Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA
Published: February 18, 2025

DOI: 10.46254/AN15.20250175

Integration of IoT and Automated Systems for Optimized Hydroponic Cultivation of Red Oak Lettuce

Atipat Plaiyduang
Department of Industrial and Systems Engineering
Suranaree University of Technology
Nakhon Ratchasima, Thailand
max0848293366@gmail.com

Nattawat Pinrath
Department of Industrial Engineering
Suranaree University of Technology
Nakhon Ratchasima, Thailand
nattawat.p@g.sut.ac.th

Abstract

Hydroponic farming has emerged as an efficient and sustainable agricultural method, particularly suitable for urban and resource-constrained environments. This study integrates Internet of Things (IoT) technologies with automated control systems to optimize the growth of Red Oak lettuce. Key environmental parameters—temperature (maintained between 20°C and 30°C), humidity (averaging 52.5%), and nutrient solution pH (kept between 6.6 and 7.2)—were precisely controlled using an IoT-enabled system. Experimental results demonstrated a 15% improvement in plant yield and a 10% reduction in water and nutrient usage compared to traditional methods. By employing the Nutrient Film Technique (NFT) with LED lighting and automated monitoring, the system achieved consistent plant growth and resource efficiency. This research underscores the transformative potential of IoT in hydroponic farming, providing a scalable solution for modern agriculture.

Keywords
Hydroponic Farming, Internet of Things (IoT), Automated Control Systems, Precision Agriculture, Smart Farming

1. Introduction
Hydroponic farming, a soil-free cultivation method, has gained popularity due to its efficient control over growth factors like pests, nutrients, and environmental conditions, reducing chemical use and appealing to health-conscious consumers. Achieving optimal yields requires farmers to understand key variables such as pH, electrical conductivity, temperature, humidity, and light. Recent studies have advanced hydroponic techniques, covering areas such as automated nutrient detection, controlled-environment systems, and consumer responses to pesticide-free crops. The Internet of Things (IoT) is transforming hydroponic agriculture by providing real-time environmental monitoring, remote management, and data-driven analysis, which enhance efficiency. IoT-enabled systems—such as climate-controlled greenhouses and wireless sensor networks—help conserve resources, maintain stable conditions, and boost productivity. With continuous technological integration, hydroponics presents a promising solution for sustainable, precise, and consumer-friendly agriculture in the modern era.

1.1 Objectives
Develop an automatic system and research on nutrient light in hydroponic Red Oak lettuce with the following objectives:

(1) To develop an automatic system to control temperature, humidity and nutrient solution in growing Red Oak lettuce in hydroponic system.
(2) To automatically control the use of light resources and nutrient solution for vegetables grown in hydroponic system.

2. Literature Review
Yeowpa and Nisa (2010) studied the growth of Red Oak lettuce grown in a hydroponic system with various nutrient solutions. The results of the experiment concluded that Red Oak lettuce grown in the Resh Tropical Dry Summer and Enshi nutrient solutions had significantly greater height compared to those grown in the Lettuce and DTWC1 solutions. However, there were no significant differences in the width of the plant, leaf number, fresh and dry weight of the plant and root across all four solutions. Nonetheless, the cost of preparing the Enshi nutrient solution was the lowest, at 1.57 THB per liter, making it the most suitable option for growing Red Oak lettuce.

Assistant Professor Phak Sathanasaowapak (2019) researched and developed an automatic hydroponic vegetable growing system to control factors that affect the growth of Green Oak lettuce, including sunlight, temperature, and nutrient solutions. This system consists of a plant growing chamber and a fertilizer mixing tank, with each component controlled by a microcontroller that manages the operation of various devices. Overall, the system can control artificial sunlight, regulate temperature, and provide consistent and accurate nutrient solutions. The system is designed to display sensor data on a website and store data in a database. The experimental results showed that the developed system significantly improved the yield compared to traditional hydroponic systems, with an average yield of 26.56 grams more than the traditional system. Additionally, the width and leaf size of the Green Oak lettuce grew larger than in the conventional system.

Thanadech Premaseelo and colleagues (2016) designed and constructed a hydroponic plant growing device to test and evaluate the performance of the hydroponic system. Hydroponic plant cultivation is a new alternative for growing plants in limited spaces, using less water and fertilizer compared to soil-based cultivation. It allows for better control over the root environment, such as temperature, pH level, and nutrient solution concentration. In this project, a hydroponic device was developed for growing sunflower seedlings. The design was divided into four parts.

The first part involved calculating the structural strength of the device made from a cylindrical acrylic tube, which was divided into two sections: one for water used for plant growth, with a height of 200 millimeters, and the other for plant growth, also 200 millimeters in height. The second part described the functioning of the humidity control system, which used a humidity sensor and a controller to operate the fan motor and mist pump to regulate the humidity. The third part covered the temperature control system, which used a temperature sensor to send data to a controller, which then activated the intake and exhaust fans to maintain an optimal temperature for plant growth. The fourth part addressed the control system for the pH of the nutrient solution, where a pH sensor transmitted data to a controller, which then triggered the solution pump to adjust the pH level for optimal plant growth.

The results showed that the hydroponic plant growing device could maintain a relative humidity of 77.29% on average and a pH level of 7.21. However, the temperature could not be adjusted to the desired range but remained close to the target, which was better than the temperature in the cultivation area. Sunflower seedling cultivation in the hydroponic device achieved the highest germination rate at 92.86%.

3. Methods
The hydroponic plant cultivation control system is divided into three main subsystems:
Temperature Control System: This subsystem monitors and adjusts the internal temperature of the growing environment to ensure that it remains within the optimal range for plant growth. Proper temperature regulation is crucial for maximizing plant productivity and health.

Nutrient Control System: This system ensures that plants receive the correct balance of nutrients. It monitors and adjusts nutrient concentrations in the water to meet the specific requirements of the plants (Figure 1).

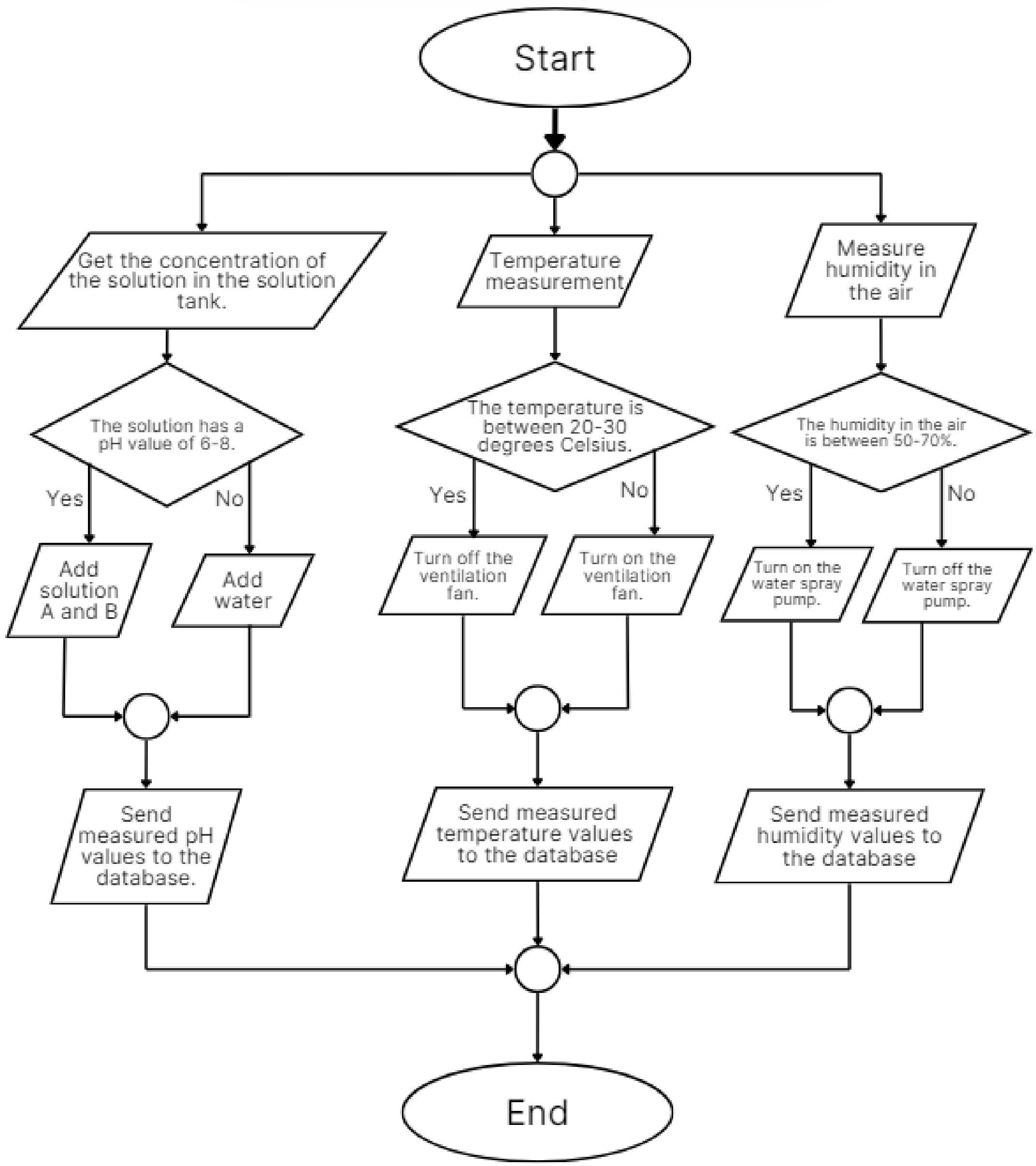

Figure 1. Shows a workflow diagram of automatic system and study of the effects of light and nutrient solution on the growth of Red Oak lettuce grown in hydroponic system.

3.1 Solution Concentration Control System

The solution concentration control system is designed to maintain the pH level of the solution within a range of 6 to 8. The system uses a pH sensor to detect any deviations in the pH level and sends the data to the processing unit. Based on the analysis, signals are sent to either Pump 1 (for Solution A) or Pump 2 (for Solution B) to adjust the concentration and balance the pH (Figure 2 and Figure 3).

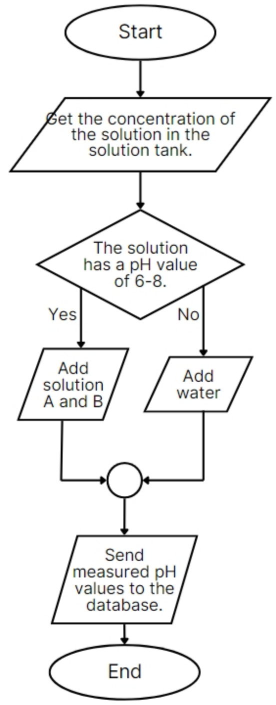

Figure 2. Shows a workflow diagram of solution concentration control system

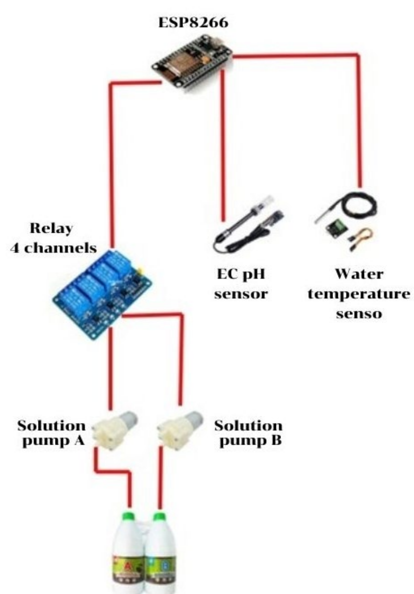

Figure 3. Shows a solution concentration control system

3.2 Temperature and humidity control system

In temperature control, the system's role is to regulate and maintain the temperature at a specified level. Any deviation detected by the system will be caused by external temperature fluctuations affecting the hydroponic plant growing equipment. In this system, there are sensors that detect temperature anomalies and send the data to the processing unit, which will then decide whether to activate Fan 1 and Fan 2 to cool down the environment or trigger the water pump to spray water to reduce the temperature and increase humidity. Once the temperature reaches the desired level, the system will stop its operation (Figure 4-Figure 5).

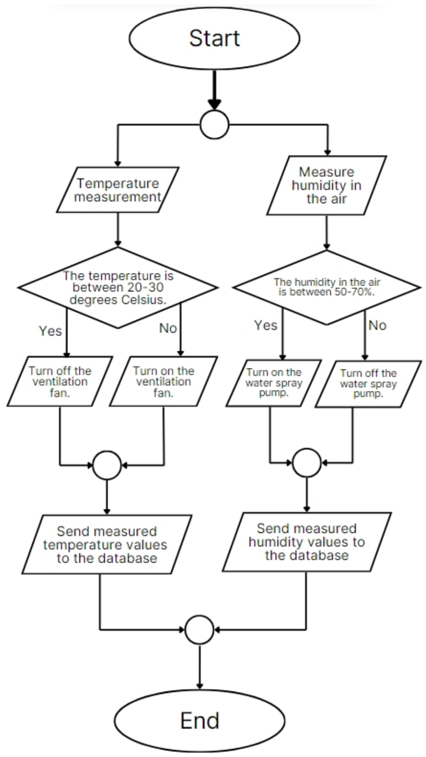

Figure 4. Show the IoT system that the project creator has designed

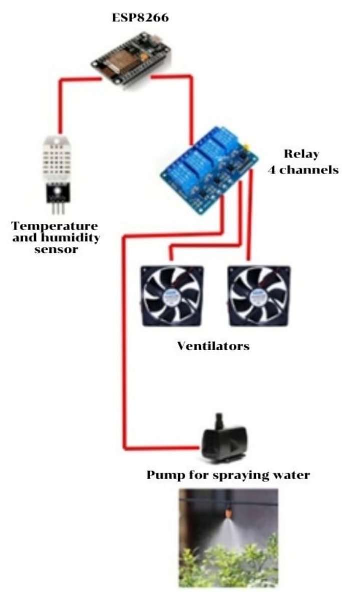

Figure 5. Shows the location and distance of sensor installation

3.3 Hydroponic Growing System

For the experiment, a hydroponic system known as the Nutrient Film Technique (NFT) will be utilized. In this system, plants are grown with their roots submerged directly in a nutrient solution. The solution flows in a thin film (about 2-3 mm thick) over the roots in wide plant-growing channels, which range from 5 to 35 cm in width and 5 to 10 cm in height. The length of the channels can vary between 5 to 20 meters depending on the type of plant and available space.

The nutrient solution can flow continuously or intermittently. Typically, it flows continuously with a flow rate of 1-2 liters per minute per channel. The channels may be made from materials such as plastic sheets (white and black, 80-200 microns thick) or PVC molded into finished channels. Additionally, metal materials like galvanized steel or aluminum may be used for the channels, with an internal plastic lining to prevent corrosion from the nutrient solution.

A pump circulates the nutrient solution through the channels and around the plant roots. After the solution passes through the plants, it returns to a storage tank, creating a closed-loop system that helps conserve water and nutrients.

In this specific experiment, the plants will be grown in PVC pipes with a 4-inch diameter, where the top of the pipe is cut longitudinally. The pipe is sealed at both ends to hold the nutrient solution. These pipes are arranged at a 1% incline to ensure consistent flow of the solution through the plants. The length of the pipes should not exceed 20 meters, and they may be stacked in multiple tiers to maximize space. The nutrient solution is drawn from a lower-level storage tank and delivered to the plant pipes via PVC piping. After passing through the plants, the solution is returned to the storage tank for recirculation (Figure 6).

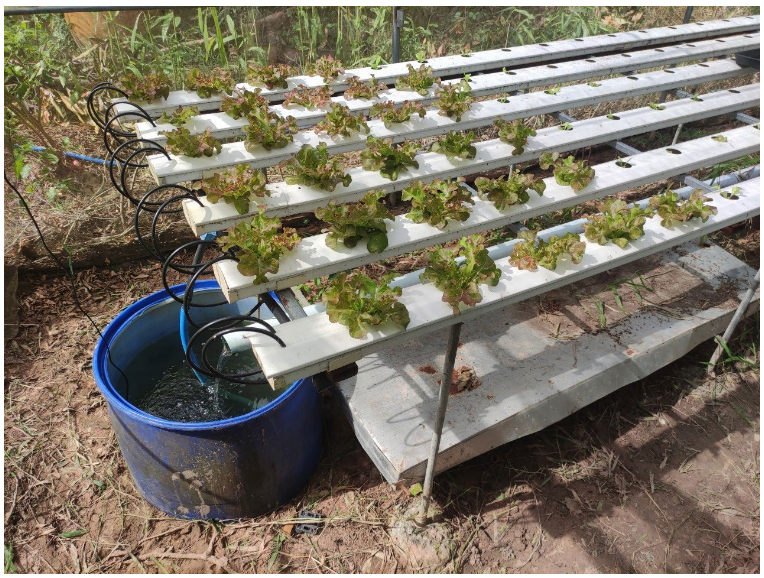

Figure 6. Hydroponic Growing System

4. Results and Discussion

This study designed a controlled LED grow light and nutrient solution management system for optimal plant growth in a vegetable planting area. The LED grow light operates from 6:00 AM to 6:00 PM daily, providing artificial sunlight positioned 60 cm above the plants to effectively cover a planting area with 16 vegetable plants (Table 1- Table 2).

A temperature control system was integrated, utilizing temperature sensors to maintain the environment between 20°C and 30°C, the ideal temperature range for vegetable growth. When the temperature drops to 20°C, water misting is stopped to conserve warmth, and misting resumes when the temperature reaches or exceeds 30°C.

From the experiment of the automatic solution mixing system, the ratio used is 5 cc of fertilizer A and B per 1 liter of water. In the mixing process, fertilizer A and B will be mixed with water in the reservoir using a water pump to mix thoroughly before sending it to the plants. The concentration control system controlled by NodeMCU ESP8266 and connected to the sensor will monitor and adjust the concentration of the nutrient solution in the reservoir. When the pH changes in the solution, solution A is added to lower the pH and solution B is added to increase the pH to an equilibrium level of pH 6 – 8 (Figure 7-Figure 9).

Table 1. Shows an example of temperature and metal control for a hydronic bone plant on January 6, 2025, with values displayed every 1 hour.

Date	Time	Temperature (Celsius)	Humidity level (%)
6/1/2025	0:00:03	24.4	61.9
6/1/2025	1:00:03	23.8	63.1
6/1/2025	2:00:04	23.2	64.4
6/1/2025	3:00:03	22.7	65.4
6/1/2025	4:00:03	22.2	66.4
6/1/2025	5:00:03	21.9	67.4
6/1/2025	6:00:03	21.6	68.1
6/1/2025	7:00:03	20.9	70.2
6/1/2025	8:00:03	23.4	67.7
6/1/2025	9:00:04	24.5	63.2
6/1/2025	10:00:04	26.5	59.8
6/1/2025	11:00:04	27.7	53.2
6/1/2025	12:00:04	28.3	51.8
6/1/2025	13:00:04	26.8	54.2
6/1/2025	14:00:04	24.8	57.5
6/1/2025	15:00:04	23.7	58.7
6/1/2025	16:00:06	22.2	66.1
6/1/2025	17:00:04	20.4	82.3
6/1/2025	18:00:04	19.7	88.8
6/1/2025	19:00:05	20.2	77.5
6/1/2025	20:00:05	27.5	56.2
6/1/2025	21:00:05	26.4	58.2
6/1/2025	22:00:05	25.5	60.4
6/1/2025	23:00:05	24.8	61.4

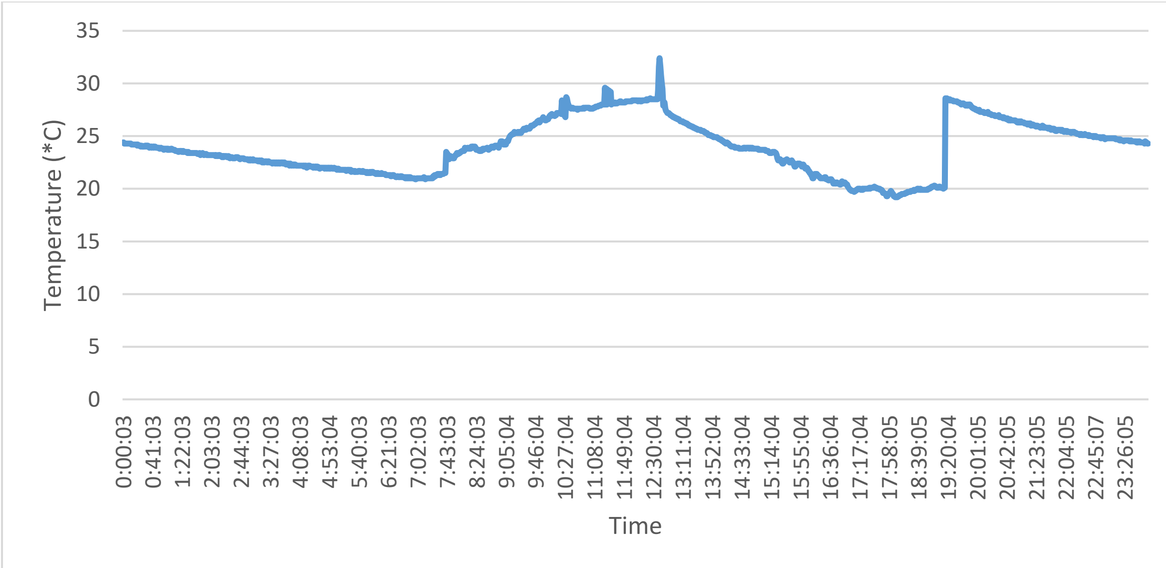

Figure 7. Graph showing temperature control versus time on January 6, 2025, with values displayed every 1 hour.

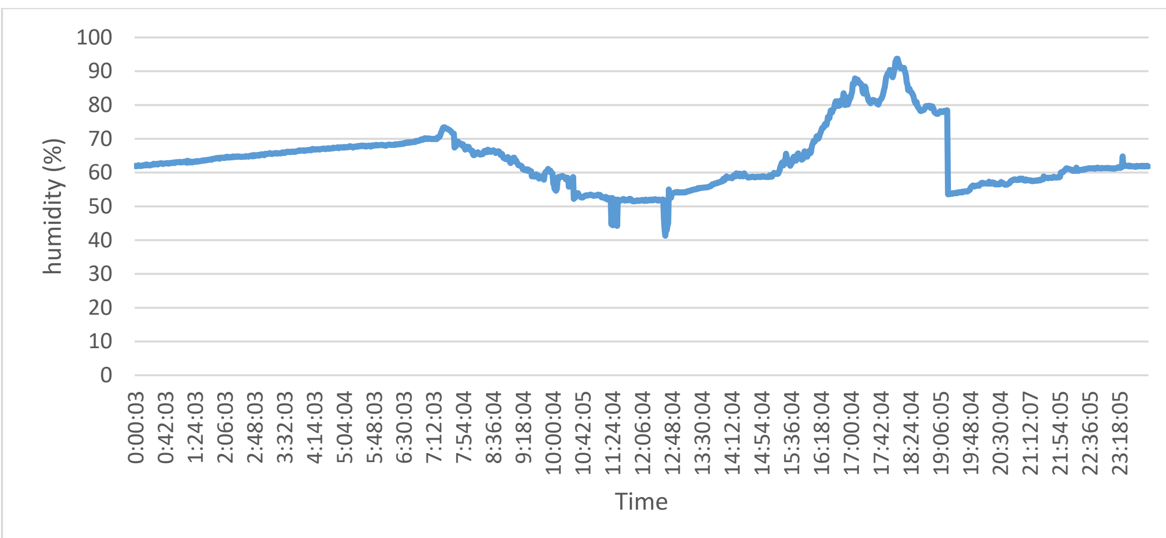

Figure 8. Graph showing humidity level control versus time on January 6, 2025, with values displayed every 1 hour.

Table 2. Shows pH control for hydroponic cultivation on January 6, 2025, with values displayed every 1 hour.

Date	Time	pH
6/1/2025	0:00:41	7.38
6/1/2025	1:00:24	7.40
6/1/2025	2:00:24	7.42
6/1/2025	3:00:25	7.42
6/1/2025	4:00:24	7.43
6/1/2025	5:00:00	7.43
6/1/2025	6:00:00	7.43
6/1/2025	7:00:00	7.42
6/1/2025	8:00:28	7.39
6/1/2025	9:00:29	7.37
6/1/2025	10:00:29	7.35
6/1/2025	12:00:30	7.32
6/1/2025	13:00:29	7.31
6/1/2025	14:00:29	7.31
6/1/2025	15:00:29	7.30
6/1/2025	16:00:29	7.30
6/1/2025	17:00:29	7.31
6/1/2025	18:00:30	7.33
6/1/2025	19:00:29	7.34
6/1/2025	20:00:30	7.36
6/1/2025	21:00:30	7.38
6/1/2025	22:00:30	7.39
6/1/2025	23:00:30	7.39

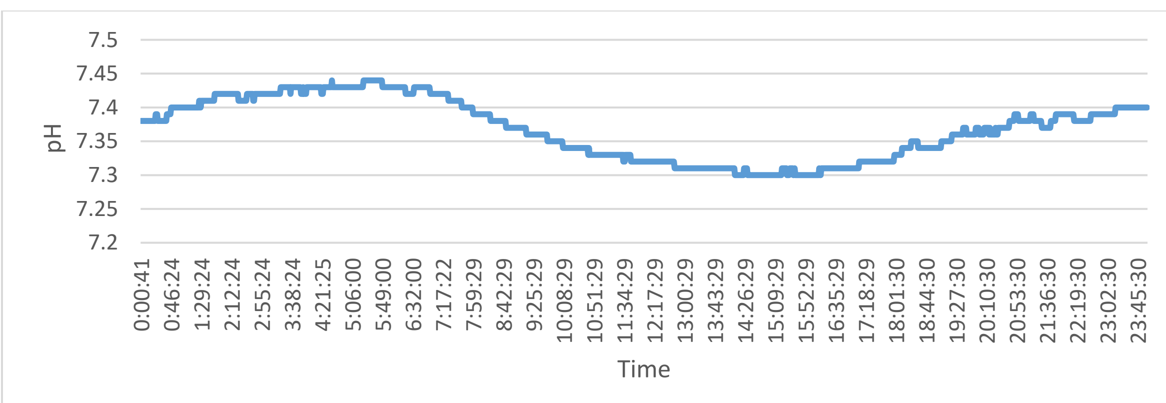

Figure 9. Graph showing pH control versus time

The experiment measuring electricity consumption found that the automated system consumes significantly more energy due to the use of artificial sunlight, temperature and humidity control systems, and power for various devices such as microcontrollers, sensors, fans, air pumps, and water pumps. The automated system consumes an average of 1,261 watts per day, with artificial sunlight alone accounting for 768 watts per day. In contrast, the conventional system primarily uses electricity for continuous water pumping, consuming an average of 50 watts per day.

The experiment measuring fertilizer consumption found that the developed automated system used an average of 1.27 liters of Fertilizer A and Fertilizer B combined. In contrast, the conventional farming system used an average of 0.8 to 1.0 liters, depending on the accuracy of the farmer's nutrient solution mixing.

The quality of the produce from conventionally grown hydroponic vegetables shows larger leaf and stem sizes compared to those grown using the automated hydroponic system, as shown in Table 3.

Table 3. Shows a comparison of yields between automatic and normal systems after 30 days of planting.

Red Oak	Plant Height (cm)		Plant Width (cm)		Number of Leaves	
	Automation	Normal system	Automation	Normal system	Automation	Normal system
1	11.30	9.50	16.30	14.20	10.00	6.00
2	11.20	7.60	18.20	12.30	12.00	6.00
3	11.50	8.30	16.10	13.20	8.00	6.00
4	12.30	8.50	16.50	13.10	10.00	6.00
5	10.90	9.20	15.80	13.50	8.00	6.00
6	11.20	8.30	17.50	12.30	8.00	6.00
7	11.50	11.20	17.80	13.80	10.00	8.00
8	10.20	11.90	14.30	14.30	6.00	8.00
9	10.80	12.10	15.20	14.50	6.00	8.00
10	11.30	9.50	17.90	14.20	10.00	6.00
11	11.50	7.60	17.60	12.30	10.00	6.00
12	11.10	8.30	16.50	13.20	8.00	6.00
13	10.80	8.50	16.20	13.10	8.00	6.00
14	12.40	11.40	18.10	13.10	12.00	8.00
15	12.50	9.50	17.20	14.20	8.00	6.00
16	12.10	7.60	17.10	12.30	8.00	6.00
Average	**11.42**	**9.31**	**16.77**	**13.35**	**8.88**	**6.50**

The IoT system demonstrated its potential for enhancing vegetable cultivation in controlled environments. By integrating precise environmental controls and real-time monitoring, the system improves productivity and operational efficiency, making it a valuable tool for modern agriculture.

5. Conclusion
This research successfully developed and implemented an IoT-enabled automated hydroponic system for cultivating Red Oak lettuce. The system integrates temperature, humidity, light, and nutrient control subsystems to provide a highly optimized growth environment. Experimental findings reveal significant improvements in plant yield, resource efficiency, and operational control compared to traditional hydroponic methods. By leveraging real-time monitoring and automation, this system offers a scalable and sustainable solution for urban farming and precision agriculture. Future studies may focus on refining the system for broader crop varieties and enhancing user-friendly interfaces for widespread adoption.

References
Thanadech P., Pinit P. and Eakpol H., Hydroponic system, Bachelor's Degree in Engineering, Mechanical Engineering Major, Burapha University. , 2016

Wannapan G. and Siripapa P., The Effect of Different Nutrient Solutions on Growth of Lettuce CV. Green Oak and Red Oak in Hydroponic System, Special Project Bachelor of Science Program Agricultural Science (Plant Production Technology)Faculty of Agricultural Technology and Industrial Technology Academic, 2018

Arnut T. and al, Study on Nutrients Solution Management in Soilless Culture, Final Research Report Under Research Project No. 3011-3004 Budget Years 2002-2004, 2004

Pak S., Research and Development of Automated Hydroponics System., Mahasarakham Rajabhat University (This research was funded by the government budget for research in the fiscal year 2018), 2019

Deanram P., The Application of NanoBubble Technology for DRFT Hydroponics, Journal of Innovation Technology Research, Volume 3, Issue 2, Pages 33-41, 2019

Pornkid U., Intelligent Hydroponic Planting Control System for Farmers, Research was funded by the revenue budget for the fiscal year 2020, Faculty of Business Administration, Rajamangala University of Technology Phra Nakhon,2020

Biographies
Atipat Plaiyduang is an vocational teachers in the field of electronics in Thailand. He holds a bachelor's degree in Telecommunication Engineering from Suranaree University of Technology and is pursuing a master's degree in Systems Engineering at the same university. Atipat's research interests include hydroponic farming IoT systems, and clean energy. He is dedicated to exploring innovative solutions and advancements in these fields to contribute to sustainable development and technological progress.

Nattawat Pinrath is a lecturer at Suranaree University of Technology, specializing in Industrial and Mechatronic Engineering. He holds a Ph.D. in Functional Control Systems and a Master's in Mechanical Engineering from Shibaura Institute of Technology, Japan, as well as a Master's in Industrial Engineering from Suranaree University of Technology, Thailand. His research interests include manufacturing automation systems, the industrial Internet of Things (IoT), and mobile robotics.