APPLYING MACHINE LEARNING FOR ENVIRONMENTAL FACTOR PREDICTION ON DESIGNING IOT APPLIED HYDROPONIC SYSTEM
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ỨNG DỤNG PHƯƠNG PHÁP HỌC MÁY ĐỂ DỰ ĐOÁN CÁC YẾU TỐ MÔI TRƯỜNG TRONG THIẾT KẾ HỆ THỐNG THỦY CANH IOT

Van-Tinh NGUYEN*, Tan-Hoang NGUYEN, Ngoc-Kien NGUYEN
School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam.
Tel: +840985800038; E-mail: tinh.nguyenvan@hust.edu.vn
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ABSTRACT
In IoT hydroponics, the integration of Internet of Things (IoT) and Machine Learning (ML) has opened up great opportunities to increase the productivity and smart system's management. With the collected data from sensors in the environment, the machine learning model would analyze and predict the trend of the environmental factors, this combination not only improves the outcome quality but also helps saving the resources. Integrating machine learning into an IoT hydroponics system could not only create a smart, autonomous and adaptable system to changing conditions of environment in real-time but also optimize resources for a cost-effective and productive hydroponic system. In this study, a novel method was presented for predicting environmental factors using Machine Learning algorithm for smart IoT hydroponic systems. By applying this method, an IoT hydroponic system can predict the trends of environmental factors which affects the plants such as temperature, moisture, pH levels…. The experiment results show that the accuracy of the predicted data is reliable, it reached 94.2% for a day and 92.6% for a week. These results could help users take proactive measures to improve the cultivation quality.

TÓM TẮT
Trong hệ thống thủy canh IoT, sự tích hợp của công nghệ kết nối vạn vật (IoT) và thuật toán học máy (ML) đã mở ra nhiều cơ hội để tăng năng suất và quản lý hệ thống. IoT cho phép thu thập dữ liệu từ các cảm biến trong môi trường, trong khi thuật toán học máy cung cấp khả năng phân tích và dự đoán dựa trên dữ liệu quá khứ. Sự kết hợp này không chỉ cải thiện chất lượng kết quả mà còn giúp tiết kiệm tài nguyên. Khả năng dự đoán của thuật toán học máy giúp người nông dân quản lý hệ thống một cách hiệu quả, tiết kiệm nguyên liệu đầu vào và duy trì các điều kiện lý tưởng cho cây trồng. Bài báo này trình bày một phương pháp mới để dự đoán nhiệt độ môi trường bằng thuật toán học máy, áp dụng cho hệ thống thủy canh IoT. Phương pháp này có thể dự đoán xu hướng thay đổi của các yếu tố môi trường dựa trên dữ liệu thời tiết có sẵn của một khu vực trong quá khứ. Kết quả thí nghiệm chỉ ra rằng độ chính xác của dữ liệu dự đoán đạt 94.2% cho một ngày và 92.6% cho một tuần. Nó có thể cung cấp trước thông tin cho người dùng thông qua giao diện trang web để họ có thể thực hiện các biện pháp chủ động nhằm cải thiện năng suất của quá trình thủy canh và đảm bảo chất lượng sản phẩm.

INTRODUCTION
Hydroponics is an agricultural method where plants are cultivated in a nutrient-rich liquid, essentially water. The core concept is to utilize water as a way to supply plants with essential elements and nutrients for optimal growth. The suitable amount of sunlight is maintained to facilitate the photosynthesis and respiration processes, therefore, promoting robust plant development and productivity. In traditional soil environments, plants can only absorb around 5% of nutrients from the soil, with the remaining 95% synthesized through the process of photosynthesis. The soil serves as a reservoir for nutrients, gradually utilized by plants as they grow. In hydroponics, nutrients are converted into a liquid form, the most easily absorbable state for plants during their growth. This eliminates the necessity for soil as a growth medium, as plants can readily assimilate nutrients from the liquid environment throughout their development. Another benefit of hydroponics is that it helps restricts contact with harmful worms and limits the need of using pesticides therefore, makes it safer for humans' health.

Based on the conditions of the applied environment, there are four main models of hydroponics: wick-based, static, recirculating and drip hydroponics. Wick-based hydroponics utilizes a wick to supply nutrients to the plant by placing one end of the wick into the nutrient solution, the other end touches the plant's roots, the wick will absorb water and nutrients to nourish the plant, ensuring it receives sufficient nutrients for growth. Static hydroponic model employs a container, tank, tray, or reservoir for the hydroponic solution, the plant support component is typically made of lightweight material at the top. Plant roots are submerged in the hydroponic solution. Recirculating model is quite similar to static one with a slight difference is that it uses a pumping machine to control the amount of the nutrient’s liquid coming in and out of the tray following a certain cycle and therefore, the roots will not be drowned in the water all the time and make space for natural respiratory. In contrast to recirculating model, dripping hydroponics can use soil or other growing mediums as a substrate, but the irrigation water permeates instead of circulating back to the reservoir. When the moisture level in the garden falls below a threshold, the pump system is activated, or water is periodically pumped based on a predefined schedule. There have been many attempts to improve the tradition hydroponics systems such as developments of new hydroponic chemicals, installs devices to automatically control natural conditions in the systems entirely such as using LEDs to provide light in a specified spectrum that is beneficial for the plants’ growth, pumping systems to control the water circulation, etc.… As technology evolves, the trend of utilizing cutting-edge techniques to monitor the growing process of the plants in the hydroponic garden is inevitable. The advanced hydroponic farming methods in 4.0 industrial revolution usually integrates sensors, smart and IoT technology for automatic monitoring and controlling the farming processes *(Yanes et al., 2020)*.

The challenges of applying IoT technology into the recirculation hydroponics is a precise supervision of factors such as pH, nutrients amount, temperature, air moisture and watering amount. These environmental indexes would be directly sent to the control center and the owner’s smartphone. As a result, the technicians could provide suitable technical support to always make the best condition for growing plants. In automated mode, the system’s component such as misting and rolling mechanisms, shading nets, and lighting on/off switches could automatically operate to provide light, temperature balance in the greenhouse can be maintained by opening/closing misting nozzles, adjusting the pH level in the nutrient solution, and dosing the fertilizer formula. Across the history of agriculture’s automation, there have been many published research and completed IoT applied systems on cultivating plants. For example, Farhan Mohd Pu’ad et.al designed a IoT based water quality monitoring system for aquaponics *(Farhan et al., 2020)*, Chien Lee et. al developed a cloud-based IoT monitoring system for Fish metabolism and activity in aquaponics *(Lee et al., 2020)* and Isabella Wibowo built an IoT based automatic water nutrition monitoring system *(Isabella et al., 2019)*. Maritel Dawa also designed and built an IoT based aquaponics management system which can adapt to climate change *(Maritel et al., 2022)* while S. B. Dhal et. val introduced an IoT system designed for managing nutrient supply within a commercial hydroponic environment *(Dhal et al., 2022)*. There is the research on smart farming IoT platform based on edge and cloud computing of Zamora-Izquierdo and the colleagues *(Zamora-Izquierdo et al., 2019)*. R. Barosa applied image recognition technique on leaf to detect diseases along with IoT incorporated to collect and transfer data *(Barosa et al., 2019)* and J. P. Mandap et. al used Raspberry Pi as network backbone to control and monitor aquaponics pH level, temperature, and dissolved oxygen *(Mandap et al., 2019)*. In addition, the machine learning algorithm is also integrated into the IoT hydroponic system to predict trends of the environment based on the historical data. Some remarkable papers can be mentioned such as the WPART method applied the machine learning technique to predict crop productivity and drought for proficient decision support making *(Rezk et al., 2021)*. Tanzila Saba’s team developed a trust-based decentralized blockchain system with machine learning using IoAT *(Tanzila et al., 2023)*. Plant disease diagnosing method using computer vision and deep learning models were proposed by Gaytri Bakshi and Silky Goel *(Gaytri et al., 2023)*. A weather monitoring system using OSSA and MA Techniques was developed by Rani Chandrabhan et. al *(Rani et al., 2023)*.

In this paper, a novel IoT applied hydroponics system was introduced to enhance the performance of planting process and be convenient for the farmers in use. The proposed approach combines the machine learning algorithm and IoT to predict trends of environment based on the available weather data. In addition, the state of the system would be continuously updated to the center unit and the warning text would be sent to the user. The remain of the paper is organized into four main sections. For details, the second section explains the design of the system and how the machine learning algorithm works. The fabrication of the prototype of the designed system will be described in the third section and the new features testing and results will be discussed in the fourth section. The final section consists of some conclusions of this research.

MATERIALS AND METHODS

Structure design of IoT hydroponics system

The above hydroponics system was designed with two cultivation layers, each layer has two hydroponic pipelines. Each pipeline has 4 holes to plant vegetables. The mechanical design has two main modules: the pipelines supporting aluminum frame and the water supply and misting system as presented in Fig. 1.

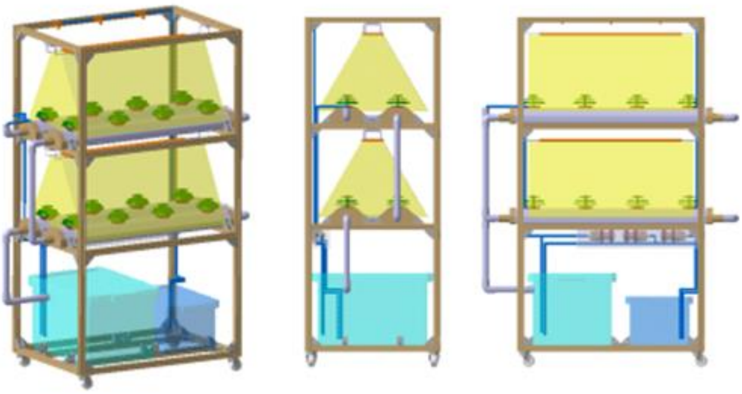


Fig. 1 – Overview of two-layer recirculating hydroponics system

The designed supporting frame is 1150 mm in height, 440 mm in width and 610 mm in length as shown in Fig. 2. The material of the frame is aluminum alloy 6063-T5 which has yield and tensile strength of 145 and 186 MPa, respectively. The aluminum framework utilizes 20x20 mm shaped aluminum bars interconnected by corner brackets and T-nuts. Four wheels are affixed at the bottom for mobility. The water supply and misting system is constructed using hydroponic tubes, PVC pipelines, M8 pumping tube, a 10 L and 25 L water tanks as shown in Fig. 3. The dissolved nutrient solutions will be contained in the large 25 L tank to circulate completely in the hydroponic tubes. The small 10 L tank will provide water for both the large tank and the mist spraying pipelines. Before fabrication, the frame is verified to ensure the technical requirements. The numerical simulation is implemented by SolidWorks software. Figure 4 shows the setting process where the down arrows express the external force from the gravity of the devices acting on the frame, the bottom of the frame is fixed. The simulation results are expressed in Fig. 5; as can be seen in Fig. 5a, the maximum stress is 0.001 MPa which is much less than the yield stress of 145 MPa while Figure 5b shows that the maximum displacement is $4.18*10^{-5}$ mm and is insignificant. In conclusion, the frame meets the technical requirements for fabrication.

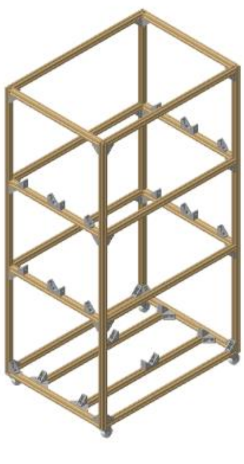


Fig. 2 – Pipelines supporting aluminum frame

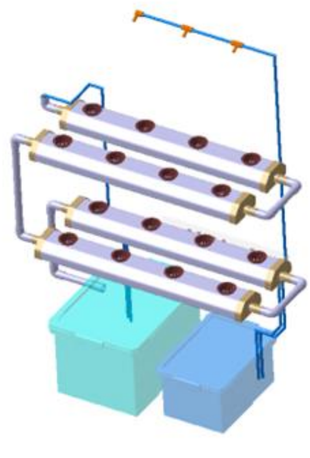


Fig. 3 – Water supply and misting system

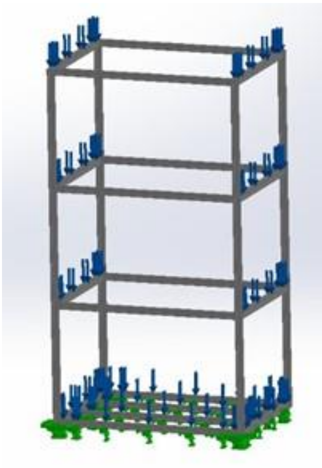


Fig. 4 – Setting process

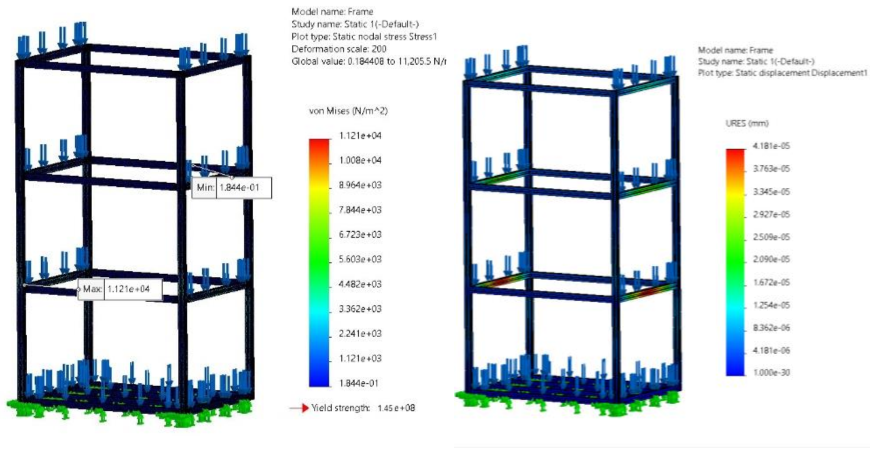


Fig. 5 – Simulation results: *a) Stress graph; b) displacement*

Design of control system

Overview of control system

The control system consists of three main modules: controller, programming module and peripheral module. The overview of the control system is shown in Fig. 6.

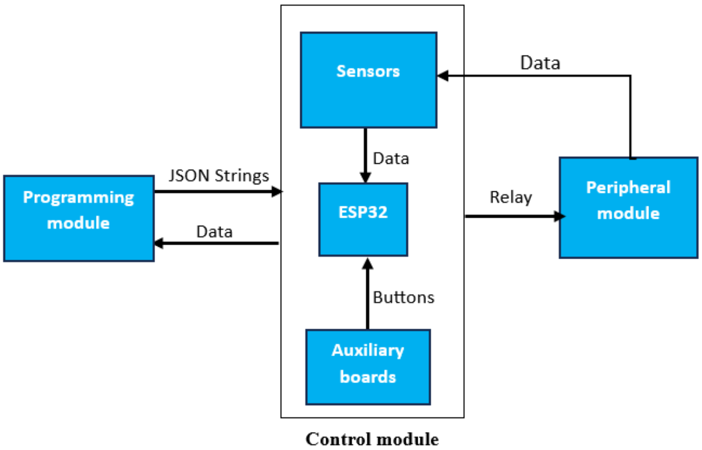


Fig. 6 – Overview diagram of control system

The embedded board and sensors module is the combination of the sensors and auxiliary boards to collect data from the peripheral module's operating parameters along with the button signals from auxiliary boards to send to the main ESP32 board. The system incorporates various sensors, including the DHT22 temperature-humidity sensor, HC-SR04 ultrasonic sensor, TSL2561 light intensity sensor, and a pH sensor and an LCD display module with physical buttons included for control. The programming module uses Web Server programming to remotely control and monitor the system's operation through the website. Peripheral devices consist of two power supply pumps, a misting pump, and two illumination bulbs. With the block model as described, the system can meet all the requirements of a modern IoT system: remote control via the web with a response time of under 1 second, the ability to monitor environmental parameters online, and the system can be controlled both through a physical control circuit and operate automatically based on programmed structures.

Controller and peripheral module

The IoT hydroponics system utilizes the ESP32 microcontroller with the DOIT V1 board version to read sensor data, send and receive data with a web server, while also controlling peripheral devices such as pumps and lights. The structural diagram of two modules is shown in Fig. 7.

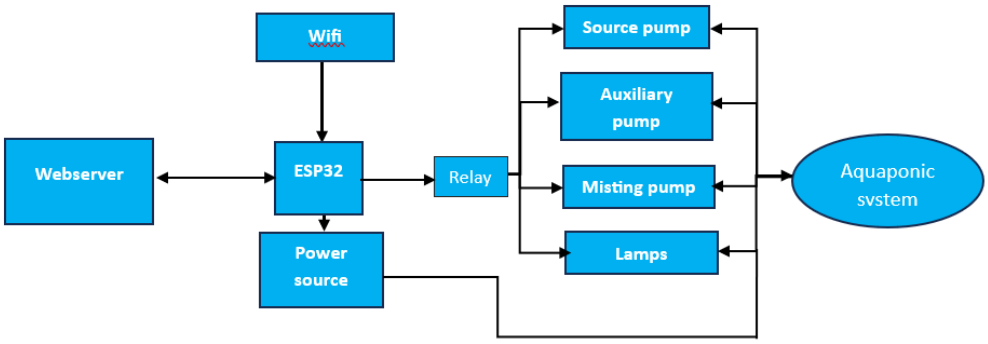


Fig. 7. Control and peripheral module's block diagram

In the diagram, it can be observed that the ESP32 serves as the coordinating component for the entire system. With the advantage of being controllable at a minimum voltage of 3 V and optimal performance at 5 V through relays, it influences the operation of opening and closing peripheral devices, including power pumps, auxiliary pumps, misting pumps, and lights. The ESP32 directly receives input signals from various sensors, including temperature-humidity sensors, light sensors, water level sensors, and pH sensors. The microcontroller is connected to Wi-Fi to synchronize data with the Webserver data management system. Through the Webserver, an automatic alert system and remote control via a mobile phone can be seamlessly integrated.

Programming module designed for user interaction and environmental factors prediction

In this paper, the term "programming module" refers to the program designed for data storage, management and the website interface to communicate with the user. The server used to store the data of the sensor's reading, designed websites and user account's operation are called webserver. Web servers, whether hardware or software, manage data efficiently and ensure continuous operation for internet data delivery. Hardware servers store and deliver website files to end-users, accessed through domains. Software servers control user access, understanding website addresses and browser protocols like HTTP. The HTTP protocol facilitates communication, enabling browsers to request and receive files from the server. Server software, installed on suitable computers, allows users to access website information over the internet.

The structure of the programming block is described in Fig. 8. The data received from ESP32 of the controlling module will be stored in a MySQL database. The directory containing PHP script files manages the input and output of data from the database, redirects paths, handles user addition and deletion, and includes modules used in the project, particularly the design of the management interface for administrators.

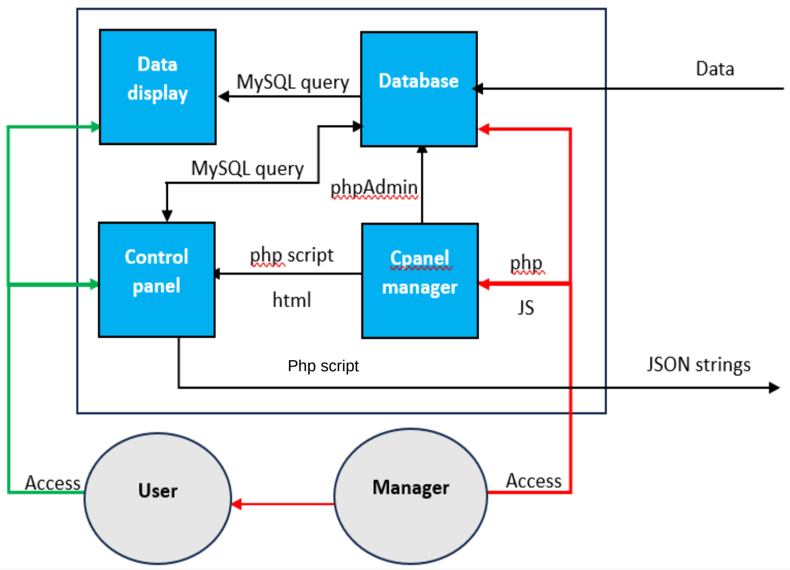


Fig. 8 – Web server programming module block diagram

The user can access the data by utilizing the control panel and monitoring the data display. MySQL query commands are used to extract data from the database. To access the data, the user will have to access the programmed website and login to the registered account. If the account belongs to a regular user, the interface will display modules for monitoring and control. If the selected module is a control module, pressing the buttons on the web will trigger the web to return a JSON string to control the ESP32. For other modules, when data is sent, it will be stored in the database, and simultaneously checked to see if the value exceeds the permissible threshold, triggering an email alert. For admin accounts, there will be an additional interface to modify settings and add/remove system modules.

For monitoring data and remote control in case there is sign of abnormality in the system, a custom website interface was designed for the user. For the admin account, the user interface will appear as in Fig. 9. In this system, some key factors that influence the plant's development such as temperature, humidity, pH level, and the amount of watering for the plants are measured and sent to the web for real-time monitoring. Simultaneously, the data is checked to ensure it falls within permissible thresholds. If the values exceed these limits and adversely affect plant growth, an email notification is promptly sent to the user through Gmail as shown in Fig. 10. The email subject corresponds to the management code of the IoT system, enabling users to quickly address the alert, especially when managing multiple hydroponic systems simultaneously. There are four tabs to display the data of temperature, humidity, pH level and water level.

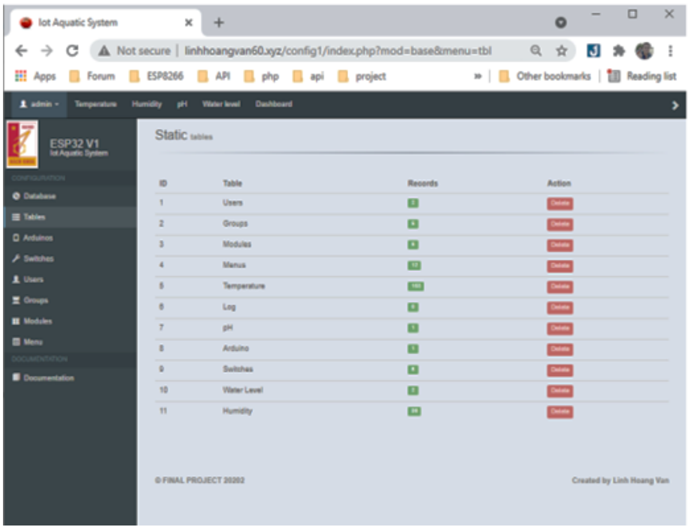


Fig. 9 – Admin's account website interface

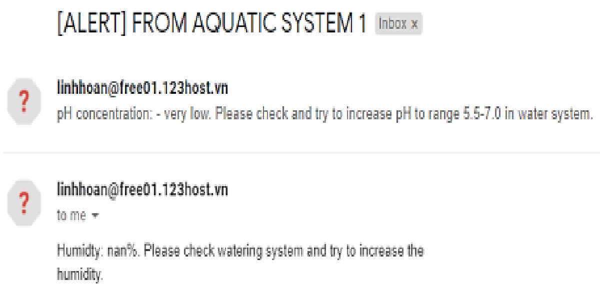


Fig. 10 – Warning email from the system

The novelty of the designed system is applying machine learning for the environmental factors (temperature, humidity, pH level) data prediction at hydroponic cultivation site which will allow users to take proactive measures. To apply machine learning for predicting these factors' parameters in the city requires a substantial amount of environmental data to achieve accuracy, ideally spanning over a year. The idea is to gather the environmental data from the available official sources (websites) and make prediction on the factors' parameters based on the variation trend of the built actual data graph and sensors' reading data of the system. This approach not only enhances reliability but also incorporates innovative technology to support users. Then, a machine learning algorithm based on the collected data will be implanted. The predicted temperature data will be displayed on the website. By integrating these steps, the system will provide users with accurate temperature predictions, leveraging machine learning and real-time weather data collected from IoT hydroponic systems. This not only increases reliability but also incorporates innovative technology to support users in making informed decisions about their cultivation practices.

RESULTS AND DISCUSSIONS

Fabrication of proposed system

To see how the idea works out, a real IoT aquaponic system was built for experimental determinations. It is tested by applying the machine learning algorithm for predicting temperature. The fabricated system has a total height of 1150 mm, 610 mm in length and 440 mm in width with three main floors.

The first floor contains two water tanks while plants will be planted on the second and third floor. The image of the fully assembled system can be found in Fig. 11.

Fig. 11 – Fully assembled IoT hydroponic system

The working principle for feeding water and misting is described in Fig. 12. As for the lighting, a large LED as shown in Fig. 13 is incorporated to provide light for plants on both floors. Since the LED takes power from AC 220V power source, it must have intermediate relays built in to adjust following the electrical signal sent from the control module. As shown in the diagram, pump 1 will take water from 10L tank and provide for the misting system while pump 3 will take water from 25L tank and pump up to the hydroponic tube, then the water will be recirculated back to the tank, pump 2 will pump water from 10 L to 25 L tank.

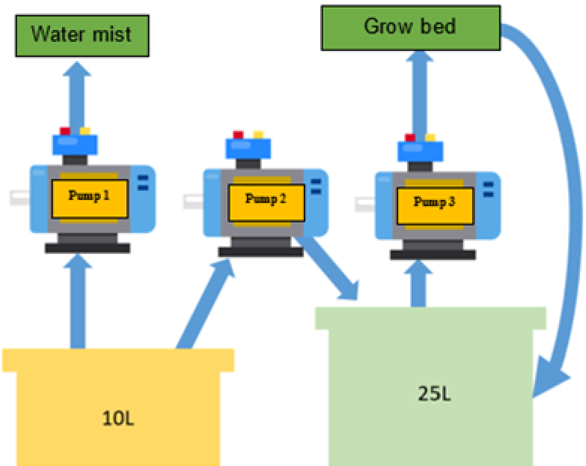


Fig. 12 – Diagram of working principle for feeding water and misting

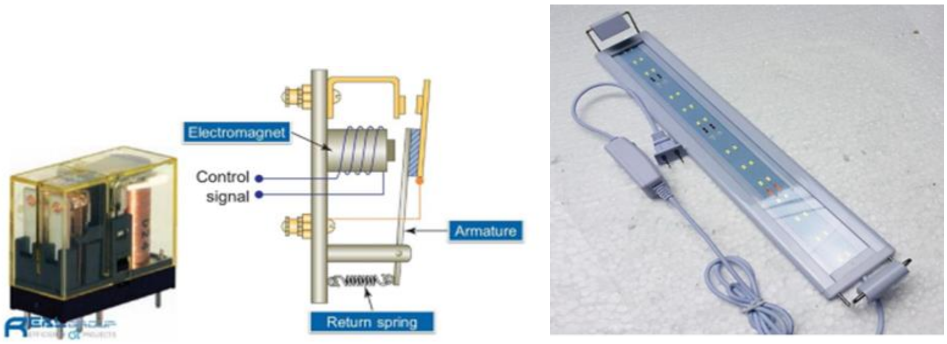


Fig. 13 – LED and intermediate relay

The chosen embedded programming board for controlling sensors and peripheral devices was ESP DOIT V1 – a dev kit developed by DOIT with BLE (Bluetooth Low Energy) along with Wi-Fi function available and multiple peripheral communication channels supported. The sensors' reading will also be displayed on an LCD attached onto the control board, and the data will be processed and sent to Webserver through Wi-Fi. The control board and LCD are attached onto a PCB to avoid electrical signal jam in transmission. The assembled IoT control board is shown in Fig. 14.

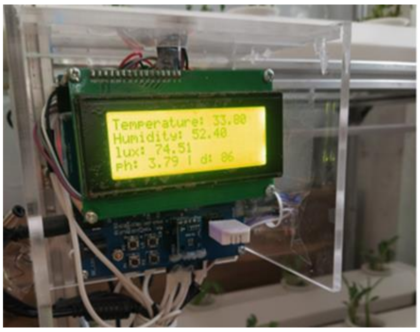
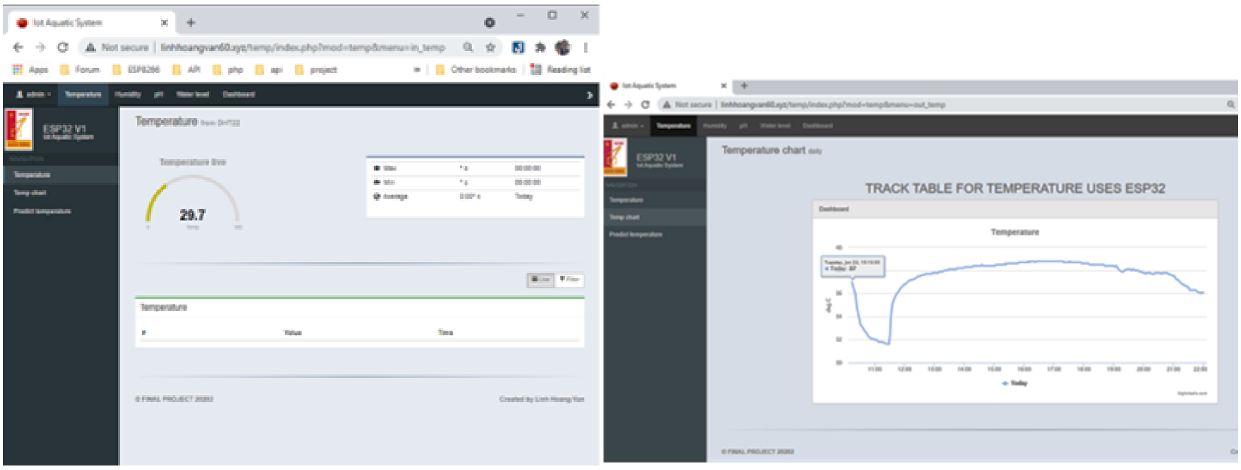


Fig. 14 – Controller board

Implementation of the experiment

An experiment was conducted to test the ability of temperature prediction of the proposed method. Firstly, the system collected temperature data from January 1st, 2019 to March 31st, 2024 for training. Hourly live weather data collected by the IoT system could be monitored through the live weather data and the track table in the temperature tab on the user's website which looks like in Fig. 15. Then, the predicted data was compared to the weather data stored on https://www.wunderground.com from April 1st to June 17th 2024. This website is among the top 10 largest weather data statistics websites globally, with an average monthly traffic of around 50 million visits (according to SimilarWeb statistics). The city chosen for the data collecting is Hanoi. The data comparison between the forecast and real data was made by cross-referencing the hourly collected data points with the actual temperature data graph. If the forecast data points matched the points on the actual data graph, then the experiment would prove its accuracy and the proposed system could be applied.



a) *b)*

Fig. 15 – Hourly live weather

a) Temperature live data; b) Track table

As a result, the accuracy of the predicted data in a day is 94.2% as shown in Fig. 16 and 92.6% in 7 days as shown in Fig. 17. As it can be seen, the measured points are remarkably close to the original data. Red dots represent the predicted results which are either close or coincidental to the actual temperature plot line. Difference between the predicted results and the actual temperature fluctuates within 0.2 to 0.5°C. Its accuracy decreased as the test time got longer.

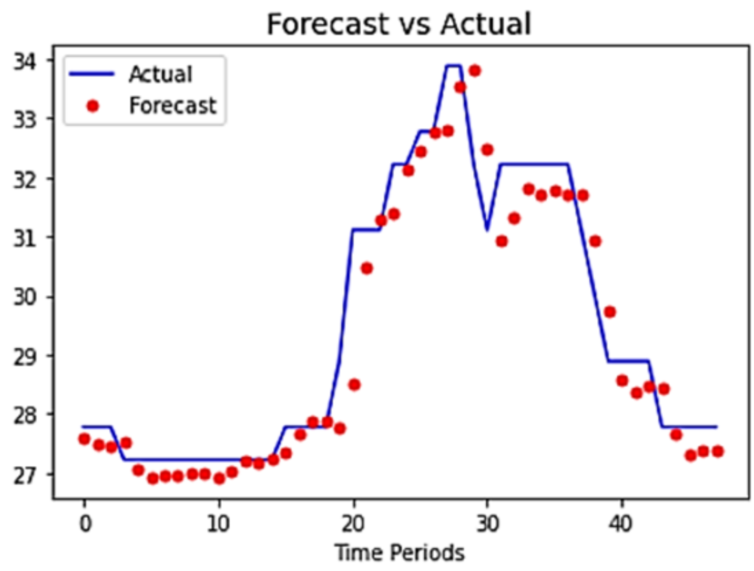


Fig. 16 – Predicted temperature in one day

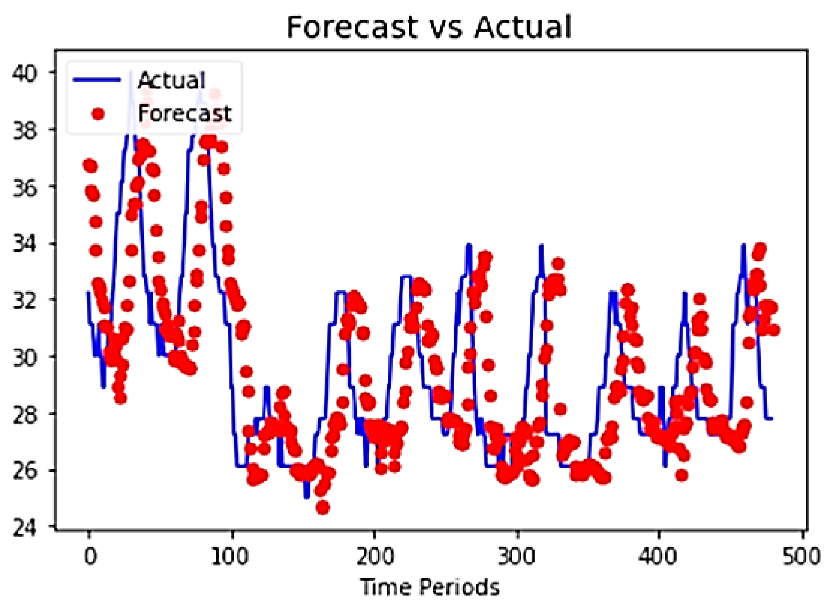


Fig. 17 – Predicted temperature in one week

In summary, the use of the machine learning model was enable to predict the trends of the temperature of the environment that supports the farmers to provide the plants with the neccesary adjustment of the technical system such as water, misting, and light to make the best condition for the development of the plants. In addition, this method ulitized IoT technology to manage and process the information of the system where the data was stored online on Web server and the warnings were intermediately sent to the user via email if the value of any factors was over the threshold. The proposed system is developed for the small families and is suitable with the low-income countries such as Vietnam, Cambodia, Laos…

CONCLUSIONS

In this paper, a novel hydroponic system integrating machine learning algorithm and IoT to predict the temperature of the outdoor environment was presented. The proposed system was designed with three floors and is suitable for small families. The control system consisted of three main modules: web server programming, controller and peripheral modules. The programming module was to store the data, communicate with the user and apply the machine learning algorithm for the environmental factors' prediction.

The controller used ESP board controls sensors, peripheral equipment and sent the readings data to the webserver. The environmental indices and warnings were sent to the users through Gmail so that they could take proactive action. The experiment results showed that the accuracy of the predicted data were reliable, it reached 94.2% for a day and 92.6% for a week.

The limitations of the study are that the machine learning algorithm was currently applied to predict the temperature data only and the accuracy of the machine learning model needs improving, thus, the operation of the system was not optimized. Future research will focus on increasing the number of the forecasted output such as humidity and enhance the performance of the predicted model.

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