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IoT-Based Smart Vertical Hydroponic System for Chili Plant

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ABSTRACT

Agriculture serves as the primary source of food for the global population, playing a critical role in meeting the nutritional needs of people worldwide. With the projected population reaching 9.7 billion by 2050, ensuring an adequate and sustainable food supply becomes increasingly challenging. Hydroponics, a technique that cultivates plants without soil by delivering mineral nutrients through water, offers a potential solution. Hydroponics requires only 10% of the space and 90% less water compared to conventional farming, enabling year-round production of nearly organic food. Vertical hydroponic systems, which arrange plants in stacked or suspended layers, optimize the use of vertical space and are particularly suitable for indoor and urban agriculture where land is limited. However, these systems require regular maintenance and monitoring, including managing nutrient solution balance, pH levels, water quality, and lighting conditions. This complexity can pose challenges for growers lacking time, resources, or technical expertise. To address these issues and ensure sustainability, an automated monitoring method is proposed for vertical hydroponic farming. This project aims to develop a system that automates the checking and maintenance of nutrient levels in the vertical farming process, monitoring factors such as Electrical Conductivity (EC), pH, liquid level, and water temperature. The integration of automation technologies in vertical hydroponics enhances precision, efficiency, and productivity by reducing labour requirements, optimizing resource utilization, and granting growers greater control over the growing environment. These advancements result in healthier plants, higher yields, and more sustainable agricultural practices.

1. Introduction

The global population is projected to increase by 2 billion people by 2050, posing a significant challenge in feeding an ever-growing number of individuals with limited available land [1]. Addressing this challenge requires innovative technologies that promote sustainability [2]. Hydroponics, an emerging technique, holds promise for feeding the population by efficiently growing nutrient-rich plants with minimal resource consumption [3-5]. Among the various hydroponic approaches, vertical farming has gained attention as a solution to the land scarcity issue. This method involves cultivating

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plants and vegetables on vertically inclined surfaces, allowing for increased crop production within a limited growing area [6]. Compliance with internationally recognized food safety and quality standards, such as Codex Alimentarius Commission guidelines or certifications like Global Good Agricultural Practices (GlobalGAP), ensures that vertical farms maintain hygiene, pest control, traceability, and crop quality standards [6].

The primary objective of this study is to monitor essential parameters in vertical farming systems, including environmental conditions (temperature, humidity, light intensity), nutrient levels, and water quality. Real-time monitoring enables prompt detection of deviations or anomalies, facilitating timely corrective actions. Moreover, monitoring plays a vital role in ensuring optimal nutrient provision to the plants. In addition, the proposed solution aims to minimize electricity and water usage during the cultivation of chili plants [7].

2. Literature Review

Hydroponics, a vertical farming technique that uses nutrient solution as the growing medium, has gained popularity for cultivating various plants and leafy vegetables [7]. This approach eliminates issues associated with soil-borne diseases and pests like cutworms, which can harm plants and jeopardize crop yields [8]. The Nutrient Film Technique (NFT) system is a widely adopted hydroponic method for plant cultivation. In an NFT system, a thin film of nutrient-rich water continuously flows over the plant roots, providing essential water, oxygen, and nutrients [8,9]. Regular monitoring of key parameters, including pH, electrical conductivity (EC), and nutrient levels, is crucial in NFT systems. Adjustments to the nutrient solution may be necessary to maintain optimal conditions for plant growth and prevent nutrient imbalances. Another hydroponic method, known as flood and drain, involves flooding the grow tray with nutrient solution for a set period before draining it back into the water tank. Typically, this is achieved using a submerged water pump connected to a timer. Continuous flow is essential to prevent the roots from drying out, so any interruption in nutrient solution flow can be detrimental to plant health [10].

Maintaining the pH level is vital in hydroponic systems, as it significantly affects plant health. Studies indicate that the ideal pH range for hydroponic plants is between 5.8 and 6.2. Adjusting the pH value can be done using pH up and down solutions or household items like white vinegar or citric acid to lower the pH and baking soda to increase it. In this study, a pH down solution is used to lower the pH level of the nutrient solution [11]. Chili plants have specific nutrient requirements. It is important to measure and adjust the electrical conductivity (EC) or total dissolved solids (TDS) of the nutrient solution to ensure appropriate nutrient strength at different growth stages. Furthermore, maintaining the nutrient solution temperature between 18°C and 23°C (64°F to 73°F) promotes optimal nutrient uptake and helps prevent issues like root rot. Chili plants thrive in warm and humid conditions, so maintaining air temperature between 20°C and 30°C (68°F to 86°F) and relative humidity around 50-70% mimics their natural habitat and supports healthy growth. Adequate light intensity and duration are also critical. Providing a light intensity of 400-800 µmol/m²/s using suitable grow lights, such as LED or high-intensity discharge (HID) lamps and adjusting the light duration to provide 12-16 hours of light per day for both vegetative and flowering stages contribute to optimal photosynthesis and fruiting [10-13].

3. Methodology

Figure 1 illustrates the overall setup of the monitoring system. The study utilized an Arduino Mega board due to its capacity to accommodate more analog pins required for the sensory system. For the data logging process, NodeMCU was chosen to transmit all monitored data to the Ubidots cloud. MQTT protocol was employed for device communication (M2M), and the data was converted to JSON format to enable the system to make post requests to the Ubidots cloud server using NodeMCU. The system incorporated four sensors for various monitoring purposes, with the ultrasonic sensors specifically employed to measure the nutrient solution level in the vertical farming setup. To regulate water flow within the vertical farming system, an electric motorized valve was employed [14].

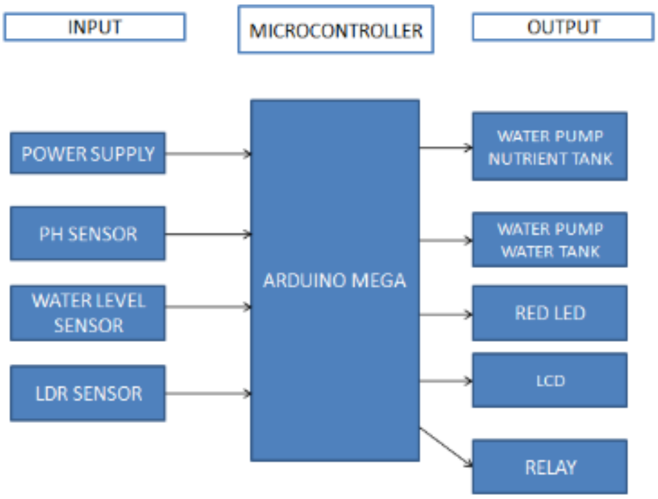

Fig. 1. Block diagram of the entire system

Figure 2 depicts the hardware setup design created using SolidWorks software. The setup consists of two levels: the first level houses the water tank, while the second level is dedicated to the vertical farming structure. The bottom level incorporates two water tanks: one for clean nutrient solution and another for collecting the used nutrient solution drained from the vertical farming. A small water filter is connected between the two tanks to filter the used nutrient solution before it flows back into the tank with clean nutrient solution. Three sensors, including EC, pH, and temperature sensors, are placed in the water tank to continuously measure the nutrient level, pH level, and water temperature. Additionally, two small nutrient pumps are included to deliver the concentrated A and B nutrients into the water tank for adjusting the nutrient composition. Along each vertical farming unit, four sensors are placed. An ultrasonic sensor is positioned at the edge of the vertical farming to detect the nutrient solution level within the system. The EC sensor, temperature sensor, and pH sensor are situated in the middle of the vertical farming structure to measure the EC, temperature, and pH values [15].

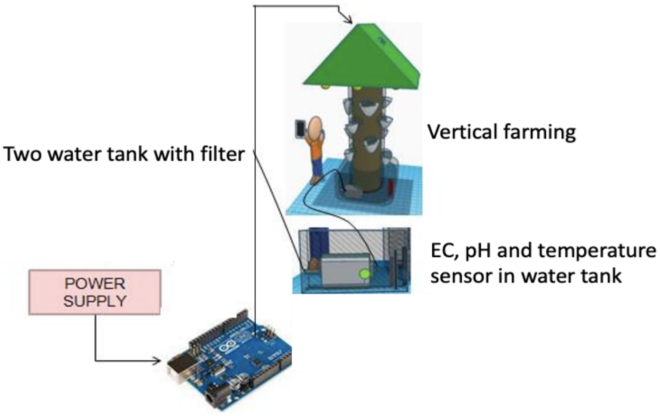

Fig. 2. Monitoring system for vertical hydroponic plant

The general flowchart development of the Automated Control System for vertical hydroponic plants is depicted in Figure 3. To implement the system, a customized code is programmed in the Arduino IDE to establish the required connections and ensure compatibility with the hardware circuit. The hardware setup allows for observation and verification of successful connections and the functionality of the components when connected to the Arduino Mega. The system incorporates an LDR sensor that detects the intensity of light. When the LDR sensor detects low light intensity, the LED will turn on, and when it detects high light intensity, the LED will turn off. Additionally, a DHT22 sensor measures the temperature, and when the temperature is below 28 degrees, the LED will turn on. Conversely, when the temperature is 28 degrees or higher, the LED will turn off. The water level sensor monitors the water level in the container. If the water level falls below 420 liters, water will be pumped into the container until it reaches 520 liters. Furthermore, the system includes a pH sensor that detects the pH value in the container. When the pH value is between 6.0 and 6.5, the system will stop the fertilization process as instructed by the user [15].

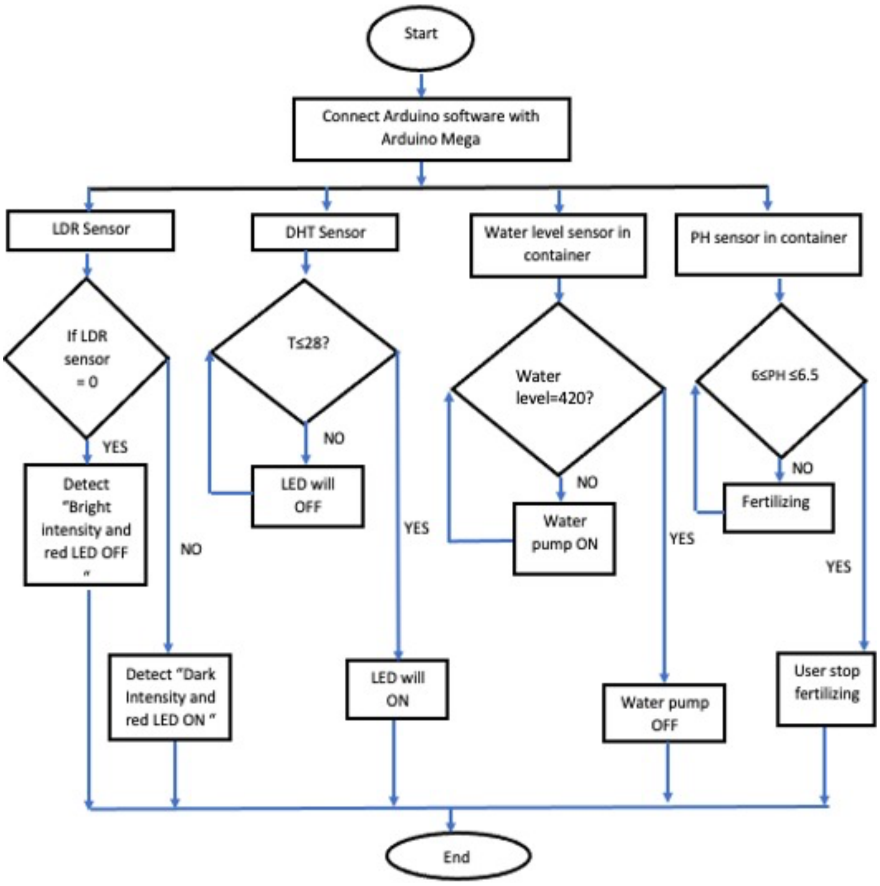

Fig. 3. Flowchart setup development of Automated Control System for vertical hydroponic plant

4. Result and Discussion

This section presents the findings and analysis derived from the conducted experiments and explores their implications and significance. This section provides an in-depth examination of the collected data, including the verification of the EC sensor, the control system output, the electrical energy consumption, the performance of the water level sensor, the behaviour of the pH sensor, and other relevant aspects. The results are discussed in relation to the project's objectives, and their implications for the overall effectiveness and feasibility of the automated control system for vertical hydroponic plants are thoroughly examined.

4.1 EC Sensor Verification

The comparison between a TDS meter and a DIY EC sensor is presented in Table 1. The calculated percentage error between the measured values obtained from the DIY EC sensor and the TDS meter is 3.22%, indicating a relatively small margin of error [15].

Table 1
Comparison between TDS meter and DIY EC sensor

	EC (ppm)	Temperature (^{0}C)
TDS & EC meter (in clean water)	49	15
DIY EC & temperature sensor (in clean water)	50	1500
TDS & EC meter (nutrient solution in water tank)	1433	27.5
DIY EC & temperature sensor (nutrient solution in water tank)	1400	25

4.2 Output System

The filling process for both layers of the vertical farming system is completed within approximately 2 minutes. This efficiency is achieved by utilizing a high-powered water pump that significantly reduces the required time. The output power of the pump can be adjusted to ensure a controlled flow rate that is not excessively fast. The pump's maximum flow rate is capable of reaching 1200L/hour, but for safety reasons, the power is set to the minimum during testing. The calculated flow rate output from the water pump is 221.22L/hour, which corresponds to approximately 20% of the maximum power output. In contrast, the drainage process from the vertical farming system is slower due to the gentle slope of the structure. This slope is designed to allow the water to naturally flow back to the water tank, aided by the force of gravity. When the electrical motorized valve is opened, the water utilizes the slope and gravity's assistance to drain downwards [15].

The submersible water pump flow rate:

$$\begin{aligned} \textit{Total volume required for both regular PVCs} &= 2[100\textit{cm(length)} \times 10.16\textit{cm(width)} \times 3.53\textit{cm (height)}] \\ &= 7374\textit{cm}^3 / 7.374\ \textit{liter} \end{aligned}$$

$$\begin{aligned} \textit{Flow rate of the water pump} &= 7.374\textit{L}/2\ \textit{minutes} \\ &= 221.22\textit{L/hour} \end{aligned}$$

4.3 Energy Consumption

The electrical energy consumption of various electronic components in the system, such as growing lights, water pumps, nutrient pumps, air pumps, and electrical motorized ball valves, was assessed. A comparison was made between the electrical consumption of the implemented monitoring vertical farming system and a conventional NFT system [15].

The following formula was used to calculate the electrical energy consumption:

Electrical consumption for NFT system (per day):

$$E(\text{Growing light}) = P \times t(h/day)y\ 1000(W/kW) = 14W \times (8h\ day)/1000(W/kW) = 0.112kWh$$
$$E(DB-6612\text{water pumps}) = (18W \times 20\%) \times 24/1000 = 0.0864kWh$$
$$E(DB-6618\text{water pumps}) = (22W \times 20\%) \times 24/1000 = 0.1056kWh$$
$$E(2 \times \text{air pumps}) = [(2.5) \times 24/1000] \times 2 = 0.12kWh$$
$$E(\text{Electrical Ball Valves}) = (0w) \times 24/1000 = 0kWh$$

Total Electrical consumption = 0.424kWh per day

Electrical consumption for current monitoring system (per day):

$$E(\text{Growing light}) = 14w \times (8h/day)/1000(W/kw) = 0.112kWh$$
$$E(DB-6612\text{water pumps}) = (18W\ x\ 20\%) \times 3{,}2/1000 = 0.01152kWh$$
$$E(DB-6618\text{water pumps}) = (22W\ x\ 20\%) \times 3.2/1000 = 0.01408kWh$$
$$E(2 \times \text{air pumps}) = [(2.5) \times 24/1000] \times 2 = 0.12kWh\ E(\text{Electrical Ball Valves})$$
$$= (5W) \times 0.8/1000 = 0.004kWh$$

Total Electrical consumption = 0.2616kWh per day

Based on the calculations conducted, it can be concluded that the current monitoring system exhibits lower energy consumption compared to the NFT system.

4.4 Data Monitoring Process

Figure 4 showcases the Ubidots dashboard and displays the measured pH value. Utilizing the Ubidots cloud platform offers several advantages, including a user-friendly graphical user interface (GUI) for data visualization. Additionally, Ubidots automatically generates graphs based on the collected data, eliminating the need for manual data assignment. The pH value demonstrates considerable variation initially but gradually stabilizes over time, eventually falling within the optimal range of 5.9 – 6.2. It is worth noting that, from the figures presented, only the pH value and temperature sensor data were successfully transmitted to the cloud. This limitation arose due to a parsing error encountered when attempting to make a post request containing JSON data from the three DIY EC sensors.

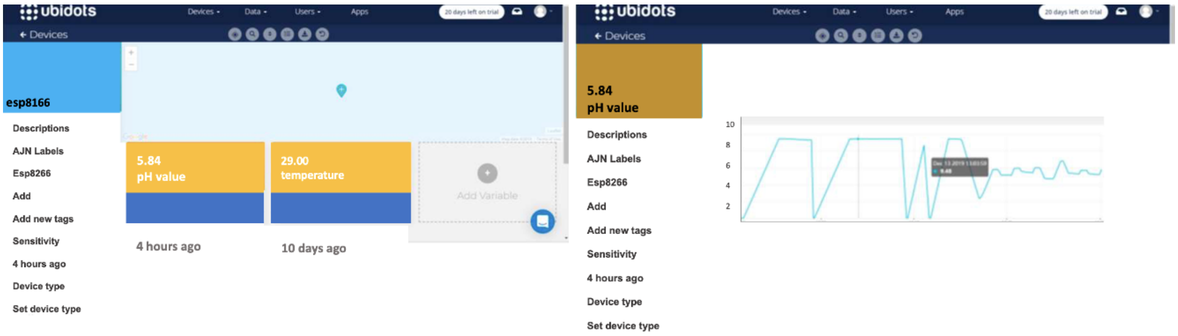

Fig. 4. Ubidots dashboards (left) and pH reading measurement (right)

Figure 5 presents a line graph displaying the temperature measurements taken over a 30-minute period, from 6:30 PM to 7:00 PM. The temperature range for the DHT11 sensor is -40 to +125 degrees Celsius, with an accuracy of ±0.5 degrees, while its precision for temperatures within 0 to 50 degrees Celsius is ±2 degrees. On the other hand, the DHT11 sensor has a humidity measurement range of 20% to 80% with an accuracy of ±5%, whereas the DHT22 sensor covers a humidity range of 0% to 100% with an accuracy of ±2-5% [5]. In the graph, the initial temperature reading was relatively high, starting at 32.90 degrees Celsius. However, over the course of minutes 7 to 30, the temperature gradually decreased to 29.90 degrees Celsius. These measurements are within the capabilities of the temperature sensor employed in the study.

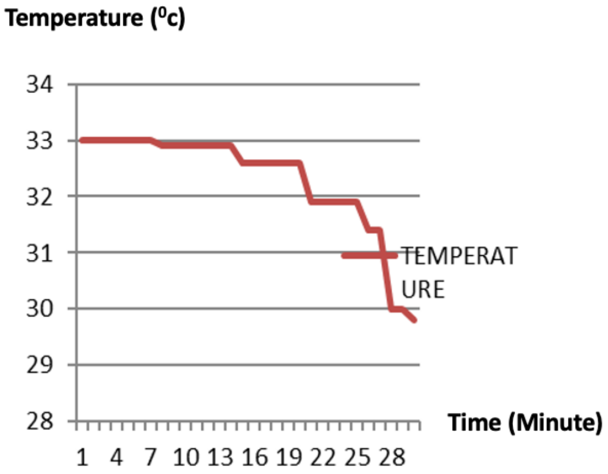

Fig. 5. Line chart of temperature vs. time in 30 minutes duration

Figure 6 illustrates the Humidity line graph, depicting data collected over a 30-minute duration. The graph clearly shows an increase in humidity percentage once rainfall began. During this period, the humidity ratio rose from 65.10% to 66.80%. This rise in humidity can be attributed to the process of water evaporation. After rainfall, there is an increase in water vapor in the air due to evaporation. Additionally, as evaporation requires heat, the air cools during rainfall. This cooling effect, coupled with increased moisture content, contributes to an elevation in relative humidity over the short term [14,15].

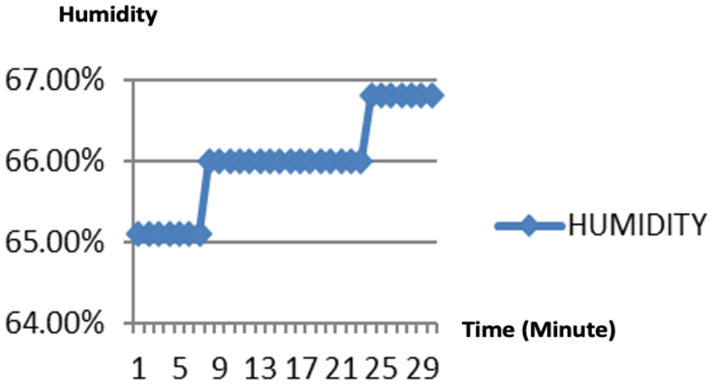

Fig. 6. Line Chart humidity vs. time in 30 minutes duration

Figure 7 depicts the line graph for LDR (Light Dependent Resistor) and LED. In this project, three RED LEDs were utilized as artificial sunlight for indoor plant cultivation. The graph represents data collected between 6:30 PM and 7:00 PM. During minutes 1 to 19, the LDR detected bright intensity

(0), resulting in the LED being turned OFF (0). Conversely, when the LDR sensor detected dark intensity (1), the LED was turned ON (0). From minute 20 up to minute 30, both the LDR and LED values remained at 1.

4.2 Temperature and Humidity (DHT 22)

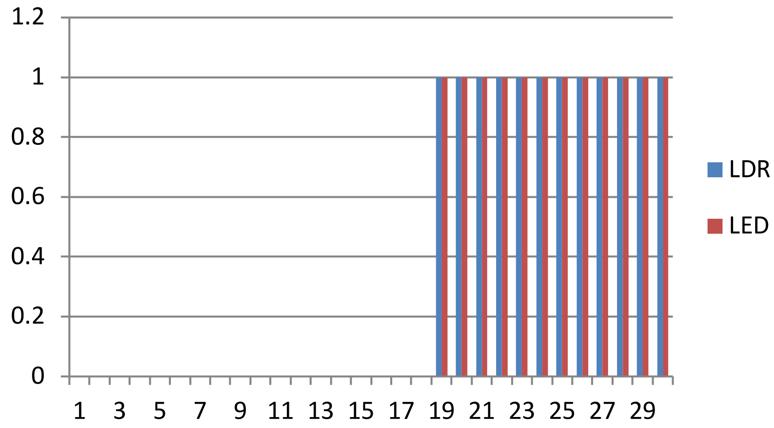

Fig. 7. Intensity of LDR and LED vs. time in 30 minutes duration

The water level sensor consists of ten exposed copper traces, with five acting as power traces and the other five as sense traces. These traces are arranged in an interlaced pattern, with one sense trace positioned between every two power traces. Normally, these traces are not connected, but when the sensor is submerged in water, the water bridges the gaps between the traces. The board includes a Power LED that illuminates when the sensor is powered. The functionality of the water level sensor is straightforward. The series of parallel conductors act as a variable resistor, with its resistance changing based on the water level. The resistance corresponds to the distance between the top of the sensor and the water surface. When the sensor is immersed in more water, the conductivity improves, resulting in a lower resistance. Conversely, when the sensor is immersed in less water, conductivity decreases, leading to a higher resistance [8]. Figure 8 illustrates the behavior of the water level sensor. When the sensor detects a water level below 420 liters in the container, the water pump activates. The red line on the figure represents the threshold of 420 liters. Once the water level reaches or exceeds this range, the water pump automatically turns off.

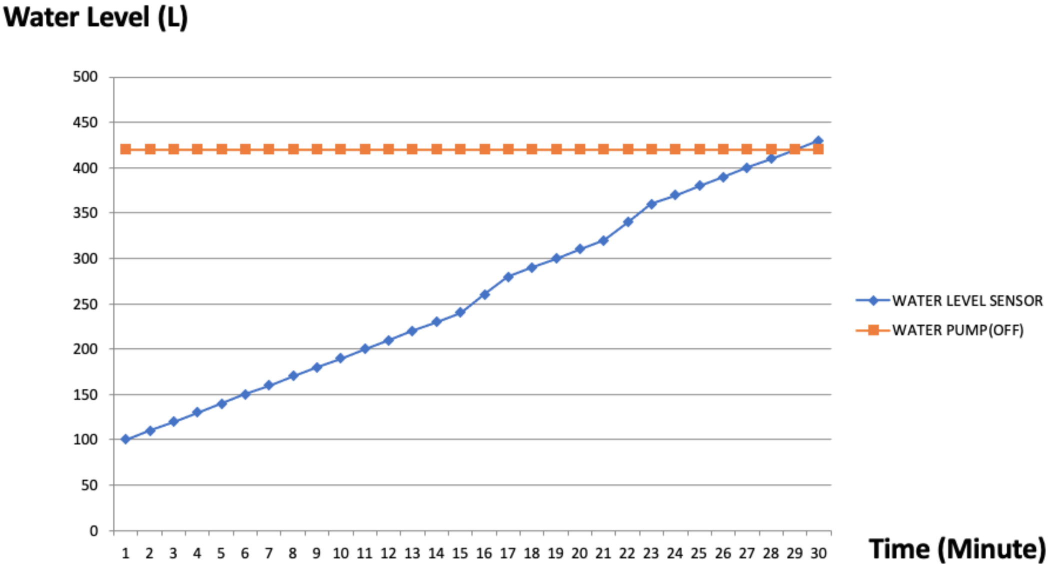

Fig. 8. Water Level Sensor vs. time in 30 minutes duration

Figure 9 presents a line graph of the pH sensor readings for six different liquids, namely lemon juice, soda, coffee, milk, pure water, and baking soda. The pH scale is used to determine the acidity or alkalinity of a substance. The scale ranges from 0 to 14, with 7 representing neutrality. Values below 7 indicate acidity (0 to 6), while values above 7 indicate alkalinity (8 to 14). For example, lemon juice has a pH value of 2, indicating its acidic nature. Pure water, with a pH value of 7, is considered neutral, and baking soda, with a pH value of 9, is alkaline. The pH scale measures the concentration of free hydrogen and hydroxyl ions in water. This study focuses on developing a system for chili plants, which require a pH range of 6.0 to 6.5 for optimal growth. The user should continue fertilizing the plants until the pH sensor readings on the LCD display within the desired range of 6.0 to 6.5. Once the container's pH level reaches the required range, fertilization should be discontinued.

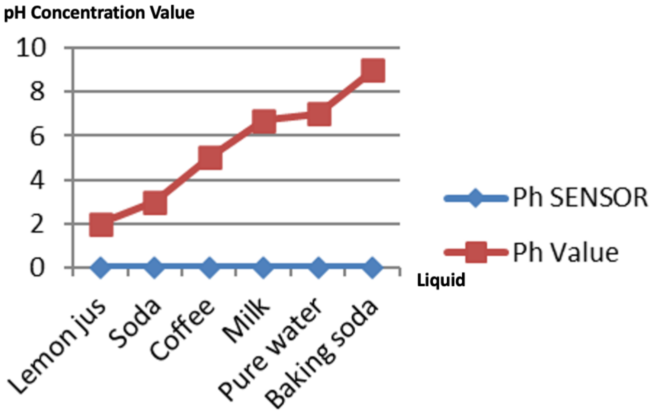

Fig. 9. pH Sensor line graph vs. different liquid

5. Conclusions

In conclusion, the Automatic Vertical Hydroponic system represents a versatile, affordable, and user-friendly solution for modern agricultural practices. It has emerged as one of the most popular and practical automated systems, providing convenience and efficiency to users in various settings. This system offers an excellent gardening solution while requiring minimal energy consumption. As highlighted, the water level sensor plays a crucial role in monitoring the water level in the tank or container. It ensures that the water pump operates when the water level is insufficient and shuts off when the water level reaches an adequate level. This automated control system for vertical hydroponic plants presents an innovative approach, incorporating the appropriate sensors and architecture to enhance the efficiency and productivity of hydroponic cultivation. Generally, the development of this automated control system for vertical hydroponic plants offers a promising solution for optimizing agricultural practices, promoting sustainability, and reducing manual effort and time requirements for growers.

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References

[1] Vidhya, R., and K. Valarmathi. "Survey on automatic monitoring of hydroponics farms using IoT." In *2018 3rd International Conference on Communication and Electronics Systems (ICCES)*, pp. 125-128. IEEE, 2018. https://doi.org/10.1109/CESYS.2018.8724103

[2] Al-Gharibi, Ruaa Suliman. "IoT-Based Hydroponic System." In *2021 International Conference on System, Computation, Automation and Networking (ICSCAN)*, pp. 1-6. IEEE, 2021. https://doi.org/10.1109/ICSCAN53069.2021.9526391

[3] Mahaidayu, Marsha Gresia, Arif Nursyahid, Thomas Agung Setyawan, and Abu Hasan. "Nutrient Film Technique (NFT) hydroponic monitoring system based on wireless sensor network." In *2017 IEEE International Conference on Communication, Networks and Satellite (Comnetsat)*, pp. 81-84. IEEE, 2017.

[4] Gultom, Judika Herianto, Maruf Harsono, Tubagus Dhika Khameswara, and Handri Santoso. "Smart IoT water sprinkle and monitoring system for chili plant." In *2017 International Conference on Electrical Engineering and Computer Science (ICECOS)*, pp. 212-216. IEEE, 2017. https://doi.org/10.1109/ICECOS.2017.8167136

[5] Ahmad, Yasser Asrul, Teddy Surya Gunawan, Hasmah Mansor, Belal Ahmed Hamida, Adam Fikri Hishamudin, and Fatchul Arifin. "On the evaluation of DHT22 temperature sensor for IoT application." In *2021 8th International Conference on Computer and Communication Engineering (ICCCE)*, pp. 131-134. IEEE, 2021. https://doi.org/10.1109/ICCCE50029.2021.9467147

[6] Malika, Naila Zakia, Md Gapar Md Johar, Mohammed Hazim Alkawaz, Asif Iqbal Hajamydeen, and Lilysuriazna Raya. "Temperature & humidity monitoring for poultry farms using IOT." In *2022 IEEE 12th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, pp. 76-81. IEEE, 2022. https://doi.org/10.1109/ISCAIE54458.2022.9794520

[7] Runkle, Erik. "Red light and plant growth." *Technically speaking - gpnmag.com* (2016).

[8] Hidayat, M. Reza, Susanto Sambasri, Firman Fitriansyah, Atik Charisma, and Handoko Rusiana Iskandar. "Soft water tank level monitoring system using ultrasonic HC-SR04 sensor based on ATMega 328 microcontroller." In *2019 IEEE 5th International Conference on Wireless and Telematics (ICWT)*, pp. 1-4. IEEE, 2019. https://doi.org/10.1109/ICWT47785.2019.8978229

[9] Despommier, Dickson. *The vertical farm: feeding the world in the 21st century*. Macmillan, 2010.

[10] Despommier, Dickson. "Farming up the city: The rise of urban vertical farms." *Trends in Biotechnology* 31, no. 7 (2013): 388-389. https://doi.org/10.1016/j.tibtech.2013.03.008

[11] Brechner, M., and A. J. Both. *Hydroponic Lettuce Handbook*. Cornell Controlled Environment Agriculture, Cornell University, 2020.

[12] Berry, Wade L., and Sharon Knight. "Chapter 8 : Plant Culture in Hydroponics." *Plant Growth Chamber Handbook* (1997): 119-132.

[13] Mattson, Neil S., and Cari Peters. "A recipe for hydroponic success." *Inside Grower* (2014): 16-19.

[14] Hensen, Robert. "Manage pH and Soluble Salts in Hydroponics." *Greenhouse Grower*. September 6, 2012. https://www.greenhousegrower.com/crops/ornamentals/manage-ph-and-soluble-salts-in-hydroponics/.

[15] Michael, G. W., F. S. Tay, and Y. L. Then. "Development of automated monitoring system for hydroponics vertical farming." In *Journal of Physics: Conference Series*, vol. 1844, no. 1, p. 012024. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1844/1/012024