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IoT-based Smart Hydroponics Experimental Module in Lima, Peru

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The project focuses on the development of an IoT-based smart hydroponics experimental module in Lima, Peru, as a response to the food crisis and the challenges associated with traditional agriculture. Hydroponics offers a promising alternative, allowing for more efficient use of water, eliminating the use of agricultural fertilizers and insecticides, and guaranteeing a controlled, contaminant-free environment for growing vegetables. The research was carried out at the Faculty of Electronic and Electrical Engineering of the Universidad Nacional Mayor de San Marcos. An IoT-based experimental module was designed and implemented with a capacity of 180 plants in a 6 x 12 x 3.5-meter multi-crop mesh house to monitor and record the parameters associated with the cultivation of silk lettuce. This module incorporates Internet of Things (IoT) technologies, including sensors to measure environmental and nutrient variables, a data acquisition and processing unit, a monitoring and control platform, and connectivity to the cloud for data storage and analysis. The proposed system includes a hydroponic growing facility combining NFT and floating root techniques, fed by a controlled nutrient solution. A sensor module was used to measure physical parameters such as temperature, relative humidity, pH, and conductivity. The collected data was transmitted via the MQTT protocol to a cloud platform for storage and analysis. The results obtained after 45 days of development showed notable success, with lettuce harvests of up to 745 grams, in contrast with lettuces of 350 grams available in the local market, exhibiting good coloration of the leaves and roots. This project represents a significant advance in precision agriculture, using innovative technologies to improve the efficiency and productivity of hydroponic systems, thus contributing to food security and agricultural sustainability in the region.

Keywords: Agricultura, IoT, Hydroponic, MQTT.

1. Introduction

Hydroponics is an important alternative to consider for the country's food security. The global economic crisis has generated the rise and scarcity of food [1], creating a critical situation in relation to food [2]. Likewise, there is a shortage of fertilizers and water availability limitations [3]. On the other hand, regarding the cultivation of vegetables, the contamination of chemicals and bacteriological contaminants is high and harmful to health. There is a need to conduct various research on the cultivation of vegetables, to improve cultivation processes and achieve quality products efficiently. Therefore, it is necessary to have experimental modules with sensors that allow for monitoring cultivation conditions and recording the data obtained during the process. The study was carried out inside a mesh house built in the facilities of the Faculty of Electronic and Electrical Engineering of the Universidad Nacional Mayor de San Marcos in Lima, Peru. We see that [4] researched the evolution of agriculture in developing countries, highlighting the transition from traditional methods to smart agriculture techniques, specifically hydroponics. It is mentioned that, although old methods depended on soil quality and required a lot of time and labor, new techniques optimized with IoT platforms have allowed greater efficiency and productivity. Using Rockwool sensors and IoT, hydroponics allows you to grow without soil and with less space and resources. The text highlights the implementation of vertical hydroponics to maximize space and reduce costs. It concludes with the description of a study on the design and implementation of these automated techniques, using big data analysis to improve agricultural production. On the other hand [5] addresses the importance of agriculture in economic development and the need to increase food production due to demographic growth. By 2050, cereal demand will reach 3 billion tons. The Sustainable Development Goals aim to achieve zero hunger and sustainable agriculture by 2030, despite shrinking arable land and water scarcity. Vertical farming, an advanced technology, increases crop yield per unit area. The study describes the design and construction of an IoT-enabled smart vertical farming system, using deep flow hydroponic technique (DFT), sensors, and an automatic pH and TDS balancing system. The growth of romaine lettuce was compared in controlled and uncontrolled environments, finding that the fresh weight was greater in the automated system (58.66 g vs. 48.81 g). Both systems maintained the optimal levels of necessary nutrients. The study by [6] seeks to monitor specific nutrients during hydroponic cultivation using miniaturized ion sensors connected to IoT. Solid contact ion-selective electrodes (SCISEs) were fabricated as a sensor array and integrated with wireless embedded systems to create an IoT nutrient sensor system (IoNSS). This system includes a sampling and detection module controlled by an Arduino Due® microcontroller, a Wio Terminal® microcontroller for automation, logging, and data transmission, a cloud server for data management, and MQTT-based web interfaces. Experiments showed that the resolution and signal noise of the SCISEs were significantly improved with an additional ADC chip, enabling high-quality data at a low cost. The sensors were calibrated and compared with commercial ion chromatography and electrodes. The IoNSS was tested by monitoring concentrations of K+, NO3–, and NH4+ during hydroponic cultivation of arugula in a plant factory and a greenhouse, demonstrating its capacity for real-time observation and remote reporting of growing conditions. This work establishes novel cyber monitoring of specific nutrients and promotes intelligent hydroponics management. It is also shown that the study of [7] describes an energy optimization technique for the continuous operation of sensor nodes in hydroponic systems based on energy harvesting. The technique is based on a self-tuning model that dynamically adjusts the duty cycle of the node, allowing autonomous operation of the IoT system. This model, programmable on a low-power microcontroller, allows the decision-making process to occur in the sensor node itself. Experimental results show that the self-tuning model allows 3.5 times more data transmissions in the same period as a uniform 5-minute duty cycle while maintaining a minimum voltage level on the storage device. This ensures enough stored energy for continuous monitoring, providing a clean and cost-effective alternative to powering the hydroponic system in perpetuity. The research conducted by [8] also describes a smart irrigation system using the Internet of Things (IoT) for a hydroponic system. In India, the agricultural sector contributes around 16% of GDP and 10% of export earnings. Advanced technologies such as hydroponics and aeroponics allow for higher crop yields in small areas. In this work, a smart irrigation system for hydroponics is proposed, and an experimental prototype that monitors, controls, and records real-time data (temperature, humidity, and water flow) is developed using the ThingSpeak IoT platform. The results demonstrate that the system can monitor and control the hydroponic environment, achieving greater crop production. The study by [9] uses IoT-connected miniaturized ion sensors to monitor specific nutrients during hydroponic cultivation in a greenhouse. These sensors provide information on crop nutrient uptake efficiency and changes in ion concentrations in response to vapor pressure deficit (VPD) fluctuations. Solid contact ion-selective electrodes (SCISEs) were fabricated into a sensor array and integrated with wireless embedded systems to create an IoT nutrient sensor system (IoNSS). The IoNSS, which includes microcontrollers, a cloud server, and interactive web interfaces, enables real-time evaluation of changes in electrical conductivity (EC) and concentrations of specific elements (NO3-, NH4+, Ca2+, and K+) in solutions. Nutritious in a commercial hydroponic greenhouse. It also facilitates the determination of the NO3-/NH4+ ratio, which helps to track the nitrogen fertilization absorbed by plants. Decreases in K+ concentration correlate with deviations from normal VPD levels, indicating the transpiration efficiency of the leaves. Measurement of other ions reflects physiological disorders resulting from abnormal VPD. The study [10] describes how microscale smart hydroponic (MSH) systems can help improve urban food security by using fewer resources and space. Managing these systems can be complex, but the use of IoT simplifies management for home users. Previous studies have used expensive or less accurate detection methods. This study presents a cost-effective nutrient management system for MSH, using a waterproof IoT spectroscopy sensor (AS7265x) in a transflective application. The sensor, immersed in the hydroponic solution, monitors nutrients and the MSH system predicts and recommends settings in milliliters. A three-phase model was developed with significant results (R2 of 0.997). In a 30-day experiment growing lettuce, the system successfully adjusted and maintained nutrient levels, outperforming the control group. The results showed a significant correlation of 0.77 with the traditional method of measuring electrical conductivity. This novel system has the potential to transform nutrient management in hydroponics, simplifying its management and encouraging its adoption, which would contribute to food security and environmental sustainability. We also have that [11] explores the integration of Internet of Things (IoT) technologies to optimize hydroponic systems by monitoring and controlling crucial parameters. An IoT-based hydroponic monitoring system was developed, including sensors for solution temperature, acidity (pH), total dissolved solids (TDS), electrical conductivity (EC), ambient temperature and humidity, and light intensity. It uses WiFi and LoRaWAN technologies to improve connectivity and ensure reliable communication over long distances. This system allows growers to monitor and adjust key parameters for plant growth in real-time, maximizing productivity and yield in hydroponic agriculture. The study results highlight the potential of IoT technologies to revolutionize precision agriculture and sustainable food production. The research of [12] mentions that vertical farming is gaining importance in the current era of urbanization and industrialization 5.0. These methods improve sustainability by using less space and reducing carbon and greenhouse gas emissions. The Green Internet of Things (G-IoT) offers greater environmental sustainability by switching to a sleep mode when not in use, thus consuming less energy. Each growing method has a different effect on the growth of the aerial parts and roots of the plants. Therefore, it is necessary to identify specific cultivation methods for each crop according to the type of plant considered. This leads to the need to compare and analyze the growth trends of roots and aerial parts of crops in different growing media and using different growing methods, to identify the most suitable method. A comparative analysis of barley shoot and root growth in hydroponics and substrate growing methods with integrated green IoT has shown that hydroponics exhibits two times higher shoot growth than growing in substrate. Furthermore, the results were verified with those obtained from the simulator, confirming that the hydroponic cultivation method produced a qualitative product throughout the year with 17,112 tons of biomass and 8,556 tons of dry yield. Another research by [13] describes the design and implementation of an IoT-enabled hydroponic farming system to monitor plant environmental conditions and control nutrient supply. The system uses sensors, actuators, a microcontroller unit (Arduino), and a single-board computer (Raspberry Pi) connected to the hydroponic system. It can monitor environmental conditions through temperature, humidity, pH, and total dissolved solids (TDS) sensors, and control water pumps to circulate nutrients to plants. The Raspberry Pi acts as an MQTT server to distribute sensor data and control the nutrient pump. Node-RED is used to connect the system to hardware devices, and users can monitor environmental conditions through a web browser on their mobile devices and laptops. This IoT-based indoor hydroponic system automates the delivery of nutrients and water to plants, ensuring they receive the optimal amount at the right time. Finally, also the work carried out by [14] describes various methods of soilless agriculture, such as hydroponics, aquaponics, and aeroponics, with emphasis on the use of the Nutrient Film Technique (NFT) technique to grow high-quality hydroponic plants, specifically Brassica Rapa (Pak Choi). The project uses pH, humidity, TDS, and water level sensors to build an IoT-based smart hydroponic system, with the aim of monitoring and controlling crop conditions and reducing labor costs. Experiments were carried out to identify suitable parameters for the growth of white mustard plants, with results showing differences in the time required to reach average sales weight and final harvest weight. This project has the potential to benefit both small and large farmers by offering an efficient and controlled way to grow high-quality hydroponic crops.

This research project arises in response to the challenges identified in previous research on the control and monitoring of hydroponic crops. Below are some of the main objectives that motivated the development of this system:

- Provide a solution to the possible problems faced by small and medium-sized hydroponic producers, as well as cultivation enthusiasts.

- Monitor the status of the system using sensors to obtain accurate information about crop conditions.

- Store the collected data in the cloud, allowing remote access and centralized management of information.
- Create a history of stored data for analysis and subsequent consultation, facilitating decision-making and monitoring of crop progress

2. Methodology:

Choosing a process model is one of the most important definitions of a software development project. They are important because they create the functions necessary to modify the requirements established by the user or volunteer responsible for hydroponic cultivation. Therefore, the model to be used must be correctly chosen, since a poor choice is likely to reduce the quality or usefulness of the product being developed. Prototypes allow the adoption of technologies used in the development of the work of the title, integrating the functionality of each iteration into the final system. In addition, they allow better management of the changes or proposals that appear in the different stages of the project evaluation, as shown below:

- Requirements Capture: This step is very important because the requirements must be clear to develop any plugin.
- Design: Different UML diagrams are developed to better understand the requirements. In addition, the architectural design of the problem solution is implemented.
- Further development: The addition is based on the selected requirements and further design of the solution. Various techniques selected in previous analyses are used.
- Incremental validation and testing: The prototype is tested and if it meets the requirements, it is integrated into the complete system. You must pass the test plan according to the requirements in repetition.

A. <u>Hydroponics:</u>

Hydroponics is a method used to grow plants without the need for agricultural soil. Unlike growing in soil, plants grow in a liquid solution rich in nutrients that are made up of minerals such as nitrogen, phosphorus, potassium, and other nutrients essential for the development of plants. There are different methods for its implementation, including the Deep Flow Technique (DFT) used in the present study, in which the roots of the plants are suspended in an aqueous solution rich in nutrients, which is recirculated through PVC tubes or other plastic material, through electromechanical mechanisms.

For a healthy crop, it is advisable to maintain an appropriate PH and conductivity for each type of crop. In the case of lettuce, it is important to have a PH of 5.8 and a conductivity of 1.5 mS/cm. Which must be controlled daily manually or automatically. If the conductivity of the solution is very low about the reference, nutrients should be added and if it is high, water should be added. In the case of high PH, phosphoric acid should be added in drops in the recommended proportion, in the case of low PH, an alkaline regulator composed of potassium hydroxide is used.

B. Internet of things:

Hydroponic agriculture has emerged as an efficient and sustainable alternative for crop production in controlled environments. However, its success depends largely on the ability to accurately monitor and control environmental variables and nutrients provided to plants. The implementation of Internet of Things (IoT) technologies in hydroponic systems offers a unique opportunity to improve the efficiency and productivity of these systems. This theory proposes a specific IoT architecture designed for the optimal management of hydroponic crops. IoT architecture enables precise management of water and nutrients, reducing waste and improving resource use efficiency. Farmers can monitor and control their crops from any location with Internet access, facilitating real-time decision-making. By adjusting environmental conditions and plant nutrition in real-time, faster and healthier crop growth can be achieved. The integration of IoT architectures in hydroponics systems marks an important advance in precision agriculture. By offering greater visibility and control over the factors that influence plant growth, it is possible to achieve larger and more sustainable harvests. The combination of advanced sensors, real-time data processing, and reliable connectivity lays the foundation for the promising future of hydroponic agriculture.

- Environmental Sensors: These include meters for temperature, relative humidity, CO2 levels, and light sensors, designed to monitor environmental conditions.

- Nutrient Sensors: These are responsible for measuring the concentration of nutrients in the nutrient solution. pH and conductivity sensors are crucial to monitor and adjust these parameters in the nutrient solution.

- Data Acquisition and Processing Unit (DPU): This unit collects and processes data from the sensors before sending it to the monitoring and control platform. Additionally, you can make real-time adjustments, such as releasing additional nutrients or modifying pH, based on the data received.

- Monitoring and Control Platform: This is a user interface that offers real-time access to the collected data, allowing farmers to make informed decisions. Additionally, it provides capabilities to configure alerts and automation based on predefined thresholds.

- Connectivity and Communication: The architecture is supported by a robust network infrastructure that can be Wi-Fi, Bluetooth, or even low-power network technologies, such as LoRa, especially useful in remote areas.

- Cloud and Data Storage: The collected data is sent to a cloud platform for secure storage and long-term analysis. This solution allows access from any location and facilitates integration with other agricultural management solutions.

3. PROPOSED SYSTEM:

A. Mesh house:

The mesh house used has a base area of 12 x 6 m. 2.2 m side walls and 4.5 m high gable roof. The structure is made of pine wood and has a white anti-aphid mesh coating. The floor is made of crushed stone and has water, electrical, and LED lighting installation. Inside there are several experimental modules in development for various crops. The main module for growing lettuce has been used for this research. It has furniture for the nutrients, tools, instruments, and accessories used for hydroponic cultivation and a space for technical meetings as can be seen in the figure below.

Fig. 1: Mesh house implemented.

B. Hydroponic modules:

The implementation of a hydroponic cultivation facility was carried out, designed with an approach that combines the NFT (Nutrient Film Technique) and the floating root technique. This combination offers an optimal environment for plant growth, providing a thin film of nutrients through PVC tubing while ensuring the roots are completely submerged in the fluid. The installation design includes an array of 4-inch diameter, 6-meter-long PVC pipes. These tubes are interconnected with 2-inch and ½-inch tubing to allow for uniform flow of the nutrient solution.

Fig. 2: Hydroponic Module.

In addition, a 0.5HP water pump is incorporated to maintain a constant flow, and a storage tank with a capacity for 250 liters of liquid with nutrients. To ensure adequate nutrient supply, the liquid level inside the tubes was constantly maintained at 2 inches. The flow rate was set to 0.6 liters per minute, which allowed for uniform distribution of nutrients throughout the tubes. It is important to highlight that the facility operates continuously 24 hours a day, thus guaranteeing a constant supply of nutrients for the optimal development of plants. The following Fig. 2 shows how the hydroponic modules were implemented.

The nutrient solution used for hydroponic cultivation was supplied by the company HIROPONICA S.A.C. Solutions A, B, and C were used in specific proportions per liter of water: A (5 ml/liter), B (2 ml/liter) and C (2 ml/liter). This combination of nutrients was carefully selected to provide plants with the essential elements needed for healthy growth. Once the nutrient solution was prepared, the pH was adjusted to 6 and an average conductivity of 2000 μS/cm was reached. These parameters were meticulously controlled to ensure an optimal environment for plant development. The cultivation process began with the germination of the seeds, called JUSTINE, over 15 days. During this crucial stage, the seeds were provided with ideal moisture and temperature conditions to promote successful and healthy germination. After completing the germination process, the seedlings were transferred to the PVC pipe arrangement for their development phase. This period, which spanned 60 days, allowed the plants to establish and develop their root systems in the hydroponic environment. Finally, once the optimal growth stage was reached, the crops were harvested. This moment marked the successful outcome of a carefully planned and executed process, which involved meticulous attention to detail and the use of innovative agricultural practices to ensure the quality and yield of hydroponic crops.

C. Parameter recording and monitoring module:

To carry out the implementation of this project, various essential components were required for monitoring physical parameters through the use of sensors. The coordination and management of these sensors were carried out by an Arduino Uno board, which acted as the brain of the system. The Arduino Uno's processing and control capabilities allowed data to be collected accurately and efficiently. Once the data was collected, the Arduino Uno system transmitted it via serial communication to an ESP module, which facilitated connection to the cloud. This two-way communication with the ESP enabled the transfer of information to a cloud platform, where the data could be managed, viewed, and stored remotely.

As for the sensors used, they were carefully selected to capture a wide range of physical parameters relevant to hydroponic cultivation. These include:

- The DS18B20 is a digital temperature sensor that uses the 1-Wire protocol for communication. It is possible to connect several sensors on the same bus since it only requires one data pin. It comes in a TO-92 type package, preferably inside a waterproof stainless steel tube for convenience and robustness. With this sensor, temperatures can be measured from -55°C to 125°C, with programmable resolution from 9 to 12 bits. Each sensor has a unique 64-bit address, allowing it to be identified on a 1-wire bus with multiple devices.

- The PH-4502C pH and temperature measurement module operates on a supply voltage of 5VDC, with a wide pH measurement range from 0 to 14 and temperature from 0 to 80°C. It provides fast measurements, with a response time of 5 seconds, and a stabilization time of 60 seconds. It has a compact size of 42.5 x 32.6 x 20 mm, which makes it easy to integrate into various projects. This module offers analog and digital outputs for temperature and pH, with a ground connection and a 5V input for power.

- The TDS Gravity sensor SKU SEN0244 indicates the amount of soluble solids in a liter of water. A higher TDS value indicates less clean water. It supports input voltages of 3.3 ~ 5.5 V and provides an analog voltage output of 0 ~ 2.3 V, making it adaptable to 5V or 3.3V control systems. Its excitation source is the AC signal, which prevents polarization of the probe and prolongs its useful life. The probe is waterproof, allowing long-term measurements in submerged water.

The diagram in Fig. 3 details the connections used to establish communication between the sensors and the Arduino. Each sensor is connected to the Arduino following the technical specifications and the feasibility of correct readings concerning the compatibility between the sensor and the Arduino. It is important to ensure a proper connection for each sensor, ensuring that the input and output pins are correctly configured on the Arduino to receive and process data from the sensors efficiently and accurately.

Fig. 3: Sensorization architecture.

Fig. 4 represents in detail the process by which the data captured by the sensors, managed by the Arduino, are transferred to the cloud through the ESP. This process is essential to convert our local system into an IoT architecture, which allows us to take advantage of the advantages of cloud computing for data management and analysis. Once the data is transmitted to the "thinger" platform, it becomes accessible from any location with an Internet connection. This not only facilitates remote monitoring of hydroponic cultivation parameters but also enables long-term storage and analysis to extract relevant information. In short, this connection to the cloud significantly enriches our ability to understand and optimize the cultivation process, thus contributing to research success.

Fig. 4: Arduino and ESP Serial Communication.

4. Results:

After 45 days dedicated to the development of the lettuces, the harvest was carried out, obtaining specimens that reached a maximum weight of 745 grams. These lettuces had excellent coloration on their leaves and roots, suggesting healthy growth and optimal growing conditions. This result is indicative of the success of the hydroponic cultivation process implemented, highlighting the quality and productive potential of this system in the production of fresh, high-quality vegetables. Fig. 5 shows lettuce that represents an optimal result obtained from the hydroponic modules implemented.

Fig. 5: Lettuce obtained from the hydroponic module.

The architecture presented for data collection, visualization, and storage worked successfully, proving to be of vital importance for the decision-making and optimization of the hydroponics modules detailed in this research work. This architecture includes three fundamental sensors: one for temperature, pH, and water conductivity. These sensors made it possible to accurately measure crucial factors for the growth of lettuce, which was the crop developed in this Project. The implementation of this IoT data acquisition module is shown in Fig. 6.

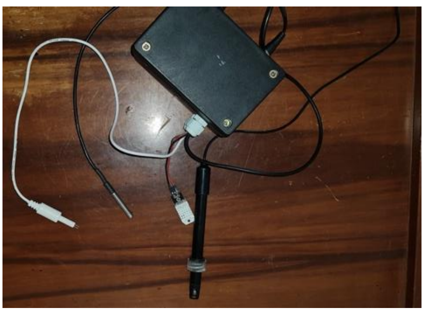

Fig. 6: Data acquisition module.

Furthermore, the collected data was stored on the "thinger.io" platform through the use of an ESP32, which facilitated the conservation and management of the collected information. The ability to store this data was essential for the optimization of hydroponic processes, as it provided a detailed history that allowed the evolution of the research project to be observed and analyzed over time. This historical record not only served to evaluate the performance and effectiveness of the implemented system but also laid the foundations for future improvements and adjustments in the hydroponic cultivation technique used. The dashboard implemented in the aforementioned Platform is shown in Fig. 7, this data is collected and stored in real-time.

Fig. 7: Dashboard of data collected in real time.

These data, as shown in the previous figure, can be viewed from any device with an internet connection, be it a cell phone, a laptop, a tablet, etc. This facilitates the analysis and monitoring of the temperature, conductivity, and pH parameters, which are essential for this research project.

5. Conclusion

The project to develop an IoT-based smart hydroponics experimental module in Lima, Peru, has proven to be an effective response to the food crisis and the challenges of traditional agriculture. Hydroponics is presented as a promising alternative that allows for more efficient use of water, eliminates the need for agricultural fertilizers and insecticides, and ensures a controlled, contaminant-free environment for growing vegetables. The results obtained after 45 days of lettuce development in the experimental module demonstrate the success of the implemented system. The harvested lettuces reached a maximum weight of 745 grams, significantly higher than the 350 grams of lettuce available on the local market. Additionally, these lettuces showed excellent coloration in their leaves and roots, indicating healthy growth under optimal growing conditions. The architecture designed for data collection, visualization, and storage, including temperature, pH, and water conductivity sensors, turned out to be crucial for monitoring and optimizing hydroponic processes. The integration of IoT technologies made it possible to accurately measure the key factors for the growth of lettuce and store the collected data on the "thinger.io" platform through the use of an ESP32. This data storage facilitated the conservation and management of information, providing a detailed history that allowed the evolution of the project to be analyzed over time.

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Data Availability:

This study did not involve the creation or analysis of new data. Therefore, data sharing is not applicable.

Conflict of interest:

The authors declare no conflicts of interest.

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