Asian Journal of Agriculture and Rural Development
Volume 12, Issue 3 (2022): 210-219.
http://www.aessweb.com/journals/5005

AUTOMATIC MONITORING SYSTEM FOR HYDROPONIC FARMING: IOT-BASED DESIGN AND DEVELOPMENT

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Article History
Received: 10 May 2022
Revised: 19 September 2022
Accepted: 3 October 2022
Published: 14 October 2022

Keywords
Environmental parameters
Hydroponic farming
Internet of things
Monitoring system
Nutrient solution
Wireless communication.

ABSTRACT
Traditional agriculture is currently facing many difficulties and obstacles. One reason is that climate change has led to a harsher environment and more pests and diseases. Also, the expansion of industrial zones has significantly reduced the arable land area. To overcome these difficulties, farmers need to change their farming methods and apply scientific and technological advances to their practice. In this paper, we report on the design and development of an automatic monitoring system for hydroponic farming based on the internet of things technique. This system allows sensor data to be collected in real time. An IoT gateway and virtual server were developed to transmit this gathered data to the cloud and store it. Via the web interface, the user can observe all the sensor data of the environment and hydroponic solution, as well as control the farming equipment. The system has been tested and evaluated during lettuce growth in an NFT hydroponic system. The experimental results show that the proposed system operates stably and achieves high reliability. The collected sensor data stored on the server can be used to analyze and evaluate the impact of environmental parameters on plant growth during cultivation.

Contribution/Originality: This study reports on the design and implementation of a system to monitor culture parameters in hydroponic farming. Using this system, farmers can monitor environmental and nutritional parameters throughout the entire farming process. The collected data allows agricultural experts to analyze and evaluate the effects of farming parameters on the development of produce.

DOI: 10.55493/5005.v12i3.4630
ISSN(P): 2304-1455/ ISSN(E): 2224-4433
How to cite: Huu Cuong Nguyen --- Bich Thuy Vo Thi --- Quang Hieu Ngo (2022). Automatic Monitoring System for Hydroponic Farming: IoT-Based Design and Development. *Asian Journal of Agriculture and Rural Development*, 12(3), 210-219. 10.55493/5005.v12i3.4630

1. INTRODUCTION
Agriculture plays an important role in the world's food security. Traditional farming is facing the problems of climate change, crop failure, and pests. Many researchers have studied various ways to improve yield (Datta & Behera, 2022; Shi, Lou, Zhang, & Xu, 2021), including the use of different cultivars, farming methods, crop changes, etc. Nowadays, in modern agriculture, growing in greenhouses has become more common (Forkuor, Amponsah, Oteng-Darko, & Osei, 2022; Notte et al., 2020; Tomaselli, Russo, Riguccio, Quattrone, & D'Emilio, 2020). The growing environment directly affects production and output, so it is necessary to implement a stable and reliable monitoring system to closely monitor the growing environment. Modern agricultural systems need an internet of things (IoT)

platform to store and process data and allow users to remotely monitor their crops. Most IoT system architectures are divided into three layers: a perception layer, a transport layer, and an application layer. However, this division has some limitations; it cannot distinguish between differences in technology in applications, or between differences in specific user characteristics. To overcome these drawbacks, some IoT system architectures are divided into four layers: an application layer, a service support and application support layer, a network layer, and a device layer (Verdouw, Sundmaeker, Tekinerdogan, Conzon, & Montanaro, 2019).

In recent years, environment monitoring systems that use new communication and information technologies have become available in the agriculture sector. Data transmission is an important part of an IoT platform. Wireless data transmission technologies, such as ZigBee, Bluetooth, LoRa, WiFi, GPRS, 4G, and 5G, have created the possibility of building distributed sensor networks. This allows the monitoring of environmental parameters on a large scale in real time. Muangprathub et al. (2019) designed and developed a wireless sensor network between node sensors in a field of crops to optimally water the crops and gather data via smartphone and web applications. Benyezza, Bouhedda, and Rebouh (2021) developed a zoning irrigation system based on IoT to optimize plant growing conditions and reduce water and energy consumption. The monitoring system was installed in different zones of a greenhouse based on a wireless sensor network (WSN). Dasgupta, Saha, Venkatasubbu, and Ramasubramanian (2020) fed a WSN model, combined with AI technology, into a crop prediction and weed detector system based on a list of factors, including temperature, annual precipitation, total available land size, past crop growth history, and other resources, to quickly and effectively recommend suitable crops to farmers. Codeluppi, Cilfone, Davoli, and Ferrari (2020) employed a Long-Range Wide-Area Network (LoRaWAN) technique to develop a smart farming modular IoT architecture that aimed to improve the management of generic farms in a highly customizable way. Wang et al. (2021) designed and implemented a LoRaWAN to provide remote data sensing functions for a planned smart agriculture recycling rapid processing factory.

Hydroponics is a method of growing plants. Instead of using soil, hydroponics depends on a water-based nutrient-rich solution. Hydroponics is clean and easy compared to traditional farming. Hydroponics is the best solution to help plants grow well in regions with harsh climates, such as arid deserts and urban areas. Nutrient parameters, climate, and growing solutions play key roles in hydroponics (Niu & Masabni, 2021). Over the years, many hydroponic farming systems have begun to use sensors and actuators to control and measure environmental and plant growth parameters. This allows farmers to create a suitable environment for large-scale production and high-quality farming. Bakhtar, Chhabria, Chougle, Vidhrani, and Hande (2018) built an IoT-based hydroponic farm that monitors and controls water levels and pH values for spinach. The user receives an alert from the system if the pH level or water level does not match a required value stored in the system's database. Changmai, Gertphol, and Chulak (2018) developed a smart hydroponic farm using IoT technology. This farm can monitor the growing environment, including the nutrient solution, air temperature, and humidity. Rajkumar, Dharmaraj, and Scholar (2018) implemented an IoT-based system that employed a Zigbee protocol for communication between sensors. They replaced fluorescent lights with LEDs to reduce electricity consumption in large farming spaces. Komal and Bhardwaj (2014) implemented an IoT-based automated farming system that uses lamps instead of normal light. The system includes a seed selection robot, a data analysis system, and a direct ventilation control system. Mishra and Jain (2015) implemented a plant box, which is a very small box that uses LED lights and provides water and necessary nutrients to the plant tank. Lakshmikantha et al. (2021) introduced a smartphone application-based control system. Deokar, Iyer, Badgujar, Yadav, and Venkat (2021) and Rahman, Sultan, Dash, and Khan (2018) addressed the limitation of smartphones, as they are not always available, by introducing web-based applications instead. IoT techniques for monitoring various components, such as nutrient solutions, humidity, electrical conductivity, and pH, have been very successful. Charumathi, Kaviya, Kumariyarasi, Manisha, and Dhivya (2017) implemented an Arduino-based system with an IoT to analyze and maintain the data gathered from various sensors and actuators. The author implemented the same on the Android platform, where JSON is helpful for combining information gathered from various sensors and devices. The use of a microcontroller with an MQ Telemetry Transport (MQTT) protocol was also implemented to give connectivity to the IoT gateway. Sudharsan, Vargunan, Raj, Selvanayagan, and Ponmurugan (2019) proposed the implementation of a wireless sensor network.

This study focuses on building a system to monitor the parameters of the environment and nutrient solution of a hydroponic farming system. This system performs automatic monitoring of parameters such as temperature, air humidity, illumination, water temperature, pH, and TDS of the hydroponic solution and is expandable to include other parameters as needed. The monitoring system is based on IoT technology and uses sensors with high reliability and stability.

The remainder of this article is structured as follows. The next section describes the materials and methods and presents the architecture and operating principle of the monitoring system, along with the hardware design and webserver program. In the following section, the experimental results are described and discussed. Finally, conclusions are drawn.

2. MATERIALS AND METHODS

The proposed system is built on an IoT platform with a 3-layer architecture, including a perception layer, a communication layer, and an application layer. The main components of the proposed system are illustrated in Figure 1.

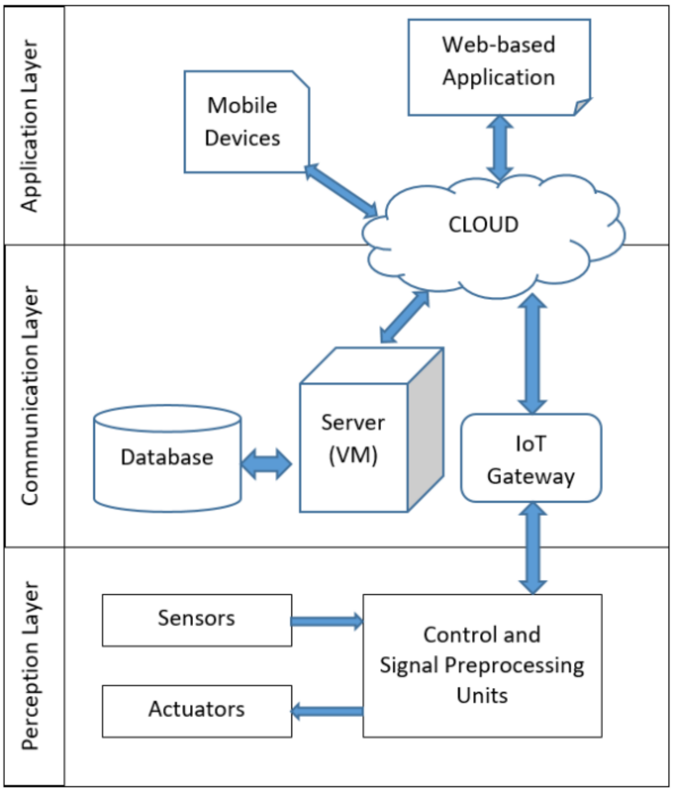

Figure 1. The architecture of the proposed system.

The proposed system operates according to the following process: Sensors sense information about the environment and the hydroponic nutrient solution. This information is converted into digital data and processed in the signal pre-processing unit. The IoT gateway has the function of forwarding these data to the cloud platform (internet). A webserver is installed on a virtual server machine that provides the user interface and stores data in the database. The data stored in the database can be retrieved for later uses such as analysis, forecasting, crop quality control, etc. Aside from the ability to monitor the farming parameters, the user can control the operation of pumps and fans by interacting with the web interface via a mobile device to change these parameters. The control signals are returned to the control units via the IoT gateway. After receiving the control signal, the controller will activate the corresponding actuators to on/off.

The control and signal pre-processing units are designed to include a microcontroller (Arduino UNO R3 kit) that collects the sensor probe's signal, normalizes the signal, and then transmits this normalized data to the IoT gateway via a ZigBee module (XBee shield). They also receive commands from the IoT gateway and control actuators (pumps, fans, etc.). The diagram of the sensor cluster is shown in Figure 2.

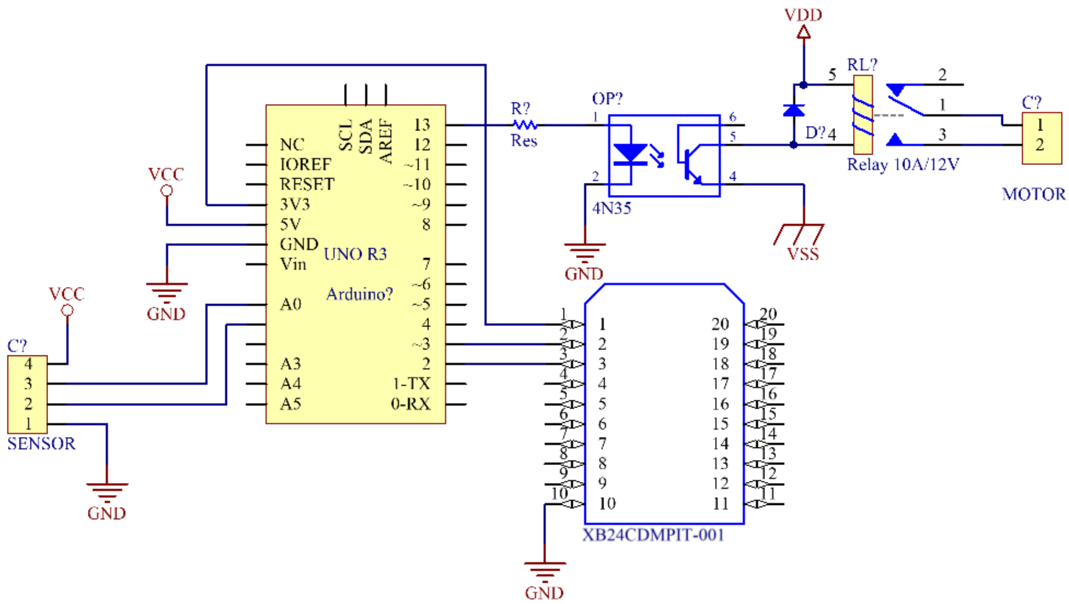

Figure 2. Control and signal pre-processing unit circuit diagram.

The IoT gateway is implemented using the NodeMCU ESP8266. An Arduino Mega 2560 kit is used to receive the data from the signal processing unit via the ZigBee module and displays these collected parameters on an LCD screen. Simultaneously, the received data is uploaded to the internet via the NodeMCU ESP8266's WiFi communication protocol. The schematic of the IoT gateway is illustrated in Figure 3.

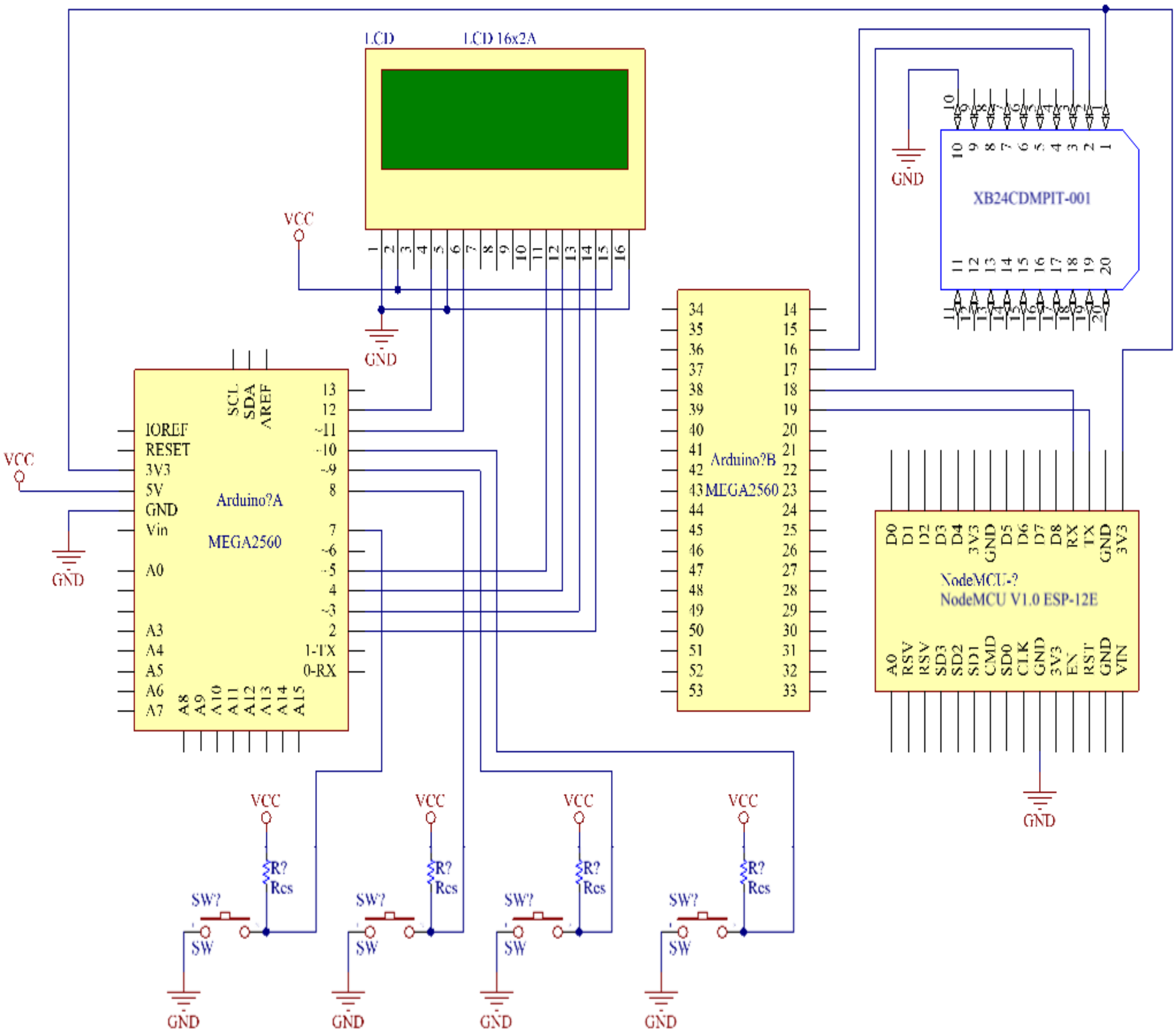

Figure 3. IoT gateway box circuit diagram.

A personal computer is used to build the virtual server machine based on Node-RED and built-in MQTT. MQTT is an OASIS standard messaging protocol for the IoT. It is a lightweight open messaging protocol that provides resource-constrained network clients with a simple way to distribute telemetry information in low-bandwidth environments. The protocol, which employs a publish/subscribe communication pattern, is used for machine-to-machine (M2M) communication. Node-RED is a programming tool for wiring together hardware devices, APIs (Application Programming Interfaces), and online servers. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single click.

The webserver is implemented with Node-RED and installed on a virtual server. The Node-RED dashboard is used to program a web page as an interface for the user and create a web application to process the information that is received from the sensors through the IoT gateway and store that information in a database. The website's interface is developed using the Node-RED dashboard as shown in Figure 4. The user can observe the parameters of the environment and the hydroponic nutrient solution through the displays and graphs on the interface. In addition, the web interface includes a switch to turn the water pump on/off. The data, which is collected in real-time, is stored in a CSV (Comma Separated Values) file. The flow of the webserver is shown in Figure 5.

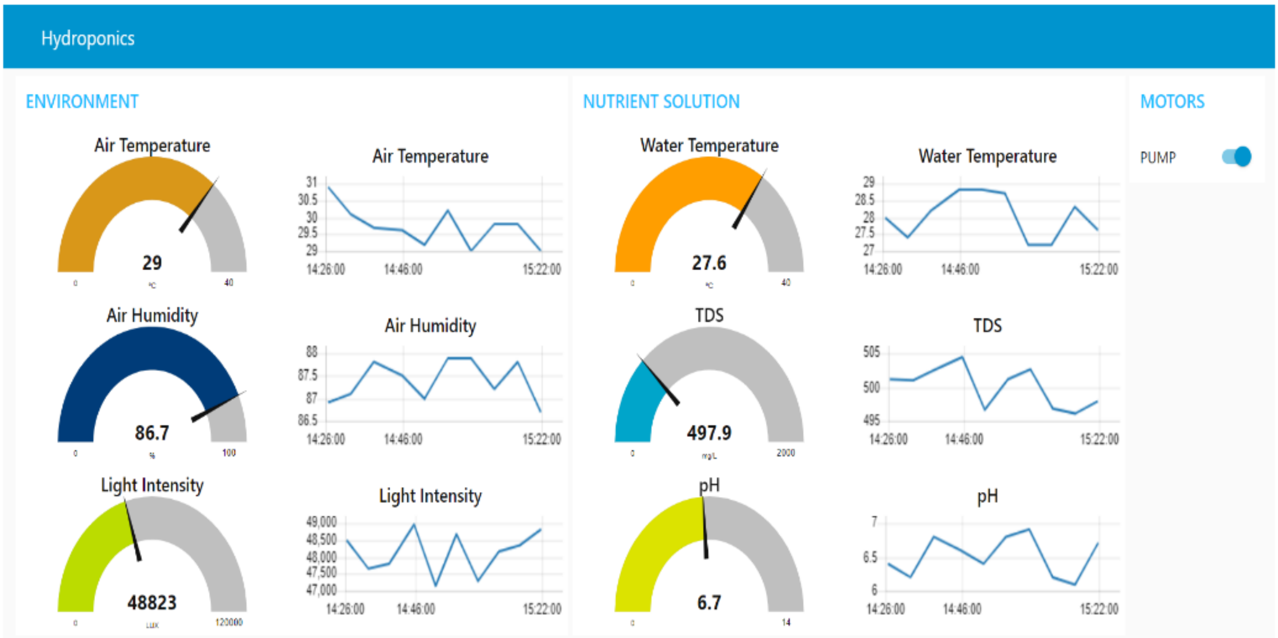

Figure 4. The interface of the monitoring system website.

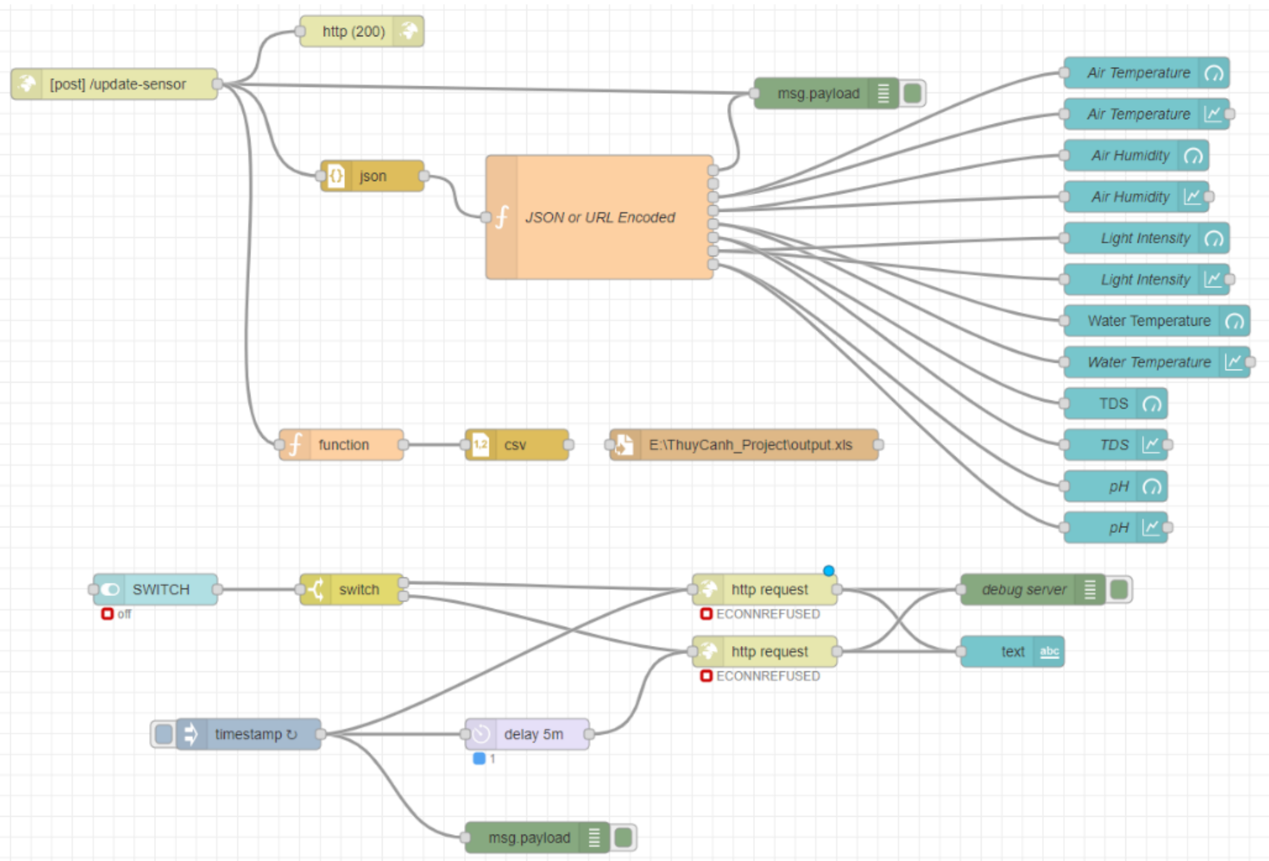

Figure 5. The webserver's Node-RED flow.

3. RESULTS AND DISCUSSION

To verify the stability of the proposed monitoring system, it was set up and tested on a hydroponic rig, which was built according to the Nutrient Film Technique (NFT) (Kori, Veena, Basarkod, & Harsha, 2021). NFT is a larger-scale technique that uses the slope of the channels to allow excess nutrient solution to flow back into a reservoir. The hydroponic rig consists of 8 troughs placed on a suitable slope so that the nutrient solution flows from the top to the bottom points of the rig in the direction of the arrows, as shown in Figure 6. A controllable water pump is placed inside the tank to help return the nutrient solution to the hydroponic rig.

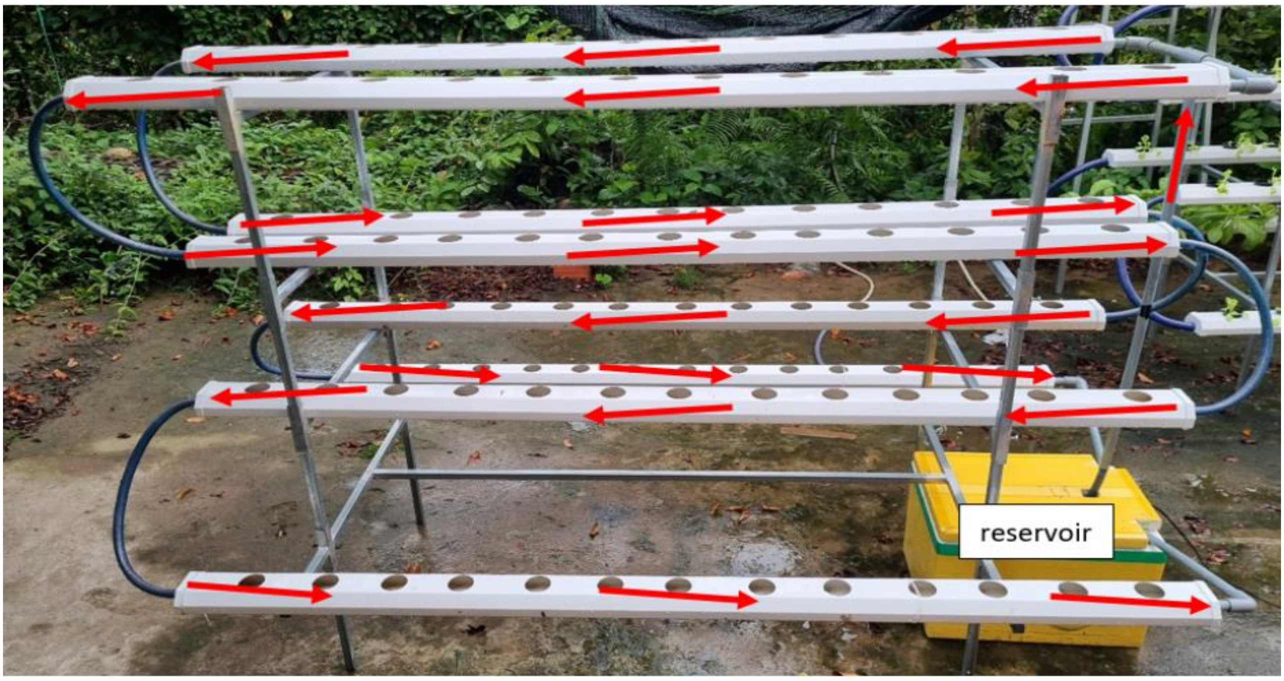

Figure 6. Experimental hydroponic rig.

In this study, we designed and built an IoT-based hydroponic system. This system can automatically monitor various parameters such as the humidity and temperature of the air, the light intensity of the environment, and the temperature, pH, and electrical conductivity of the nutrient solution. To achieve this, an air temperature and humidity sensor, a light intensity sensor, a water temperature sensor, a pH sensor, and a TDS sensor are used to collect the environmental and nutrient solution parameters of the hydroponic system as follows:

- The air temperature and humidity sensor AH001 is employed to detect the temperature and air humidity of the ambient air and convert the measurements into a standardized 4–20 mA analog signal. The sensor detects the ambient conditions in enclosed spaces – the machinery area and protected outdoor area – even when subjected to vibration. It offers a range of potential uses. The humidity and temperature measurements range from 0% to 100% RH and from -40°C to 60°C, respectively.
- DOL 16 is a robust light sensor that measures light intensity and is specially made for the harsh environment of livestock houses. However, it can also be used in various industrial applications. The DOL 16 light sensor is available in two variants: one with a fixed cable, and one with an M12 connector/cable. The sensor has two 0-10 V analog outputs with very low output resistance and full protection against short circuit and cable failure.
- The Stainless Steel Temperature Probe (a Vernier's product) is a rugged product that is used to measure the temperature of the nutrient solution. This general-purpose temperature sensor can be used in organic liquids, salt solutions, acids, and bases. It can be used just like a thermometer in experiments in the fields of chemistry, physics, biology, earth science, and environmental science.
- The CSIM11, manufactured by Wedgewood Analytical, measures the full pH range of liquids. It can be submerged in water or inserted in tanks, pipelines, or open channels. The CSIM11 is intended for non-pressurized systems and was not designed for applications above 30 psi. The pH range is from 0 to 14. The output is ±59 mV/pH unit.
- The HI7634-00 is a two-pole amperometric EC/TDS probe for panel-mounted mini controllers that measure in the low range (µS/cm and ppm). This probe has a built-in temperature sensor for automatic temperature compensation and a ½ " male NPT threaded connection for insertion mounting. The HI7634-00 probe provides a rapid response and high accuracy EC or TDS measurement. The BL983319 mini controller can support a measurement range from 0 to 1999 ppm.

The AH001 and DL16 sensors were placed outside to collect data on the temperature and humidity of the air and the intensity of sunlight, while the others were placed in the reservoir to determine the temperature, pH, and EC/TDS of the nutrient solution. Lettuce plants were placed in the holes in the troughs so that their roots were in the nutrient solution. Experiments were implemented during the lettuce plants' growing period from day 20 to day 40, as shown in Figure 7.

Figure 7. 20-day-old (left) and 40-day-old (right) lettuce plants.

Data on the status of the environment and the nutrients in the solution were collected in real time by the proposed monitoring system at periodic intervals of 6 minutes. The collected data can be observed by the user locally via the LCD screen on the IoT gateway box or remotely on a mobile device through the web browser interface (see Figure 8). The user can also control the water pump on/off switch at will by pressing the buttons on the IoT gateway box or sliding the switch in the web interface. Correction work was executed for air temperature and humidity, illumination, water temperature, etc. Figure 9 demonstrates the accuracy of the monitoring system.

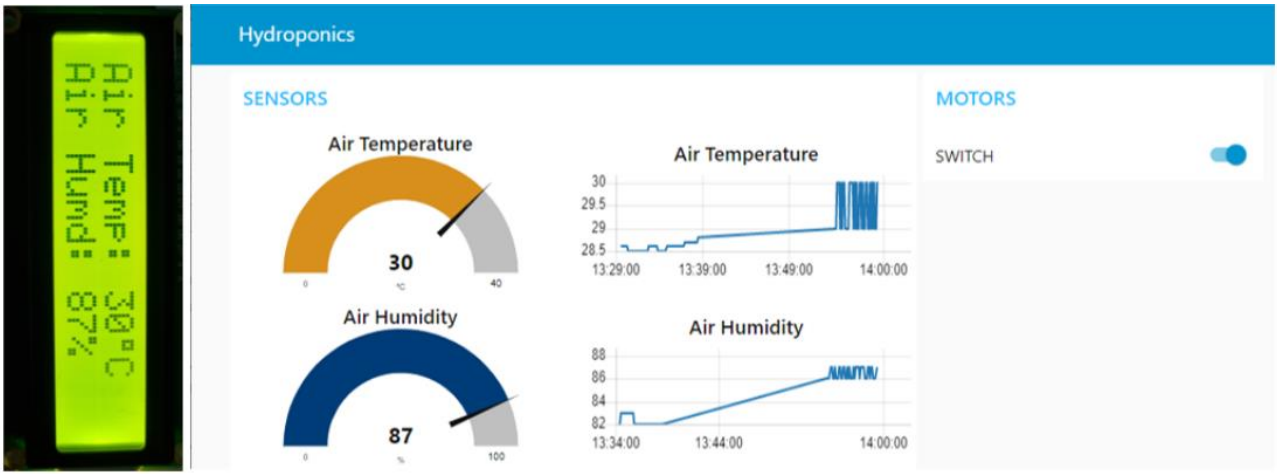

Figure 8. Air temperature and humidity values are displayed on the LCD screen (left) and the website (right).

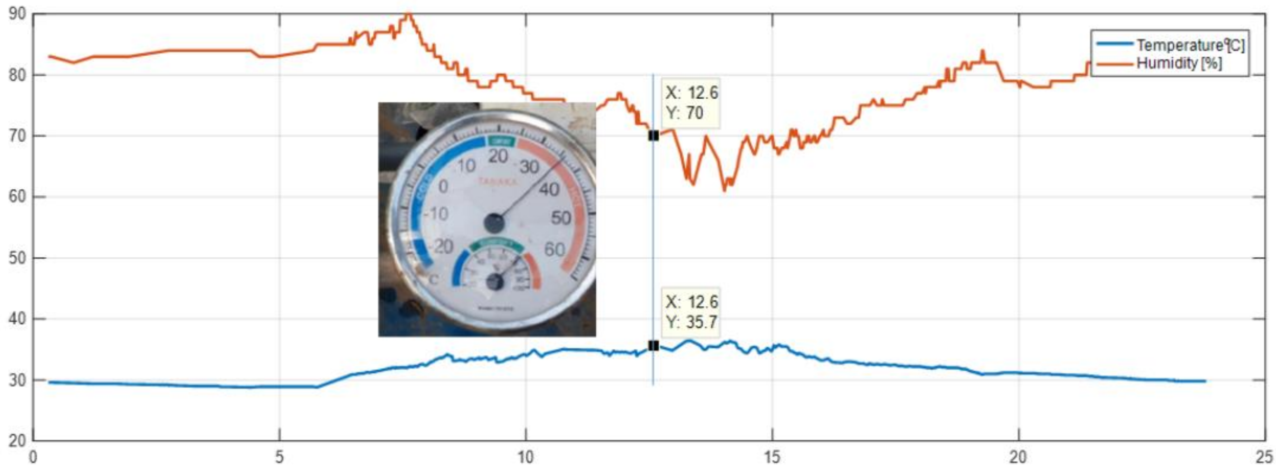

Figure 9. Comparison of system data with a portable measurement device.

Figure 10 presents the collected data on water temperature. This data was collected every 6 minutes, continuously for 20 days. The graph shows that the data did not fluctuate abnormally. Throughout the production process, the system maintained continuity and stability. Specifically, the sensors and communication devices did not experience any problems or lose connectivity.

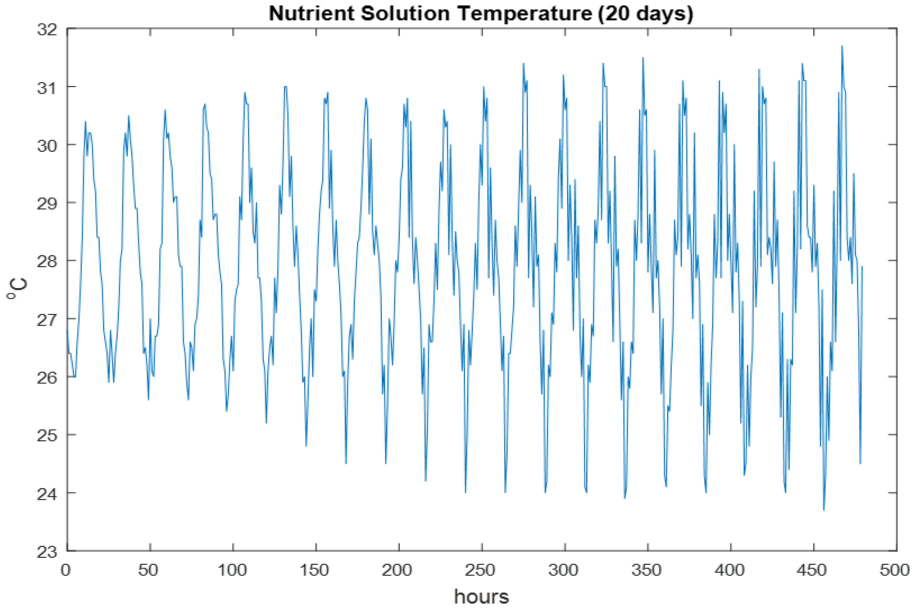

Figure 10. The data on nutrient solution temperature over 20 days.

All data collected from the sensors were stored in the system memory. In this way, it becomes a database that can later be used to analyze and evaluate the influence of the environment and the farming method on the growth of the plants. The graphs showing the data of the environmental and nutrient solution parameters collected over 20 days are shown in Figure 11.

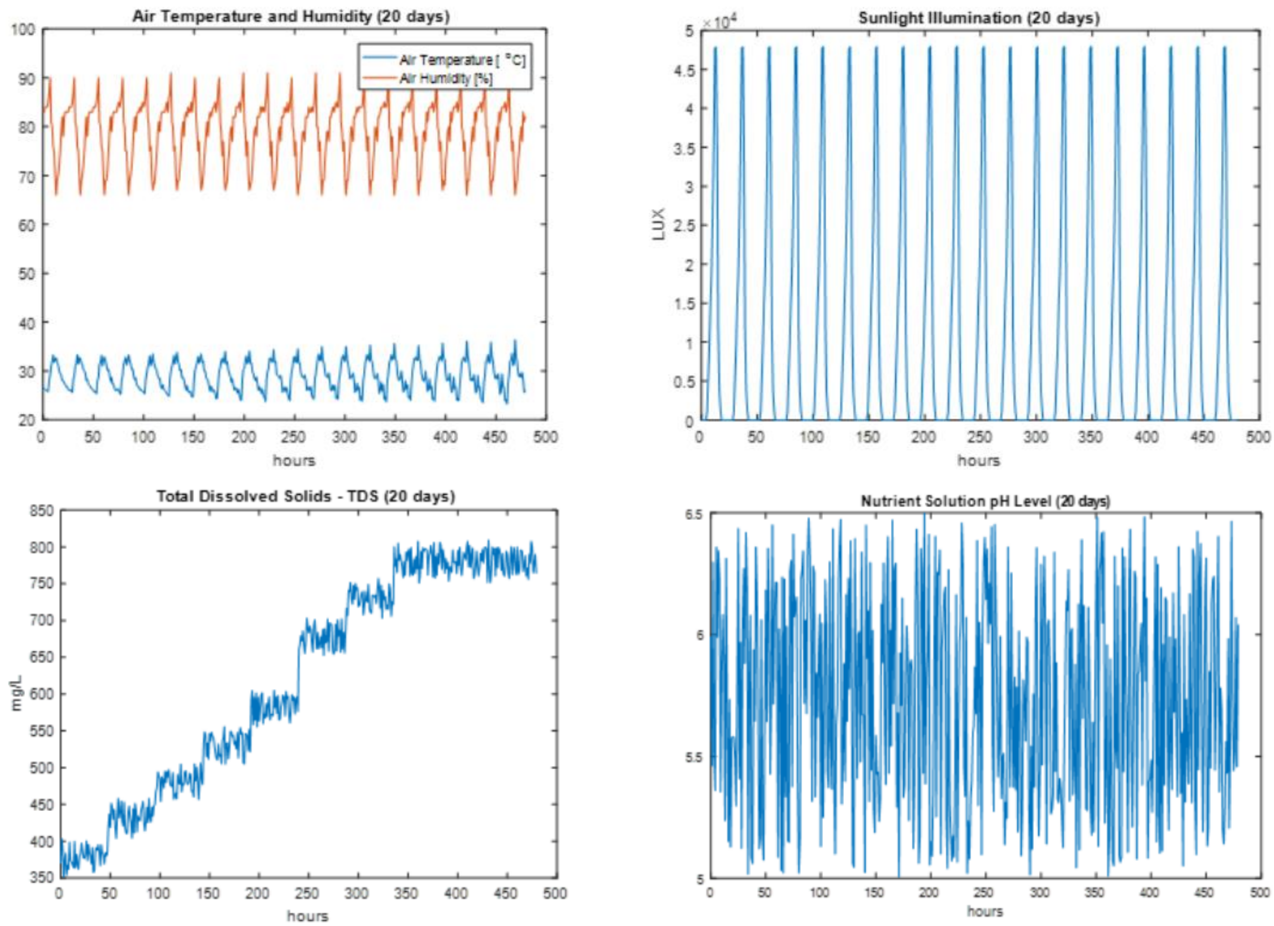

Figure 11. The collected data on the environment and nutrient solution over 20 days.

Based on the database that was obtained during the operation of the system, we conducted a correlation analysis between the air temperature and the hydroponic solution temperature (see Figure 12). It can be seen that the water temperature was delayed compared to the air temperature. This allows us to develop a strategy to stabilize the temperature of the nutrient solution by using the air temperature to predict changes in water temperature.

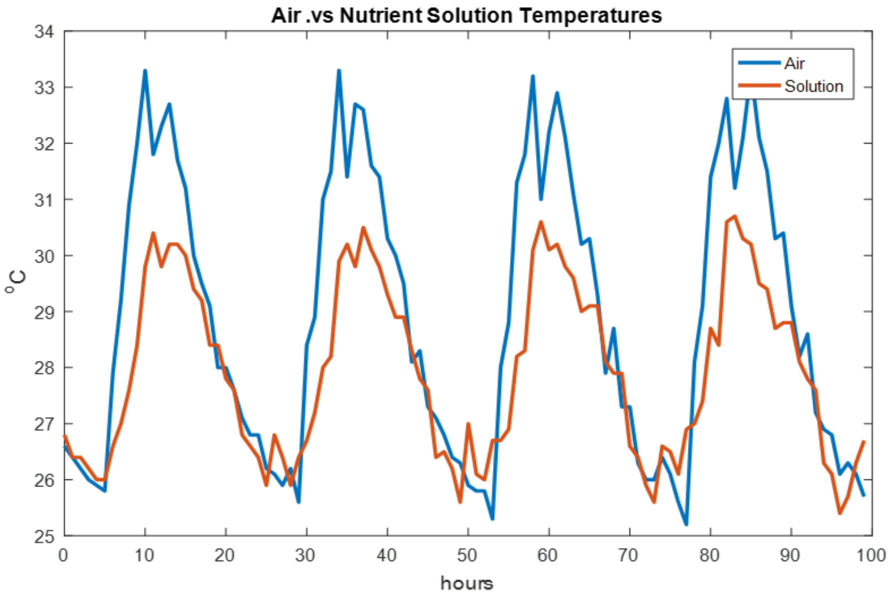

Figure 12. Comparison between air temperature and nutrient solution temperature.

4. CONCLUSION

This paper has presented a monitoring system for environmental and nutrient solution parameters in hydroponic farming. The system was built on an IoT platform that included three main layers: the perception layer, the communication layer, and the application layer. Data were collected from sensors and transmitted to an IoT gateway via ZigBee communication. From here, the data was displayed for users to observe on-site and transmitted to a webserver (cloud platform) for storage and to allow the user to observe the data remotely through an internet-connected device.

The experimental results show that the monitoring system operated stably and accurately during the cultivation period. The system will be helpful for farmers to monitor environmental and nutritional parameters in real-time, and also allows them to use the collected data to analyze and evaluate the impact of the environment and cultivation methods on the growth of plants so that appropriate adjustments can be made in subsequent seasons.

For our further research, we now have a basis for perfecting a fully automatic system to monitor and control the parameters of the hydroponic farming environment by combining the existing system with modern control algorithms such as fuzzy, neural networks, etc.

Funding: This research is supported by Vietnamese Ministry of Education and Training (Grant number: B2020-TCT-04).
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

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