Design and Implementation of an Automatic IoT-Based Monitoring System for Hydroponic Farming

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Abstract

Traditional agriculture is currently facing difficulties and obstacles, which is leading to declining soil fertility, unsustainable farming practices and climate changes causing harsh environment with more pests and diseases. In addition, the expansion of industrial zones has significantly reduced the arable land area. To overcome these challenges, farmers need to change their farming methods and apply scientific and technological advances to their practice. This paper presents the Design and Simulation of an Automatic Internet of Things (IoT) -Based Monitoring System for Hydroponic Farming. This paper describes designing and implementing an IoT-enabled hydroponic farming system to monitor the environmental condition of plants and control the nutrient supply plants. The system is built from sensors, actuators, a micro-controller unit Arduino Mega. Hydroponics is a method of growing plants in water based nutrient solution instead of soil. The sensors monitors the temperature, humidity, nutrient, pH, water, and light levels of the plants. These sensors are connected to a programmed microcontroller. A prototype was designed and simulated using Proteus Design Suite Software. Experimental results demonstrate the system's effectiveness in maintaining optimal conditions for plant growth. The experimental results show that the proposed system operates with stablility and high efficiency. Mobile app is used to communicate the current status of the hydroponic system to the user through the use of internet to mobile phones.

Keywords: *Hydroponic, IoT, Agriculture, Microcontroller, Sensors, Proteus*

1. Introduction

Historically, agriculture has been the primary food source for the world. It plays an important role in the world's food security. Agriculture is essential for sustainable livelihood development (Ogbolumani, 2023). One of the biggest problem that open field soil-based agriculture has had to face since the rise of civilization is the reduction in the available land (Venkatraman. M and Surendran. R, 2023). Due to rapid increase in population, urbanization, and industrialization the per capita land is decreasing. The soil fertility has reached saturation level, because of this crop yield is not increasing even after the increased application of fertilizers (P. Usha et. al, 2024) Traditional farming is facing the problems of climate change, crop failure, and pests. Many researchers have studied various ways to improve yield (Nguyen et al., 2022). The traditional farming face lots of challenges for increasing the productivity. Some of the challenges in rural areas are the global climate changes, pollutions, loosing soil integrity to grow the crops, rapid increment in urbanization, and agricultural land sacristy etc (Al., 2022).

The world population is increasing every day and it is expected to reach 9.3 billion in 2050. Therefore, crop production has to be increased in order to maintain a sufficient amount of food. However, the production of crops is affected by many factors like the unusual weather changing, lack of water and the lack of sufficient arable lands available to grow the crops (Khandakar & Haque, 2020). The human population is expanding at a startlng rate. To feed the growing population, agricultural output must rise (Venkatraman. M and Surendran. R, 2023).

Hydroponics is a revolutionary method of plant cultivation that eschews soil, and is reshaping conventional farming practices. Plants are grown in nutrient-rich aqueous solutions, providing precise control over their growing environment (P. Usha et. al, 2024). Hydroponics is the soil less agriculture farming, which consumes less water and other resources as compared to the traditional soil-based agriculture systems (Al., 2022). The hydroponic system is a method that depends on growing. Regarding environmental impact, hydroponic farming does not require using pesticides, herbicides, or other chemicals that can negatively impact the environment (Niswar, 2024) the plants in the water without the use of soil, it has been proved that the plants do not need soil as long as the essential nutrients, minerals and the suitable pH maintained stable within a certain range inside the water (Khandakar & Haque, 2020). With the integration of Internet of Things (IoT) technology, hydroponics has entered a new era of smart farming. IoT-based hydroponics systems incorporate sensors, microcontrollers, and networking capabilities to automate and monitor plant cultivation with unprecedented precision (Waigumo, 2024). Internet of Things (IoT) is reshaping industries, integrating internet connectivity with everyday items, transforming work, lifestyle, and technology (Ogbolumani, 2023)

The advantage of hydroponic farming is the more efficient use of resources because it uses less water than traditional soil-based farming, as water can be recirculated and reused (Niswar, 2024), Hydroponic cultivation is prevalent in the modern agricultural world as a clean and easy method compared to the traditional types of cultivation. The absence of soil makes the crops quite clean, removing the need for washing at the same time, this agricultural system faces a low risk of contamination (Pomoni, D. I. et. al., 2023). Hydroponics offers numerous advantages over traditional agriculture. By eliminating the need for soil, hydroponics allows precise control over environmental factors like nutrient composition, pH levels, and water availability. This control leads to higher crop yields, reduced water consumption, and efficient nutrient utilization (Nguyen, H. C., Thi B. T. V. & Ngo, Q, 2022). The advantages of hydroponics are making it more popular over soil-based cultivation. However, integrating IoT technology into hydroponics enhances the efficiency, precision, and scalability of cultivation (P. Usha et. al, 2024). IoT in agriculture might be a game changer for humans and the whole planet (Al., 2022).

Automation is a crucial aspect of IoT-based hydroponics. With real- time sensor data, the system can reduce manual labor by automatically adjusting to changing conditions. This level of automation ensures consistent plant care and enables remote monitoring and control. The ability to remotely monitor and control the system increases scalability and ease of management, whether in a small urban garden or a large commercial hydroponic facility (Waigumo, 2024).

hydroponics can effectively control the use of not only water but also fertilizers and chemicals which are applied to combat diseases and pests. On the other hand, conventional agriculture uses pesticides and nutrients extensively, which is another disadvantage of conventional crops. Therefore, hydroponics is safer than open-field cultivation because it can ap- ply natural barriers against specific bacterial agents and reduce contamination factors. Hydroponic products are grown without pesticides, prompting consumers to trust them more and be willing to spend more on their acquisition, thus creating food security hydroponic cultivation in a greenhouse dramatically reduces the environmental impact compared to greenhouse soil cultivation due to the use of pesticides and fertilizers

2. Related Literature

Some related literatures were reviewed where numerous studies and comprehensive reviews in the literature focus on the design and implementation of hydroponic systems. Dutta S., Mukherjee B., and Sawarkar A. (2023) developed an Enhanced Agricultural Productivity using Hydroponic Techniques: A Smart Farming System which demonstrates that hydroponics leads to higher crop yields in a shorter time frame compared to traditional soil-based farming, while integrating smart farming technologies, including automation, can make hydroponic systems more efficient, sustainable, and suitable for addressing modern food security challenges. Monitoring of Hydroponics System using IoT Technology by Patil et. al., (2020) was presented The system can control lighting, nutrient supply, and water flow independently based on real The system integrates sensors (for parameters like pH, electrical conductivity, temperature, water level) with a microcontroller (ESP8266) to automate plant growth conditions within a vertical hydroponic setup. The system successfully cultivated various crops such as mint, lettuce, tomato, cucumber, and herbs indoors. The developed system offers a cost-effective, scalable, and autonomous indoor vertical hydroponic solution suitable for the Gulf region's climate. This research provides a practical framework for personal and small-scale hydroponic farming in desert environments and lays the groundwork for future enhancements. Khandakar & Haque, (2020) designed and implemented a cost-effective, automated vertical hydroponic system integrated with IoT. The system components include sensors for pH, electrical conductivity (EC), temperature, humidity, water flow, and water level, all connected to a central microcontroller

(ESP8266). Data from sensors are transmitted wirelessly to the using IoT platform via Wi-Fi. The system successfully maintained optimal growing conditions for various crops. JWater usage was minimal (8–10 liters per month), although the nutrient circulation was substantial (~104,000 gallons/month). The IoT interface provided timely alerts, such as SMS notifications for pump failures, and allowed users to remotely visualize and analyze environmental data. It effectively addresses the challenges of indoor farming in arid regions, providing a scalable solution for personal food production in Qatar and similar environments.

Enhanced Agricultural Productivity Using Hydroponics Technique: A Smart Farming Hydroponic Farming Systems which significantly improve agricultural productivity by utilizing resources such as water, nutrients, and space more efficiently than traditional soil-based methods. The results indicate higher and more consistent crop yields, shorter growth cycles, and the potential for year-round production, especially when integrated with automation and IoT technologies. The long-term benefits include increased profitability, sustainability, and adaptability to urban and peri-urban environments (Dutta S., 2023). Smart Hydroponic Systems: Optimizing Nutrient Levels with IoT Connectivity was discussed by Vishram & Kulkarni, (2024), where a smart hydroponic setup that integrates IoT-enabled sensors, specifically pH and TDS sensors, connected to ESP32 microcontrollers for real-time data acquisition were used. Measurements were taken at different times of the day and under varying environmental conditions to analyze their impact on plant health. The findings demonstrated that higher TDS levels (around 1100-1200 ppm). Lowering the pH to below 5, especially near 2-3, significantly hindered plant growth, causing signs such as dried leaves, spots, and reduced shoot height. Stable parameters within the optimal ranges (pH=6.0-6.5, TDS=1000-1200 ppm) produced the best growth outcomes, with fresh-looking, vigorous plants.

Revolutionizing Agriculture with IoT, Mobile Apps, and Computer Vision in Automated Hydroponic Greenhouses was presented by (Hanafi, A. M., 2025). The paper reviews various existing studies and systems that integrate IoT, sensors, and automation technologies to develop automated hydroponic systems. It discusses design approaches for different hydroponic methods. The research incorporates real-time data collection via sensors, data processing through AI and fuzzy logic algorithms, and remote management via mobile applications and web interfaces.

C H. Lakshmi, (2020) developed a Hydroponic Farm Monitoring . The system uses various sensors—measuring TDS, water level, water temperature, and pH—that are connected to a Raspberry Pi via IoT. Python code is uploaded to the Raspberry Pi to process sensor data. The IoT-enabled hydroponic farm allows real-time monitoring, reducing manual oversight and potential plant loss due to neglect. Using hydroponics reduces soil-borne pests, disease costs, water wastage, and allows farming in urban settings like rooftops and vertical farms.

Eridani, D.; Wardhani, O.; & Widianto, E.D. (2017). built an automated aeroponic system that is based on Arduino platform to measure the important system parameters such as temperature, humidity, and potential of hydrogen (pH) levels. However, the system is highly expensive in comparison with the other hydroponic systems.

Most papers advocates for the adoption of hydroponic greenhouses as versatile and sustainable solutions for agricultural production, environmental conservation, and community development, particularly in constrained areas like protected zones and urban environments.

3. Methodology

The control flow of an IoT-based efficient hydroponics system typically involves several components working together to monitor and control various aspects of the hydroponic setup as shown in Fig. 1.0. The system utilizes various sensors to collect data about environmental conditions such as temperature, humidity, light, pH, and nutrient levels in the hydroponic system. These sensors can be connected to a microcontroller an Arduino, which gathers the sensor data. The collected sensor data is then transmitted to a central hub or cloud server using wireless communication protocols such as Wi-Fi, Bluetooth, or cellular networks. The IoT-based hydroponics system often includes a user interface, such as a mobile application, that enables users to remotely monitor and control the system. This allows users to access real-time data, receive alerts or notifications, and manually intervene if the need arise.

The web-interface can be visualized anytime from smart phone or computer and the mobile application is also simple and easily accessible. Thingspeak web-interface is shown. However, Thingspeak web-interface can show several days' data at a time while the mobile application can show for a shorter duration with last data-point highlighted.

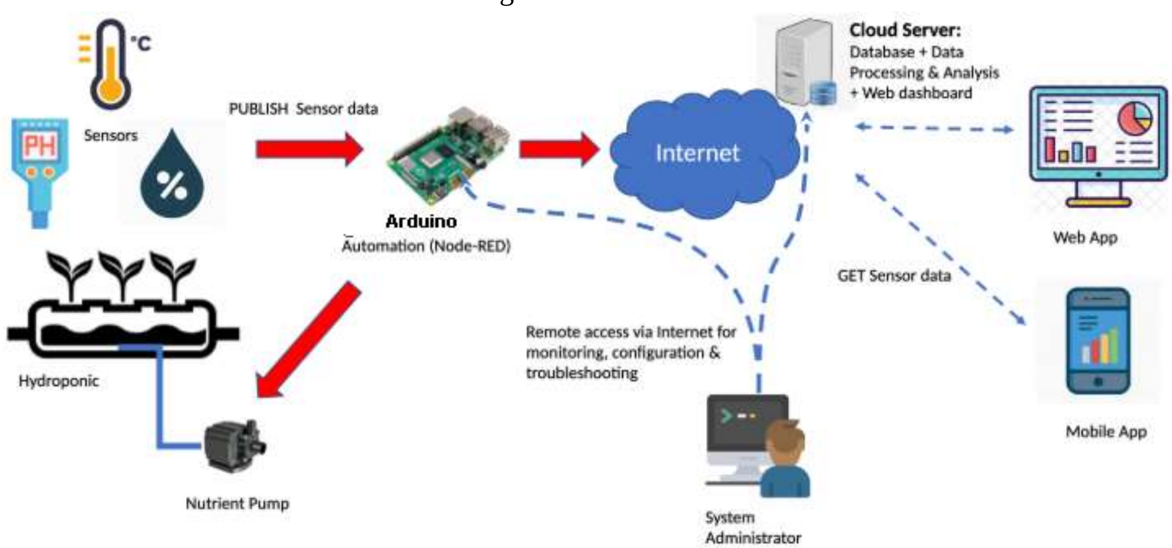

Fig 1.0 Architecture of the Hydroponic System

Actuators such as pumps or relays are used to carry out the control actions. Nutrient pumps can be activated to deliver the right amount of nutrients to the plants. The system continuously monitors the effects of the control actions by collecting feedback data from sensors. This feedback data is used to evaluate the impact of the control actions on the hydroponic system's performance. It allows for continuous monitoring and adjustment of the control to ensure optimal plant growth and resource efficiency.

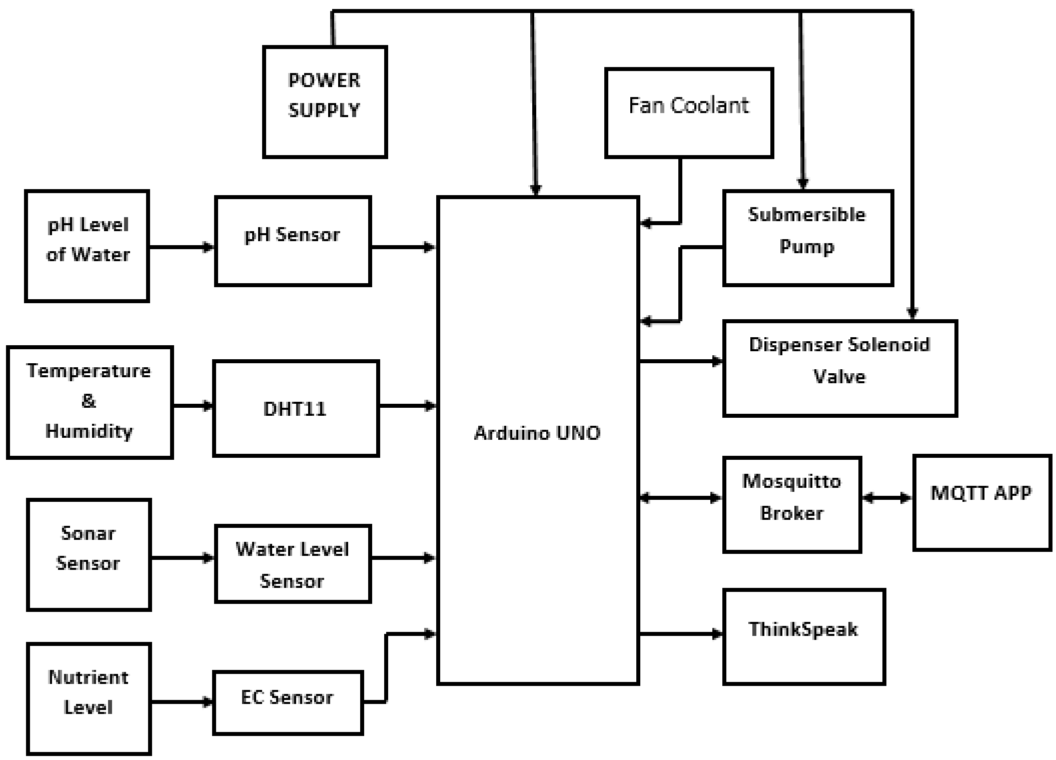

Fig 2.0 Block Diagram of the Proposed Hydroponic System

The Block diagram is seen in fig 2.0 which consist of the power supply, sensors, microcontroller, actuators, pumps and the cloud. The control of the whole system is automated using Arduino and IoT. However, there is manual controlling provision through Mobile App with the help of LAN connection in case of absence of internet connection. The dispenser is used to mix the nutrients with the water. The containing nutrients is passed to the pipes with help of submersible pumps, An alerting system in the form of text messages has successfully implemented whenever the user intervention is required. The pump is one of the major components that must be continuously on in an automated hydroponic system in order to supply the nutrient solution from the nutrition tank to the system.

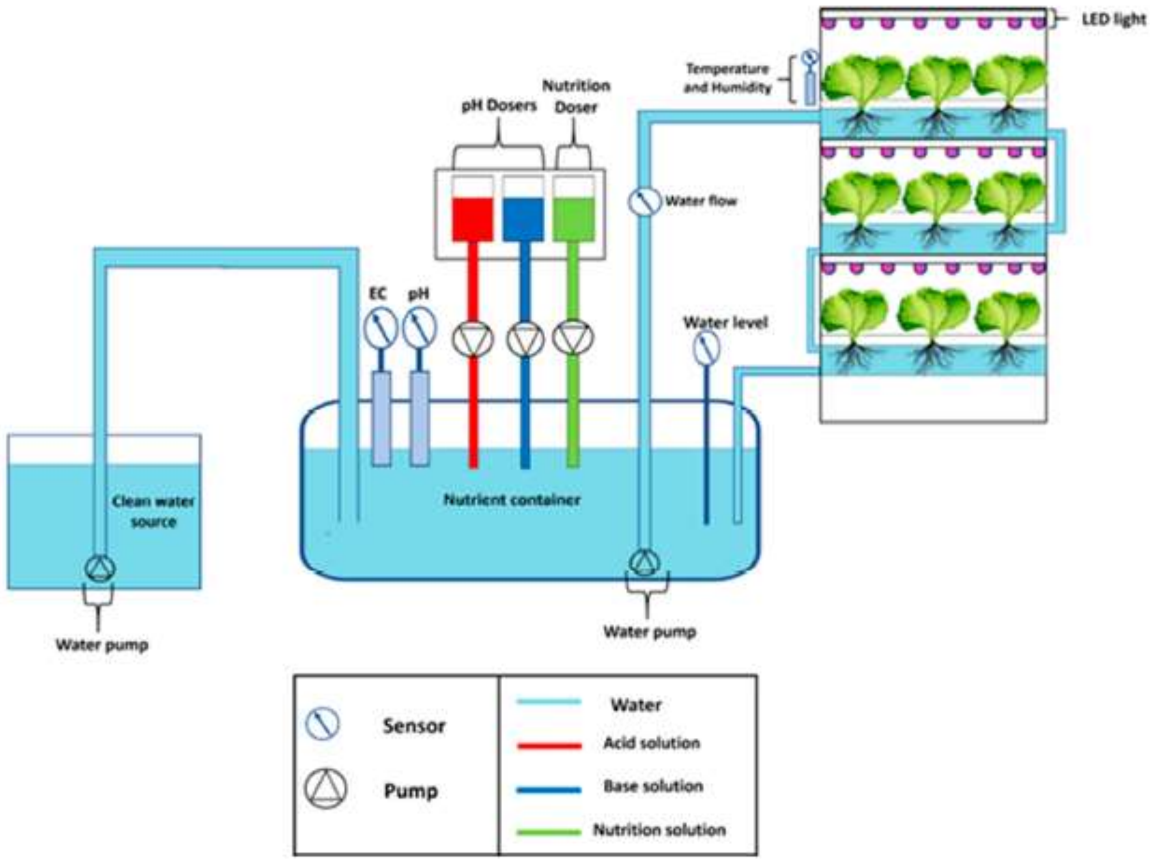

Fig 3.0 Schematic Diagram of the Hydroponic System

The schematic diagram of the hydroponic system is shown in fig 3.0. The designed system is capable of maintaining healthy growing parameters for the plants with minimal input from the user. The functionality of the overall system was confirmed by evaluating the response from individual system components and monitoring them in the IoT platform.

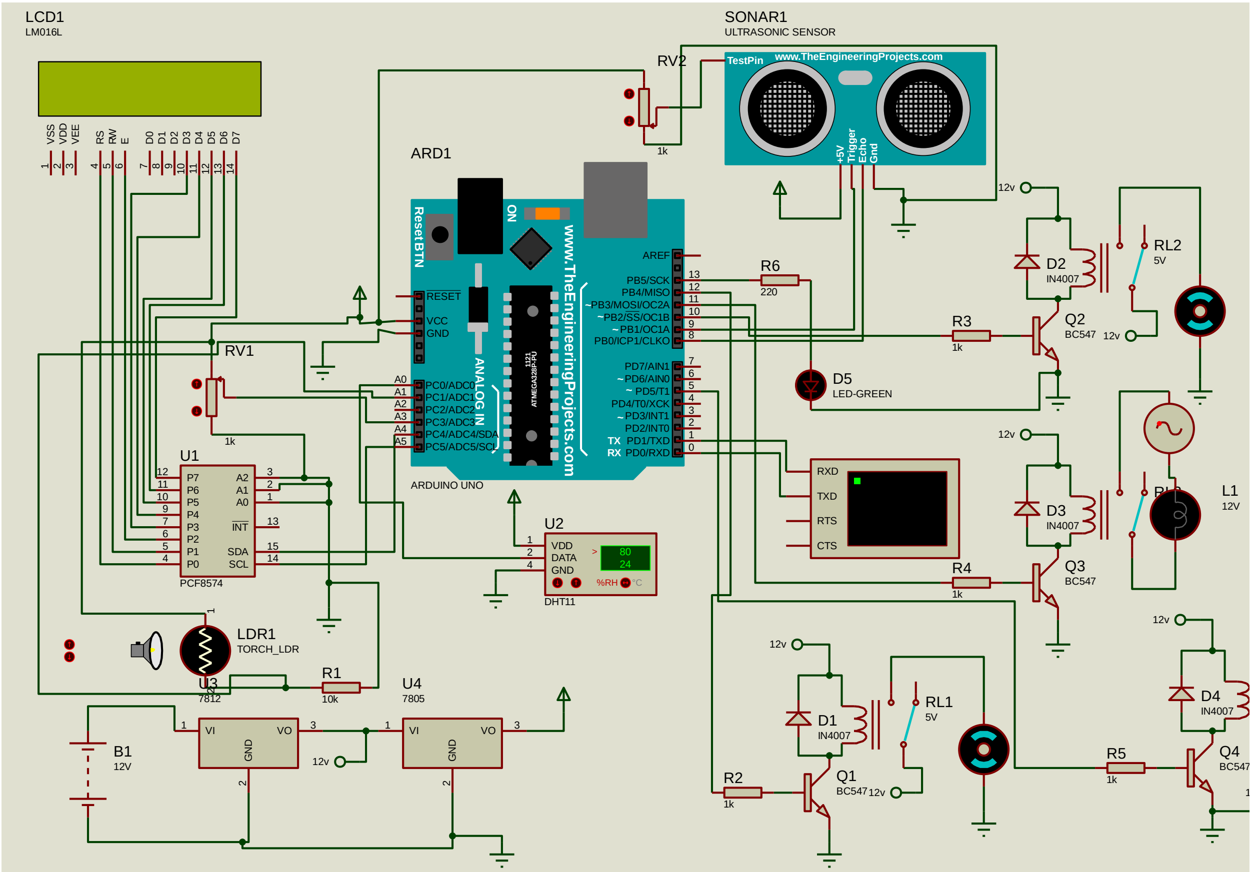

Fig 4.0 Simulation Circuit of Hydroponic System

4. Result

The step-by-step experimental situations as conducted to establish the compliance of each sensor with its specification of this research. Each sensor was subjected to laboratory test one after the other according to the established rules and norms for testing sensors. Various sensors used in the design had to be calibrated before using them. The overall circuit diagram of the system is shown in Fig 4.0, which comprises of all the sensors and the AC appliances connected with each other to the microcontroller. Figure 3.0 illustrates the schematic diagram of the Hydroponic System. The system was designed to get the data from the sensors and collected in a central microcontroller, then send it to IoT platform. IoT platform is capable to store, analyze and preview the data to the user in private and also in a mobile application. The web-interface can be visualized anytime from smart phone or computer and the mobile application is also simple and easily accessible. Data from the sensors and nutrient dispenser is uploaded to a user interface called thinkspeak application. Below pictures shows the thinkspeak application templates and controller for nutrient dispenser. Nutrients can also be manually dispensed using thinkspeak app and user can dispense NPK solutions along with pH up- down solutions manually based on the requirements.

However, Thingspeak web-interface can show several days' data at a time while the mobile application can show for a shorter duration with last data-point highlighted. An alerting system in the form of text messages was successfully implemented, whenever the user intervention is required. The pump is one of the major components that must be continuously on in an automated hydroponic system in order to supply the nutrient solution from the nutrition tank to the system.

5. Conclusion

The core of a hydroponic system is to maintain and control the environmental parameters and the efficient supply of nutrition and water for healthy growth of the plants. In The design and execution of a cutting-edge, low-cost IoT-based hydroponics monitoring and control system were demonstrated in many circumstances.. It offers the customer a simple web-based application to keep tabs on their crops while also alerting them with the proper alarms and warnings. This makes it much easier to observe numerous hydroponic greenhouses with little effort and without having to take any action.

Hydroponically grown plants do not come in contact with soil borne pests and diseases thus saves costs of soil preparation, insecticides and fungicides. Since the amount of nutrients is fed directly to the plants, there is no wastage of water due to run off or evaporation. Today, hydroponics is an established branch of farming. Progress has been on large scale and results obtained in various countries in the world have proved that this technology is thoroughly practical and has very definite advantages over conventional methods of crop production.

The water temperature sensors on the hydroponics farm can identify the temperature loss and alert the farmer as necessary. Expanding the research area, and study period, and investigating alternative methods of a more cost-effective hydroponic farming system, farmers allow to innovate in the farming system at a lower cost to produce high-quality crops.

Automated hydroponic systems represent a significant advancement in agricultural technology, offering efficient and sustainable solutions to the challenges of food production. This paper has highlighted the effectiveness of various hydroponic methods and the integration of advanced technologies such as IoT, mobile applications, and computer vision. These innovations enable precise control over environmental factors, optimize resource utilization, and enhance crop yields, positioning hydroponics as a viable alternative to traditional farming.

Future development could involve integrating high-data analytics, expanding remote control capabilities, and encouraging cooperation from governments and corporations to promote urban hydroponic farming, which can be a sustainable food production solution.
Expanding the research area, and study period, and investigating alternative methods of a more cost-effective hydroponic farming system, farmers allow to innovate in the farming system at a lower cost to produce high-quality crop.

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