of the MathWorks laboratory into the ThingSpeak platform of our intelligent irrigation system, improves data storage, analysis, and irrigation control decision-making through scalable storage, remote access to all data, and real-time analytics on ThingSpeak. This contributes to cost-effectiveness, improved security, collaborative management, reliability, efficient data processing, collaborative decision-making, and good results.

This study presents a method for calibrating the moisture sensor used in the research. To calibrate the moisture sensor input, a two-point calibration method was used in the studies (Ndunagu et al., 2022; Tiglao et al., 2020). Moisture sensor data were taken during the first 2 s of the system loop, indicating the lowest and maximum predicted values of the readings. The function moisture = map (moisture, 4095, 2413, 0, 100) was used to do a two-point calibration on the moisture sensor's natural outputs.

The function mapping approach is used in the demonstration section to calibrate the humidity sensor. A few configurations must be made before the ESP32 Microcontroller can be started. The moisture sensor's minimum and maximum readings are defined specifically. Values for the moisture sensor vary from a minimum of 4095 to a high of 2413. A function is used to transform the sensor value from 0 % to 100 %, with 100 % indicating the maximum value, in order to make the reading procedure easier for consumers. The user-friendly interpretation of the sensor readings is ensured by this change. Two-point calibration is of significant importance in the calibration process of the moisture sensor of our intelligent irrigation system. This method involves calibrating the sensor to two different moisture levels, typically representing the extremes of the moisture spectrum. The importance of using a two-point calibration method lies in its ability to improve accuracy, account for variability in soil conditions, account for dynamic moisture ranges and allow customization for specific agricultural applications. This meticulous calibration approach is fundamental to ensuring the efficiency of the smart irrigation system in optimizing water.

4.2. Results on the platform in real-time

The ThingSpeak cloud receives data obtained by our system. So we can use our mobile app or our PC to obtain or download it for free using the platform ThingSpeak or the app ThingView. Fig. 9 shows some farm temperature readings displayed on the ThingSpeak. The farm owner can now connect to the cloud and see the graphical output to check the status of the farm. The maximum value of the temperature read is 25.5 °C, and the minimum value is 24.9 °C. On the ThingSpeak platform, Fig. 10 displays some on-farm air humidity data. The maximum value of the humidity read is 35.00 % and the minimum value is 39.4 %. The farm owner may now connect to the cloud and examine the farm's status using the graphical output.

The soil moisture data of farm is shown in Fig. 11 on ThingSpeak. It shows that the soil was initially dry. When the water pump was turned on, the moisture sensor registered around 80 %. The range of soil moisture measured ranged from 0 % to 82 %. On the other hand, Fig. 12 illustrates how the water level was around 80 % when the irrigation water pump was switched on, which caused the water storage to be depleted. The data from the moisture sensors combined with the observations of the water level sheds light on the dynamic interaction between soil moisture levels, water pump performance, and water storage management and offers useful insights into the irrigation process. These findings support wise agricultural practices by enabling informed decision-making and effective water resource management.

Every 2 s, the ESP32 microcontroller sends data on the temperature, humidity, soil moisture, and water level to the ThingSpeak IoT analytics platform. The farmer may easily access this information via the ThingSpeak channel, giving them a simple and precise way to keep an eye on their field. Additionally, the data may be exported to an Excel document using the ThingSpeak channel's "export recent data" function, enabling additional analysis and investigation. Additionally, an application called ThingView, which is available for free download from the Google Play Store, makes it simple to retrieve the data from ThingSpeak on mobile devices. The farm owner may remotely access all the data with this smartphone application, making it simple and convenient to manage the irrigation system. The use of this smart irrigation system is essential because it guarantees precise and timely irrigation of agricultural plants,

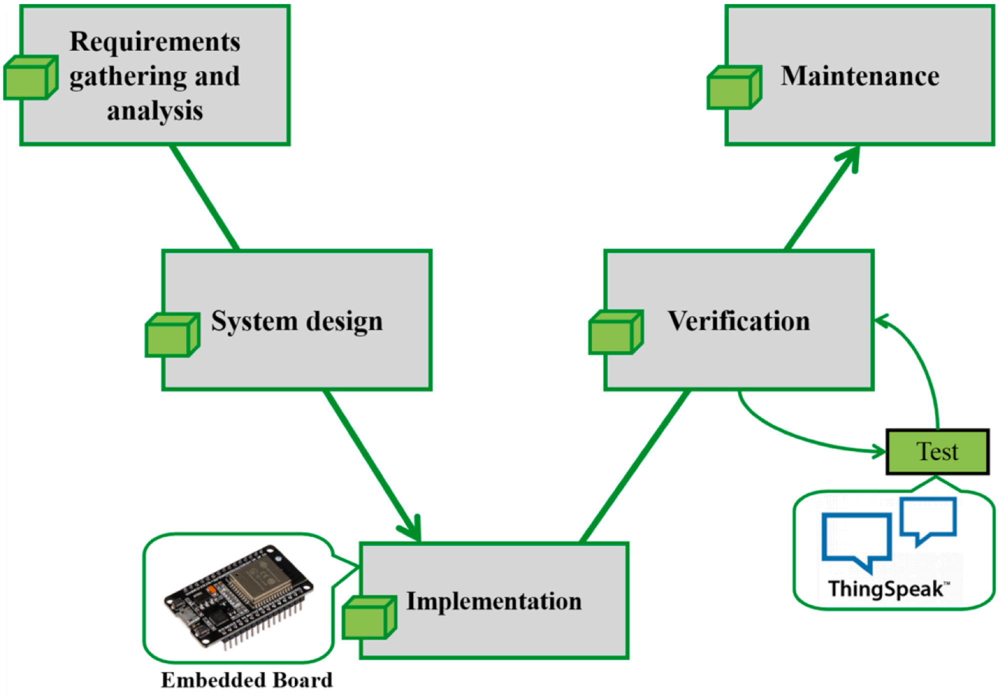


Fig. 8. V model for smart irrigation system.

Table 3
Tables experimental results of the proposed study.

No.	Temperature (°C)	Humidity (%)	Soil moisture (%)	Water level (Cm)	Water level caliber (%)	Send data to cloud	Response time (s)
1.	25.20 °C	35.00 %	40.50 %	06.81 Cm	90.00 %	Yes	2 s
2.	26.30 °C	36.00 %	55.30 %	07.42 Cm	87.00 %	Yes	2 s
3.	25.10 °C	69.25 %	60.10 %	09.44 Cm	77.00 %	Yes	2 s
4.	27.56 °C	40.22 %	75.10 %	14.89 Cm	50.00 %	Yes	2 s
5.	28.12 °C	39.13 %	76.12 %	15.90 Cm	54.00 %	Yes	2 s
6.	26.80 °C	59.20 %	80.01 %	16.61 Cm	40.00 %	Yes	2 s
7.	27.90 °C	45.30 %	65.10 %	10.45 Cm	72.00 %	Yes	2 s

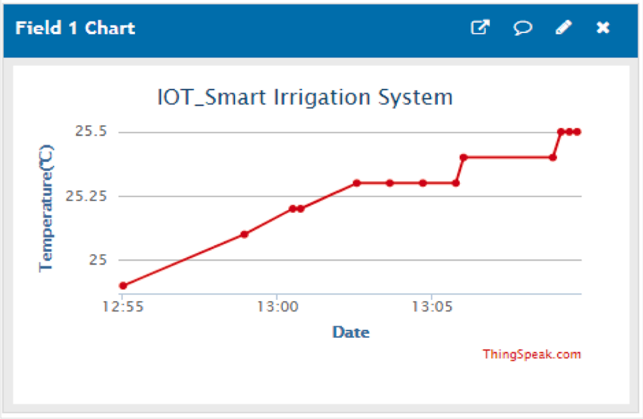


Fig. 9. The value of temperature on the ThingSpeak platform in real-time.

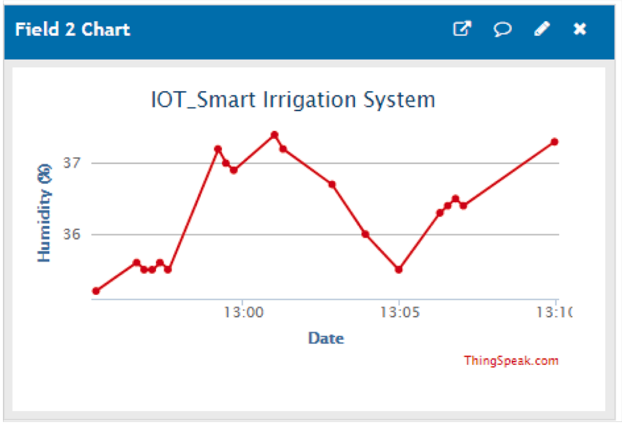


Fig. 10. The value of humidity on the ThingSpeak platform in real-time.

creating the ideal environment for plant growth. The field or farm owner's overall farming experience is considerably improved by this method. Further, implementing our smart irrigation system requires a high level of technical expertise. The system is designed and implemented by specialists before being delivered to farmers. Farmers, meanwhile, benefit from a ready-to-use system that requires a minimum of technical knowledge for daily operations.

The graphical display of the smart irrigation system includes needle values that represent the real-time sensor data. Colored sections can be applied to various measurement sites (widgets) to improve clarity. A red number on the water sensor in the tank, which indicates that the water level is critically low, is an example of how red color is used to indicate danger. As illustrated in Fig. 13, the green color denotes no problems, whereas the yellow color stands in the center of problems and no

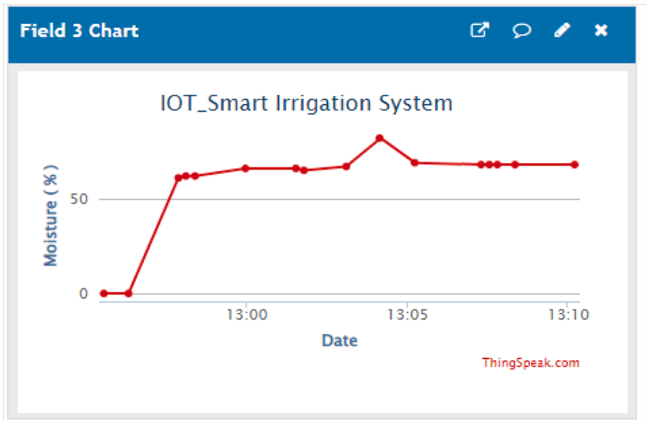


Fig. 11. The value of moisture on the ThingSpeak platform in real-time.

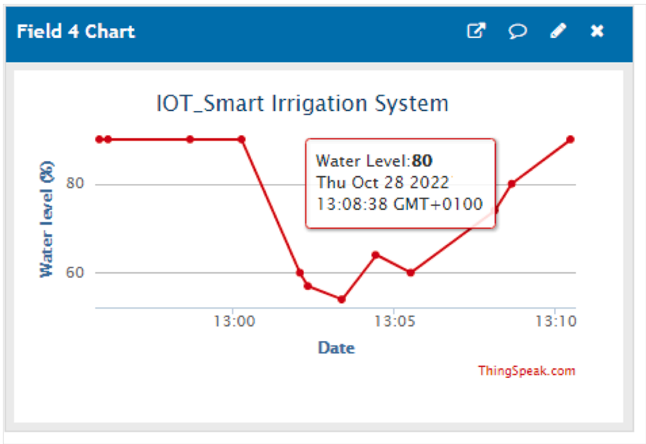


Fig. 12. The value of water level on the ThingSpeak platform in real-time.

problems, indicating the start of a potentially troublesome period. The solution also enables tracking of channel locations and particular modifications to channel content. In order to do this, a channel sitemap is created, which details the placement of feed data. By inputting the latitude and longitude coordinates in the “Channel settings” tab of the channel view, the channel location may be displayed. The channel map of our system is shown in Fig. 14, which gives a summary of the data’s spatial distribution. These functions and visual representations help users gain a deeper knowledge of the system’s data, making it simpler for them to recognize urgent circumstances and efficiently monitor channel content.

4.3. *Results on the app in real-time*

The ThingView app, depicted in Fig. 15, provides a comprehensive display of all the values obtained from our proposed system, including temperature, humidity, soil moisture, and water level. The farm owner may simply view all the data remotely through their phone thanks to this user-friendly mobile application. This strategy is particularly important since watering agricultural plants demands close attention. Our Smart Irrigation System seeks to solve this by providing an accurate study to guarantee timely and effective plant watering. A farm owner may properly monitor and manage the irrigation process thanks to the system’s capabilities, which improve agricultural operations and guarantee the health of the farm or field.

4.4. *Calculated the water usage decrease*

Through a combination of observation and testing, it is possible to quantify and demonstrate the decrease in water use compared to traditional irrigation techniques. Table 4 may be used to show how our intelligent irrigation system, which is based on the IoT and embedded technology, lowers the water level:

The information gathered from the conventional and smart irrigation systems was then compared and examined. By subtracting the quantity of water used in a smart irrigation system from the amount used in a traditional irrigation system and dividing the result by the amount used in a conventional irrigation system, the decrease in water consumption can be computed.

The water usage of the area’s conventional irrigation system should first be monitored and documented. The amount of water utilized during a particular time period in this paper’s 10 days was measured using sensors. The next step is to install and set up a smart irrigation system based on IoT and embedded devices. The system has sensors that can monitor temperature, humidity, and other environmental variables including humidity, temperature, moisture, and water level. An expected 10-day testing and monitoring period are used to compare the smart irrigation system to the conventional irrigation system. The same measurements and records are utilized to determine how much water is consumed in a smart irrigation system as in a traditional irrigation system. The water level decrease is calculated by taking the water level used by the traditional irrigation system (100 %) and subtracting the water level used by the smart irrigation system (30 %). The result is (100–30)/100, which equals 0.7 or 70 % of the original water level. Reducing irrigation water consumption by more than 70 % faces challenges such as potential impacts on crops, environmental considerations, climate change adaptation, effective soil moisture management, technological limitations, and farmer education.

This research successfully transforms conventional methodologies by articulating a breakthrough in irrigation accuracy and efficiency. It presents a smart irrigation system that combines cloud computing, embedded systems, and the IoT. It makes use of state-of-the-art sensors, such as DHT22 and water level sensors coupled to ESP32, for data transfer to the cloud and real-time monitoring. The accuracy and operating efficiency of water-level sensors are enhanced by a new mathematical function called linear interpolation. By using 70 % less water, the system that has been put in place is in line with environmentally beneficial standards. The study explores more general implications for agricultural sustainability and worldwide food security, highlighting significant advancements in accuracy and efficacy achieved by the suggested smart irrigation system.

4.5. *Comparison and discussion*

Table 5 provides a comparative analysis of various IoT-based water use monitoring systems, highlighting key functionalities, devices, Parameters, calibration approaches, v-models, and their ability to reduce water consumption. The articles included in the comparison were selected based on their relevance to water usage monitoring and IoT applications.

The paper (Pramanik et al., 2022) focuses on an IoT-based water usage monitoring system using the Croplytics platform with Arduino Uno, LoRa devices, and a GSM model. In comparison, our paper (PS) differs by using the ThingSpeak platform and ESP32 device to monitor temperature, humidity, soil moisture, and water level. Unlike paper (Pramanik et al., 2022), our system incorporates sensor calibration, which improves data accuracy. In addition, your paper introduces the V Model software and helps to reduce water consumption by 70 %, presenting a more advanced and comprehensive approach to water conservation. The authors of this work (Abba et al., 2019), present an IoT system using Arduino Uno and ThingSpeak to monitor humidity, temperature, and soil moisture. Our paper (PS) goes further by using ESP32

(a) (b)

(c) (d)

Fig. 13. The graphic data display widgets in the smart irrigation system offer easy access to visual representations of the measured and processed data on ThingSpeak channels. The widgets of the sensors, including, respectively, (a) temperature, (b) humidity, (c) moisture, and (d) water level.

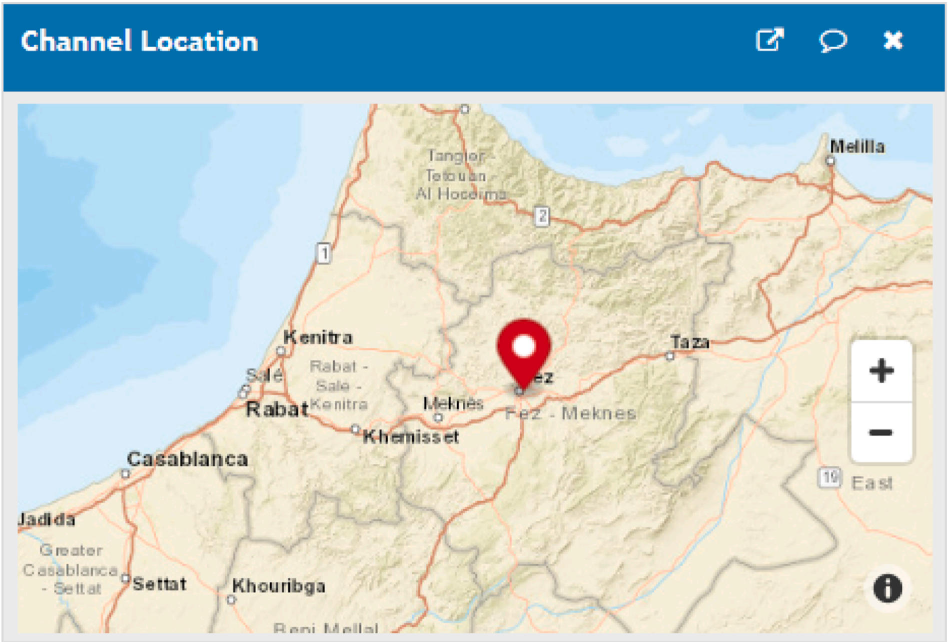
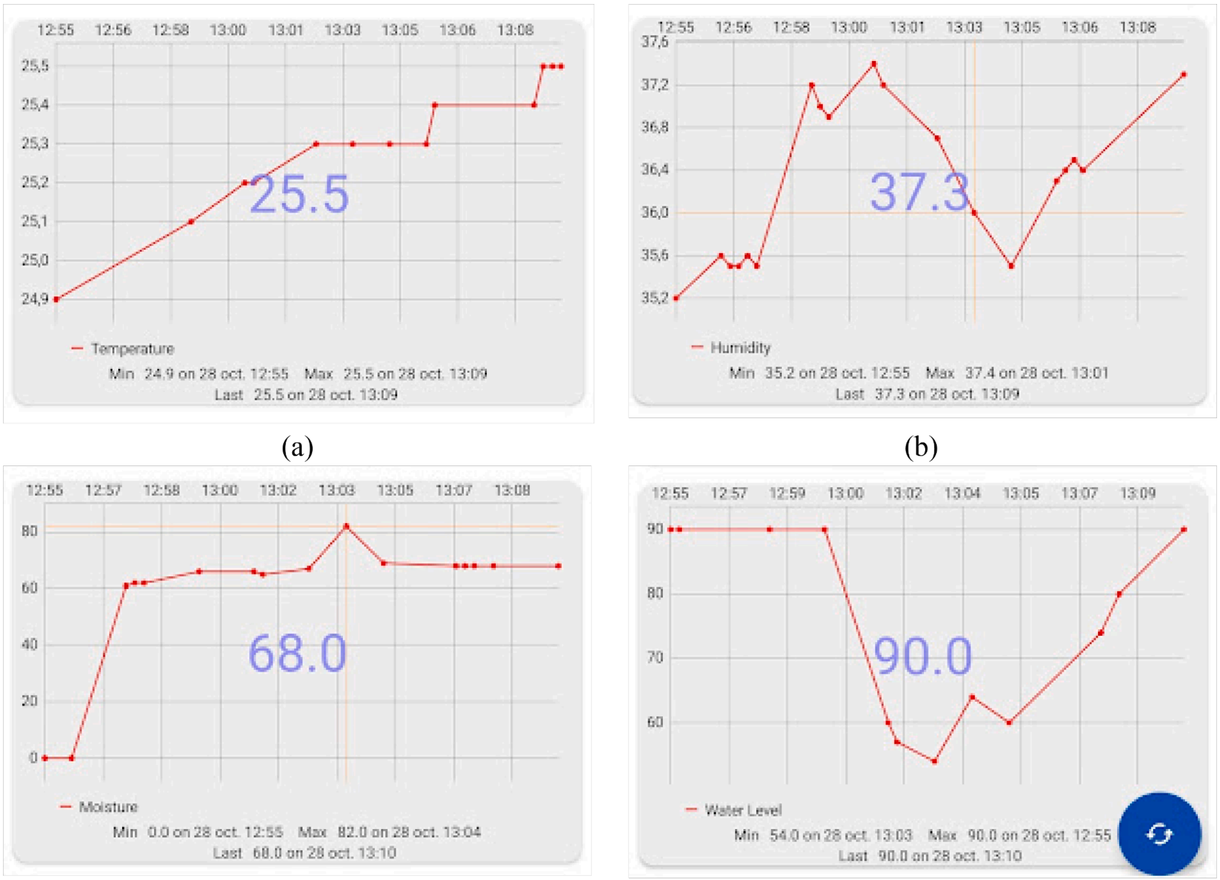


Fig. 14. Location of the system.

to improve data collection, covering additional parameters (water level) and incorporating sensor calibration for soil moisture and water level measurements. This increases the accuracy and reliability of your system's data. In addition, our integration of V Model software and the successful reduction in water consumption underlines the depth of our approach beyond what work (Abba et al., 2019) offers. The authors of this study (Munir et al., 2021), focus on a water consumption monitoring system based on an Android platform with GSM and Arduino Uno



Min 24.9 on 28 oct. 12:55 Max 25.5 on 28 oct. 13:09
Last 25.5 on 28 oct. 13:09

(a)

Min 35.2 on 28 oct. 12:55 Max 37.4 on 28 oct. 13:01
Last 37.3 on 28 oct. 13:09

(b)

Min 0.0 on 28 oct. 12:55 Max 82.0 on 28 oct. 13:04
Last 68.0 on 28 oct. 13:10

(c)

Min 54.0 on 28 oct. 13:03 Max 90.0 on 28 oct. 12:55
Last 90.0 on 28 oct. 13:10

(d)

Fig. 15. The output of the sensors on the ThingView app, including, respectively, (a) temperature, (b) humidity, (c) moisture, and (d) water level.

Table 4
Calculated the water usage decrease.[1]

System	Period	Water level (%)
Traditional	10 days	100 %
Smart Irrigation (IoT)	10 days	30 %

[1] IoT is the acronym of the internet of things.

models. In contrast, our proposed scheme (PS) uses the ESP32 device via the ThingSpeak platform. Our system (PS) measures temperature, humidity, soil moisture, and water level, providing a wider range of data points compared to the study (Munir et al., 2021). The addition of sensor calibration and V Model software to our (PS) study improves the accuracy and robustness of our solution. On the other hand, the authors of this study (Pasika et al., 2020), presented an Arduino Mega-based system using ThingSpeak to monitor soil pH, turbidity, temperature, humidity, and water level. Our PS extends its capabilities by using the ESP32 to monitor temperature, humidity, soil moisture, and water level. The integration of sensor calibration, Model V software, and a 70 %

Table 5
Comparison of related research.[2]

Paper ID	Year	Platform	Application	Embedded Devices	Parameters	Sensor Calibration	V model Software	Reduce Water Usage
Pramanik et al., 2022	2022	Croplytics	Croplytics cl	Arduino Uno, GSM Model, LoRa	Soil moisture	No	No	No
Abba et al., 2019	2019	ThingSpeak	No	Arduino Uno	Temperature, Humidity, Soil moisture	Yes (moisture)	No	No
Munir et al., 2021	2021	Firebase	Android platform	Arduino Uno, GSM Model	Temperature, Humidity, Soil moisture	No	No	No
Pasika et all., 2020	2020	ThingSpeak	ThingView	Arduino Mega	Turbidy, Soil pH, Temperature, Humidity, Water level	No	No	No
García et al., 2020	2020	No	No	No	No	No	No	No
Tiglao et al., 2020	2020	Web page		ATMega328, NRF24L01	Temperature, Humidity, Soil moisture,	No	No	No
PS	2024	ThingSpeak	ThingView	ESP32	Temperature, Humidity, Soil moisture, and Water level	Yes (Soil moisture, and Water level)	Yes	70 %

[2] PS is the acronym of the proposed scheme.

reduction in water consumption in our PS system represent developments beyond the scope of this study (Pasika et al., 2020). The authors (García et al., 2020), presented a research paper in 2020 related to a study of the latest smart irrigation techniques to determine the factors observed in existing systems. This paper does not use the realisation of the irrigation system including the integration of sensors and embedded systems to drive the irrigation. However, our PS use of ESP32, full parameter coverage, sensor calibration, V Model software, and reduced water consumption contributes to a more sophisticated and impactful system than suggested by the study (García et al., 2020). The authors [29] presented a paper focusing on temperature, humidity, and soil moisture monitoring using ATMega328 and NRF24L01. Our PS features by integrating an ESP32 to monitor temperature, humidity, soil moisture, and water level via ThingSpeak. The inclusion of sensor calibration, Model V software, and a significant reduction in water consumption improve the robustness and efficiency of our solution beyond that proposed in the study (Tiglao et al., 2020). The studies conducted by the authors (Abba et al., 2019; Tiglao et al., 2020), employed the DHT11 device for temperature and humidity measurements. However, this sensor exhibits low accuracy when measuring temperatures above zero, rendering decimal value transfer unnecessary and impacting agricultural productivity. In contrast, our approach involved utilizing the DHT22 device which offers the capability of measuring temperatures and humidity, with a precision of 0.1 units. This kind of sensor enables more precise and trustworthy readings, improving data accuracy and encouraging better agricultural results. Our intelligent irrigation system is based on the ESP32, known for its outstanding features such as low power consumption, ample memory, Wi-Fi, Bluetooth, and exceptional speed. Moreover, ESP32-based boards are cost-effective and offer analog and digital inputs and outputs, making them ideal tools for reading numerous analog input values in intelligent farming and Smart Irrigation Systems.

The estimated total cost of the proposed intelligent irrigation system is approximately US $60, making it an affordable and cost-effective solution. This low-cost nature of the system aligns with our goal of providing a practical and accessible option, particularly for low-income farmers, in contrast to the methods described by the authors in systems (Pramanik et al., 2022; Abba et al., 2019). In contrast to conventional irrigation methods that rely on groundwater drainage and can lead to excessive water consumption and crop flooding, our system utilizes innovative technologies to provide precise and demand-based soil irrigation. By adapting to the specific water needs of the crops, our system has the potential to significantly reduce water usage by more than 70 %. This efficient and targeted approach ensures optimal resource utilization while promoting sustainable agriculture practices. None of the scientific papers referenced in this study have used the V model. In contrast, our paper which used the V model software design, presents a methodical and organized approach to software development, significantly improving the overall quality of our irrigation system.

4.6. Smart irrigation improves food security

The use of the IoT, cloud computing, and other cutting-edge technologies in Smart Irrigation Systems can have a significant impact on food security as seen in the Fig. 16. Here are some of the ways this technology enhances food security:

(1) *Improved Crop Yields*: By implementing intelligent irrigation systems based on IoT to provide crops with the right quantity of water at the right time, crop yields may be boosted. This can help ensure a steady supply of food by reducing the likelihood of crop failures caused by droughts or other environmental factors.
(2) Improved Water Efficiency: Smart irrigation systems based on IoT use information from sensors and weather stations to choose the best irrigation schedule, reducing water waste and maximizing water efficiency.
(3) Remote Access and Control: Through a mobile application, smart irrigation systems using IoT can be accessed and operated remotely, allowing farmers to check on and make adjustments to their irrigation systems even when they are not in their fields. Farmers who live in rural places or who have access issues owing to physical restrictions may find this to be of particular benefit.
(4) Making Decisions Based on Data: Intelligent irrigation systems based on IoT gather a lot of information on soil moisture, weather, and crop growth. This information may be used to make better decisions about crop planning, irrigation schedules, and other aspects that impact crop yields.
(5) Climate Change Adaptation: Smart irrigation systems based on IoT can assist farmers in adapting to the shifting weather patterns brought on by climate change. These devices can assist farmers in modifying their irrigation schedules and other management measures to take into account such as changes in temperature, precipitation, and other environmental factors by giving real-time data on soil moisture and meteorological conditions.

Overall, by increasing crop yields, raising water efficiency, and giving farmers the resources, they need to make wiser decisions, smart irrigation systems could have a significant impact on food security. In addition, it can promote sustainable agriculture and help adapt to climate change. The proposal of this paper will contribute effectively to ensuring food security. The use of the IoT, cloud computing, and other cutting-edge technology in smart irrigation systems has the potential to have a significant influence on food security. In addition to increasing agricultural yields and water efficiency, these technologies also enable

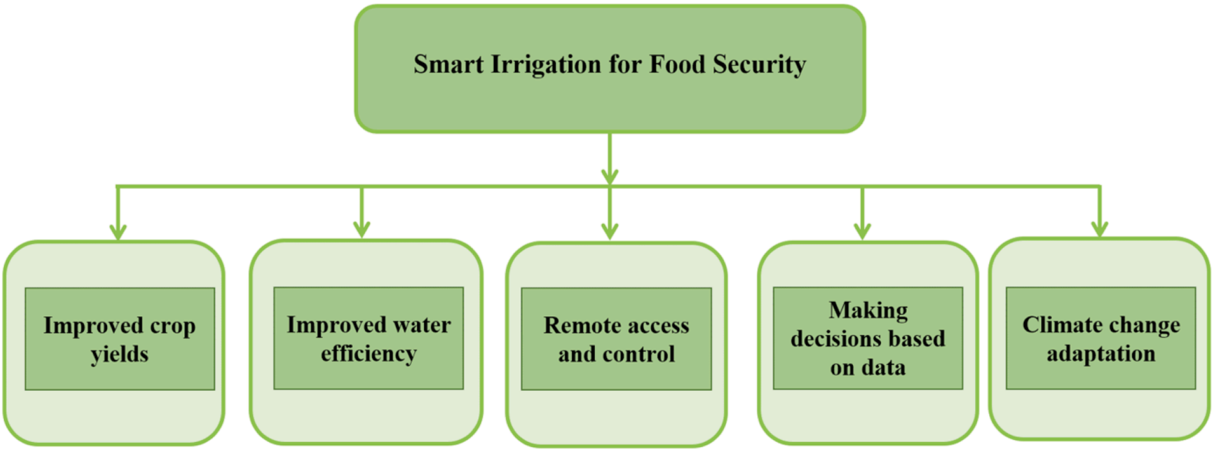


Fig. 16. Smart irrigation for food security.

remote monitoring and data-driven decision-making, all of which may help ensure a more reliable food supply. This essay will examine how smart irrigation affects food security and how it may help maintain agriculture.

The research paper highlighted smart irrigation systems as a groundbreaking approach to integrating new technologies like the IoT, embedded systems, and cloud computing. One notable innovation is the real-time data transmission to the ThingSpeak cloud and the visualization of the data through the ThingView app. This implementation allows for seamless monitoring and control of the irrigation system. By leveraging these technologies, the paper enables farmers and agricultural stakeholders to access vital information about soil moisture, temperature, and other environmental parameters in real-time. This innovation improves decision-making processes, enhances resource management, and promotes sustainable agricultural practices. The utilization of the ThingSpeak cloud and ThingView app for data visualization represents a significant advancement in smart agriculture, providing a user-friendly interface for efficient irrigation management. This paper presented a mathematical method for sensor calibration that brings innovation to the field by ensuring precise and reliable measurements. Additionally, the V model software design offers a systematic and structured approach to software development, enhancing the overall quality of our irrigation system. The paper focus on examining the impact of smart irrigation on food security. Better resource management in smart irrigation systems results in more sustainable, efficient, and environmentally friendly agricultural practices, with observable benefits in terms of water conservation, energy efficiency, crop yield, cost reduction, and overall agricultural sustainability. The analysis and interpretation of data in smart agriculture transforms the raw data of sensors into actionable information through many functions such as data cleaning and integration, application of advanced analytics, providing visual representations, interpreting models and providing real-time recommendations to farmers for informed decision-making and optimized farming practices.

5. Conclusion and future work

In conclusion, the article proposed the concept of a “smart irrigation system using embedded Systems, IoT, and cloud computing” as an innovative solution to enhance food security and promote sustainable agriculture. By harnessing advanced technologies, this system aims to optimize irrigation practices, conserve water resources, and support long-term agricultural sustainability. The system makes use of cutting-edge technology like cloud computing, embedded system, and the IoT to provide real-time monitoring, control, and data analysis of irrigation operations. This system supervised real-time monitoring of crucial environmental factors such as moisture, humidity, temperature, and water levels in smart agriculture practices. The system used the ThingSpeak cloud to enable wireless communication between the device and the farm owner, enhancing their interaction. Furthermore, the ESP32 controller is linked to both a watering pump for soil irrigation and a water pump to refill the tank during low water levels. The automated control of the two water pumps is based on the readings of various environmental factors. Farmers can access comprehensive farm data from anywhere in the world as the sensor data is transmitted in real-time to both the ThingSpeak cloud and the ThingView application. This capability allows for more precise crop irrigation and increased production. Moreover, this will also present a mathematical-driven function known as linear interpolation to calibrate the water level sensor in percentage. This smart irrigation system was created using the V model software development approach. The solution suggested in this paper uses 70 % less water for soil irrigation than conventional techniques. In addition, this paper addressed the impact of smart irrigation using the latest technology on food security and its ability to support sustainable agriculture. The implementation of this smart irrigation system has the potential to revolutionize the agricultural sector, addressing key challenges and paving the way for a more secure and sustainable food production system.

The future work of this paper involves integrating modern technologies and utilizing an MQTT broker to enhance the Smart Irrigation System. By merging multiple nodes, the system can handle increased data analysis and control elements for large-scale applications such as smart farms spanning thousands of hectares. The MQTT broker can further optimize irrigation strategies and resource management. On the other hand, future work of this paper will include the integration of the concept of smart agriculture within the framework of cyber-physical human systems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abba, S., Wadumi Namkusong, J., Lee, J.-A., Liz Crespo, M., 2019. Design and performance evaluation of a low-cost autonomous sensor interface for a smart IoT-based irrigation monitoring and control system. Sensors 19, 3643. https://doi.org/10.3390/s19173643.

Abi Saab, M.T., Jomaa, I., Skaf, S., Fahed, S., Todorovic, M., 2019. Assessment of a smartphone application for real-time irrigation scheduling in mediterranean environments. Water 11, 252. https://doi.org/10.3390/w11020252.

Ahmed, N., De, D., Hussain, I., 2018. Internet of things (IoT) for smart precision agriculture and farming in rural areas. IEEE Internet Things J. 5, 4890–4899. https://doi.org/10.1109/JIOT.2018.2879579.

Assouli, O., Bilali, H.E., Abouabdillah, A., Harbouze, R., Jaouhari, N.E., Chaoui, M., Bouabid, R., 2018. Transition from surface to drip irrigation in morocco: analysis through the multi-level perspective. AGROFOR 3. https://doi.org/10.7251/AGRENG1803142A.

Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A., Aggoune, E.-H.-M., 2019. Internet-of-Things (IoT)-based smart agriculture: toward making the fields talk. IEEE Access 7, 129551–129583. https://doi.org/10.1109/ACCESS.2019.2932609.

Bathaei, A., Štreimikienė, D., 2023. A systematic review of agricultural sustainability indicators. Agriculture 13, 241. https://doi.org/10.3390/agriculture13020241.

Beckman, J., Countryman, A.M., 2021. The importance of agriculture in the economy: impacts from COVID-19. Am. J. Agric. Econ. 103, 1595–1611. https://doi.org/10.1111/ajae.12212.

Blakeney, M., 2022. Agricultural innovation and sustainable development. Sustainability 14, 2698. https://doi.org/10.3390/su14052698.

Elijah, O., Rahman, T.A., Orikumhi, I., Leow, C.Y., Hindia, M.N., 2018. An overview of internet of things (IoT) and data analytics in agriculture: benefits and challenges. IEEE Internet Things J. 5, 3758–3773. https://doi.org/10.1109/JIOT.2018.2844296.

FAO, IFAD, UNICEF, WFP, WHO, 2022. The State of Food Security and Nutrition in the World 2022: Repurposing food and agricultural policies to make healthy diets more affordable, The State of Food Security and Nutrition in the World (SOFI). Rome, Italy.

García, L., Parra, L., Jimenez, J.M., Lloret, J., Lorenz, P., 2020. IoT-based smart irrigation systems: an overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture. Sensors 20, 1042. https://doi.org/10.3390/s20041042.

Giller, K.E., Delaune, T., Silva, J.V., Descheemaeker, K., van de Ven, G., Schut, A.G.T., van Wijk, M., Hammond, J., Hochman, Z., Taulya, G., Chikowo, R., Narayanan, S., Kishore, A., Bresciani, F., Teixeira, H.M., Andersson, J.A., van Ittersum, M.K., 2021. The future of farming: Who will produce our food? Food Sec. 13, 1073–1099. https://doi.org/10.1007/s12571-021-01184-6.

Habib, S., Alyahya, S., Islam, M., Alnajim, A.M., Alabdulatif, A., Alabdulatif, A., 2023. Design and implementation: an IoT-framework-based automated wastewater irrigation system. Electronics 12, 28. https://doi.org/10.3390/electronics12010028.

Hanan, H., Gunawan, A.A.N., Sumadiyasa, M., 2019. Water level detection system based on ultrasonic sensors HC-SR04 and ESP8266-12 modules with telegram and buzzer communication. Media I2M 18, 305–309. https://doi.org/10.18280/i2m.180311.

Hussen Hajjaj, S.S., Hameed Sultan, M.T., Moktar, M.H., Lee, S.H., 2020. Utilizing the Internet of Things (IoT) to develop a remotely monitored autonomous floodgate for water management and control. Water 12, 502. https://doi.org/10.3390/w12020502.

Idoje, G., Dagiuklas, T., Iqbal, M., 2021. Survey for smart farming technologies: challenges and issues. Comput. Electr. Eng. 92, 107104 https://doi.org/10.1016/j.compeleceng.2021.107104.

Kamienski, C., Soininen, J.-P., Taumberger, M., Dantas, R., Toscano, A., Salmon Cinotti, T., Filev Maia, R., Torre Neto, A., 2019. Smart water management platform: IoT-based precision irrigation for agriculture. Sensors 19, 276. https://doi.org/10.3390/s19020276.

Khan, N., Ray, R.L., Kassem, H.S., Hussain, S., Zhang, S., Khayyam, M., Ihtisham, M., Asongu, S.A., 2021. Potential role of technology innovation in transformation of sustainable food systems: a review. Agriculture 11, 984. https://doi.org/10.3390/agriculture11100984.

Lindgren, E., Harris, F., Dangour, A.D., Gasparatos, A., Hiramatsu, M., Javadi, F., Loken, B., Murakami, T., Scheelbeek, P., Haines, A., 2018. Sustainable food systems-a health perspective. Sustain Sci 13, 1505–1517. https://doi.org/10.1007/s11625-018-0586-x.

Lloret, J., Sendra, S., Garcia, L., Jimenez, J.M., 2021. A wireless sensor network deployment for soil moisture monitoring in precision agriculture. Sensors 21, 7243. https://doi.org/10.3390/s21217243.

Morchid, A., El Alami, R., Raezah, A.A., Sabbar, Y., 2024. Applications of internet of things (IoT) and sensors technology to increase food security and agricultural sustainability: benefits and challenges. Ain Shams Eng. J. 15, 102509 https://doi.org/10.1016/j.asej.2023.102509.

Morchid, A., El Alaoui, M., El Alami, R., Qjidaa, H., El Khadiri, K., Mehdaoui, Y., 2021. Design and Realization of Fire Safety System for Controlling and Monitoring a Siren Using Arduino Uno, in: Motahhir, S., Bossoufi, B. (Eds.), Digital Technologies and Applications, Lecture Notes in Networks and Systems. Springer International Publishing, Cham, pp. 433–445. https://doi.org/10.1007/978-3-030-73882-2_40.

Morchid, A., El Alami, R., Qjidaa, H., El Alaoui, M., Touati, H., El Khadiri, K., Ouazzani-Jamil, M., 2022. Fire Safety System Implementation for Controlling and Monitoring a Siren in Smart Farm Using Gas Sensor and Flame Sensor, in: Motahhir, S., Bossoufi, B. (Eds.), Digital Technologies and Applications, Lecture Notes in Networks and Systems. Springer International Publishing, Cham, pp. 733–742. https://doi.org/10.1007/978-3-031-01942-5_73.

Munir, M.S., Bajwa, I.S., Ashraf, A., Anwar, W., Rashid, R., 2021. Intelligent and smart irrigation system using edge computing and IoT. Complexity 2021, e6691571.

Ndunagu, J.N., Ukhurebor, K.E., Akaaza, M., Onyancha, R.B., 2022. Development of a wireless sensor network and IoT-based smart irrigation system. Appl. Environ. Soil Sci. 2022, e7678570.

Ojha, T., Misra, S., Raghuwanshi, N.S., 2015. Wireless sensor networks for agriculture: the state-of-the-art in practice and future challenges. Comput. Electron. Agric. 118, 66–84. https://doi.org/10.1016/j.compag.2015.08.011.

Olisa, S.C., Asiegbu, C.N., Olisa, J.E., Ekengwu, B.O., Shittu, A.A., Eze, M.C., 2021. Smart two-tank water quality and level detection system via IoT. Heliyon 7, e07651.

Pasika, S., Gandla, S.T., 2020. Smart water quality monitoring system with cost-effective using IoT. Heliyon 6, e04096.

Pathak, A., AmazUddin, M., Abedin, Md.J., Andersson, K., Mustafa, R., Hossain, M.S., 2019. IoT based Smart System to Support Agricultural Parameters: A Case Study. Procedia Computer Science, The 16th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2019), The 14th International Conference on Future Networks and Communications (FNC-2019), The 9th International Conference on Sustainable Energy Information Technology 155, 648–653. https://doi.org/10.1016/j.procs.2019.08.092.

Pramanik, M., Khanna, M., Singh, M., Singh, D.K., Sudhishri, S., Bhatia, A., Ranjan, R., 2022. Automation of soil moisture sensor-based basin irrigation system. Smart Agric. Technol. 2, 100032 https://doi.org/10.1016/j.atech.2021.100032.

Rahman, M.W., Hossain, M.E., Islam, R., Rashid, M.H.A., Alam, M.N.A., Hasan, M.M., 2020. Real-time and Low-cost IoT based farming using raspberry Pi. Indones. J. Electr. Eng. Comput. ScienCe 17, 197–204. https://doi.org/10.11591/ijeecs.v17.i1.pp197-204.

Saleem, M.H., Potgieter, J., Arif, K.M., 2021. Correction to: automation in agriculture by machine and deep learning techniques: a review of recent developments. Precis. Agric. 22, 2092–2094. https://doi.org/10.1007/s11119-021-09824-9.

Subeesh, A., Mehta, C.R., 2021. Automation and digitization of agriculture using artificial intelligence and internet of things. Artif. Intell. Agric. 5, 278–291. https://doi.org/10.1016/j.aiia.2021.11.004.

Talaviya, T., Shah, D., Patel, N., Yagnik, H., Shah, M., 2020. Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. Artif. Intell. Agric. 4, 58–73.

Tham, P.E., Ng, Y.J., Vadivelu, N., Lim, H.R., Khoo, K.S., Chew, K.W., Show, P.L., 2022. Sustainable smart photobioreactor for continuous cultivation of microalgae embedded with internet of things. Bioresour. Technol. 346, 126558 https://doi.org/10.1016/j.biortech.2021.126558.

Tiglao, N.M., Alipio, M., Balanay, J.V., Saldivar, E., Tiston, J.L., 2020. Agrinex: a low-cost wireless mesh-based smart irrigation system. Measurement 161, 107874. https://doi.org/10.1016/j.measurement.2020.107874.

Weersink, A., Fraser, E., Pannell, D., Duncan, E., Rotz, S., 2018. Opportunities and challenges for big data in agricultural and environmental analysis. Ann. Rev. Resour. Econ. 10, 19–37. https://doi.org/10.1146/annurev-resource-100516-053654.

Zervopoulos, A., Tsipis, A., Alvanou, A.G., Bezas, K., Papamichail, A., Vergis, S., Stylidou, A., Tsoumanis, G., Komianos, V., Koufoudakis, G., Oikonomou, K., 2020. Wireless sensor network synchronization for precision agriculture applications. Agriculture 10, 89. https://doi.org/10.3390/agriculture10030089.