Delving into Arduino Integration for Nutrient Film Technique Hydroponic Systems, An App-Based Approach for Monitoring and Analysis

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This study examines the use of hydroponics to achieve efficient crop production in the context of the growing importance of sustainable agriculture techniques. More precisely, the article centers on the Nutrient Film Technique (NFT), a hydroponic system widely recognized for efficiently utilizing resources. Although NFT hydroponics offers numerous benefits, a major obstacle lies in the need for more accurate monitoring and control systems capable of effectively managing the delicate equilibrium of nutrients and environmental factors required for ideal plant development. It is necessary to investigate integrated solutions that can improve the effectiveness and dependability of NFT hydroponic systems. The paper utilizes a systematic literature review methodology, exploring several sources to examine the use of Arduino microcontrollers and Internet of Things (IoT) technologies in NFT hydroponics. The study focuses on using Arduino-based sensors in combination with a React-based application for monitoring and analyzing real-time data. The literature study demonstrates that IoT and Arduino technologies greatly enhance the regulation of crucial environmental factors in NFT hydroponic systems. This integration facilitates more effective resource management, improving agricultural yields and growth efficiency. The results emphasize the significance of technical progress in precision agriculture, specifically by using intelligent sensing and Internet of Things (IoT) frameworks. This research adds to the continuing discussion on sustainable agriculture practices and lays the groundwork for future advancements in hydroponic farming that offer increased production and sustainability.

Keywords: hydroponics, Arduino, nutrient film technique, urban farming.

1. Introduction

With the world struggling to meet the growing needs of food production while facing a scarcity of natural resources, cutting-edge agricultural methods have gained international attention.

Among these, the technique of growing plants without soil, known as hydroponics, has become a symbol of sustainable agriculture. A contemporary farming approach called hydroponics uses nutrient solutions in place of soil and has benefits over conventional farming techniques like control and predictability. The Nutrient Film Technique (NFT), a methodology well known for its effectiveness and low water and nutrient consumption, lies at the heart of this method. However, the true potential of NFT lies untapped, hindered by the need for precise, real-time monitoring and control systems. Hydroponics, particularly with regard to the Nutrition Film Strategy (NFT), plays a crucial role in today's farming practices as it is of essential importance for environmentally friendly agriculture today. This paper offers insight into how soilless agriculture widely known as hydroponics provides notable benefits compared to traditional farming techniques. One benefit of this is quicker plant growth and bigger harvests are made possible One reason for this is that nutrients go straight to the roots, thus increasing the efficiency with which resources are used [1]. Recent advances in Internet of Things (IoT) technology have revolutionized numerous industries, yet its application in hydroponics, particularly NFT, still needs to be explored more. While IoT has shown promise in enhancing hydroponic farming through advanced monitoring and control systems, its integration with NFT systems has yet to be extensively investigated.

The implementation of IoT technologies in hydroponic systems emphasizes the design and development of an automatic monitoring system based on IoT that enables real-time data collection and control of the farming environment. A system can enhance the efficiency and reliability of hydroponic farming, particularly focusing on the monitoring of environmental and nutrient parameters critical for plant growth. The integration of IoT in this way highlights the potential of automating cultivation processes to improve plant growth and overall system efficiency [2].

Farming practices are being transformed today by the use of sensors to monitor the real-time environment and crop health, automated irrigation systems, invariant precise nutrient addition, and data analytic-driven decision making will help improve resource management through optimization of agricultural operations using the Internet of Things. IoT brings many advantages, such as increased agricultural productivity, greater sustainability, and greater profitability. More improvements in the IoT are anticipated, which will drive smart agricultural practices by incorporating artificial intelligence and machine learning into more predictive farming [3]. Despite the fact that it costs a lot, is challenging to handle, and seems to be at risk of being abused at the same time with other internet-connected appliances or gadgets, there is an acceptance of such potential impediments to all-encompassing implementation.

This study offers an all-inclusive perspective on how IoT solutions are modifying present-day agricultural practices or procedures and where they still have prospects for totally transforming agribusiness later on.

This study aims to bridge this gap by examining the academic literature about developing IoT-enabled devices tailored for NFT hydroponics. The framework uses Arduino-based sensors to monitor critical parameters such as pH, total dissolved solids (TDS), water temperature, and reservoir levels are integral to NFT systems' success. The objective of this literature review is not only to promise enhanced crop yields and resource efficiency but also to offer a blueprint for the future of sustainable agriculture.

Addressing these challenges, the research explores How IoT technology can be effectively integrated into NFT hydroponics? What impact do real-time monitoring and data analysis have on the efficiency and sustainability of NFT systems? This investigation fills a critical research void and paves the way for a new era in precision agriculture, where technology and sustainability converge to foster a more food-secure future.

2. Materials and Methods

This work used systematic literature research and gathered and analyzed academic resources and scholarly articles using the Internet. This review focuses on creating a React application for environmental parameter monitoring and analysis and integrating Arduino-based systems with hydroponic technology, especially the Nutrient Film Technique (NFT).

The researchers did a comprehensive literature analysis to understand better the many technologies used in an Arduino-based hydroponic system. The scholarly publications, conference proceedings, and other magazines were meticulously categorized based on their pertinence and the objective of the literature study.

The information can be grouped using theme approaches such as statistical analysis and crop management in hydroponic systems, React in agricultural data presentation, and Arduino-based sensor integration. The selection of these issues was made to comprehensively outline the primary study areas, facilitating the process of performing a systematic literature evaluation.

This research aims to provide a clear strategy for using Arduino in hydroponic systems and a React application for efficient environmental monitoring and analysis of the factors affecting crop growth in NFT hydroponics.

3. Literature Survey

The literature study focused on many areas, such as Sensor Integration and IoT, Data Communication and Processing, and Statistical Analysis and Crop Management.

The paper of Desausa & Fernandes [4] explains the planning and construction they did for an Arduino-based hydroponic system that employs the Nutrient Film Technique (NFT). Different sensors within the integrated system are used to keep track of weather variables, including nutrient levels. In principle, it means an ability to automate and enhance hydroponic agriculture with systems founded on Arduino.

In addition, the research of Ula et al. [5] indicated that pH level monitoring is important in a real-time tracking system for both aquaponics and hydroponics. The technology of IoT within a system is used for the collection and analysis of data. This demonstrates the necessity of examining the level of PH in attending to hydroponic systems that can realize optimal conditions for plants.

The paper of Naveena et al. [6] studied how to automate control of nutrient solutions in hydroponics. The system uses a Total Dissolved Solids (TDS) reader to confirm the availability of nutrients in the solution. This illustration indicates the scope of IoT in automating nutrient control in hydroponic farming.

Meanwhile, the study of Lakshmanan et al. [7] examined an IoT-infused intelligent hydroponics structure that manages the temperature of the water. It exemplifies the necessity of maintaining correct temperatures in hydroponics for plant growth and enhanced productivity and the suitable application of IoT offerings.

The study of Sneineh & Shabaneh [8] focused on developing a procedure to detect water content in NFT hydroponic systems. It stresses the significance of maintaining the reservoir's water level at an appropriate concentration to ensure plants' easy nutrient access. It also looks at ways through which technological advancements can assist in achieving this end.

IoT-based smart agriculture talks about many uses, like precision farming, smart irrigation, and crop tracking. This technology is changing traditional farming methods into more efficient ones based on data [9], [10].

The paper of Mate [11] discusses in the paper a microcontroller-based automation system for mixing and watering nutrient solutions for hydroponic plants. The research emphasizes nutrient handling precision and the possibilities of automating tasks involving the same using microcontroller-based systems to increase yields and stimulate plant growth.

Furthermore, Priya et al. and Kaur et al.'s investigations exemplify the employment of Raspberry Pi and Arduino for data collection from various gadgets. Resulting in improved greenhouse conditions for germination [12], [13].

Sagar and Gupta [14] indicate a significant change due to the Internet of Things (IoT). They provide real examples that prove IoT systems are saving water and increasing how much food farmers get every season. The author also talks more generally about how these technologies have been applied within controlled agricultural environments, including automating light or CO2 control in greenhouses or plant factories and dosing nutrients and water in field installations. This paper examines several uses for Arduino boards when implementing Internet of Things-based solutions intended for various types of hydroponic operations such as NFT, Dutch buckets, other types of non-circulating systems, or even aeroponics. The IoT-based systems optimize real-time environmental parameters such as temperature, humidity, pH level, and nutrient concentration, leading to better crop yields and reduced resource consumption. Thus, this paper presents a prototype that shows how these concepts can be practically applied by demonstrating how sensor data enables plant growth conditions improvement through automation with an example. Deploying the same type of IoT technologies in an Arduino can improve the efficiency and output of hydroponic setups. This same article also examines such things as how difficult it can be to put up these systems as well as why they have to involve specialists ensuring there are no loose ends left hanging out anywhere for such a purposefully designed or programmed setup towards being branded as an Arduino-minded hydroponics 4.0 system characterized by a high level of novelty and sensibility to farmer's day-time requirements for such a prominent branch of agricultural economics. This broad investigation of using the IoT in hydroponics functions as its base, underlining the possibilities and the relevance of the high-end technology connection with sustainable agriculture outputs.

Additionally, the papers of Dhanaraju et al. [15] and Raro et al. [16] examine IoT and Arduino smart farming techniques, focusing on precision farming techniques and automatic watering systems. The study highlights how IoT and Arduino can instantaneously enhance crop productivity by regulating diverse environmental factors.

Likewise, Kumar Selvaperumal et al. [17] showed how the IoT makes remote monitoring and control of hydroponic nutrient solutions possible. The importance of accurate nutrient delivery for plant growth is discussed, and how such nutrients can be automated in the hydroponic system using IoT technology is demonstrated.

The survey papers of Barcelo-Ordins et al. [18] and Raro and Palaoag [19] have written survey papers that explore the wireless communication protocols used in the Internet of Things for agricultural purposes and point out their advantages and disadvantages. The survey recommends optimal communication protocol selection for agricultural IoT apps, such as sensor networks and remote monitoring systems.

The study of Morelos et al. [20] presents an IoT-based system for monitoring the health status of grapevines using transfer learning and deep learning techniques. While the primary focus is on implementing lightweight deep learning models (MobileNet V2 and EfficientNet B0) and semantic segmentation using Mobile-UNet for disease detection, the system also incorporates a web service interface developed using FastAPI for reporting and visualizing the results. Although the paper does not explicitly mention using the React framework, the Web service interface could be integrated into React-based front-end applications to enhance data visualization and user interaction. This integration would allow for the development of interactive and user-friendly interfaces for visualizing the health status of grapevines, thereby facilitating more informed decision-making in intelligent agriculture. React made sending and receiving data easier, allowing real-time monitoring and controlling diseases affecting grapevines.

Lu et al. [21] introduced the RL-Informer model, a new way to improve the growing environment for strawberries in Controlled Environmental Agriculture (CEA). It blends reinforcement learning (Q-learning) with a time-series prediction model (Informer). The model leverages sensor readings for tracking essential environmental features such as temperature, light intensity, and EC value in solution nutrients. Besides, it looks into various plant characteristics, among them heights or lengths of leaves and their numbers in a given area, which are conditioned by specific genetic arrangements organisms' genomes contain (genetics). The Informer part looks at all these data and provides insight into what the future growth pattern is most likely to be like. This information tells the Q-learning algorithm how to change the surroundings in real-time. The aim is to have farming conditions in a constant good state to improve food production without consuming many resources. The experiments using the RL-Informer model to guide strawberry farming indicated increased crop yields. Consequently, combined sensor data analysis and machine learning can enhance precision levels and improve productivity in hydroponic systems. This is important for creating an IoT framework for tracking and analyzing NFT hydroponic systems.

Moreover, Rathod et al. [22] explored the use of IoT in conjunction with cloud computing in agricultural settings to address food security challenges posed by the world's growing population. The developed SmartFarm AgriTech system employs top-notch microcontrollers, including Raspberry Pi and Arduino. These microcontrollers handle all kinds of sensors, relay switches, and motors. They interact with Idea solutions like Amazon Web Services (AWS) and ThingSpeak Application Programming Interface (APIs), which are used to build servers and APIs that collect and store information. This lets crops be monitored and maintained from afar. A GUI application is developed to control and monitor the data from the microcontrollers. The study highlights the importance of sensor data acquisition, animal and unknown data recognition, and cloud data computing in smart farming. By automating the monitoring process of crops, weather, water, and fertilizer spraying, the SmartFarm AgriTech system aims to improve farm maintenance, reduce waste, and optimize resource application, contributing to more sustainable and efficient agricultural practices.

Meanwhile, Lee and Wu [23] statistics were used to analyze the relationship between biofield treatments (as environmental parameters) and plant growth. Specifically, Duncan's Multiple Range Test was applied to compare means between different treatment groups. The statistical analysis helped to determine whether the biofield treatments significantly affected various growth and physiological parameters of lettuce and bok choy plants, providing insights into optimizing conditions for hydroponic cultivation.

The paper of Paradiso et al. [24] used statistics to assess the impact of PGPMs on soybean plants. A one-way analysis of variance (ANOVA) was conducted in this study, followed by Tukey's Honest Significant Difference (HSD) to compare averages in terms of leaf anatomical capacities, photosynthesis rates as well as some parameters for plant growth between those that were treated (inoculated) vs non-treated (without any form of vaccination). The authors found statistically significant differences under a certain level (usually $P \leq 0.05$) by researching and obtaining data through statistical analysis using tables and figures. This guided the researchers in learning about the impacts of PGPM on hydroponically grown soybeans in terms of growth patterns and photosynthesis process.

Precision agriculture applies Wireless Sensor Networks (WSNs) to oversee macronutrients like nitrogen (N), phosphorus (P), and potassium (K) in the soil. The goal is to optimize fertilizer efficiency in hybrid soil, which will, in reverse, boost food yields. The review emphasizes the significance of obtaining real-time data from a WSN for remote monitoring (important for sensor placement), communication technology, and data handling. These studies illustrate that WSN technology has the potential to be employed in precision agriculture to keep tabs on soil nutrients as well as environmental conditions. Such designs and methods should be preferred because they help WSNs function optimally, enabling their durability in agricultural conditions for a longer period [25], [26].

The paper of Dutta et al. [27] describes how lettuce can grow in NFT (Nutrient Film Technique). Later, a comparison is made with conventional substrate cultivation. This study proposes that some IoT benefits include real-time monitoring, automation, and data collection and analysis. As opposed to traditional ways, using IoT technology in a hydroponic farm could be more efficient and productive because it enables the observation of plants' lives and their control elements.

In the study of Setiawati et al. [28], mathematical modeling and artificial Neural Network (ANN) to identify stressed plants in the NFT hydroponic module in the greenhouse. The research investigated Tatsoi plants (Brassica rapa subsp. Narinosa) being watered on different occasions, whereby the microclimate parameters and plant shape were taken to assess the plant growth and yield determinants. The results disclosed that changes in the size and weight of leaves demonstrated a significant effect on plant stress, which received water for different periods. It is also stated by the property of artificial neural networks that the leaf canopy area could be influenced by the quantity and length of roots, hence determining plant yield. The present study revealed the importance of controlling irrigation exactly in hydroponic systems. The study's findings revealed that plants with different watering time periods suffered a lot, as shown by their physical structures, such as size and mass changes in leaves. Moreover, the artificial neural networks technique pointed out that root length and quantity could alter leaf canopy size, hence determining productivity for this type of crop production method. According to this research, the significance of carrying out precise irrigation practices in hydroponics was highlighted above. It also shows how mathematical modeling and artificial neural networks (ANN) can predict plant stress and find the best conditions for hydroponic cultivation.

4. Results and Discussion

The three main topics include Sensor Integration and IoT, Data Communication and Processing, and Sensor Integration and Crop Management. These areas reflect a joint action in modernizing agriculture technologies to become more efficient, enduring through time, and capable of meeting emergent demands as the environment changes.

Table I. Impact of IoT and Advanced Data Processing on Hydroponic Systems

Category	Key Findings	Implications for Agriculture
Sensor Integration and IoT	Effective monitoring of environmental parameters and nutrient levels using Arduino-based systems in NFT hydroponics.	Enhanced plant growth and yield through precise environmental and nutrient control.
Data Communication and Processing	Integration of IoT with cloud computing platforms like AWS and ThingSpeak for data storage and processing.	Improved operational efficiency and decision-making in hydroponic farming systems.
Statistical Analysis and Crop Management	Use of statistical methods such as Duncan's Multiple Range Test and ANOVA in studying the effects of biofield treatments and PGPMs on hydroponic crops.	Better nutrient management and irrigation practices to enhance crop productivity and biodiversity preservation.

Sensor Integration and IoT

Development of Arduino-based hydroponic systems utilizing the Nutrient Film Technique (NFT) is reviewed in the literature. Such systems are endowed with sensors that keep track of environmental parameters and nutrient amounts, which reveals the effectiveness of automated and optimized hydroponic agriculture. Furthermore, it is stated that the real-time tracking systems for aquaponics and hydroponics emphasize pH level monitoring through IoT technology. This emphasizes the significance of maintaining the best growth conditions, including using automated methods for TDS measurement and temperature management systems in hydroponics by employing IoT. Indeed, by regulating both temperature and nutrients, IoT proves crucial in enhancing plant growth and output.

Data Communication and Processing

The literature reviews discussed how IoT and cloud computing technologies can be combined in agriculture. To manage sensors, relay switches, and motors, one has to use microcontrollers such as Raspberry Pi and Arduino while storing and gathering data, which is supposed to be done by AWS and ThingSpeak. It can help supervise and fix remote crops, proving that smart farming requires sensor data collection and cloud computing. Deep learning systems in the Internet of Things should be established to monitor the health of grapevines, and the growth environment in Controlled Environment Agriculture should be improved using reinforcement learning and time-series prediction models. It demonstrates how crucial data communication and processing are to precision agriculture.

Statistical Analysis and Crop Management

The effects of biofield treatments and plant growth-promoting microorganisms (PGPMs) on different aspects of plant growth have been the subject of inquiry in many studies using statistical tests such as Duncan's Multiple Range Test and ANOVA, carried out under hydroponic conditions to make the best of hydroponic farming conditions is a major concern in these studies, emphasizing on the need for accurate nutrient management and irrigation to enhance food production rates and preserve biodiversity.

Incorporating IoT and advanced data processing technologies into Nutrient Film Technique (NFT) hydroponic systems creates a variety of agricultural implications, discussions, and summaries of the key findings. Table I presents an overview of how incorporated sensors enhance historical nutrient film technique systems.

5. Conclusion

This research explored how Arduino technology and Internet of Things (IoT) frameworks could be used together in Nutrient Film Technique (NFT) hydroponic systems. In particular, it focused on real-time monitoring and analyzing main parameters such as pH, total dissolved solids (TDS), water temperature, and reservoir levels. The findings demonstrated that IoT solutions can make modifications within hydroponics by enabling precise monitoring and control needed for optimal crop growth. This paper explores precision farming using these novel technologies in parallel with more eco-friendly and efficient ways such as hydroponics food production around urban areas. Future researchers should concentrate on adding other watched factors and more advanced analysis for NFT hydroponic cultivation.

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