iLettuse: An IoT Web-Based Green Batavia Hydroponics Lettuce Cultivation Monitoring System Using Nutrient Film Technique

Kezia R. Dimaculangan [a], Brigette Jane M. Hernandez [b], Shiela R. Folgar [c], John C. Valdoria, MIT [d], Jorge T. Jader , MIT [e]

[a] keziadimaculangan@ctsc.edu.ph, [b] brigettehernandez@ctsc.edu.ph, [c] shielafolgar@ctsc.edu.ph, [d] jvaldoria4132yahoo.com, [e] jorgejader@ctsc.edu.ph
School of Information Technology, College of Sciences Technology and Communications Inc.
Sariaya, Quezon, 4322 Philippines

Abstract

Hydroponics farming offers a sustainable and efficient approach to plant cultivation without soil by using nutrient-rich water solutions to nourish plant roots directly. However, farmers often encounter difficulties in maintaining optimal growing conditions because essential parameters such as pH level, electrical conductivity (EC), water temperature, and water level are still commonly checked manually. Manual monitoring is time-consuming and prone to error, which may produce inconsistent nutrient balance and reduced crop quality. To address this gap, this study developed an Internet of Things (IoT)-based web monitoring system for Green Batavia lettuce cultivation using the Nutrient Film Technique (NFT). The system automates and optimizes the monitoring and regulation of hydroponic parameters through real-time data acquisition and control. The web application was developed using PHP, Bootstrap, and Chart.js, with Firebase and MySQL for data storage and management. The IoT device uses an Arduino ATMega microcontroller, NodeMCU ESP8266 Wi-Fi module, pH, EC, temperature, and ultrasonic sensors, and actuators for automatic adjustments. Evaluation based on the ISO/IEC 25010:2011 Product Quality Model showed high precision, responsiveness, and timely web and SMS notification delivery when monitored parameters exceeded predefined thresholds. The results confirm the system's reliability, efficiency, and potential to improve hydroponic monitoring, management, and crop productivity.

Keywords: Batavia Hydroponics Lettuce; Electrical Conductivity Level; Hydroponics, Internet of Things;Nutrient Film Technique; pH Level

1. Introduction

1.1 Background and Problem of the Study

Hydroponics farming is a soil-less agricultural method in which plants are cultivated using a nutrient-rich water solution as the primary growing medium. Instead of relying on soil for nutrient delivery, plant roots are directly exposed to a mineral nutrient solution that supplies the essential elements required for growth and development. This method has gained attention as a modern agricultural approach because it can improve crop production efficiency, promote faster plant growth, and produce healthy and high-quality crops compared with conventional soil-based farming practices (Dudwadkar, 2020).

As global agriculture continues to face challenges such as severe weather conditions, soil degradation, ecosystem disruption, and the growing demand for food production, researchers and agricultural stakeholders have explored alternative farming systems that can improve yield while minimizing environmental impact. Hydroponics has emerged as one of the practical responses to these challenges because it enables controlled cultivation, efficient water use, and improved crop management. In this context, the integration of the Internet of Things (IoT) into agriculture further strengthens hydroponic farming by enabling automated monitoring, real-time data collection, and remote management of essential crop parameters (Kularbphettong et al., 2019).

Hydroponics farming includes several cultivation techniques, such as the Nutrient Film Technique (NFT), Deep Flow Technique, and Dynamic Root Floating system. Among these, the Nutrient Film Technique is widely used because it continuously circulates a thin film of nutrient solution through plant channels, allowing nutrients to flow directly to the roots while maintaining aeration in the upper root zone. Unlike other hydroponic approaches, NFT uses a pump-driven circulation system that constantly moves the nutrient solution, creating a thin layer of nutrients that coats the roots and supports plant growth (D'Anna, 2022). This makes NFT suitable for leafy vegetables such as lettuce, which requires stable nutrient delivery and controlled growing conditions.

Lettuce is one of the most commonly cultivated crops in NFT hydroponic systems because of its high market demand and suitability for fresh consumption. Batavia lettuce, particularly Green Batavia, is a summer crisp lettuce variety that can thrive under warm conditions and demonstrates slower bolting compared with other lettuce types. It includes both open-head and closed-head forms and may appear in green, red, burgundy, magenta, and mixed colors. Hydroponic lettuce cultivation provides several advantages over conventional soil-based production, including improved hygiene, more consistent plant growth, shorter planting distances, and better control of production conditions (Frasetya et al., 2021).

The adaption of web-based systems in agriculture has also contributed to the improvement of productivity, profitability, and sustainability. Web-based systems are accessible through browsers and can operate across different platforms without requiring installation. With internet connectivity, users can access agricultural data through computers or smartphones at any time and from any location. According to Shariff (2019), agricultural web systems can collect, store, and provide access to data related to harvest time, production location, yield information, plot details, pest monitoring, and disease information. These capabilities are useful in hydroponics farming because growers need accurate and timely information to support decision-making.

Farmers depend on agricultural information and technical knowledge to make informed decisions in crop production. The use of Information and Communication Technology (ICT) allows farmers to access relevant data, address production concerns, and expand farming opportunities. Smart technologies can optimize hydroponics farming, which has been recognized as a sustainable agricultural method (Tagle et al., 2018). Through IoT-enabled systems, farmers can remotely monitor crop conditions, collect sensor-based data, and manage production parameters more efficiently. IoT devices can gather information on environmental conditions, crops, and system performance, then transmit these data to databases for processing, analysis, and monitoring. This helps reduce production risks, maintain crop quality, improve efficiency, and minimize environmental effects.

Despite the potential of hydroponics and IoT-based agriculture, existing hydroponic systems still present limitations in monitoring and automation. Previous observations revealed that some systems do not provide automated regulation of water temperature, pH level, and electrical conductivity (EC) level. Mabitazan M. and Mabitazan R.(2021) emphasized that the limited number of Philippine studies focusing on automated pH and EC regulation in hydroponic systems remains a challenge when compared with existing international research. This gap highlights the need for an IoT-web-based automated monitoring system that can support hydroponics farm growers, particularly in Quezon Province, through real-time and remote monitoring of critical parameters.

In the local context, hydroponics farming has been recognized as a rising smart farming technique that allows farmers to cultivate crops without soil. The Agricultural and Biosystems Engineering Division, located at Dalahican Road, Lucena City, provides technical support and training to farmers and agricultural stakeholders to promote the adoption of hydroponics technology. The division also conducts research and development activities to improve the efficiency, productivity, and sustainability of hydroponic systems. Based on the preliminary interview with Department of Agriculture representative, farmers typically harvest hydroponically cultivated crops within a forty-day cycle using the Nutrient Film Technique A-frame type hydroponics system. The same interview identified pH level, EC level, and water temperature as the primary parameters that require monitoring and manual intervention.

Interviews with hydroponics farm owners in Sariaya, Quezon further revealed that most local growers use the Nutrient Film Technique in cultivating lettuce varieties such as Green Batavia. However, the water level in these systems requires daily or frequent monitoring because of continuous pump operation. Farmers also reported difficulties in measuring and monitoring the EC level and nutrient consumption of hydroponic lettuce due to the absence of appropriate instruments. During testing, problems such as yellowing leaves were observed, which were attributed to inaccurate nutrient mixture and unstable water solution. These findings support the claim that healthy hydroponic plant growth requires careful management of water temperature, water level, pH level, and nutrient solution conditions (Herman & Surantha, 2019).

The pH level of a growing medium is essential because it affects nutrient availability and plant absorption. When the pH level becomes too high or alkaline, plants may experience difficulty absorbing essential nutrients, resulting in nutrient deficiencies and poor growth. Maintaining an appropriate pH range is therefore necessary to ensure effective nutrient uptake and optimal plant development (Judith, 2019). Low pH levels may cause stunted growth, chlorosis, and dead patches on lower leaves, while high pH levels may reduce iron availability and result in interveinal chlorosis on upper leaves. Similarly, EC level is a critical indicator of nutrient concentration in hydroponic solutions. Low EC may lead to leaf discoloration and poor crop growth, while high EC may cause early bolting and excessive vegetative growth. Water temperature is also important because it affects the amount of dissolved oxygen in the nutrient solution. As water temperature increases, dissolved oxygen decreases, which can negatively affect plant growth if not properly controlled.

To address these concerns, the researchers developed an IoT-based Green Batavia hydroponics lettuce monitoring system designed to monitor and regulate pH level, EC level, and water temperature. The system aligns with the United Nations Sustainable Development Goal on Responsible Consumption and Production, which emphasizes efficient resource use and environmentally responsible production practices. The developed system includes a web-based platform that displays and analyzes real-time measurements of pH level, EC level, water temperature, water level, and grow-light status. It also provides web and SMS notifications when parameter readings fall outside the required threshold range. The system integrates a pH probe sensor, EC probe sensor, DS18B20 temperature sensor, and ultrasonic sensor to automate monitoring and improve the accuracy of hydroponic parameter management. Through this system, hydroponics farm owners can reduce manual monitoring, respond quickly to parameter changes, and prevent crop issues such as stunted growth, dead patches, and leaf discoloration. Overall, the development of the IoT-web-based automated monitoring system provides a practical technological solution for improving Green Batavia lettuce cultivation using the Nutrient Film Technique.

1.2 Review of Related Literature

Smart Farming

Smart farming, also known as smart agriculture, is an innovative agricultural technique that aims to meet the growing food demands of the population while minimizing negative environmental impacts (Ali et al., 2023). This approach integrates sustainable practices, information and communication technologies, as well as sensor- based equipment to optimize crop cultivation and enhance food production. Recent advancements in technology, such as the Internet of Things (IoT), robotics, artificial intelligence, and data analytics, have found applications in various sectors like smart homes and healthcare, and now they are revolutionizing agriculture as well (Virk et al., 2020).

The rise of Smart Farming began in the early 1990s, the use of robotic milking systems for dairy farmers and satellite images clearly showing field variations enabling farmers to cultivate that area more accurately. Kempenaar (2022), mentioned that it really gained momentum around fifteen years ago, after developments in technologies (IoT, big data, AI, and robotics) followed in quick succession and became accessible to a wider audience. Thus, precision agriculture is improving structural management practices to increase crop production and to avoid the misuse of fertilizers and pesticides (Mohamed et al., 2021).

Smart agriculture addresses many issues related to crop production as it allows monitoring of the changes in climate factors, soil characteristics, soil moisture, etc. In addition, smart agriculture is a technology that relies on its implementation for the use of AI and IoT in cyber-physical farm management (Bacco et al., 2019). Through the integration of Internet of Things (IoT) technology, they were able to link various remote sensors such as robots, ground sensors, and drones, as this technology allows devices to be linked together using the Internet to be operated automatically (AlMetwally et al., 2020). Thus, lettuce is being used as a testing crop in some projects, and designs can monitor the growing environment, nutrition levels, and other environmental factors such as temperature, light, and water level (Gokul et al., 2021).

Smart farming systems are often built on general-purpose computing platforms that overlook the implicit values driving their creation and use. As a result, computing technology is typically used to replace human labor (Streed et al., 2021). This practice has emerged as a result of technological advancements brought about by globalization. The implementation of advanced technologies, including cloud computing and the internet of things, is expected to further enhance smart farming by introducing more robots and artificial intelligence into agricultural production systems.

Hydroponics

Hydroponics is a type of horticulture and a part of hydroculture, which implies growing plants without soil where mineral nutrient solutions in a water solvent are used (Maiti and Saha, 2022). Hydroponics is a Greek term meaning "working water" derived from two words, “hydro” which means water and “ponos” means labor. Hydroponics is a crop production system that uses an inert medium and nutrients are provided with a solution. It has two types, liquid and solid cultivations. In liquid hydroponics, the Deep water culture (DWC), Nutrient Film Technique (NFT) and Aeroponics whereas in Solid Hydroponics cultivation are Dutch or Bato bucket, Ebb and Flow and Wick or Mat (Garcia, 2022).

According to Gunnam et al. (2020), hydroponics involves the method of cultivating plants in a nutrient-rich medium, a mixture of water and soluble nutrients. The effective implementation of renewable energy systems in Automated Hydroponics setups heavily relies on Monitoring and Control, which serves as a crucial innovation. In a hydroponics system, plants are nurtured in a soluble nutrient medium consisting of a nutrient solution and water. Traditionally, the concentration of nutrients is determined using indicators such as electrical conductivity (EC) or total dissolved salts (TDS). However, due to the absorption of nutrients, the TDS/EC and pH levels constantly fluctuate. Therefore, it is necessary to achieve a balanced nutrient medium and pH level that is most suitable for optimal plant growth, ideally within the pH range of 5.5-6.5 for most plant species. Plants require a diverse combination of essential components in their root zone, including macronutrients such as Nitrogen, Phosphorus, Potassium, Sulfur, Calcium, and Magnesium, as well as micronutrients like iron, Manganese, Zinc, molybdenum chloride, Boron, Copper, and nickel. Consequently, it is vital to maintain a well-balanced solution that encompasses all the necessary plant macro and micronutrients to support ideal plant development.

Hydroponics has been studied extensively in terms of its environmental performance, production yield, and economic profitability compared to conventional agriculture. It can be placed in a controlled growing environment. Hydroponics replaces the soil with water and the growing media. The growing media can be perlite, sand, rock wool, coco peat, etc. Their main role is to transfer the nutrients in the water and keep the roots oxygenated. Nutrients are added to the water and are moved to the growing media through plant roots via water pump. Thus, hydroponics is usually grown indoors or in a greenhouse. This means growers would take full management of the environment - climate, temperature, lights, ventilation, and so on. Hydroponics is particularly advantageous in areas with poor or infertile soil, as it provides people with access to healthy and fresh produce that is enriched with flavor, taste, and nutrients, offering a solution to the decreasing amount of agricultural land (Omar et al., 2020).

In addition, hydroponics has gained popularity in recent years due to its ability to produce high-quality crops with less environmental impact than traditional farming methods. It allows for year-round crop production and can be used in urban environments where space for farming is limited. This can be used to grow crops in areas with poor soil quality or limited water resources. However, hydroponics systems require significant upfront investment and ongoing maintenance. The cost of equipment and technology, such as pumps, lights, and nutrient solutions, can be expensive. Moreover, growers must be vigilant in maintaining proper pH, nutrient levels, and water quality to prevent plant diseases and pests. Despite these challenges, hydroponics offers a promising solution to sustainably feed the growing global population (Shetty, 2021).

Green Batavia Lettuce

Lettuce has gained immense popularity today due to its short maturity times and ease of cultivation, providing numerous options for field cultivation (Dawson et al., 2021). Over the course of its domestication, lettuce has evolved into various head types, leaf colors, and textures. The four main head types are romaine, crisp head, butterhead, and loose leaf, (Drost, 2020). Batavia lettuce, a type of crisp head variety, is a crispy summer lettuce that germinates quickly and bolts slowly. It is available in open and close-headed varieties, offering green, burgundy, red, magenta, and mixed hues. All Batavia lettuce varieties are open-pollinated, making them excellent choices for late- season gardening. While most lettuce varieties thrive in cool weather, Batavian lettuce plants also perform well in hot weather conditions. The seeds can even germinate at temperatures that are too high for most lettuce seeds. Summer crisp lettuce typically forms loose and wavy heads, although some varieties are more compact and resemble iceberg lettuce. The high heat tolerance of the seeds enables germination at temperatures as low as 80 degrees Fahrenheit (27 degrees Celsius) (Grant, 2021). Lettuce flourishes in full sun and well-drained soil. Batavia lettuce, in particular, is easy to grow, requiring minimal attention, and it consistently thrives in both garden beds and containers. Additionally, it exhibits tolerance to a wide range of weather conditions, ensuring a bountiful harvest of crisp and fresh lettuce (Lee, 2021).

Nutrient Film Technique

Nutrient Film Technique (NFT) was developed in the mid-1960s in England by Dr. Alen Cooper to overcome the shortcomings of the ebb and flow system. NFT is a highly popular hydroponic system in which plants are placed in channels, and a nutrient solution is constantly pumped through these channels. The Nutrient Film Technique (NFT) is a well-known hydroponics cultivation method (Mohammed, 2018). The NFT system is a method of cultivating plants that uses shallow and circulating hydroponic nutrient layers to ensure that plants get enough water, nutrients, and oxygen. As the nutrient solution reaches the end of the channel, it is directed back to the beginning of the system, making it a recirculating system (Jan et al., 2020). This technique is named NFT as the plants roots are not entirely submerged in the nutrient solution, but rather they grow in a shallow, circulating hydroponic nutrient layer. The plants are grown in layers of polyethylene with the roots constantly immersed in nutrient-rich water, which is pumped by a pump (Yasay, 2021).

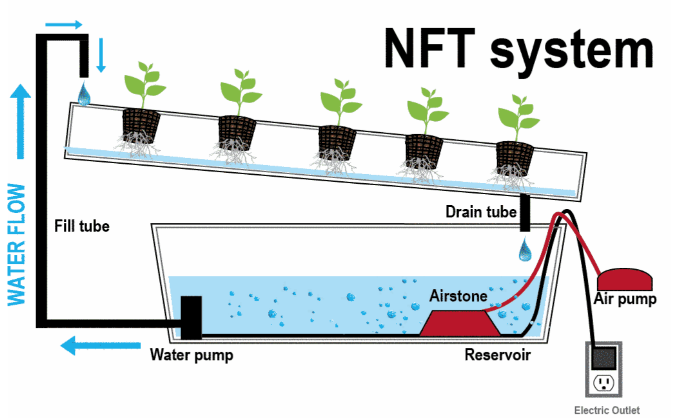

Fig. 1. Nutrient Film Technique

Nutrient Film Technique (NFT) systems did not use growing mediums. They are built using wooden channels that support polyethylene film liners. The plants are positioned above those channels. Nutrient-rich water is pumped through the channels to allow the plants to absorb nutrients. The channels are sloped slightly to allow the water collected at the end of the channel to be pumped up again. Thus, NFT hydroponic system makes it easier for humans to grow crops hydroponically without having to control the availability of water, oxygen, and nutrients for plants at any time (Iswanto et al., 2020). Since the slope of the gutter affects the flow speed of nutrients, which ultimately impacts the absorption rate of nutrients by the roots, it used modified gutters such as special NFT hydroponic gutters because the bottom surface is flat like a special NFT hydroponic gutter. The flat bottom surface allows the roots to spread freely and maximizes nutrient absorption (Puspitahati et al., 2022). The floating root system is similar to NFT, except that the plant roots are not completely submerged in the nourishing solution, but rather in a liquid stream flowing through a piping system (Gonzales et al., 2022). Likewise, NFT hydroponics has advantages such as easier maintenance, faster growth, better fertilizer utilization, and less deposition. However, NFT has drawbacks such as reliance on electricity, disease spread speed, and installation costs (Mohapatra et al., 2020).

pH Level

The potential of hydrogen or pH is a measure of the acidity or alkalinity of a solution, with values ranging from 0 to 14. Alterations in the pH levels of the nutrient solution can have a significant impact on its composition, elemental speciation, and bioavailability. This means that the distribution of elements can change among various chemical and physical forms, and it is crucial that the minerals in the nutrient solution are in a form that plants can absorb. To ensure that the plants receive the proper nutrients, it is essential to regulate the pH of the nutrient solution. (Omar et al., 2020). The pH of 7 is considered neutral and represents the concentration of hydrogen ions in pure water. Whereas a solution with a pH less than 7 is classified as acidic, while one with a pH greater than 7 is classified as basic or alkaline. A pH probe sensor is a useful tool for determining the level of acidity or alkalinity in water and other solutions (O'Danelle, 2019).

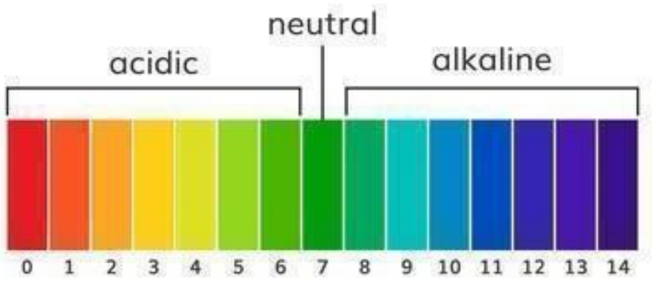

Fig. 2. Levels of pH

According to Michael et al. (2021), the optimal pH range for hydroponic plants is between 5.8 and 6.2. The nutrient solution in a hydroponics system can become too acidic, causing the plants to die. There are several ways to adjust the pH value, including using pH up and down solutions or household items such as white vinegar or citric acid to lower the pH and baking soda to increase it. Moreover, pH is one of the most important water quality factors in hydroponic plant production. It is a critical factor affecting the availability of essential nutrients in hydroponic systems and cultivating plants (Sanchez et al., 2020). It was discovered that slightly acidic pH is optimal for hydroponic production because certain nutrients such as iron, manganese, calcium, and magnesium can become unavailable at pH levels above 7. Higher pH levels were discovered to increase the amount of certain nutrients in plants, but they were stored in the roots rather than being translocated to the shoot. Furthermore, it was discovered that the availability of potassium and phosphorus is slightly reduced in nutrient solutions with high pH, whereas an increase in pH resulted in a decrease in available phosphorus for hydroponic production (Singh et al., 2019).

The nutrient solution was prepared according to commercial recommendations and carefully monitored to maintain a pH range of 5.5 to 6.5, as recommended by Moraes et al. (2018). To ensure that plants had adequate nutrient availability, the pH was measured using a digital pH meter. For successful hydroponic cultivation, Thakulla et al. (2021), also emphasized the importance of maintaining a pH range of 5.5-6.5. The pH of the nutrient solution was adjusted as needed, typically three times per week, by adding NaOH or HCl. Furthermore, distilled water was used to bring the base pH value close to 7 and then adjusted to a pH range of 5.6-6.0 after the nutrients were added (Ahmed et al., 2021). It is important to note that consistent temperature measurements were taken when measuring the pH of the water, as pH is temperature-dependent (Palande et al., 2018). The average pH value of nutrient solutions from various formulators was 6.7, which is higher than the optimal pH range of 5.6-6.2 for hydroponic plants. Overall, it is critical for successful hydroponic cultivation to maintain a consistent and appropriate pH range in the nutrient solution (Frasetya et al., 2019).

Electric Conductivity

Electrical conductivity (EC) is a crucial indicator of the amount of dissolved materials in an aqueous solution, and is directly linked to the solution ability to conduct electrical current (Brucker et al., 2021). By measuring EC in milli Siemens per centimeter, the assessing nutrient availability for plants and identifying their optimal feeding range is achievable through the measurement of conductivity using four commonly used scales: EC, PPM, TDS, and CF. The emphasis is not on supplying plants with as much food as possible, but rather on maintaining their preferred conditions for optimal health. it is essential to maintain their preferred EC range to promote optimal health (Dubaniewicz, 2021). A recent study looked at the effect of different EC levels of Hoagland nutrient solution, ranging from 0.5 to 2 dS m1, on the growth and development of basil cultivar.

The EC of the nutrient solution is used to determine the growth and development of plants based on the total ionic concentration of the solution. This is because the solution exerts a force called osmotic pressure (OP), which is directly proportional to the total amount of ions of dissolved salts in the nutrient solution. Osmotic pressure or osmotic potential is what facilitates the plants absorption of nutrients. To estimate the OP indirectly, it is necessary to measure the EC of the nutrient solution, which is a measure of salt concentration that defines the total amount of salts present in the solution. The ideal EC value for each crop is specific and depends on environmental conditions (Omar et al., 2020). Numerous studies have been conducted to determine the optimal electrical conductivity value for hydroponic lettuce cultivation, taking into account a variety of factors. Some studies suggest that lowering EC levels can improve lettuce growth in high-temperature environments, while others have discovered that lowering EC levels can increase lettuce fresh weight in soilless culture (Samarakoon et al., 2020). The EC values used in experiments are determined by the characteristics of the cultivars used and the fertilizers that allow for the simplest preparation of the nutrient solution. Salt tolerance varies greatly among lettuce cultivars, with romaine cultivars being more salt tolerant than iceberg cultivars.

Research study found that cultivars responded differently to a saline condition induced by an EC of 10 dS/m, while another found similar results. In one study, the yield was found to decrease linearly by 16.5% per unit of EC when exposed to a solution with an EC of 2.8 dS/m, and other studies confirmed a significant decrease in fresh weight with increasing EC levels (Kappel et al., 2021). Finding the right balance in determining EC levels is crucial for hydroponic cultivation. While low EC levels can stymie plant growth, excessive nutrient use and high EC levels can result in toxicity and increased farmer costs (Leibar-Porcel et al., 2020). Because of the importance of EC in hydroponic systems, numerous studies have been conducted to determine optimal EC levels (Sakamoto et al., 2020). The optimal EC levels for nutrient solutions are determined by cultivation technique and crop type. The research established a link between EC levels and growth parameters so that a model can be developed to estimate yields in vertical farming. Previous research has also looked into the best EC levels for hydroponic plant cultivation (Owen et al., 2020).

Internet of Things

The Internet of Things (IoT) technology aims to monitor and manage hydroponics gardens. Through automation and IoT technology, it aims to solve problems related to managing these resources. The system monitors pH, water level, air temperature, and relative humidity to provide the ideal environment for plant growth. Additionally, the system provides controlled irrigation of water and nutrient solution intake using simple mechanisms. Data gathered by sensors are stored and managed through cloud-based technology, which allows for information to be shared and accessed by users via the internet. The success and results of this study can potentially make the management of resources in hydroponics easier and more efficient. The index terms for this study include IoT, sensors, web management, plants, and hydroponics (Aliac et al., 2018).

According to Sahinaslan (2019), The Internet of Things (IoT) is a new technology trend gaining popularity. It enables an individual to remotely control objects and mechanisms by connecting them to the internet. the amount of data exchanged over the network will exceed 44 (ZB) by 2020. Similarly, by 2025, every connected person on the planet (roughly 75% of the total population at the time) will engage in digital data over 4,900 times per day, or roughly once every 18 seconds. It is made up of numerous networks that allow devices to communicate with one another via the Internet (Grammatikis, 2019). The widespread use of the Internet enables the introduction of new trends, and the global communication infrastructure enables machines to communicate with one another and make decisions (Cerullo et al., 2018).

Arduino

The Arduino ATMega is a microcontroller open-source platform utilized for creating electronic projects. It includes a programmable physical circuit board, which is commonly known as a microcontroller, as well as an Integrated Development Environment (IDE) software that runs on a computer. This software is used to write and download computer code to the physical board. The ATMega2560 microcontroller has various features including 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and a reset button. The Arduino ATMega controller is an upgraded version of the Uno that can be used for automatic control of nutrient solution flow with logic (Omar et al., 2020). Additionally, it can provide precise control and send data about the liquid level of the plant (solution) to the Android smartphone owners in hydroponic plant systems (Farrel, 2020).

According to Shinde (2023), programming Arduino is a vital process in translating the system design into a language that the machine can comprehend. Arduino is a platform that uses a language based on established frameworks to simplify the process of creating interactive objects. It can receive data from switches and sensors and control physical outputs such as lights, motors, or actuators. The platform also allows for interaction with other computer software. It is a great place to start and plays a critical role in controlling and receiving sensor data (Vincentdo & Surantha, 2023). Open-source projects like Arduino have lowered the barrier to entry for developers interested in experimenting with interactive objects, allowing them to quickly prototype and test before developing a final product (Sandhu, 2021). The Arduino IDE is a basic tool for creating and testing scripts for various projects (Azman, 2020). The relationship of computer science and agriculture has also resulted in the development of intelligent hydroponic systems (Raju et al., 2022). The use of IoT technology in hydroponics, such as the integration of Arduino microcontrollers and sensors, enables real-time monitoring and control of various plant growth and development parameters (Taha et al., 2022).

pH Probe Sensor

According to O'Danelle (2019), a pH sensor is a vital tool commonly employed to gauge the acidity or alkalinity levels in water and other solutions, playing a crucial role in ensuring the safety and quality of products and processes in wastewater or manufacturing plants. The pH scale, ranging from 0 to 14, serves as a standard measurement, where a value of 7 is considered neutral. Values above 7 indicate higher alkalinity, while values below 7 indicate increased acidity. As mentioned by Rico (2020), the pH probe sensor holds significant importance in automated hydroponic systems as it facilitates the measurement and adjustment of the pH level in the hydroponics reservoir. The automated pH monitoring and controlling device primarily oversee parameters like the pH of the nutrient solution in a hydroponic system under greenhouse conditions. Sensors are employed to determine the pH in the reservoir, with the probe measuring the electric potential difference between the glass electrode and a reference electrode to ascertain the pH level of the solution.

Electrical Conductivity Sensor

Electrical Conductivity is a measure of the ability of a nutrient solution to conduct electric current. EC specifically indicating the concentration of nutrients in the solution. EC can be measured in units of PPM (Parts per Million) or milli Siemens (mS). Different stages of plant growth require varying nutrient concentrations, which are determined through feedback from plant growth. A high nutrient concentration can lead to blockage of nutrient uptake due to increased osmotic pressure, while a low concentration can negatively impact plant growth and health. The rate of water uptake by plants is directly correlated to electrical conductivity. In hydroponic systems, the optimal range for EC is typically between 1.5 and 2.5 mS/cm. If the EC values fall outside this range, nutrient solution or water is added to adjust the concentration. In some cases, a complete replacement of the nutrient solution may be necessary. It is important to note that different crops have their own specific nutrient concentration requirements for achieving maximum growth and yield. Researchers have found that adjusting EC values should be done before adjusting the pH level of the nutrient solution, as EC serves as an indicator of nutrient strength (Fuangthong & Pramokchon, 2018).

In hydroponics farming, it is a method of cultivating vegetables in a shallow nutrient solution. Currently, growers are required to assess the value of the Electrical Conductivity (EC) manually and systematically in the nutrient solution within the reservoir according to a set schedule. This manual process can be arduous as it necessitates regular checking of EC values by the grower. Consequently, there is a need for an automated EC monitoring system to alleviate this challenge and provide a solution that eliminates the need for frequent manual checks (Yamin et al., 2022).

Synthesis

According to the existing research studies gathered by researchers, smart farming was considered as an advanced way of farming that provides more efficient cultivation. The Internet of Things (IoT) provides an advanced technology for farming that utilizes the efficiency, space and cost of crop cultivation. This new farming method enables the farmers to produce quality and increased quantity crops cultivation through hydroponics farming. Hydroponics, as part of the emerging farming method in agriculture, offers an advanced way of cultivation. It can improve the growing period of the crops, can efficiently use available space and eliminates the use of pesticides. Thus, full management for the environment was essential to maintain proper parameters like pH, nutrient levels, and water quality to avoid diseases and pests from the plant for this farming method usually grown indoors or in a greenhouse. Moreover, Arduino is a programming platform considered as an open-source technology making people customize and modify the platform according to their needs. This implies that it can be used by anybody to develop interactive devices that respond to their surroundings. The integration of actuators and sensors allowed them to detect changes in their surroundings and take relevant actions.

Consequently, the concept of the developed system is to create an IoT-Web- Based automated hydroponics system that regulates the pH level, EC level and water temperature of the Green Batavia hydroponics lettuce. The Internet of Things was considered to become more popular as of today utilizing the use of devices in different environments like consumer goods, industrial, sensors, smart farming and other everyday objects connected through the internet. Moreover, using precision agriculture or smart farming it allows the system to notify farmers and suggests best options, potential outcomes, and answers to achieve a specific goal. Furthermore, the importance of the pH level, EC level and water temperature according to the related studies contains a major role in the cultivation of hydroponics plants. A pH probe sensor is an essential tool used to measure the acidity or alkalinity levels in water and solutions, ensuring the quality of the water nutrient solution. It plays a significant role in hydroponic systems by measuring the pH level and ensuring that the pH level of the nutrient solution remains within the threshold range. On the other hand, electrical conductivity (EC) sensors measure and indicate the concentration of the nutrient in the solution. In accordance, an automated EC monitoring system is needed to eliminate the manual checking of EC values and ensure optimal nutrient strength for plant growth. Additionally, DS18B20 temperature sensor is a waterproof temperature sensor fitted to measure temperature changes in hydroponic setups thus providing efficient control over water temperature. An ultrasonic sensor is a device that employs sound waves to determine the distance between itself and an object wherein it could also be employed to measure water levels, enabling the detection of water height, and facilitating the flow of nutrient solutions in hydroponic systems. Moreover, regulation of the said parameters is important to produce a quality hydroponics crop like Green Batavia lettuce.

1.3 Research Gap

Despite hydroponic lettuce farming in Sariaya already uses Nutrient Film Technique, existing practices still rely on manual and frequent monitoring of water level, pH, EC level, nutrient consumption, and water temperature. Current systems lack integrated instruments that can accurately measure and regulate these critical parameters, which may result in problems such as yellowing leaves, stunted growth, chlorosis, and unstable nutrient solutions. While previous studies emphasized the importance of monitoring pH, EC, water temperature, and nutrient levels, there remains a gap in applying these findings through an automated IoT-based system specifically for Green Batavia lettuce production. There is also limited implementation of a system that provides real-time web-based analysis and SMS notifications when the measurements exceed or fall below the required threshold range. Therefore, this study addresses the gap by developing an IoT-based monitoring and regulation system that improves nutrient management, reduces crop damage, and supports efficient hydroponic lettuce production.

1.4 Scope and Delimitation

The developed system is designed to support hydroponics farm owners and the Department of Agriculture in monitoring and regulating the cultivation parameters of Green Batavia lettuce. It integrates an IoT device and a responsive web system that continuously measures water temperature, pH level, EC level, water level, and grow light status, automatically adjusting these parameters to maintain optimal conditions. Sensors such as DS18B20, pH probes, EC probes, and HR-SR04 ultrasonic sensors provide real-time data, while solenoid valves and solid-state relays manage the release of nutrients, pH regulators, and temperature control mechanisms. The system also incorporates a grow light with manual override, SMS notifications, and a backup solar-powered router to ensure uninterrupted monitoring and alerts. User access is structured with two levels—administrator (hydroponics farm owner) and personnel—with differentiated privileges for viewing, controlling, and managing hydroponics cycles, daily records, and system guidance.

Despite its extensive functionalities, the system has several limitations. It is specifically designed for 25-liter reservoirs and preconfigured to the threshold ranges set by the Department of Agriculture for Green Batavia lettuce, preventing parameter adjustments beyond these predefined values. It does not monitor air temperature, humidity, or detect pests and diseases, requiring the farm owner to manually refill nutrient solutions and water upon receiving notifications. Sensor response times and deliberate post-regulation delays may affect real-time data display, and SMS notifications may experience 1–3 minute delays depending on network traffic. Manual intervention is also required during power interruptions to switch between outlet and solar backup, and user-level accounts have restricted access to features such as Daily Records and Personnel management.

1.5 Conceptual Framework

The study is guided by the Input–Process–Output (IPO) model and grounded in Precision Agriculture Theory, where the current manual practices of hydroponics farming serve as the input, modern IoT and data-driven technologies represent the process, and the developed iLettUse system is the final output. This framework shows how integrating real-time data collection, analysis, and automation can improve farming efficiency, reduce resource waste, support better decision-making, and enhance overall productivity in hydroponics. The system was designed to address the limitations of existing practices, where farmers mainly rely on a pH meter while lacking proper tools to measure EC levels and water temperature, leading to potential risks in plant growth and yield. It allows users to monitor key parameters such as pH, EC, water temperature, water level, and grow light status, while also generating visual daily reports and providing harvest cycle notifications for better crop management. The system enables remote monitoring and SMS alerts to ensure continuous awareness even without direct access to the web interface, reducing the need for manual supervision.

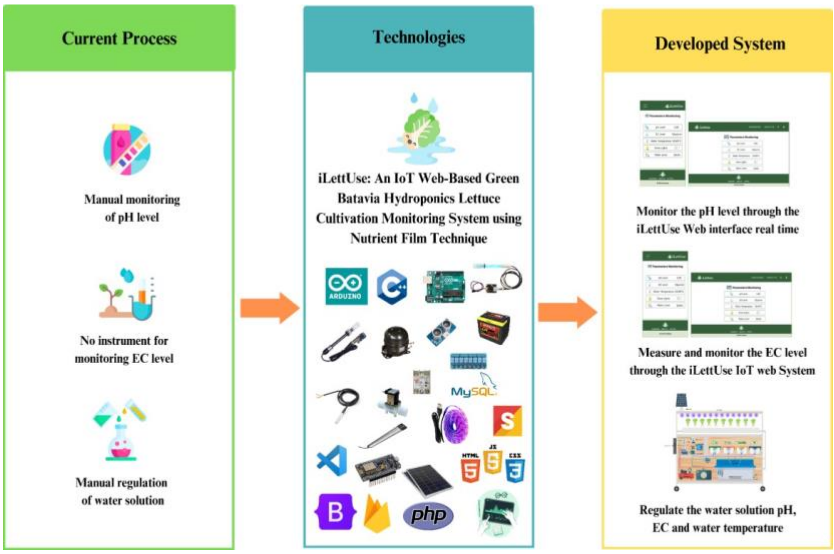

Fig. 3. Conceptual Framework for iLettuse: An IoT Web-based Green Batavia Hydroponics Lettuce Cultivation Monitoring System using Nutrient Film Technique

1.6 Research Objectives

The objective of thie study is to develop the iLettUse: IoT Web-Based Green Batavia Hydroponics Lettuce Monitoring System that automates the monitoring and regulation of key hydroponic parameters such as pH level, EC level, water temperature, water level, and grow light status in a Nutrient Film Technique (NFT) system. The project is aligned with the United Nations Sustainable Development Goals, particularly Responsible Consumption and Production, by promoting efficient resource utilization and environmentally sustainable farming practices across the production cycle. It aims to address the limitations of manual monitoring by providing real-time data collection, analysis, and automated control to improve lettuce quality and reduce farming risks. The system also incorporates a web-based platform that displays and analyzes sensor data while sending web and SMS notifications when parameters fall outside the recommended threshold range or when sensor issues occur.

Specifically, the study seeks to design and develop an IoT-based device and web system capable of monitoring and displaying real-time values of pH, EC, water temperature, water level, and grow light status for Green Batavia lettuce. It also aims to automate the regulation of pH levels, nutrient concentration, and water temperature based on established cultivation thresholds to ensure optimal plant growth. In addition, the system integrates notification features through both web and SMS to alert users of abnormal readings or system malfunctions, ensuring timely response and intervention. Overall, the project enhances hydroponics farming by introducing automation, accuracy, and efficiency while minimizing manual intervention and reducing risks such as stunted growth and nutrient imbalance.

1.7 Statement of the Problem

Hydroponics farming plays a significant role in modern agricultural innovation, particularly in supporting soil-less cultivation systems that rely on nutrient-rich water solutions. In the Agricultural and Biosystems Engineering Division in Lucena City, hydroponics especially the Nutrient Film Technique (NFT)—is actively promoted to improve productivity, efficiency, and sustainability among farmers. However, based on interviews with hydroponics farm owners in Sariaya and the Department of Agriculture representative, current farming practices still rely heavily on manual monitoring of key parameters such as pH level, EC level, water level, and water temperature. While these parameters are critical for plant health, farmers often lack proper instruments for measuring EC levels and maintaining stable nutrient solutions, leading to issues such as nutrient imbalance, leaf yellowing, and stunted plant growth. These challenges highlight the need for a more reliable and automated monitoring system that can ensure optimal growing conditions for Green Batavia lettuce and improve overall farm productivity.

Anchored on precision agriculture and IoT-based automation, this study examines the development of the iLettUse: IoT Web-Based Green Batavia Hydroponics Monitoring System as a potential solution to the identified problems in hydroponics farming. The framework assumes that integrating real-time sensor data, automated regulation, and web-based monitoring can improve the accuracy of parameter control, enhance decision-making, and reduce manual workload for farmers. Through the use of sensors for pH, EC, water temperature, and water level, the system aims to provide continuous monitoring and automatic adjustment of hydroponic conditions while also offering SMS and web notifications when values fall outside the optimal range. This study therefore explores how an IoT-based monitoring system may influence the efficiency, accuracy, and reliability of hydroponics farm operations.

Specifically, this study seeks to evaluate the system based on ISO 25010 based on the following criteria:

1. Functional Suitability
2. Performance Efficiency
3. Compatibility
4. Usability
5. Portability
6. Reliability
7. Maintainability
8. Security

2. Methodology

The methodology adapted for the study comprised the integration of the Iterative and Incremental Model in the development of the iLettUse IoT Web-Based System for Green Batavia hydroponics lettuce cultivation. This approach ensures that each module of the system is validated at every stage, allowing refinements that enhance the overall design and functionality of the final product. Using this framework, the development process was divided into structured phases including analysis, design, coding, testing, and evaluation, which supported the systematic implementation of IoT and web system modules. The researchers conducted interviews with hydroponics farm owners and a Department of Agriculture representative to gather requirements and validate system needs. Based on the collected data, the required hardware and software components were identified, designed, and developed, followed by coding and iterative testing. Continuous feedback from respondents was incorporated before proceeding to the next development cycle, ensuring system relevance and accuracy throughout the process.

The project underwent sixteen (16) incremental iterations covering key development components such as requirements analysis for both the IoT device and web system, integration of Arduino ATmega with NodeMCU ESP8266, and connectivity with Firebase and MySQL databases. Additional increments included the integration of DS18B20 temperature sensors, pH probe sensors, EC sensors, HC-SR04 ultrasonic sensors, and grow light control systems. The web system was also developed iteratively, incorporating features such as the navigation bar, Grower's Guide, Parameters Monitoring, Daily Reports, Cycle Details, Personnel management, and SMS/web notification systems. The final increments focused on system refinement, deployment, and user testing to ensure full functionality and usability for hydroponics farm operators.

2.1 System Architecture Overview

The developed system employs an integrated IoT-based architecture in which environmental and hydroponic data are continuously collected through multiple sensors, processed by a microcontroller, and transmitted to a web-based platform for real-time monitoring and remote access. The system is designed to support automated regulation of key hydroponic parameters, ensuring stable growing conditions for Green Batavia lettuce under a Nutrient Film Technique (NFT) setup. Figure 4 illustrates the overall system architecture, showing the interaction between the IoT device, web system, administrator, and user interfaces.

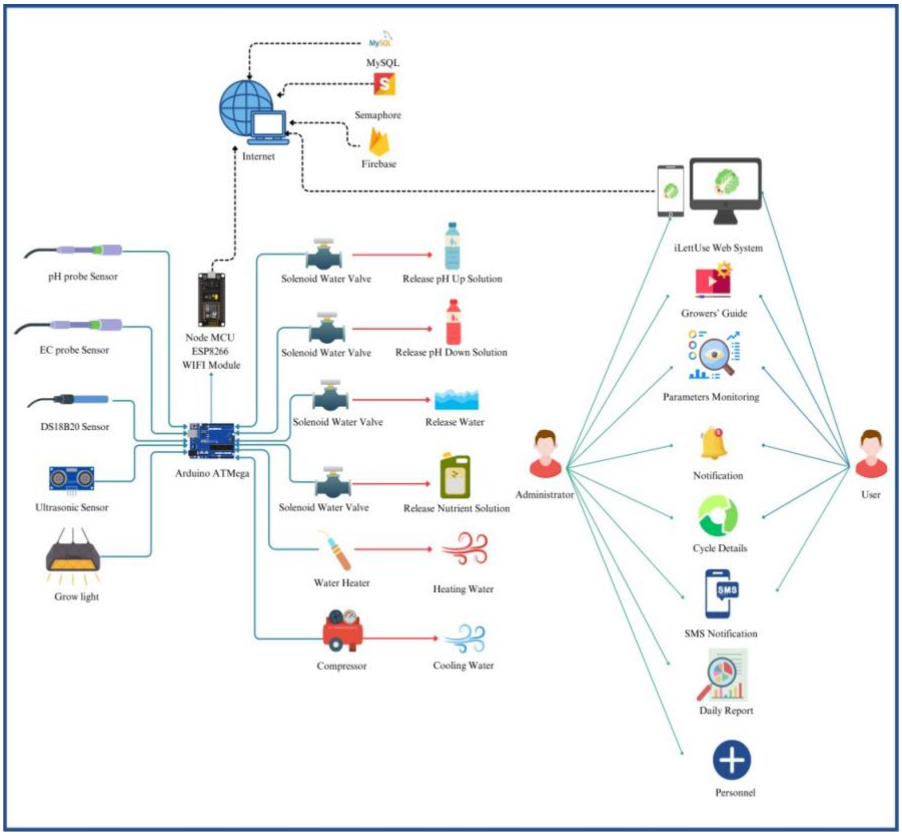

Fig. 4. System Architecture Diagram

The overall workflow of the iLettUse system includes the following components:

1. Sensing – pH probe, EC probe, DS18B20 temperature sensor, and ultrasonic sensor continuously measure pH level, electrical conductivity, water temperature, and water level of the nutrient solution. Grow lights are also monitored as part of the system environment.
2. Processing – The IoT controller (NodeMCU ESP8266 and Arduino ATmega) processes sensor data and evaluates whether parameters are within the predefined threshold ranges.
3. Actuation – When values fall outside acceptable ranges, the system automatically triggers corrective actions such as releasing pH Up/Down solutions, adding water or nutrients, and regulating temperature using a compressor and heating rod. Grow lights are also controlled as part of the system support.
4. Communication – Sensor data is transmitted via Wi-Fi to Firebase and MySQL databases, which serve as the central data storage and retrieval platform for the web system.
5. User Interaction – The web-based interface allows administrators and users to monitor system status, view reports, manage cycles, and receive real-time alerts, while SMS notifications are sent through the Semaphore API when parameters exceed threshold limits or system issues occur.

The iLettUse web system provides two levels of access: administrators, who can use full features such as Grower's Guide, Parameter Monitoring, Cycle Details, Daily Reports, Notifications, and Personnel management; and users, who have limited access to Grower's Guide, Parameter Monitoring, and Cycle Details only.

2.2 Description of Key Components

Table 1. Description of Key Components

Component	Specifications
Arduino ATmega (ATmega328P)	Operating Voltage: 5V; Input Voltage: 7–12V (recommended), 6–20V (limits); Digital I/O Pins: 14 (6 PWM); Analog Inputs: 6; DC Current per I/O Pin: 20 mA; 3.3V Pin: 50 mA; Flash Memory: 32 KB (0.5 KB bootloader); SRAM: 2 KB; EEPROM: 1 KB; Clock Speed: 16 MHz; Power: 0.29 W
pH Probe Sensor	Range: 0–14 pH; Operating Temperature: 0–80°C; Response Time: < 1 minute; Accuracy: ±0.01 (calibrated); Interference: < 0.5 mV
EC Probe Sensor	Operating Voltage: 3.3V/5V; Range: 0–2000 µS/cm; Accuracy: ±5%; Response Time: < 10 seconds; Operating Temperature: 5–80°C; Interface: BNC
DS18B20 Temperature Sensor	Temperature Range: -55°C to +125°C; Accuracy: ±0.5°C (-10°C to +85°C); Resolution: 9–12 bit; Response Time: 300 ms
Ultrasonic Sensor (HC-SR04)	Sensing Range: 40–300 cm; Response Time: 50–200 ms; Beam Angle: ~50°; Resolution: 1 mm; Accuracy: ±5%; Output Voltage: 0–10 V
Solenoid Water Valve	Type: 2-way NC; Voltage: 12/24/110/220V options; Power: 20W; Pressure: Vacuum to 50 PSI; Port Size: 3/8 inch fittings
Compressor	Model: SSR EP200; Power: 200 hp; Rated Pressure: 125 psig; Max Pressure: 135 psig; Electrical: 460V/60Hz/3-phase
Grow Light	Color Temperature: 5000–7000K (blue), 3500–4500K (red); Power: 17W; Voltage: 80–300V; Lifespan: 50,000 hours; Efficiency: 0.91
NodeMCU ESP8266	Operating Voltage: 3.3V; WiFi: 2.4 GHz (802.11 b/g/n); Flash Memory: 4 MB; SRAM: 64 KB; Digital I/O Pins: 11; ADC Range: 0–3.3V
Solar Panel (Monocrystalline)	Power Output: 30–50 W; Voc: 21.82V; Vmp: 18.22V; Current: 2.8A; Short Circuit Current: 12A
Battery	Voltage: 12V; Current Capacity: up to 800 mA
Solid State Relay (SSR-25DD)	Max Load: 25A; Surge Current: 50A; Control Voltage: 4–32VDC; Response Time: 1 ms; Isolation: 4 KVrms
Connecting Wires	Types: M-M, M-F, F-F; Length: 100–300 mm; Gauge: 28–36 AWG
LED Lights	Colors: Red, Blue, Yellow, White; Forward Voltage: 2.0V (red), 3.2V (others); Current: 16–20 mA
Resistors	Resistance: 10 kΩ; Tolerance: ±5%; Power Rating: 0.25 W; Type: Carbon Film
Electric Heating Rod	Capacity: 10 L; Power: 2100–5000 W; Voltage: 220 V; Type: Instant/tankless heater
Power Supply	Input: AC 100–240V; Output: 12V DC; Power Options: 36W–240W (3A–20A variants)
Inverter	Input: 12V/24V DC; Output: 220V AC; USB Ports: 3–4; Type: Car power inverter
Alternative Solar Panel Spec	Power: 30–60 W; Voc: 21.6V; Vmp: 12–18V; Short Circuit Current: 1.826A; Efficiency Class: A
LED Strip Lights	Length: 1–15 m; Voltage: AC 220V; LED Type: SMD 2835; Density: 120 LEDs/m; Waterproof Rating: IP67

Table 1 displays the necessary hardware specifications for the development of the iLettUse IoT responsive web-based automated monitoring system. These specifications are essential for achieving optimal performance from the system. The primary sensors utilized in the IoT automated monitoring system consists of the Arduino ATMega, NodeMCU ESP8266, pH probe sensor, EC probe sensor, DS18B20 temperature sensor and ultrasonic sensor. The Arduino ATMega functions as the microcontroller of the IoT automated monitoring system, while the NodeMCU ESP8266 establishes communication between the IoT automated monitoring system and the web-based system. The pH probe sensor determined the pH level of the water solution, the DS18B20 temperature sensor measured the temperature of the water solution, and the EC probe sensor measured the electrical conductivity of the water solution. Additionally, the ultrasonic sensor was used for monitoring the water level of the water solution, and the grow light functions as a substitute for sunlight throughout the cultivation cycle.

2.3 Project Blueprint

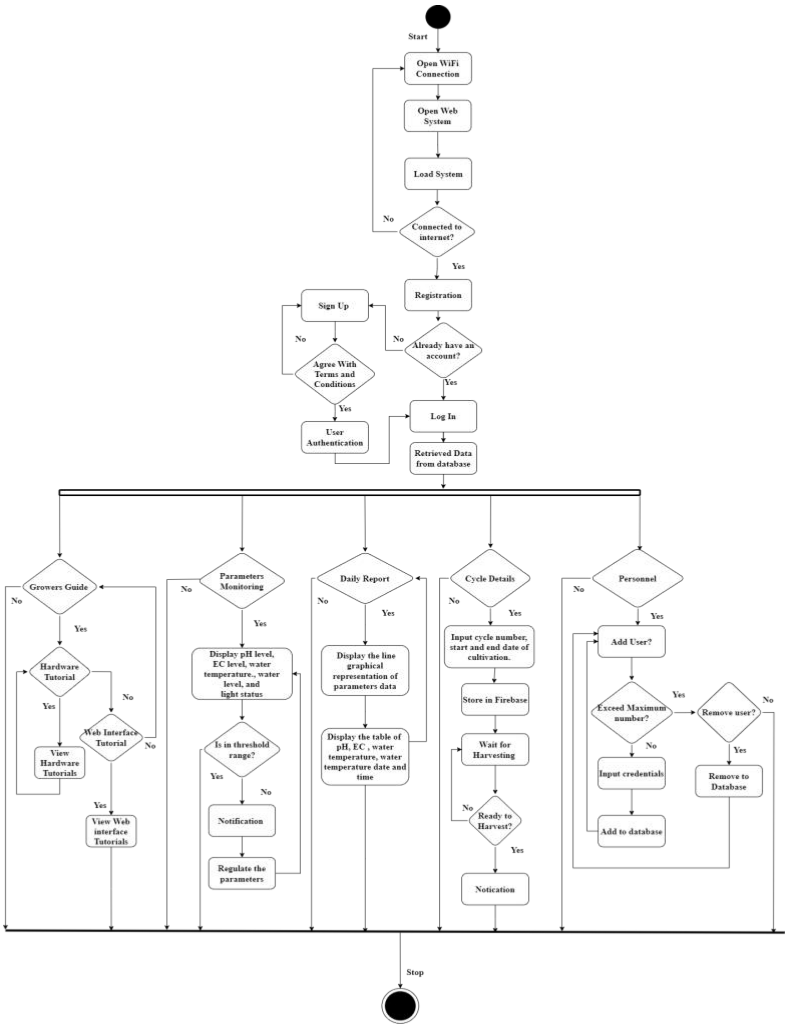

Fig. 5. Project Blueprint for the process of the developed system

Figure 5 shows the graphical presentation of procedures in the iLettUse Web System of the iLettUse IoT web-based automated monitoring system for Administrator. After logging into the web system and successfully connecting to the internet, the Administrator could access the system features. If the Administrator was not registered, they need to fill up the sign-up form and agree to the terms and conditions to access the system. The "Growers Guide" option contains two (2) options, namely "Hardware Tutorial" and "Web Interface Tutorial," where they could read and watch how to use the system. In the "Parameters Monitoring" feature, the system retrieves data from Firebase and displays the value of the pH level, EC level, water temperature, water level, and the status of the grow lights. The system also displays daily records of the pH level, EC level, and water temperature with dates and times as well as the graphical representation of data. Moreover, in the "Cycle Details" section, the Administrator could input the cycle number, start and end date of cultivation. They receive notifications when the Green Batavia lettuce is ready to harvest. Furthermore, in the "Personnel" section, the administrator was authorized to add and remove a farm worker or user who could access their system.

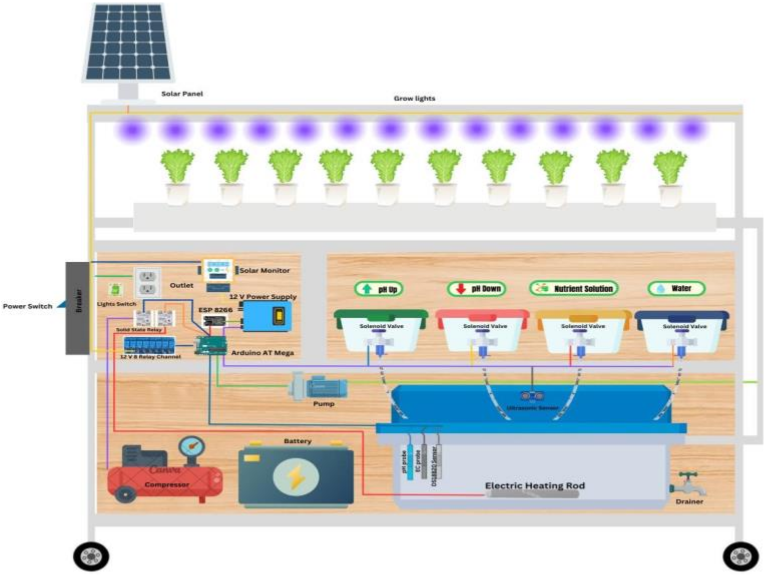

Fig. 6. Project Blueprint for the developed system

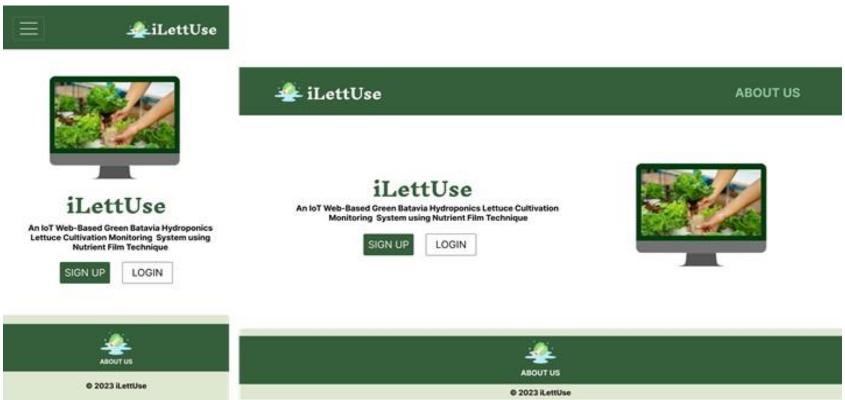

Fig. 7. Landing Page

Figure 7 presents the landing page of the developed system, where both the administrator and user can view and choose between the Login and Sign-Up options to access their respective accounts.

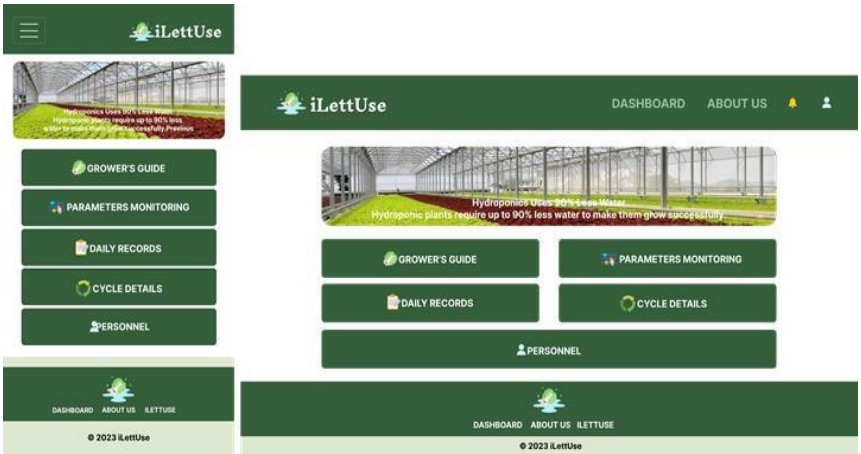

Fig. 8. Dashboard Page

This figure shows the dashboard that contains five buttons for the user to explore. These buttons are (1) Grower's Guide, (2) Parameters Monitoring, (3) Daily Records, (4) Cycle Details, and (5) Personnel.

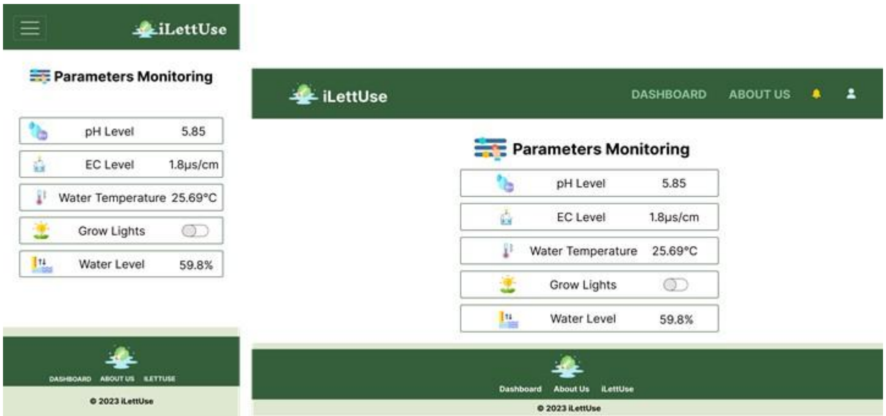

Fig. 9. Parameters Monitoring Page

Figure 9 shows the parameters monitoring where the users could monitor the status of the sensors which are pH level, EC level, water temperature, grow lights, and water level.

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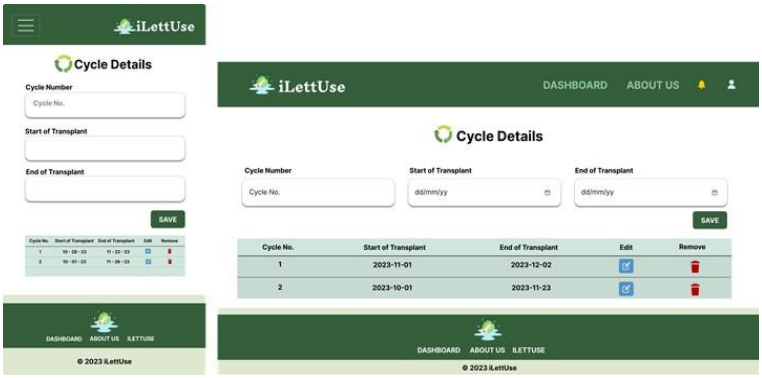

Fig.10. Cycle Details Page

Figure 10 shows the Cycle Details Page where the Administrator and users can input the cycle number, start date of transplant, and end date of transplant thereafter save it to record.

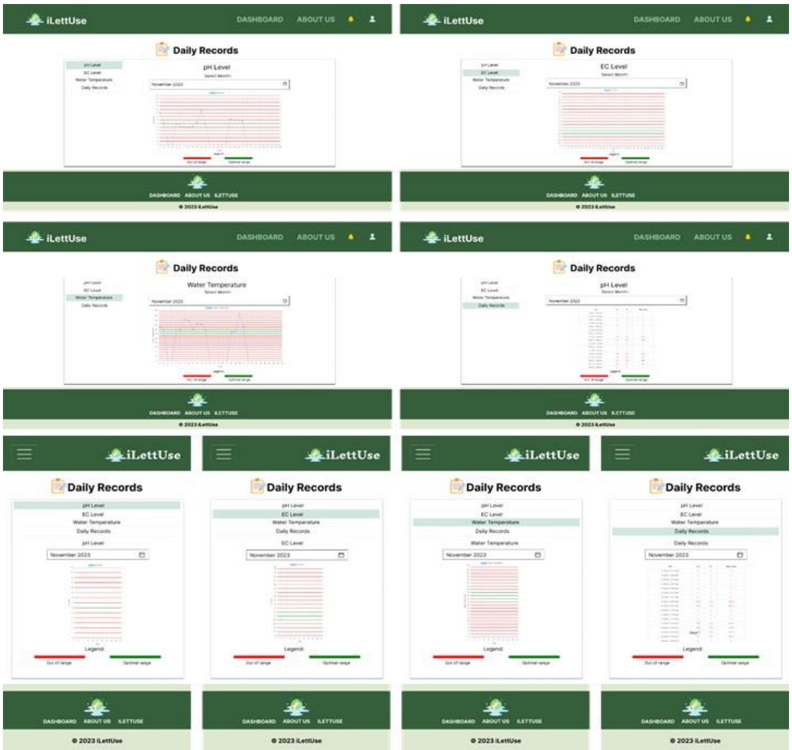

Figure 11. Daily Records Page

Figure 11 shows the Daily Records where the users can view the graph of the readings in the sensor and the daily records per hour of pH level, EC level, water temperature listed in the table.

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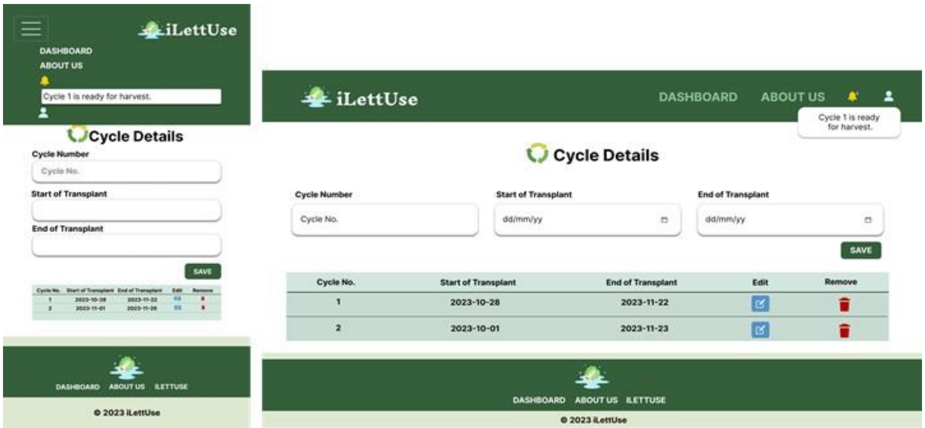

Figure 12. Notification Ready for Harvest

Figure 12 shows the notification where the system notifies the Administrator and users about harvesting if it is ready for harvest.

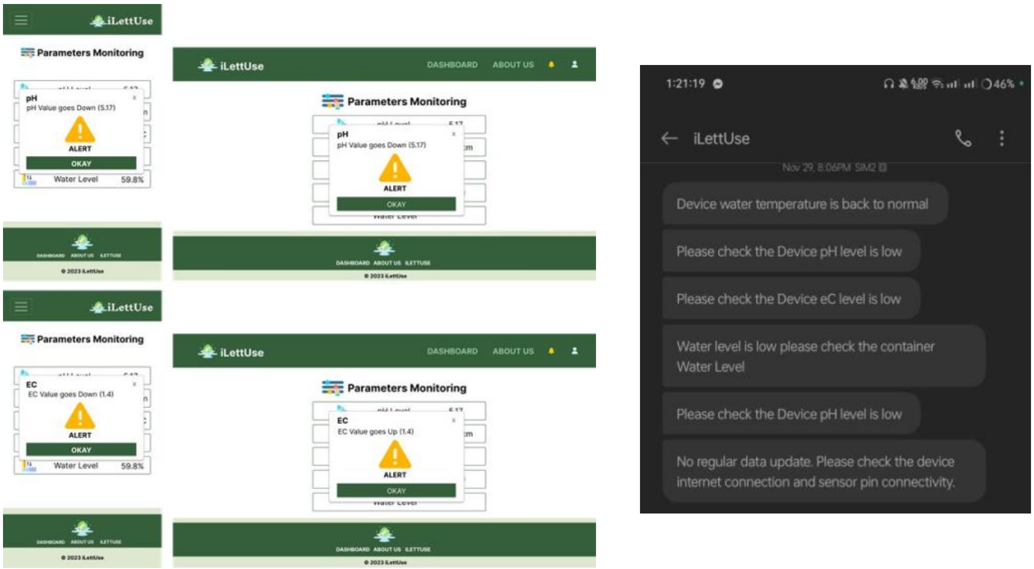

Figure 13. Notification for parameters monitoring

Figure 13 shows the pop-up notification alert to notify the Administrator about parameter status and SMS Notification where the system informs the Administrator about the parameters status..

2.4 Data Collection Instrument and Procedure

The developed iLettUse: An IoT Web-Based Green Batavia Hydroponics Lettuce Cultivation Monitoring System using Nutrient Film Technique undergoes testing according to the ISO 25010. The ISO 25010 is a set of standards provided by the International Organization for Standardization (ISO) that serves as a reference for evaluating the software. The ISO 25010 comprises the following criteria: Functional Sustainability, Performance Efficiency, Compatibility, Usability, Reliability, Security, Maintainability, and Portability. The researchers used a 4-point Scale in evaluating the responses of the participants on the given questionnaires. In choosing the respondents, the researchers used purposive sampling. In this method, researchers purposefully select individuals that possess specific characteristics or qualities relevant to their research objectives.

Table 2. Verbal Interpretation of Gathered Data

Weight	Interval	Verbal Interpretation
4	3.25-4.00	Highly Acceptable
3	2.50-3.24	Acceptable
2	1.75-2.49	Less Acceptable
1	1.00-1.74	Not Acceptable

2.5 Treatment of Data

The researchers conducted a survey and system evaluation with fifteen (15) respondents, including Hydroponics Farm owners, IT experts, and employees from the Department of Agriculture in Quezon Province. The provided survey questionnaires were in line with the characteristics of the ISO 25010 that were tailored to evaluate whether the system satisfies the stated objectives and implied needs of the client. The ISO 25010 was the software quality model that lists the characteristics used to evaluate the system based on its functional suitability, performance efficiency, compatibility, usability, portability, reliability, maintainability, and security.

The survey was conducted in a face-to-face manner and was scheduled in accordance to the respondent's availability. During the face-to-face survey, the researchers demonstrated how the iLettUse operates and showed how to use the Web system to help the respondents provide their best response in the developed system. The researchers used a Four-point scale rating, consisting of values such as Highly Acceptable, Acceptable, Not Acceptable, Less Acceptable. This was to determine the extent to which the respondents agree or disagree with each of the features of the system. In addition, following each demonstration, respondents were allowed to ask questions and give comments about the system after answering the questionnaire.

The results of each ISO 25010 quality standard were calculated using the weighted mean and were presented in tabular form. Graphs were also used to compare the results of each quality standard to determine where respondents agreed most on the features of the system.

2.6 Ethical Considerations

This study adheres to strict ethical standards throughout the development and evaluation of the iLettUse IoT Web-Based Hydroponics Monitoring System. Since the research involves a survey and system evaluation conducted with respondents, including hydroponics farm owners, IT experts, and Department of Agriculture personnel in Quezon Province, ethical concerns such as informed consent, data privacy, confidentiality, and responsible data handling were carefully addressed. All participants were fully informed about the purpose of the study, the nature of their participation, and how their responses would be used for academic evaluation based on ISO 25010 software quality standards. To ensure data protection, all collected responses were treated with confidentiality and used exclusively for research purposes. Personal information and identifiers were not disclosed in any part of the analysis or reporting, and all data were securely managed to prevent unauthorized access. Participation in the study was voluntary, and respondents were given the freedom to decline or withdraw at any stage without penalty. During the face-to-face survey, researchers demonstrated the system to ensure that respondents clearly understood its features before providing feedback using a four-point Likert scale. This process ensured informed and meaningful participation while maintaining respect for respondent autonomy. In addition, the evaluation results were computed using weighted mean and presented in tables and graphs strictly for academic interpretation. Through following ethical research practices and ensuring transparency in data collection and analysis, the study maintains integrity, minimizes ethical risks, and ensures that all stakeholder contributions are properly respected and protected.

3. Results and Discussion

3.1 Evaluation Result

Table 3. Overall Weighted Mean of the iLettUse Automated Monitoring system and Web system evaluation result for IT Expert based on ISO 25010

Criteria	Mean	Verbal Interpretation
1.Functional Suitability	4	Highly Acceptable
2.Performance Efficiency	4	Highly Acceptable
3. Compatibility	3.93	Highly Acceptable
4. Usability	4	Highly Acceptable
5. Portability	3.9	Highly Acceptable
6. Reliability	3.95	Highly Acceptable
7. Maintainability	3.95	Highly Acceptable
8. Security	3.93	Highly Acceptable
Overall Weighted Mean	**3.96**	**Highly Acceptable**

There were five (5) IT experts who participated in the survey. Like the end users, the IT experts used the ISO 25010 quality standards as criteria for their evaluation. In addition to the five criteria that end users were asked to respond to, IT experts were also asked to evaluate the program on three additional criteria such as reliability, maintainability, and security of the system.

Among these criteria, functional suitability, performance efficiency, and usability received an average rating of 4 which was interpreted as Highly Acceptable. The said result indicates that in terms of the functionality the IT experts were convinced that the developed system could perform regulation through the detection of values of pH level, EC level and water temperature and display values in the web system. The automated monitoring system and web system performed efficiently as required too. IT experts verified and evaluated that the system can be connected to standard internet speeds while the web system does not affect the performance of the devices even though it makes use of the resources. Based on usability criteria the system features and attributes that facilitate its use and control. The researchers discussed the user interface design of the web system-based and data retrieval from the system and display in the web system were designed to be easy to use and understand.

The IT experts gave an average rating of 3.95 for reliability, and maintainability, which can be interpreted as Highly Acceptable. In terms of system reliability, it was pointed out by the IT experts that the web system sends alerts if the internet connection is unavailable, and a solar panel as a backup power option in the event of an electricity outage. In evaluating the maintainability criteria, IT experts agreed that the web system provides tutorials for hardware and software manuals and provides the record of the pH Level, EC Level, and Water temperature.

3.2 Summary of Findings

1. In hydroponics farming, the proper growth of Green Batavia lettuce relies on maintaining specific parameters such as pH level, EC level, and water temperature within defined thresholds. Farmers monitor these factors manually to ensure that the pH, EC, and water temperature remain within their ideal ranges. In addition, NFT hydroponics cultivation was also significantly influenced by additional factors such as the water level and grow lights. In line with this, the researchers developed an IoT web system that measures and displays the status of the pH level, EC level, water temperature, water level and grow light of the Green Batavia Lettuce using the Nutrient Film Technique (NFT). The researchers utilized pH probe sensor, EC probe sensor and ultrasonic sensor to measure these parameters. Based on the evaluation of the developed system, the IoT web system was able to measure and display parameters such as pH level, EC level, water temperature and grow light status of the Green Batavia lettuce. However, the researchers encountered challenges, including issues with internet connectivity, resulting in delayed transmission of sensor readings to Firebase and subsequent display on the web system. The researchers addressed the issue by (1) waiting for the maximum time of delay five (5) minutes to display its accurate readings and (2) securing a stable internet connection for the Parameters Monitoring feature to accurately function.

2. The imbalance of the water nutrient solution poses a common challenge for hydroponic farmers, resulting in irregularities in the production of lettuce. Farmers regulate their pH level using pH up and down solutions, however, they lack tools to measure the EC level and water temperature, which are also important factors in lettuce growth. In accordance, the researchers developed an IoT web system that regulates the pH level, EC level, and water reservoir temperature of the Green Batavia Lettuce based on the suggested threshold range for cultivation. The developed IoT web system monitors the pH level, EC level and water temperature in the water nutrient solution reservoir and automatically drops the regulating solutions such as pH up and down for the pH level regulation, as well as the water and water nutrient solutions for controlling the EC level. However, during the system demonstration, the developed system encountered delays in regulating and obtaining accurate readings for the hydroponics system. The system was set to release a regulating solution in one (1) minute, depending on how far the parameters deviate from their normal range. The longer the nutrient imbalance persists beyond the threshold, the longer regulation it takes. Furthermore, the researchers addressed that the quality of the hydroponics system would not be affected as the minor fluctuations or short-term imbalance may be tolerated by crops like lettuce in hydroponics. The acceptable time of delay has the maximum of five (5) minutes per parameter category regulation. However, a prolonged or severe imbalance in the water nutrient solution in hydroponics can lead to nutrient deficiencies, adversely impacting the growth, yield, and quality of crops.

3. The evaluators found that the developed IoT web system provides notifications on both SMS and web system, allowing hydroponics farmers to monitor their NFT hydroponics lettuce. The researchers developed an IoT web system that integrates a notification feature in SMS utilizing Semaphore API and in the web

system if the sensor readings are not within its maintaining values and if the sensor does not work properly. The survey results showed that the iLettUse IoT web system was able to provide notification if water nutrient solution imbalance happens.

4. Conclusion and Recommendations

4.1 Conclusion

Based on the findings, the developed system effectively measures and presents real-time environmental parameter readings, enabling hydroponic farmers to monitor Green Batavia lettuce production more efficiently. Through automation, the system substantially minimizes the need for manual labor, particularly in continuous physical monitoring and the manual regulation of water nutrient solutions. Possible latency or sensor reading delays caused by unstable internet connectivity were managed by allowing the system to wait for the maximum delay threshold and by ensuring a more reliable network connection. Since sensor data are continuously transmitted to a centralized web platform, farmers can remotely monitor crop conditions from any location, reducing both time and effort. Furthermore, the IoT-based web system helps prevent water nutrient solution imbalances that often result in growth abnormalities in lettuce cultivation. The automated mechanism responds by regulating environmental conditions whenever sensor readings exceed the recommended threshold values. Although slight delays in measurements or automated adjustments may occasionally occur, these do not significantly affect the overall quality of Green Batavia lettuce because the crop can tolerate short-term nutrient fluctuations. However, prolonged imbalances can lead to serious nutrient deficiencies, making the system's automated monitoring and control functions essential. Overall, the IoT solution enables hydroponic farms to operate with minimal manual intervention, reducing the likelihood of crop abnormalities and promoting consistent, high-quality yields.

4.2 Recommendations

Based on the findings and conclusions of the study, several recommendations are proposed to further enhance the performance and functionality of the developed system. These recommendations are derived from the identified strengths and limitations of the IoT web system, as well as the feedback gathered from end-users and IT experts. To improve the accuracy, durability, and efficiency of the monitoring process, the use of industrial-grade sensors is recommended, particularly for measuring pH, electrical conductivity (EC), and water levels, since the current pH, EC, HR-SR04 ultrasonic, and DS18B20 temperature sensors are highly sensitive to prolonged water exposure. It is also recommended to utilize a larger reservoir with a greater water nutrient solution capacity to support the expansion of greenhouse operations, as the current iLettUse NFT hydroponics system is limited to a 25-liter reservoir. Furthermore, installing ultrasonic sensors in the reservoirs containing pH Up solution, pH Down solution, water nutrient solution, and water would enable the system to detect low solution levels and automatically notify users, ensuring uninterrupted operation and timely maintenance. Finally, future developments should extend the system's capability to accommodate and calibrate various lettuce varieties, rather than being limited to Green Batavia lettuce, thereby increasing the flexibility and applicability of the developed IoT web system for a broader range of hydroponic farming practices. Overall, implementing these recommendations would further optimize the system and improve its efficiency, reliability, and usability in modern hydroponic agriculture.

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