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Development of an Integrated Arduino Sensors in a Nutrient Film Technique Crop Production

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The primary motivation for this paper stems from the pressing need to optimize and modernize agricultural practices, specifically in hydroponics, with a particular focus on Nutrient Film Technique (NFT) crop production. This study aims to develop an integrated Arduino sensor for an NFT system to aid in maintenance and resource utilization by enabling real-time data monitoring and precise control of environmental parameters. The researcher's hypothesis revolves around the premise that the incorporation of these sensors will not only foster resource efficiency but also improve crop yields and quality. To achieve this, extensive data collection will be carried out through an array of Arduino sensors, encompassing measurements related to pH levels, total dissolved solids, temperature, reservoir water level, and reservoir water temperature. The results will yield the potential benefits of this innovative approach, shedding light on the impact of sensor-based precision agriculture in NFT systems. In conclusion, this research promises to revolutionize modern agriculture by providing valuable insights and practical applications for farmers and agricultural experts. Developing integrated Arduino sensors in NFT crop production can pave the way for more sustainable, resource-efficient, and high-yield agricultural practices, contributing to the global effort to meet food demand while conserving resources and mitigating environmental impacts.

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

1. Introduction

The global agricultural landscape is undergoing a transformation necessitated by the increasing demand for food production in the face of resource scarcity and environmental concerns. In this context, precision agriculture has opened new avenues for optimizing crop production, with a particular emphasis on sustainable practices. This paper embarks on a journey at the confluence of agriculture and technology, motivated by the pressing need to enhance crop production efficiency while conserving vital resources. The researchers studied how Arduino sensors application can be developed for Nutrient Film Technique (NFT) crop production systems. The primary objective of this study is to address the gap in current agricultural practices by harnessing the power of real-time data monitoring and to help control and optimize crop growth in NFT systems. To this end, this paper sets out to answer the following research questions: (1) How can integrated Arduino sensors improve crop production in NFT systems? (2) What key environmental parameters influence crop growth in NFT systems? (3) What are the implications of sensor integration for resource efficiency and crop yield? By exploring these questions, the researchers aim to contribute to the ongoing sustainable agriculture and provide valuable insights for practitioners, researchers, and policymakers in pursuing a more efficient and environmentally conscious food production system.

Dholwani and colleagues have observed that the conditions for soil growth are becoming increasingly restricted. On the other hand, projections indicate that the need for agricultural products will rise sharply in the near future. There is no choice but to use soilless farming to increase the yield and quality of commodities to provide food security because there are not many other options available to them, especially in urban areas where concrete conglomerates are quickly growing[1]. To get to the root zone, a lot of water is sprayed on the soil using the customary approach. Water only partially reaches the roots as it evaporates through the soil.

Conversely, hydroponic water swiftly reaches the roots, minimizing evaporation. Water efficiency is further increased by several systems that recycle the fertilizer solution multiple times before discarding it [2]. Traditional farming uses between 70% and 80% of the water used globally, according to research by Prazeres et al. Agricultural and environmental biotechnology that has the potential to improve food production regulation, wastewater treatment and reuse, and culture yields while reducing the risks of wastewater reuse on land is the hydroponic system [3]. Making the simple switch to hydroponic farming might save up to 90 percent of the water normally used for conventional soil farming [4].

By cultivating two varieties of seeds—cucumber and Armenian cucumber—in both the hydroponic and conventional soil systems, Gashgari et al.'s study employed a statistical experimental approach to evaluate and compare the two systems. Because plants in hydroponic systems reach their maximum height faster than in regular soil planting, the results imply that hydroponic technology has a greater impact than traditional soil planting. Conversely, the total length of the leaves is unaffected by hydroponic technology. Furthermore, the plant's ability to grow is unaffected by the type of seed used or by interactions between seed type and planting method [5]. The article by Dutta et al. [6] explains how lettuce can be grown using the NFT (Nutrient Film Technique). Subsequently, a comparison is done with the cultivation of conventional substrates. According to the findings of this study, some of the advantages of the Internet of Things include real-time monitoring, automation, and the collecting and analysis of data. Using Internet of Things technology in a hydroponic farm could be more efficient and productive than traditional methods because it permits the observation of the lives of plants and their control elements. Both Barcelo-Ordins et al. [7] and Raro and Palaoag [8] have authored survey studies investigating the wireless communication protocols utilized in the Internet of Things for agricultural purposes. These publications also highlight the benefits and drawbacks associated with these protocols. According to the survey findings, the most effective communication protocol should be used for agricultural Internet of Things applications such as sensor networks and remote monitoring systems.

This technology does not come without its share of downsides. Depending on the use of the technology, a higher level of energy consumption is required for activities such as automated watering and artificial lighting. Most vegetables cannot be grown in hydroponic systems, and the initial investment is far higher than that required for conventional crops. The price of a hydroponic setup is higher. The price of prefabricated or constructed systems is typically higher. Lights, pumps, aerators, and fans in hydroponic systems require power. An illness might spread throughout the entire plant collection within a few days. Because hydroponic systems do not rely on soil, they may react more quickly to environmental changes. This is because soil acts as a buffer against nutritional deficiencies and disease [2], [9], [10].

People frequently move to cities for better economic opportunities, social connections, and artistic opportunities. However, urbanization is not without its flaws and problems. It is estimated that by the year 2030, 77% of the population of the Philippines will reside in urban areas, up from the current figure of nearly half living. Most urbanization has occurred in major metropolitan areas such as Manila, Baguio, Cebu, and Davao. Greater Manila is home to more than 12 million people. As a result of the fact that many people live in congested neighborhoods with significant building congestion, higher fuel costs, and inadequate transport networks, it is not easy to get agricultural products from rural areas to urban marketplaces. In the provinces designated under the Special Area for Agricultural Development (SAAD) Program as the lowest of the poor, an image not dissimilar may be observed [11].

2. Methodology

This research seeks to develop a system of integrated sensors using Arduino technology to enhance the efficiency and productivity of hydroponic crop production in a Nutrient Film Technique setup. The system aims to automate the monitoring and adjusting of environmental parameters critical for optimal crop growth.

For the Nutrient Film Technique (NFT) hydroponic setup, the main goal of the system design for the integrated Arduino sensor system is to make a complete solution that automates and improves the environmental control processes necessary for food growth. WeMos D1 WiFi UNO ESP8266 and an ESP32 comprise the system's central working unit. Coordination of the functions of several sensors and showing real-time data are its jobs. Key parts include monitors for pH, TDS (Total Dissolved Solids), water temperature, and water level. Due to their ability to keep an eye on important parts of the hydroponic environment, these parts were carefully chosen. Within the system, an LCD screen gives you instant visual information about its state. This screen has an easy-to-use interface for updating and watching settings as needed. In order to keep the conditions perfect for plant growth, it ensures that the water cycles and fertilizer solutions are handled perfectly. By automating the NFT hydroponic system, this design aims to make upkeep easier while reducing the amount of manual work needed and improving the accuracy of environmental management.

The assembled Arduino sensor system starts with creating the hardware parts, which ensures that all the mechanical and electronic parts are correctly installed and set up for communication. Multiple external sensors can be connected to the ESP32 and WeMos D1 WiFi UNO ESP8266. Writing Arduino sketches controls how sensor data is collected, how it is interpreted, and how control actions are carried out based on set criteria is part of the software development process. Utilizing real-time sensor data and WiFi connection, the designs allow for the automatic transmission of features like water temperature and nutrient content. Testing and calibrating each sensor carefully is an important part of the execution. This process aims to check the correctness of the sensors' readings and rate their performance in a planned way. Assuring the accuracy of the pH and TDS monitors and keeping a close eye on the reservoir level are both very important for keeping the right conditions for growth. Before calibration, the sensors are set up to meet certain standards and the system is programmed to respond correctly to sensor inputs. This method is created for reliable, automatic monitoring of the NFT hydroponic setup.

3. Results and Discussion

Design

This study introduces a meticulously designed flowchart for the control system of an Arduino-based hydroponic farming setup, especially employing the Nutrient Film Technique (NFT), as seen in Figure 1. The flowchart regulates and records important variables, including pH, water temperature, Total Dissolved Solids (TDS), and water levels.

The flowchart is started by methodically initializing sensors, such as the pH, water temperature, TDS, and water level sensors. Subsequently, the system sets up a timer to trigger every hour, forming the foundation for the recurring execution of vital control system operations.

During the iterative loop, the system checks if the timer has expired. If the condition returns true, the system gathers sensor data, including pH, water temperature, TDS, and water levels. A crucial step in the flowchart involves merging the sensor data into a complete string and then sending it to the designated recipient. This communication delivers immediate and vital information on the current hydroponic environment.

The flowchart includes a decision point to determine if the timer has expired, which is crucial for optimizing resources and avoiding unnecessary sensor readings. After making this selection, the system initiates a process that resets the timer, preparing the system for more hourly cycles.

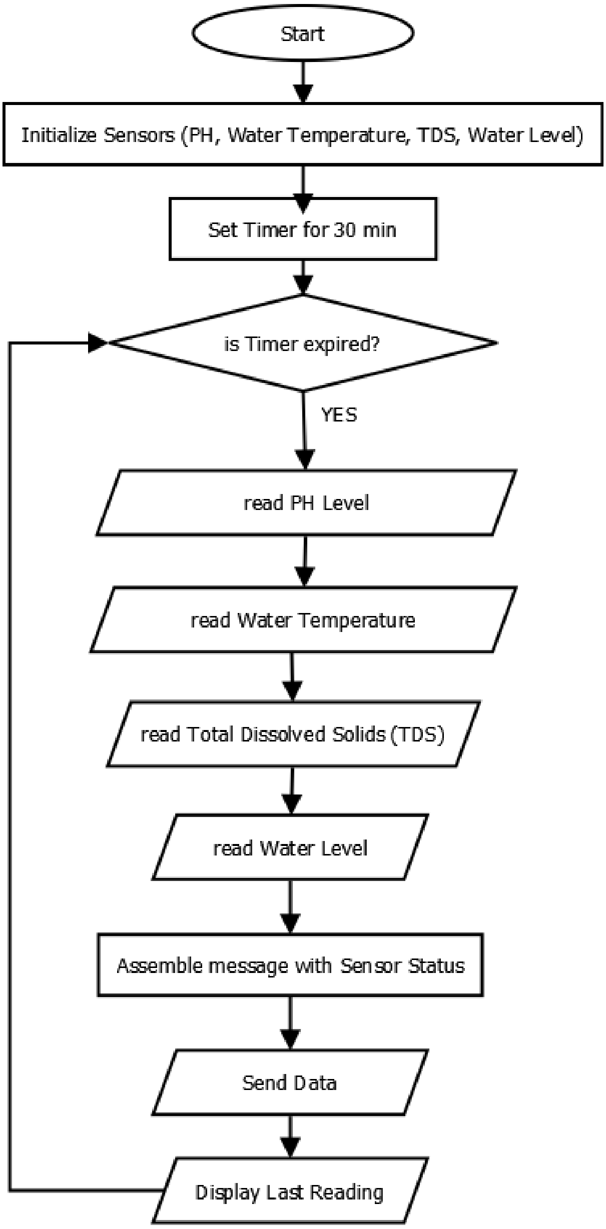

Figure 1 Device Flowchart

Hardware

The researchers meticulously chose certain hardware components to create the integrated Arduino sensor system for hydroponic crop production to ensure effective monitoring and administration of the hydroponic environment. The ESP32 development board is crucial in the system as it enables smooth integration and communication between various sensors and equipment, specifically designed to improve the accuracy of the precision agricultural setup. Every individual part, ranging from the PH-4502C Liquid PH Sensor to the Gravity Total

Dissolved Solids (TDS) Meter V1.0, has been carefully selected based on its unique functionality in ensuring the system maintains the ideal circumstances for development. The compatibility and performance problems between the ESP32 and the TDS sensor required us to utilize the Arduino WeMos D1 WiFi UNO ESP8266. This demonstrates how our system architecture is adaptable to overcome technological difficulties. This integration of technology guarantees the immediate collection and regulation of data. It improves the durability and dependability of our hydroponic management system, facilitating in-depth conversations about the role and performance of each component.

Development Boards

The ESP32, seen in Figure 2, functions as the central processing unit, enabling smooth integration and communication among several sensors, including the HC-SR04 Ultrasonic Sensor, I2C LCD, ph-4502c PH sensor, and DHT22 water temperature sensor. The hydroponic system's effective data processing and better control are ensured by its compatibility with Arduino Development and the ATmega328P CH340 CH340G.

The Arduino WeMos D1 WiFi UNO ESP8266, shown in Figure 3, was utilized alongside the TDS sensor meter v1.0. This specific sensor exhibits errors when employed using the WiFi capability of the ESP32.

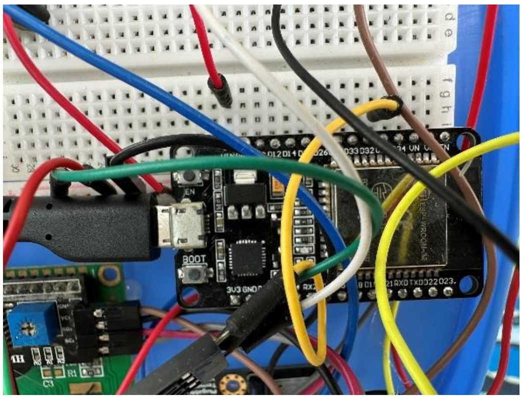

Figure 2 Initial Wiring for ESP32

Figure 3Initial Wiring for WeMosD1

PH Sensor

The PH-4502C Liquid PH Sensor with E201-BNC Electrode for Arduino enables continuous monitoring of the pH level of the nutrient solution, providing essential information about the chemical equilibrium of the hydroponic environment to ensure optimal plant development. This gadget is equipped with a water temperature sensor, which accurately monitors the temperature in the hydroponic system. Temperature is a crucial aspect that affects the development of plants. This component is crucial in establishing an ideal climate for cultivating crops.

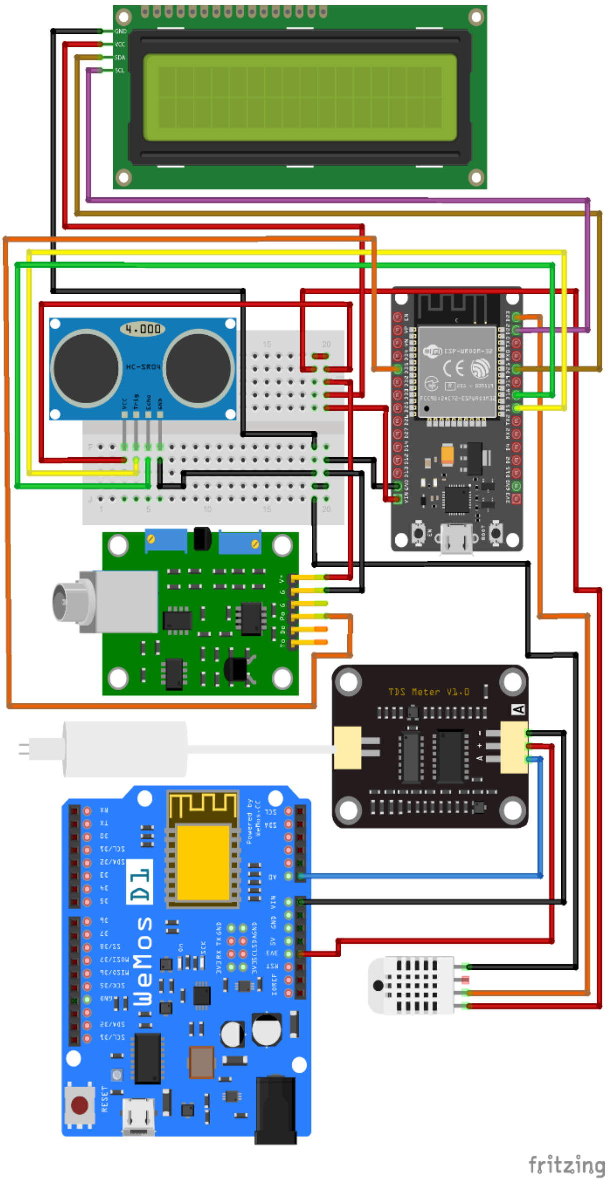

Figure 4 IoT Sensor Breadboard

Temperature Sensor

The DHT22 served as a water temperature sensor, enabling accurate monitoring of the hydroponic system's temperature, a crucial component affecting plant development. This component is crucial in establishing an ideal climate for cultivating crops.

TDS Sensor

The Gravity Total Dissolved Solids (TDS) Meter V1.0 is designed to measure the amount of dissolved solids in the nutrient solution. This sensor facilitates the maintenance of an optimal nutrient balance and reduces the likelihood of nutrient imbalances by delivering accurate TDS values, hence supporting robust plant development.

Water Level Sensor

The HC-SR04 Ultrasonic Sensor Distance Measuring Module provides immediate data on the vertical distance of the nutrient solution in the NFT channels. This data is crucial for effective irrigation management, guaranteeing uniform and effective plant water allocation.

Communication

The ESP32 and WeMos D1 WiFi UNO ESP8266 Development Board provide remote connectivity, enabling users to get real-time data updates and alarms. This improves the system's usability by allowing prompt reactions to fluctuations in the hydroponic environment.

Power Supply

A 5V 2A Micro USB cable will be used for the ESP32 and ESP8266 to ensure a stable and reliable energy source for the Arduino board and associated sensors, guaranteeing continuous and uninterrupted operation of the integrated system.

Display

For instant feedback on critical system parameters, enhancing the accessibility and usability of the hydroponic setup for users, I2C LCD was utilized with its compatibility with ESP32. This was used to display the PH, water, and temperature. The additional built-in potentiometer to control the contrast of the background and the screen characters provided a simple way for the researchers to make the display readability easier.

Development

Developing an integrated Arduino-based sensor system for NFT hydroponic systems is a significant stride in precision agriculture. The researchers focused on addressing the intricacies associated with managing nutrient film technique setups, aiming to ensure optimal crop growth and resource utilization.

The central processing unit responsible for coordinating flawless communication among a carefully chosen set of sensors is achieved by integrating the ESP32 and WeMos D1 WiFi UNO ESP8266. This evolution is depicted in Figure 4. The researchers employed real-time monitoring capabilities to measure pH, TDS, water temperature, and fertilizer solution depth. This allowed farmers to get valuable insights, make educated decisions, and prompt interventions.

The device's primary focus is on the precise regulation of water. The Water Level Sensor ensures precise irrigation, thereby reducing the likelihood of over-watering or insufficient watering, while the Water Temperature Sensor regulates the surrounding environment. This level of precision enhances the efficiency of resources and enhances the assimilation of nutrients by the plants, thereby fostering sustainable hydroponic techniques. The Sim900 GSM Shield Development Board's incorporation of remote communication capabilities is an exceptional feature. This feature improves the capabilities of producers by allowing them to promptly receive notifications and access information on their mobile devices. The researchers recognize that the hydroponic system must be accessible remotely to enable flexible monitoring and management, thereby circumventing geographical limitations. The LCD Display is a practical device that is used for real-time monitoring at the location. The study recognizes that this design consideration allows farmers to quickly access critical metrics, thereby enabling them to make well-informed decisions and promptly implement the necessary system modifications.

Performance of the System

The evaluation of the Arduino-integrated hydroponic system, as described by Arispe et al. [12], will focus on analyzing the system's response times and the precision of its environmental adjustments. The system's efficiency may be assessed by evaluating its responsiveness and efficacy in adjusting to changes in TDS, pH, or water levels.

This assessment is similar to the activation time measurements used in home automation IoT applications. The researchers assessed the device's connection response time by monitoring the length in seconds till they arrived at their conclusion. The activation time was determined by measuring the duration in seconds using two different types of connections: a wired access point and a wireless mesh topology. These connections were established using the identical Internet Service Provider (ISP). The system was initiated from the moment the gadget was plugged into the AC socket until it was linked to the internet.

Using two different internet connections, the researchers carried out ten different experiments. With five (5) attempts for each internet connection, the verified activation time is displayed in Table 1. When wireless mesh topology was utilized, it took at least four seconds and five and a half seconds to complete the task. As a consequence of this, the normal amount of time that was recorded was 5.18 seconds. 1.9 seconds was the shortest amount of time claimed to have been spent with the connected access point, while 2.4 seconds was the highest period, and 17.54 seconds was most of the time. The data that was captured makes it abundantly clear that the WiFi signal volume considerably influences the amount of time it takes for the system to establish a connection.

The descriptive statistics for the connection times of Wireless Mesh Topology and Wired AP provide insights into their central tendencies and variability, as seen in Table 2. For Wireless Mesh Topology, the mean connection time is 5.18 seconds, with a standard deviation of 0.63 seconds, indicating a moderate spread around the mean. The minimum recorded connection time is 4.00 seconds, while the maximum is 5.80 seconds, showing some variability in connection times. Wired AP's mean connection time is 2.20 seconds, with a smaller standard deviation of 0.21 seconds, suggesting less variability than the Wireless Mesh Topology. The minimum and maximum connection times for Wired AP are 1.90 seconds and 2.40 seconds, respectively. These statistics reveal that the connection times for Wireless Mesh Topology are generally higher and more variable than those for Wired AP.

Table 1 Connection Time

Recorded Connection Time		
Trials	Wireless Mesh Topology	Wired AP
1	5.5	2
2	5.8	2.3
3	5.1	2.4
4	4	1.9
5	5.5	2.4
Mean	5.18	2.2

Table 2 Descriptive Statistics of Connection Time

	Wireless Mesh Topology	Wired AP
count	6	6
mean	5.18	2.2
std	0.6305553	0.2097618
min	4	1.9
25%	5.12	2.05
50%	5.34	2.25
75%	5.5	2.375
max	5.8	2.4

Table 3 Correlation Matrix for Connection Time

	Wireless Mesh Topology	Wired AP
Wireless Mesh Topology	1	0.6048399
Wired AP	0.6048399	1

Table 3 shows that the correlation between Wireless Mesh Topology and Wired AP is 0.605. This indicates a moderate positive relationship, suggesting that as the connection time for the Wireless Mesh Topology increases, the connection time for the Wired AP tends to increase as well.

Table 4 Correlation Matrix of Data-sending Performance

	TDS	PH	Water Level	Water Temperature
TDS	1	0.25835	-0.1946	0.16044
PH	0.25835	1	-0.232	0.3576
Water Level	-0.1946	-0.232	1	-0.0072
Water Temperature	0.16044	0.3576	-0.0072	1

The reaction time from the data-sending performance of the four elements—namely, pH level, Total Dissolved Solids (TDS), water temperature, and water level—were the data that were utilized in order to determine whether or not there was a significant difference between the four (4) groups of samples. According to the findings of the correlation analysis of TDS, PH, Water Level, and Water Temperature in the dataset, there are varied degrees of correlations between these factors, as seen in Table 4. There is a modest tendency for PH to increase with

TDS, as indicated by the fact that there is a weak positive association between TDS and PH (0.258). Similarly, the PH and water temperature have a moderately positive association (0.358), which suggests that greater PH values are partly connected with higher water temperatures. Conversely, Water Level displays weak relationships with TDS (-0.195), PH (-0.232), and Water Temperature (-0.007), showing that changes in Water Level are not strongly linked to changes in the other parameters.

Additionally, a weakly positive association between TDS and water temperature equals 0.160. The correlations suggest that while there are connections between the characteristics, they are generally of low to moderate strength. This implies that many events or variables can impact each measure.

4. Conclusion

The research showed high potential for hydroponic agricultural farming when considering the combination of sensor systems on the Arduino platform that aids in tracking or managing key environmental factors, including Ph level, TDS, water temperature, and water level. This integration enhances resource efficiency and crop yields and addresses technological issues by implementing creative solutions, such as using Arduino WeMos D1 WiFi UNO ESP8266 for improved system compatibility. With an eye toward the future, the study paves the way for additional research opportunities, such as the enhancement of predictive capabilities through the utilization of machine learning algorithms, the automation of broader agricultural processes, and the development of user-friendly interfaces in order to make these complex systems accessible to a wider audience. Future research has the potential to make hydroponic systems more efficient, less labor-intensive, and capable of meeting the growing global food demands. This would be a significant contribution to the sustainability and productivity of agricultural practices all over the world. This could be accomplished by expanding the integration of Internet of Things technologies and improving data analytics platforms.

References

1. S. J. Dholwani, S. G. Marwadi, V. P. Patel, and V. P. Desai, "Introduction of Hydroponic system and it's Methods," vol. 3, no. 3, p. 5, 2018.
2. Trees.com, "Advantages & Disadvantages of Hydroponics," Trees.com. Accessed: Feb. 10, 2022. [Online]. Available: https://www.trees.com/gardening-and-landscaping/advantages-disadvantages-of-hydroponics
3. A. R. Prazeres, A. Albuquerque, S. Luz, E. Jerónimo, and F. Carvalho, "Hydroponic System: A Promising Biotechnology for Food Production and Wastewater Treatment," in Food Biosynthesis, Elsevier, 2017, pp. 317–350. doi: 10.1016/B978-0-12-811372-1.00011-7.
4. K. Espiritu, "Hydroponics vs. Soil: 7 Reasons Hydroponics Wins," Epic Gardening. Accessed: Feb. 17, 2022. [Online]. Available: https://www.epicgardening.com/hydroponics-vs-soil/
5. R. Gashgari, K. Alharbi, K. Mughrbil, A. Jan, and A. Glolam, "Comparison between Growing Plants in Hydroponic System and Soil Based System," presented at the The 4th World Congress on Mechanical, Chemical, and Material Engineering, Aug. 2018. doi: 10.11159/icmie18.131.
6. M. Dutta et al., "Evaluation of Growth Responses of Lettuce and Energy Efficiency of the Substrate and Smart Hydroponics Cropping System," Sensors, vol. 23, no. 4, Art. no. 4, Jan.

2023, doi: 10.3390/s23041875.
7. J. Barcelo-Ordinas, J.-P. Chanet, K.-M. Hou, and J. García-Vidal, A survey of wireless sensor technologies applied to precision agriculture. 2013.
8. E. R. Raro and T. D. Palaoag, "Exploring Advanced Smart Sensing Technology for Enhanced Drip Irrigation Management in Greenhouses," in 2024 International Conference on Advances in Computing, Communication, Electrical, and Smart Systems (iCACCESS), Mar. 2024, pp. 1–5. doi: 10.1109/iCACCESS61735.2024.10499624.
9. K. Zacharaki, "Hydroponics and its role in urban agriculture," Interreg Europe. Accessed: Feb. 10, 2022. [Online]. Available: https://www.interregeurope.eu/cityzen/news/news-article/11981/hydroponics-and-its-role-in-urban-agriculture/
10. Campbells, "Hydroponics Advantages and Disadvantages (Best Guide)," Farming Aquaponics. Accessed: Feb. 10, 2022. [Online]. Available: https://farmingaquaponics.com/hydroponics-advantages-and-disadvantages/
11. J. Canlas, "Urban Agriculture: Coping With Crisis Towards Food Security," Special Area for Agricultural Development. Accessed: Feb. 10, 2022. [Online]. Available: http://saad.da.gov.ph/2020/06/urban-agriculture-coping-with-crisis-towards-food-security-4/
12. M. C. Arispe, R. Jaucian, A. Platon, F. S. Relucio, and B. Saminiano, "Developing an Electrical Outlet using Internet of Things (IoT)," IJATCSE, vol. 9, no. 1.3, pp. 280–286, Jun. 2020, doi: 10.30534/ijatcse/2020/4291.32020.