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Application of Internet of Things (IoT) on Monitoring EC and pH Values for Fertigation System

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ABSTRACT

This paper introduces a novel Internet of Things (IoT) based fertigation control system designed to enhance traditional agricultural practices in Malaysia, particularly in rural areas. The system integrates a fertigation approach, combining fertilization and irrigation, with smart devices and a NodeMCU ESP32 microcontroller to automate the tracking of data from liquid fertilizer mixtures. By utilizing EC and pH sensors, the system accurately monitors the nutrient concentration and pH levels of the fertilizer mix, with data displayed on an IoT platform for real-time observation and control. This approach mitigates common issues such as overfertilization and inefficient nutrient use, offering significant improvements over manual data collection methods. The system's performance was validated, showing successful monitoring and control of the fertilization process, leading to enhanced plant health and crop quality. Key findings indicate that the system's integration with IoT technology provides a more efficient, automated solution for managing fertilizer applications, reducing labor and time while ensuring optimal plant nutrient levels. The study also highlights the potential for future development, including the integration of additional sensors and advanced data analytics to optimize fertigation practices further. The implementation of this IoT-based system represents a significant advancement towards sustainable agriculture, offering practical benefits for Malaysian farmers and setting a foundation for further innovation in fertigation technology.

1. Introduction

Malaysia's government officials' support and endorsement of fertigation systems have significantly impacted the improvement of the country's agricultural methods. Farmers with small plots of land are taught and given the necessary information and equipment to utilize fertigation technologies in different agricultural extension activities. The proactive stance adopted by the government reflects a dedication to improving agricultural efficiency and conservation in Malaysia. Furthermore, MARDI has spearheaded research efforts that have revealed significant insights into the efficacy of fertigation systems [1]. This demonstrates that this method has the potential to

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decrease significantly the utilization of water and fertilizers while also preserving or potentially enhancing crop production. By encouraging the adoption of fertigation systems, Malaysia is improving agricultural productivity while tackling important issues like water scarcity and environmental sustainability [2]. Malaysia is committed to upgrading its agriculture industry by implementing fertigation systems to enhance productivity and long-term viability.

Consequently, the extensive use of fertigation systems in Malaysia has boosted crop production and enhanced the sustainability of agricultural practices in the nation. Fertigation is essential for improving the effective utilization of resources, particularly water and fertilizers, which is advantageous for farmers and the environment. Fertigation systems can reduce water usage by 50% and fertilizer application by 30% while increasing productivity levels, thus aiding in conserving vital resources [3,4]. These findings align with worldwide initiatives for sustainable farming and underscore the significance of employing modern technologies like fertigation to tackle urgent problems like water shortage and environmental harm. As Malaysia places importance on sustainable agricultural development, it is crucial for long-term food security and economic growth to widely implement fertigation systems across different crop types and farming sizes.

Implementing fertigation systems in Malaysia has resulted in a marked rise in crop production and has benefitted farmers' earnings by enhancing efficiency and effectiveness. Fertigation, which is the combination of fertilization and irrigation, offers a beneficial solution for cultivating high-value crops, thereby significantly influencing the agricultural economy. The Ministry of Agriculture and Food Industries in Malaysia has announced a significant rise in crop production, showing 20-30% enhancements compared to conventional farming techniques [5]. Furthermore, approximately 15% of commercial farms in Malaysia are currently employing fertigation systems, with this figure on the rise thanks to government assistance in training and subsidies [5]. Additionally, research carried out by the Malaysian Agricultural Research and Development Institute (MARDI) has indicated that fertigation can improve the effectiveness of water and fertilizer utilization, which is crucial for promoting sustainable agriculture in Malaysia in the face of water shortages and environmental issues [3].

In agronomy, managing fertigation systems is complex and requires improvements to enhance crop production and protect the environment. It is essential to consider the significant effects of poor nutrient management practices on groundwater pollution when facing challenges related to nutrient management in fertigation systems. Despite advancements in agricultural technology, the haphazard use of nitrogen and phosphorus fertilizers poses a significant risk to water sources [6]. In addition, monitoring pH and EC levels manually in these systems brings challenges, including time and energy inefficiencies, leading to inconsistent results and inadequate data management [7]. To tackle these issues, it is essential to implement IoT-based monitoring systems to oversee fertigation. These systems allow for monitoring and adjusting nutrient solution strengths and pH values in real-time, which can enhance plant growth and decrease risks of over-fertilization or nutrient runoff, ultimately improving the overall effectiveness and sustainability of the system.

Manual monitoring in fertigation systems is plagued by human error, lack of uniformity, and the extensive time and effort required. These challenges result in inconsistent pH and EC level readings, leading to inaccurate nutrient adjustments that negatively impact plant health and growth. Additionally, traditional monitoring methods lack the in-depth insights needed for effective fertigation management, making it difficult to track trends and make informed decisions [8]. As agricultural operations scale up, manual monitoring becomes increasingly impractical and unsustainable. Implementing an IoT-driven monitoring system offers a reliable and automated solution, providing real-time data collection, advanced analysis tools, and precise control of nutrient levels from [9-11]. This technology enhances crop productivity, reduces resource wastage, and adapts to changing operational requirements, ensuring efficient and sustainable fertigation management.

The primary objective of this study is to design and develop an IoT-based fertigation control prototype. An analysis of previous research reveals various approaches and technologies applied to fertigation systems. Past studies have focused on various enhancements in fertigation management, including the use of capacitive soil moisture sensors, pH and nutrient level monitoring, and remote control through mobile applications. These earlier works underscore the evolution of fertigation systems, emphasizing improvements in automation, real-time data collection, and remote management to optimize agricultural productivity and sustainability.

Recent advancements in automatic fertigation systems demonstrate various approaches and technologies to improve irrigation and nutrient management. For instance, Zubair and Adebiyi [12] developed an automatic fertigation system incorporating capacitive soil moisture sensors and a JXCT-IOT Frequency Domain Reflectometry soil nitrogen sensor to monitor soil properties. The system uses a microcontroller Arduino Nano and ESP8266 for the Wi-Fi Module to determine the amount of water or nutrients the plant needs and supply it through a drip irrigation framework. A Blynk IoT client was also integrated into the system to allow remote monitoring and control of the fertigation process.

Another example is provided by J *et al.,* [13] on an automatic fertigation system; the primary components include an Arduino Uno microcontroller, which processes data and controls the system, a fertilizer sensor to measure nutrient levels, a moisture sensor to determine soil moisture levels, relays that act as electrical switches to control the pump, and the pump itself, which delivers water and fertilizer to the plants. Additionally, the system uses an ESP8266 Wi-Fi module for internet connectivity, allowing for data transmission and remote monitoring. The software components mentioned are the Arduino Application for programming and controlling the Arduino Uno and MIT App Inventor, which suggests the development of a mobile application interface for system monitoring and control.

The study by Joseph *et al.,* [14] also highlights an automatic system for managing soil moisture and NPK ratios, employing the Blynk platform and ESP8266 for remote access. An Arduino board is the central control unit, processing sensor inputs and user-defined parameters to manage water and fertilizer pumps. The user interface, built on the Blynk mobile application platform, allows users to input parameters, monitor real-time system status, and control the system remotely via Wi-Fi, facilitated by an ESP8266 Wi-Fi module.

The development of an automated nutrient composition control fertigation system, as described by Kaur and Kumar [15], involves managing the primary parameters of pH and electrical conductivity (EC) of the fertilizer solution. The system utilizes a PIC16F877A microcontroller to handle the process, integrating pH and EC sensors to collect data, which is then processed to make necessary adjustments. Control over the flow of fertilizers and solution adjustments is achieved through solenoid valves. The interface includes signal conditioning circuits to amplify and filter sensor signals, with an LCD providing real-time pH and EC values and other relevant information.

The web-based monitoring system for automated fertigation described by Abidin and Ibrahim [16] includes three main components: a user-friendly web-based interface, an automatic fertigation system, and a communication network. The web interface enables farmers to monitor and control the fertigation system remotely, presenting data from an SQLite database on water levels, valve and pipe flow conditions, and overall system status. It also offers functionalities for setting fertigation schedules, determining fertilizer formulations, and activating an emergency stop. The automatic fertigation system is managed through sensors, valves, and pumps, while the communication network facilitates real-time data exchange and remote control using the 'lighttpd' web server. The system employs a queue technique to prioritize updates and prevent database errors to ensure reliability.

The IoT-based fertilizer system described by Lavanya *et al.,* [17] employs a fuzzy logic control algorithm, which is well-suited for managing the imprecise nature of soil parameters and fertilizer requirements in agricultural automation. This system receives readings from an NPK sensor that measures soil nitrogen, phosphorus, and potassium levels. The fuzzy logic algorithm processes these readings using pre-defined rules, such as "IF Nitrogen is LOW, THEN increase fertilizer," to determine the necessary actions. The microcontroller then sends signals to actuators, such as valves or motors, to adjust fertilizer application accordingly. This approach ensures precise control over nutrient levels, optimizing plant growth and minimizing environmental impact.

In the study on fertigation management for sustainable precision agriculture based on the Internet of Things by Lin *et al.,* [18], the focus includes using critical sensors to measure both water and nutrient levels in the soil. The system likely incorporates soil moisture sensors to gauge soil water content and nutrient sensors to detect essential nutrients such as nitrogen, phosphorus, and potassium. Additionally, it may utilize sensors to monitor crop growth by measuring parameters like leaf area index, plant height, or biomass and environmental conditions, including temperature, humidity, light intensity, and rainfall. This comprehensive monitoring optimizes irrigation and fertilization based on real-time weather data.

The smart digital farming projects described by Cambra *et al.,* [19] aim to optimize crop yields and enhance agricultural efficiency while maintaining environmental sustainability. This objective is achieved by integrating sensors, microcontrollers, and applications. Sensors gather real-time data on soil conditions (including moisture levels, temperature, and nutrient content), weather conditions (such as rainfall, humidity, wind speed, and solar radiation), and plant health (measuring parameters like leaf area index and chlorophyll content). Microcontrollers then process this data using intelligent algorithms, while applications leverage the information to make informed decisions on irrigation, fertilization, and pest and disease control. For instance, the system has been shown to reduce irrigation water use by 8%, highlighting smart farming technology's efficiency and environmental benefits.

Ferrarezi and Peng [20] developed a soil moisture monitoring system using a commercial standalone embedded computer programming with Python. This system employs a serial data interface-12/analog sensor adapter and digital sensors to upload collected data to the internet for remote access automatically. Although this study does not specifically use microcontrollers, it notes that Arduino boards are well-suited for small-scale projects. At the same time, embedded computers are more appropriate for larger systems due to their superior processing capacity. The study's primary goal was to control irrigation efficiently and affordably based on soil moisture levels.

In conclusion, the review of previous studies highlights significant advancements in developing and implementing IoT-based fertigation control systems. These systems have evolved to incorporate a variety of sensors and microcontrollers to optimize irrigation and nutrient management, enhancing agricultural productivity and sustainability. Researchers such as Zubair and Adebiyi [12] and Lavanya *et al.*, [17] have developed sophisticated systems that utilize capacitive soil moisture sensors, NPK sensors, and fuzzy logic algorithms to control nutrient levels precisely. Studies by Joseph *et al.,* [14] and Abidin and Ibrahim [16] demonstrate the effectiveness of remote monitoring and control through platforms like Blynk and web-based interfaces, facilitating real-time data collection and management. The integration of environmental sensors and intelligent algorithms in projects described by Cambra *et al.,* [19] underscores the potential of smart farming technology to reduce resource usage and improve efficiency. Additionally, the work by Ferrarezi and Peng [20] emphasizes the scalability and affordability of these systems, making advanced fertigation management accessible to a broader range of agricultural operations. Overall, these innovations contribute to a more sustainable and efficient approach to agriculture, leveraging IoT technology to meet the growing demands of food production.

2. Methodology

2.1 Block Diagram of the IoT-based Fertigation System

This project develops an IoT-based fertigation system to monitor and control pH and Electrical Conductivity (EC) values, optimizing plant nutrient delivery. Utilizing a NodeMCU ESP32 microcontroller with Wi-Fi capabilities, the system collects data from EC and pH sensors installed in a fertilizer tank. It transmits it to the cloud for real-time monitoring. Users can access and manage the system remotely through a smartphone app, enhancing environmental management and decision-making.

Figure 1 describes the project's block diagram, emphasizing the system inputs and outcomes. The block diagram of the IoT-based fertigation system for monitoring pH and EC values consists of several components and blocks. The main component is the Segmented Meter Box, where fertilizer data is read before application to the plants, allowing pH and EC values to be measured in the fertilizer solution. The open-source NodeMCU ESP32 Microcontroller powers the system, assembled using the Arduino IDE, operating at a supply voltage of 5V [21]. EC and pH Sensors are installed in the fertilizer tank to monitor fertilizer injection and nutrient availability. The EC sensor measures electrical conductivity related to dissolved salts and nutrient concentration [22]. In contrast, the pH sensor measures solution acidity or alkalinity [23]. The IoT Module-equipped NodeMCU 32S continuously gathers data from these sensors, equipped with Wi-Fi capabilities to store data in the IoT cloud [24].

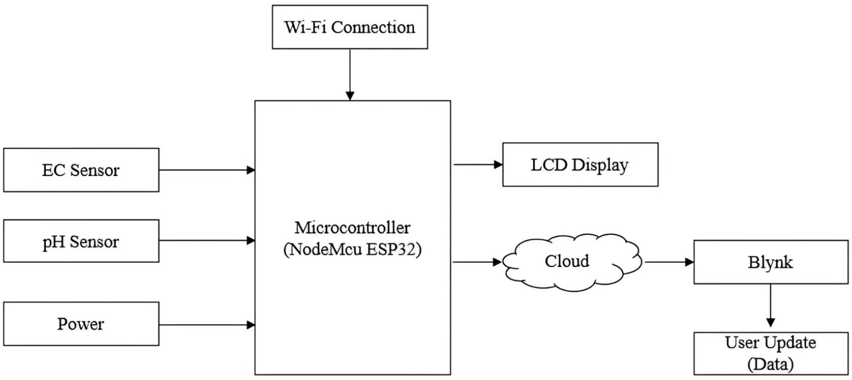


Fig. 1. Block Diagram of Proposed System

Figure 2 shows a schematic of an IoT system created to oversee and manage environmental conditions using sensors, microcontrollers, gateways, cloud servers, and user devices. The process starts with sensors, namely EC and pH sensors, that assess a substance's electrical conductivity and pH levels. These measurements are essential for evaluating environmental quality, identifying physical changes in the nutrient solution, and delivering electrical and electronic signals [25]. The sensors function within the physical realm of the IoT system.

The NodeMCU ESP32 processes the data collected by the sensors. This microcontroller is a go-between, transforming unprocessed sensor information into a format appropriate for sending over a network [26]. The microcontroller transforms analog signals from the sensors into digital signals for the IoT system [26]. It changes the data transmission format and transmits it using protocols like

MQTT or XMPP [27]. The ESP32 is a great fit for this job thanks to its integrated Wi-Fi and Bluetooth features, which are perfect for IoT use.

The processed data is transmitted to the cloud server through a Wi-Fi modem, which acts as the gateway within this system [28]. The gateway guarantees seamless communication between the microcontroller and the cloud server. In this situation, the Blynk server acts as the cloud server, collecting, storing, and handling data from the microcontroller on a cloud-based platform.

Blynk provides a simple remote control and monitoring interface, making it a practical platform for IoT use [29]. Users access the data using a smartphone application like the Blynk app. This enables them to track sensor data in real time, get alerts, and manage the system from a distance, leading to well-informed decision-making using the monitored environmental parameters.

To summarize, the system operates by having sensors gather environmental data, which is then analyzed by the NodeMCU ESP32 microcontroller. The information is later transferred to the cloud server through a Wi-Fi modem. The data is processed and stored by the Blynk server, allowing users to access and control it using their smartphones. Analytical software can remotely track the EC and pH values of the fertigation system, enabling device control from anywhere.

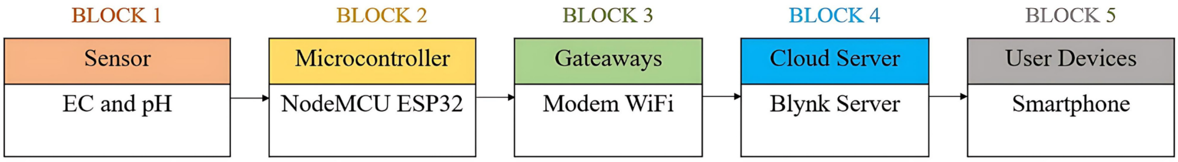


Fig. 2. Internet of Things (IoT) Block Diagram

2.2 NodeMCU ESP32 Microcontroller

A significant advancement in microcontroller technology has resulted in the introduction of the NodeMCU ESP32, a potent tool widely used in Internet of Things (IoT) applications. This microcontroller stands out due to its built-in Wi-Fi and Bluetooth features, which enable smooth wireless connections crucial for instant data transfer and remote management [30]. For example, in systems that monitor water quality, these characteristics help in sending important sensor data to cloud platforms or mobile devices, which improves user access and data usage. An inventory management system was created for a solar-powered freezer using an Arduino microcontroller to encourage energy efficiency and sustainable food practices. An Arduino-based inventory management system does not come equipped with a built-in Wi-Fi module and has a significantly less powerful processor than a NodeMCU [31]. Furthermore, the ESP32's dual-core processing capability allows for effective multitasking and fast sensor data processing, surpassing older microcontroller models. The variety of GPIO pins on offer allows for the connection of different sensors and actuators, making it an excellent option for a wide range of IoT applications [32]. As a result, engineers and researchers are increasingly choosing the NodeMCU ESP32 for creating IoT solutions that require reliability, performance, and affordability.

Among the various microcontrollers suitable for IoT applications, the NodeMCU ESP32 enhances connectivity for transmitting critical water quality metrics to cloud platforms or mobile applications. It also efficiently manages sensor data with its dual-core processing architecture, allowing for rapid analysis and response time to changing water conditions [33]. Furthermore, its extensive array of GPIO pins provides flexibility for connecting various sensors, including pH, turbidity, and temperature sensors, essential for comprehensive water quality assessment [34]. The rich community support surrounding the NodeMCU ESP32 enables quicker development cycles and troubleshooting, which is invaluable in maintaining the reliability of monitoring systems. Thus, the implementation of the

NodeMCU ESP32 in water quality monitoring emerges as an effective solution that balances performance, cost, and scalability.

Demonstrating the versatility of the NodeMCU ESP32, multiple case studies highlight its application across diverse IoT projects, underscoring its superior functionality. For instance, a project focused on lung sound data processing utilized the ESP32 to capture and transmit sound signals effectively. This implementation employed the microcontroller's advanced analog-to-digital conversion capabilities, enabling real-time monitoring via mobile devices through the Blink software [35]. Another compelling use case involved an electric power monitoring system that leveraged the NodeMCU ESP32's Wi-Fi capabilities to facilitate remote data access via a customizable WebApp dashboard, integrating various sensors for comprehensive data collection [36]. Additionally, a water quality monitoring system for Koi fish farming demonstrated the ESP32's ability to process multiple environmental parameters and relay information directly to users' smartphones, thereby reinforcing the microcontroller's role as a central component capable of integrating diverse technologies for enhanced IoT solutions [37].

In this project, it is essential to keep measuring the nutrient solution in real time and to control the concentration and pH value of the nutrient solution automatically. ESP32 is used to measure the nutrient solution continuously and in real-time. This microcontroller has a built-in programme that takes the signals from the sensors and does something with them. The values are shown in the apps so that they can be watched. The ability to record and collect data was also built into this project to make sure that data is managed and recorded better. This is very important because it will be used as a guide for any future changes.

2.3 Electrical Conductivity (EC) and pH Sensor

Accurate measurement of solution properties is essential for many scientific and industrial purposes, especially in assessing nutrient levels and the overall composition of the solution. EC sensors are crucial instruments for measuring how well a solution can conduct electricity, which is closely related to the amount of dissolved ions like nutrients [38]. These sensors work by placing two electrodes in the solution and applying a voltage to measure the resulting current, which is used to calculate the EC value in microsiemens per centimeter (S/cm) [39]. Their uses are varied, such as analyzing soil for farming, monitoring water treatment quality, and improving efficiency in industry. As the need for effective and eco-friendly resource management increases, incorporating EC sensors with new technologies like the Internet of Things (IoT) enhances their usefulness by enabling real-time monitoring and control, improving nutrient delivery, and ensuring optimal operational settings for different conditions.

pH sensors are crucial in various industries as they play a key role in tracking important chemical properties for different processes. Knowledge of the pH level of a solution is essential for maintaining ideal conditions in agriculture, especially since it affects the availability of nutrients and the growth of plants [40]. The pH scale ranges from 0 to 14, with 0 being the most acidic, 7 being neutral, and 14 being the most basic [41]. An example is soil analysis, where pH sensors assist in identifying the soil's acidity or alkalinity, leading to recommendations for improving soil health and crop productivity. In the same way, sensors in aquaculture systems regulate water quality by keeping the pH within appropriate levels to support the well-being of aquatic creatures. Additionally, in the field of food science, pH sensors play a crucial role in guaranteeing the safety and quality of processed goods by confirming that the pH levels meet the standards for consumption. Therefore, the incorporation of pH detectors not only improves effectiveness in farming techniques but also upholds safety and quality management in the food manufacturing industry.

The effectiveness of smart farming is more and more dependent on accurate environmental regulation, highlighting the importance of incorporating Electrical Conductivity (EC) and pH sensors into fertigation systems. EC sensors enable growers to monitor nutrient levels in irrigation water, ensuring plants receive optimal nutrients for health and productivity. An effective monitoring system using EC data can adjust nutrient solutions in real time to reduce imbalances that may impact crop yield. In the same way, pH sensors are essential in maintaining the appropriate acidity or alkalinity levels of the nutrient solution for optimal nutrient absorption. These sensors work together with IoT technology to analyze data and make decisions remotely, improving the efficiency of fertigation systems. This collaboration enhances resource utilization and underscores the importance of integrating these technologies for better crop management in sustainable agriculture.

2.4 Blynk Application

An in-depth knowledge of contemporary IoT applications requires exploring efficient interfaces that make it easier to monitor and control connected devices. An innovative mobile app in this field allows users to create user-friendly dashboards for interacting with real-time data. The Blynk app is known for working well with different microcontrollers, such as the popular NodeMCU ESP32, which is essential for numerous IoT ventures [42]. The user-friendly drag-and-drop interface makes it easy for all users, even those with less technical knowledge, to create personalized dashboards effortlessly. Moreover, Blynk's ability to offer live updates not only boosts user interaction but also aids quick decision-making in crucial situations [43]. By incorporating key aspects like notifications and data recording, Blynk successfully shifts the user experience from passive watching to active control, establishing itself as a crucial element in modern monitoring systems.

Incorporating Blynk into water quality monitoring systems significantly improves the capability to monitor and control important environmental factors in real time. Utilizing the NodeMCU ESP32 enables developers to effectively send sensor data, such as pH, electrical conductivity (EC), and temperature, directly to the Blynk app. This link allows for real-time data visualization on a user-friendly dashboard and also allows users to get immediate alerts if values go beyond set limits. This immediacy helps in making proactive decisions, ensuring that any significant changes in water quality can be dealt with promptly. Furthermore, Blynk's easy-to-use layout enables a wide range of users, from environmental experts to casual enthusiasts, to easily engage with the system. The use of Blynk changes water quality management from manual to efficient, highlighting its importance in contemporary environmental monitoring.

Figure 3 showcases the real-time display of EC and pH sensor readings from the fertigation system through a live graph using the Blynk application. The graph exhibits the trend of nutrient levels and concentration in the fertilizer and water mixture tank, allowing users to monitor the changes as they occur. This system's continuous operation relies on its internet connection, and with the NodeMCU ESP32 utilizing Wi-Fi, data is transmitted in real-time to the Blynk application. This seamless communication ensures that users can access and view the data instantaneously.

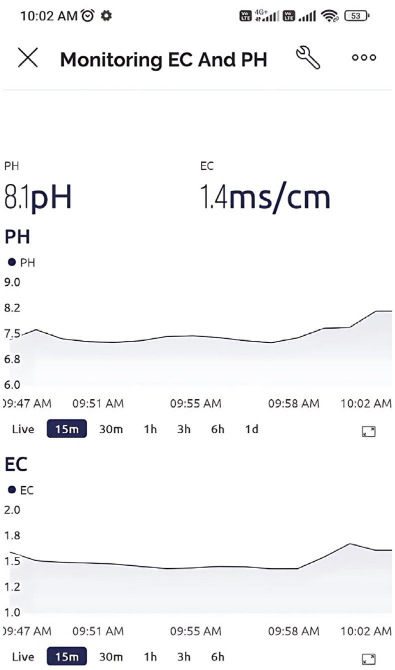


Fig. 3. Blynk application for monitoring EC and pH Value

3. Result

3.1 Calibration Hardware Setup and Sensor Specifications

The hardware setup for the calibration test includes several components. The main element is an onboard voltage regulator chip module that supports a wide voltage supply range of 3.3V to 5.5V. This module is compatible with both 5V and 3.3V main control boards, providing flexibility in the choice of microcontrollers.

The calibration test also utilizes specific sensors for data collection. The pH sensor used is the DF Robot brand, and the test uses two standard buffer solutions with pH values of 4.0 and 7.0. These buffer solutions are used to calibrate the pH sensor and establish the standard reading value. For the EC sensor, which is also from DF Robot, two standard buffer solutions with electrical conductivity values of 1413us/cm and 12.88ms/cm are used for calibration. Figure 4 depicts the connection diagram of the EC sensor, while Figure 5 illustrates the connection diagram of the pH sensor.

The microcontroller used in the calibration test is the Arduino UNO. The Arduino UNO is a widely used microcontroller board that provides a user-friendly interface for programming and controlling hardware components. Its compatibility with the voltage regulator chip module and its ease of use make it a suitable choice for this calibration test.

The selection of these components is based on their compatibility with each other and their ability to perform the required functions. The voltage regulator chip module ensures a stable power supply for the sensors and microcontroller. The DF Robot pH and EC sensors are specifically chosen for their ability to measure pH and electrical conductivity accurately. The Arduino UNO was selected for its ease of programming and compatibility with the other components in the system. By using these hardware components, the calibration test can accurately measure pH and electrical conductivity values and establish the standard reading values for the sensors.

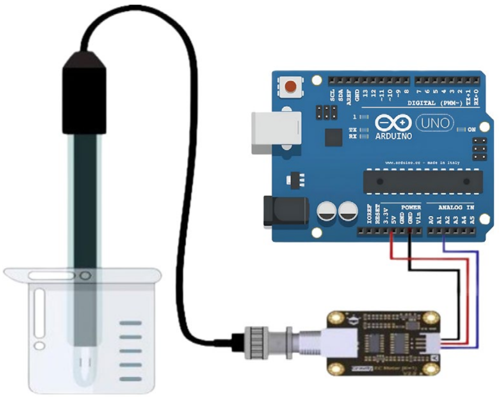


Fig. 4. Connection diagram of EC sensor

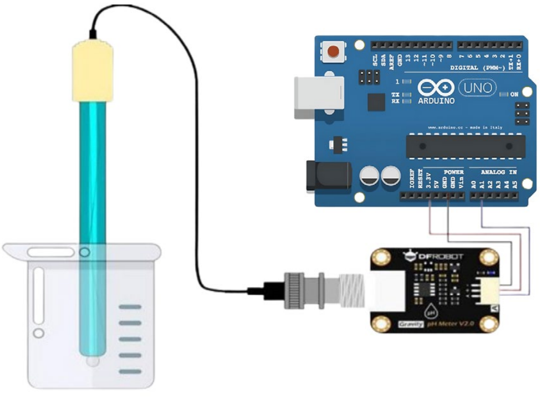


Fig. 5. Connection diagram of pH sensor

3.2 Sensor Calibration and Software Integration

For accuracy, the probe should be calibrated before its first use and after not being used for an extended period (preferably once a month). Two-point calibration is performed, requiring two standard buffer solutions of 4.0 and 7.0 pH values for pH sensor calibration. For EC calibration, the sensor needs standard buffer solutions of 1413µS/cm and 12.88mS/cm. The buffer solution function is essential and serves as an example for pH meter calibration because it helps maintain pH stability even if a small amount of acid, base, or water is accidentally added. It ensures that the pH of the solution and the internal environment remain stable over time. The step-by-step calibration process for both sensors is outlined below:

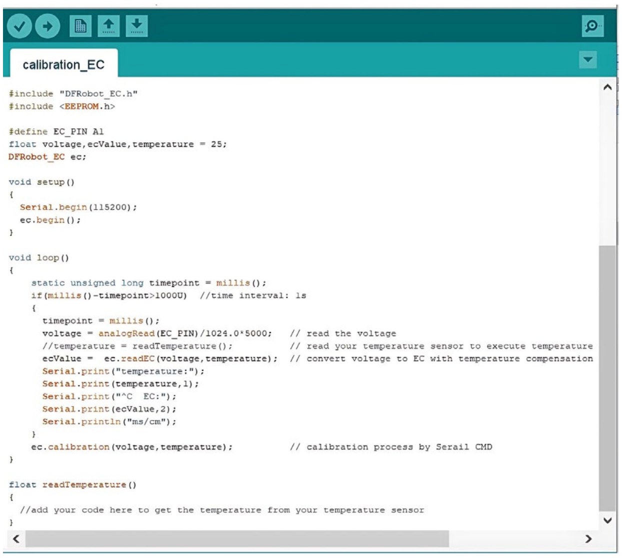
i. Upload the sample code and open the Arduino IDE's serial monitor to examine the sensor's reading value.
ii. Wash the probe with distilled water and use a paper towel to absorb any remaining water drops. Place the probe in a buffer solution and gently swirl it until the values stabilize.
iii. Once the readings are steady, the single-point calibration is possible.
iv. To enter the calibration mode, type "enterec" for the EC sensor or "enterph" for the pH sensor in the serial monitor.
v. To begin the calibration, enter "calec" for the EC sensor or "calph" for the pH sensor instructions. The application will automatically identify the buffer solution present.
    a. The program will determine which of the two standard buffer solutions is being used: either 1413µS/cm and 12.88mS/cm for the EC sensor or 4.0 and 7.0 for the pH sensor. For two-point calibration, the buffer solution is stored using the relevant parameters.
vi. To save the relevant parameters and exit the calibration mode, use "exitec" for the EC sensor or "exitph" for the pH sensor.
    a. The last standard buffer solution for the EC sensor is 12.88mS/cm.
    b. The standard buffer solution of 7.0 will be identified for the pH sensor.
vii. Once these processes are completed, the sensors can be used for actual measurements. The calibration parameters are recorded in the main control board's EEPROM for future reference.

In the development of the calibration test for the EC and pH sensors, the Arduino Integrated Development Environment (IDE) was utilized as the primary software tool. The Arduino IDE provides a user-friendly platform for programming the NodeMCU ESP32 microcontroller, which is at the core of the fertigation system. The custom code written in the Arduino IDE enables the calibration process for both sensors to be executed smoothly. The microcontroller communicates with the Blynk application, which acts as the IoT monitoring platform. Through the Blynk app, users can receive and refer to real-time data on the EC and pH values of the fertigation system, allowing for remote monitoring and control. Figures 6 and 7 show the interface coding in Arduino IDE for EC and pH sensors.

For the calibration process, the custom code implements two-point calibration for both sensors. This calibration method ensures greater accuracy by calibrating the sensors at two different buffer solution values. By dipping the probe into the buffer solution during the calibration process, the sensors are calibrated to provide precise and reliable readings. The custom code also includes control algorithms that manage the calibration mode, allowing users to enter calibration instructions and save relevant parameters to the main control board's EEPROM.

```
 * date  2018-04
 */

#include "DFRobot_PH.h"
#include <EEPROM.h>

#define PH_PIN A1
float voltage,phValue,temperature = 25;
DFRobot_PH ph;

void setup()
{
    Serial.begin(115200);
    ph.begin();
}

void loop()
{
    static unsigned long timepoint = millis();
    if(millis()-timepoint>1000U){                  //time interval: 1s
        timepoint = millis();
        //temperature = readTemperature();         // read your temperature sensor to execute temperatur
        voltage = analogRead(PH_PIN)/1024.0*5000;  // read the voltage
        phValue = ph.readPH(voltage,temperature);  // convert voltage to pH with temperature compensatio
        Serial.print("temperature:");
        Serial.print(temperature,1);
        Serial.print("^C  pH:");
        Serial.println(phValue,2);
    }
    ph.calibration(voltage,temperature);           // calibration process by Serail CMD
}

float readTemperature()
{
  //add your code here to get the temperature from your temperature sensor
}
```

Fig. 6. Arduino IDE for Calibration pH Sensor



```
#include "DFRobot_EC.h"
#include <EEPROM.h>

#define EC_PIN A1
float voltage,ecValue,temperature = 25;
DFRobot_EC ec;

void setup()
{
  Serial.begin(115200);
  ec.begin();
}

void loop()
{
    static unsigned long timepoint = millis();
    if(millis()-timepoint>1000U)  //time interval: 1s
    {
      timepoint = millis();
      voltage = analogRead(EC_PIN)/1024.0*5000;   // read the voltage
      //temperature = readTemperature();          // read your temperature sensor to execute temperature
      ecValue =  ec.readEC(voltage,temperature);  // convert voltage to EC with temperature compensation
      Serial.print("temperature:");
      Serial.print(temperature,1);
      Serial.print("^C  EC:");
      Serial.print(ecValue,2);
      Serial.println("ms/cm");
    }
    ec.calibration(voltage,temperature);          // calibration process by Serail CMD
}

float readTemperature()
{
  //add your code here to get the temperature from your temperature sensor
}
```

Fig. 7. Arduino IDE for Calibration EC Sensor

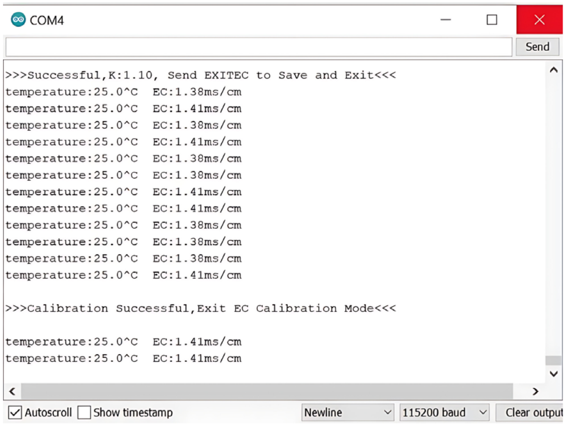
3.3 Calibration Process for EC and Ph Sensors

The calibration process for the EC and pH sensors used in the system involves precise procedures to ensure reliable and accurate readings. Two calibration methods, namely single-point and two-point calibration, are employed to calibrate both sensors. During the calibration test, the sensors are directly connected to the microcontroller and immersed in specific buffer solutions.

For the single-point calibration, the first test is conducted using the first buffer solution. The obtained value is then used to calibrate the sensor, and this calibrated value is stored in the microcontroller for future reference. Figure 8 shows the single-point calibration for the EC sensor, which requires standard buffer solutions of 1413µS/cm. Subsequently, the second buffer solution is used for the two-point calibration. Figure 9 shows the two-point calibration for the EC sensor, which requires standard buffer solutions of 12.88mS/cm.

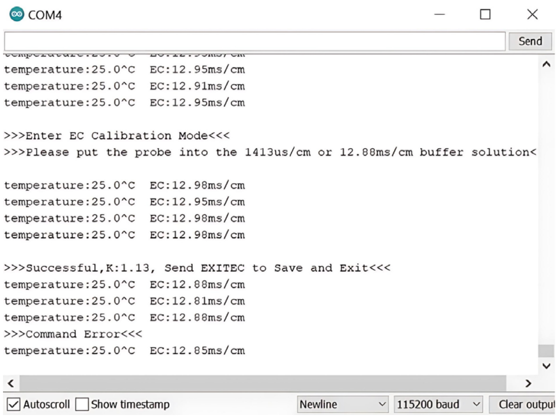
For the pH sensor, the single-point calibration uses a buffer solution with a pH value of 4.0, as shown in Figure 10. The two-point calibration uses a buffer solution with a pH value of 7.0, as shown in Figure 11. During this process, the sensor is tested twice, and the parameters for this calibration test are written to the EEPROM on the main control board. The two-point calibration ensures greater accuracy by calibrating the sensor at two different buffer solution values.

The calibration process should be repeated periodically to maintain the sensors' accuracy over time. It is recommended that the sensors be calibrated before their first use and after prolonged periods of non-use, ideally once a month. Regular calibration helps compensate for any drift or changes in sensor readings, ensuring that the sensor remains precise and reliable in its measurements. By following a consistent calibration schedule, the fertigation system can continue to provide accurate EC and pH values, thereby optimizing the nutrient levels for crop growth and productivity.



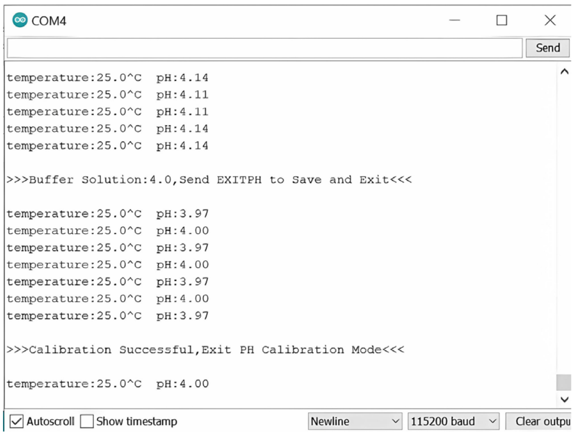
```
>>>Successful,K:1.10, Send EXITEC to Save and Exit<<<
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.41ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.41ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.41ms/cm
temperature:25.0^C  EC:1.41ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.38ms/cm
temperature:25.0^C  EC:1.41ms/cm

>>>Calibration Successful,Exit EC Calibration Mode<<<

temperature:25.0^C  EC:1.41ms/cm
temperature:25.0^C  EC:1.41ms/cm
```

Fig. 8. Single-point calibration EC sensor requires standard buffer solutions of 1413us/cm



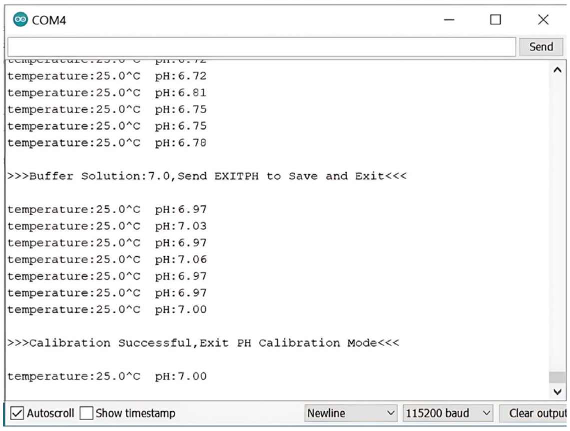
```
temperature:25.0^C  EC:12.95ms/cm
temperature:25.0^C  EC:12.91ms/cm
temperature:25.0^C  EC:12.95ms/cm

>>>Enter EC Calibration Mode<<<
>>>Please put the probe into the 1413us/cm or 12.88ms/cm buffer solution<

temperature:25.0^C  EC:12.98ms/cm
temperature:25.0^C  EC:12.95ms/cm
temperature:25.0^C  EC:12.98ms/cm
temperature:25.0^C  EC:12.98ms/cm

>>>Successful,K:1.13, Send EXITEC to Save and Exit<<<
temperature:25.0^C  EC:12.88ms/cm
temperature:25.0^C  EC:12.81ms/cm
temperature:25.0^C  EC:12.88ms/cm
>>>Command Error<<<
temperature:25.0^C  EC:12.85ms/cm
```

Fig. 9. Two-point calibration EC sensor requires standard buffer solutions of 12.88ms/cm



```
temperature:25.0^C  pH:4.14
temperature:25.0^C  pH:4.11
temperature:25.0^C  pH:4.11
temperature:25.0^C  pH:4.14
temperature:25.0^C  pH:4.14

>>>Buffer Solution:4.0,Send EXITPH to Save and Exit<<<

temperature:25.0^C  pH:3.97
temperature:25.0^C  pH:4.00
temperature:25.0^C  pH:3.97
temperature:25.0^C  pH:4.00
temperature:25.0^C  pH:3.97
temperature:25.0^C  pH:4.00
temperature:25.0^C  pH:3.97

>>>Calibration Successful,Exit PH Calibration Mode<<<

temperature:25.0^C  pH:4.00
```

Fig. 10. Single-point calibration pH sensor requires standard buffer solutions of 4.0



```
temperature:25.0^C  pH:6.72
temperature:25.0^C  pH:6.81
temperature:25.0^C  pH:6.75
temperature:25.0^C  pH:6.75
temperature:25.0^C  pH:6.78

>>>Buffer Solution:7.0,Send EXITPH to Save and Exit<<<

temperature:25.0^C  pH:6.97
temperature:25.0^C  pH:7.03
temperature:25.0^C  pH:6.97
temperature:25.0^C  pH:7.06
temperature:25.0^C  pH:6.97
temperature:25.0^C  pH:6.97
temperature:25.0^C  pH:7.00

>>>Calibration Successful,Exit PH Calibration Mode<<<

temperature:25.0^C  pH:7.00
```

Fig. 11. Two-point calibration pH sensor requires standard buffer solutions of 7.0

3.4 Analysis and Discussion on the Calibration Result

The calibration test results revealed that both the EC and pH sensors require specific calibration procedures to ensure accurate and reliable readings. A two-point calibration process was performed for the pH sensor. Initially, a neutral standard buffer solution of 7.0 was used for a single-point calibration to establish the absolute zero point of the pH probe. Subsequently, a second calibration was conducted using a standard buffer solution of 4.0 to determine the natural slope of the pH probe and validate the correctness of the measurement. For the EC sensor, a two-point calibration was conducted with standard buffer solutions of 1413us/cm and 12.88ms/cm, respectively. This dual calibration approach ensures precision across the entire range of sensor readings, enhancing the accuracy of the fertigation system.

To maintain the system's accuracy over time, it is essential to follow a regular calibration schedule. It is recommended that calibration be conducted using new standard buffer solutions every month to ensure the sensors remain calibrated and provide precise EC and pH readings. This periodic calibration process serves as a critical metric to evaluate the effectiveness of the system's performance. It contributes to the optimization of fertigation practices for enhanced crop growth and productivity.

3.5 Circuit Configuration of the Project System

The circuit configuration of the entire project system, as shown in Figure 12, involves interconnecting various components and devices to meet the system's requirements. The NodeMCU ESP32 microcontroller serves as the main controller, powered by a 12V adapter that supplies the necessary power to activate all components. The NodeMCU is responsible for connecting and interacting with the sensors and devices used in the project. Pin connections between the NodeMCU and the sensors are defined in the Arduino IDE, ensuring proper communication and data exchange.

This circuit configuration enables the system to gather data from the EC and pH sensors, process it, and communicate with the Blynk platform for real-time monitoring and control. The NodeMCU's ability to integrate with various sensors and devices allows for seamless coordination of data acquisition and system operation. The 12V adapter provides sufficient power to drive the entire system, ensuring stability and reliable functionality. Through proper component connections and precise programming of the NodeMCU, the fertigation system can achieve efficient and accurate monitoring of EC and pH values, contributing to improved crop yield and quality.

In summary, the circuit configuration involves the NodeMCU ESP32 microcontroller as the main controller, powered by a 12V adapter. The NodeMCU connects and interacts with the sensors and devices, enabling the system to gather and process data from the EC and pH sensors and communicate with the Blynk platform for real-time monitoring and control. The use of a 12V adapter ensures system stability and reliability. Proper component connection and programming allow the fertigation system to achieve efficient and accurate monitoring of EC and pH values, leading to improved crop yield and quality.

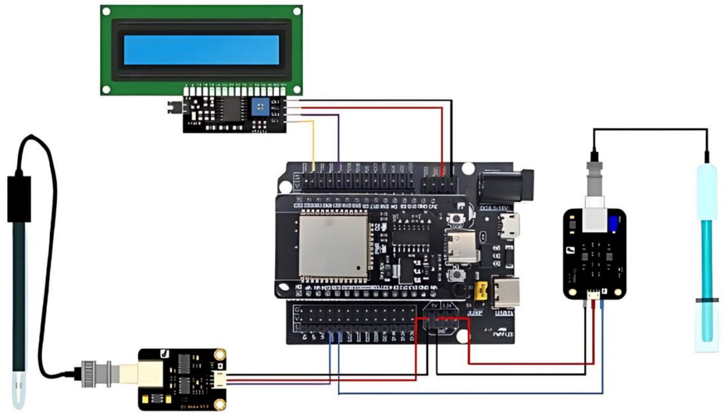


Fig. 12. Circuit configuration for overall project system

3.6 Data Analysis and Visualization on the IoT Platform

The tank holding the fertilizer mixture at the fertigation plant was sampled three times daily—morning, afternoon, and evening—with three-hour intervals between each collection. EC and pH sensors, calibrated for accuracy, were used to measure nutrient levels in a 300-gallon tank containing 300 to 400 milliliters of fertilizers A and B. The goal was to fill 30 to 70 polybags with the mix. Morning data captured initial nutrient levels, and afternoon data showed changes due to temperature and plant uptake, and evening data assessed daily nutrient stability. This monitoring process ensured optimal nutrient balance, leading to improved crop yield and sustainable agricultural practices.

3.6.1 Result 1-hour morning

Once the fertilizer tank has been filled with the new fertilizer combination, the following data is collected. Table 1 and Figure 13 present an analysis of the data collected during the morning hour. The graph displays the examination of pH and EC levels. Sensor data readings from 9:00 a.m. to 10:00 a.m. are depicted in the diagram. At the commencement of fertilizer intake, a pH value of 7.53 and an EC concentration of 1.57 were discovered, which aligns with the appropriate levels for fruiting vegetables and is compatible with plant growth. Subsequently, the pH and EC readings remain consistent with their initial values. However, at around 10:00 a.m., there is a significant change in the pH of the fertilizer tank, which is attributed to the entry of water into the tank. Additional observations include the initial pH and EC values indicating optimal conditions for nutrient uptake, and the stability of readings initially confirms the proper mixing of fertilizers. The recorded change in pH at 10:00 a.m. suggests the need to monitor and adjust the water inflow rate to maintain consistent nutrient conditions.

Table 1
Morning data in 1 hour

Time	pH Value	EC Value
9:00 am	7.53	1.57
9:10 am	7.46	1.59
9:20 am	7.54	1.62
9:30 am	7.39	1.61
9:40 am	7.40	1.65
9:50 am	7.20	1.50
10:00 am	5.90	1.80
10:10 am	7.30	1.40

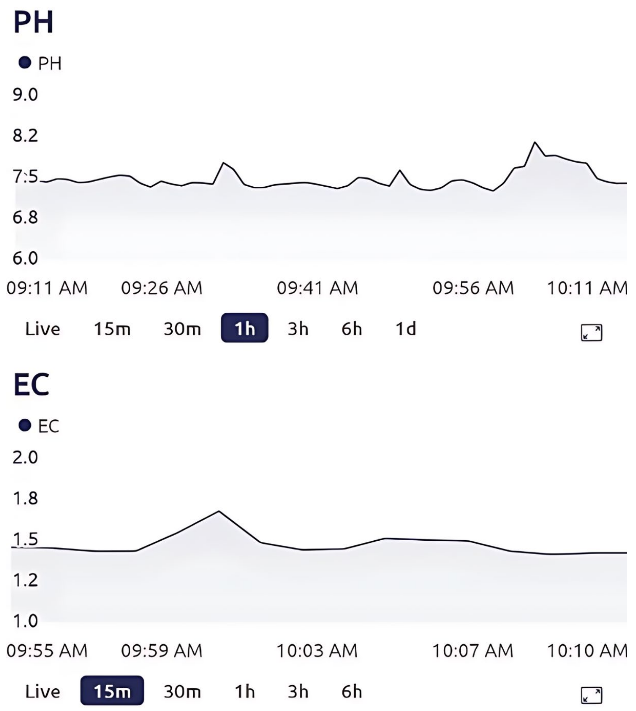


Fig. 13. Result morning 1 hour from Blynk display

3.6.2 Result I-hour afternoon

The data analysis during the afternoon, conducted from 1:55 p.m. to 3:00 p.m., is presented in Table 2 and Figure 14. The table indicates a continued consistency in pH and EC values, with very few variations. The graph illustrates a slight decline in values over time, but this decline remains within the acceptable range for pH value measurements. Additional analysis shows that the afternoon values reflect the stability of the fertilizer mixture despite potential influences such as temperature fluctuations and plant uptake. The minimal decline in pH and EC values supports the efficacy of the nutrient solution throughout the day.

Table 2
Afternoon data in 1 hour

Time	pH Value	EC Value
1:55 pm	7.55	1.02
2:10 pm	7.23	1.00
2:20 pm	6.10	1.35
2:30 pm	6.08	1.49
2:40 pm	7.57	1.29
2:50 pm	7.52	1.18
3:00 pm	7.49	1.16

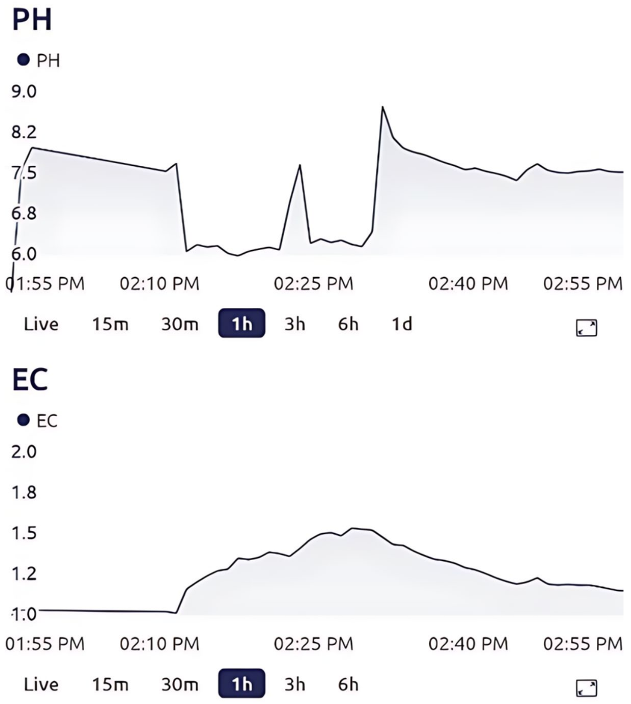


Fig. 14. Result afternoon 1 hour from Blynk Display

3.6.3 Result 1-hour evening

Table 3 and Figure 15 present the data analysis for pH and EC collected during a 1-hour evening sample conducted between 6:00 p.m. and 7:00 p.m. The graph illustrates the trends over time for this period. During this time, the electrical conductivity (EC) value gradually decreases until it falls below 1 EC, while the pH value also decreases until it approaches neutral levels. The data presented in the table and graph were measured from the IoT platform, showing the changes in the values of the new fertilizer mixture in the water molecules. Significant adjustments were observed during the evening, indicating that this high-quality pre-mixed fertilizer is suitable for fruiting plants and meets their specific requirements. The decrease in fertilizer levels was due to water flow into the plant medium and the introduction of freshwater into the fertilizer tank, which can be rectified by adding more AB fertilizer. Additionally, the gradual decrease in EC and pH values highlights the need for regular adjustments to maintain optimal nutrient concentrations. Evening data suggests that continuous monitoring and periodic adjustments are crucial for sustaining effective fertigation practices.

Table 3
Evening data in 1 hour

Time	pH Value	EC Value
6:00 pm	7.80	1.00
6:10 pm	7.40	1.00
6:20 pm	7.30	0.85
6:30 pm	7.20	0.64
6:40 pm	7.20	0.59
6:50 pm	7.09	0.55
7:00 pm	7.03	0.50

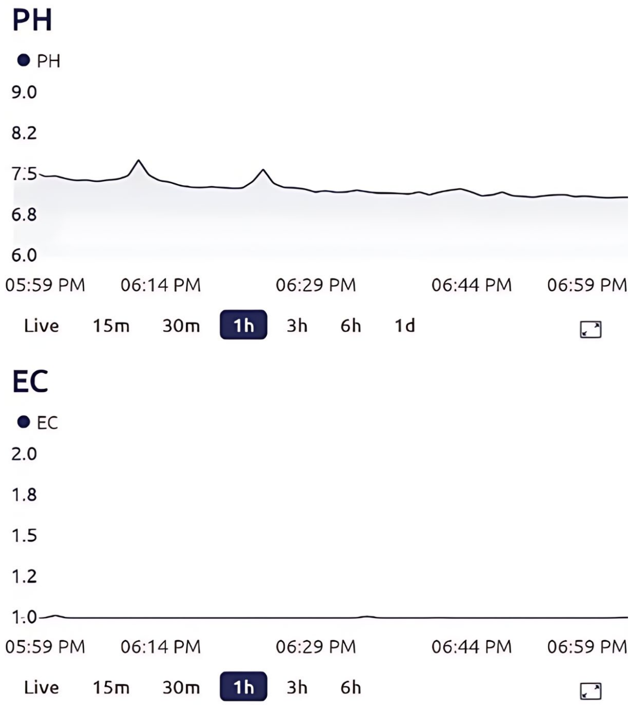


Fig. 15. Result evening 1 hour from Blynk Display

4. Conclusions

In conclusion, this project successfully developed and implemented a prototype fertigation control system designed to automatically monitor and manage liquid fertilizer mixtures using a combination of sensors and IoT technology. The system effectively integrates a power supply, EC sensor, pH sensor, NodeMCU 32S, and LCD, all enclosed in a protective panel box to ensure reliable operation. Through precise arrangement of input and output components and careful site preparation, the system has demonstrated its capability to track and manage fertilizer data accurately. By leveraging IoT technology, the project transitions from manual data collection to an automated system that provides real-time monitoring and management of fertilizer concentration and nutrient levels. The use of sensors connected to an IoT platform enhances data accuracy and efficiency, leading to better plant outcomes compared to traditional methods. For future studies, several improvements are recommended to enhance the system's functionality. These include integrating an analog output hydrostatic liquid level sensor to monitor water depth in the tank, improving Wi-Fi signal strength in rural areas by exploring alternatives like ESP32 LoRa, and adding LED indicators to better observe Wi-Fi connection status. Additionally, incorporating protective devices such as Miniature Circuit Breakers (MCB) and Surge Protection Devices (SPD) can safeguard the system from power supply instability. Exploring water purification techniques and ensuring proper pH levels before mixing with fertilizers could further optimize the system. Future research could also explore integrating with other IoT devices or expanding the system for different types of crops to provide a more comprehensive solution for modern agriculture.

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