Artificial Intelligence of Smart Agriculture with Multiple Cropping in NFT Hydroponics System

Wrintorn Booneua

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Applied Mathematics and Computing Science

Prince of Songkla University

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ ปัญญาประดิษฐ์ของเกษตรอัจฉริยะด้วยการปลูกพืชหลายชนิดในระบบไฮโดรโพนิกส์แบบ NFT

ผู้เขียน นายวรินทร บุญเอื้อ

สาขาวิชา คณิตศาสตร์ประยุกต์และวิทยาการคำนวณ

ปีการศึกษา 2565

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาโมเดลการทำนายผลการเจริญเติบโตของพืชในระบบไฮโดรโพนิกส์ด้วยการเรียนรู้ด้วยเครื่อง (Machine learning) โดยมีการพัฒนาเซ็นเซอร์สำหรับการตรวจวัดปัจจัยสภาพแวดล้อม ได้แก่ อุณหภูมิ ความชื้น อุณหภูมิน้ำ pH และ EC โดยการใช้บอร์ดไมโครคอนโทรลเลอร์ ESP 32 รับข้อมูลจากเซ็นเซอร์เพื่อส่งข้อมูลไปยังฐานข้อมูล MySQL ในการพัฒนาระบบใช้ได้ใช้ ภาษาC และ C# สำหรับการเขียนโปรแกรมลงบอร์ดไมโครคอนโทรลเลอร์ ใช้ภาษา PHP Java Script และ AJAX สำหรับการพัฒนาเว็บไซต์และออกแบบหน้าแดชบอร์ด ใช้ภาษา Python สำหรับการวิเคราะห์และการทำนายผลข้อมูลโดยใช้อัลกอริทึมการเรียนรู้ด้วยเครื่อง (Machine learning) ได้แก่ logistic regression, K-NN, random forest, decision tree และ bayesian network และหาว่าแบบจำลองใดมีค่าความแม่นยำมากที่สุดสำหรับชุดข้อมูลนี้ ข้อมูลที่จัดเก็บในฐานข้อมูลประกอบไปด้วยข้อมูลที่เป็นการวัดปัจจัยที่ส่งผลต่อการเจริญเติบโตของพืช ได้แก่ อุณหภูมิ ความชื้น อุณหภูมิน้ำ pH และ EC ส่วนความเข้มแสงจะใช้แสงจากหลอดไฟประดิษฐ์ซึ่งมีช่วงแสงที่เหมาะสมสำหรับพืช ข้อมูลที่จะเก็บในฐานข้อมูลจะจัดเก็บเวลาตามการวัดจริง ๆ ซึ่งจะเก็บในทุก ๆ 20 นาที

ผลการวิจัย พบว่า แบบจำลอง random forest มีความแม่นยำมากที่สุดโดยใช้การวัดความแม่นยำ 2 วิธีคือ Split test และ Cross validation test ซึ่งทั้ง2 ในแบบจำลองได้ใช้โมเดล logistic regression, K-NN, random forest, decision tree และ Bayesian network ในการทดสอบประสิทธิภาพซึ่งตัวโมเดลที่มีความแม่นยำที่สุดสำหรับชุดข้อมูลการทดสอบนี้คือ random forest มีความแม่นยำ ประมาณ 98% ค่าความแม่นยำของการทำนายเหล่านี้ขึ้นอยู่กับข้อมูลที่นำมาใช้ หากมีการใช้ข้อมูลที่แตกต่างกัน โมเดลอื่น ๆอาจจะให้ความแม่นยำที่มากกว่าโมเดล random forest ซึ่งอาจจะสรุปได้ว่า ความแม่นยำของโมเดลที่ใช้ในการทำนายนี้ขึ้นอยู่กับประเภทของข้อมูลที่เราใช้งาน นอกจากนี้ยังมีการแสดงผลของเซ็นเซอร์ผ่านหน้าเว็บไซต์โดยจะแสดงข้อมูลในรูปแบบตัวเลข กราฟ และตารางเพื่อให้ผู้ใช้งานสามารถรับรู้ข้อมูลในการวัดสภาพแวดล้อมของระบบไฮโดรโพนิกส์ได้ซึ่งสามารถเรียกดูได้จากทุกอุปกรณ์ที่เชื่อมต่อกับอินเทอร์เน็ต ซึ่งงานวิจัยนี้ช่วยในการตัดสินใจของผู้ใช้สำหรับการปลูกในระบบไฮโดรโพนิกส์และสามารถที่จะควบคุมผลผลิตของพืชให้มีประสิทธิภาพได้เป็นอย่างดีอีกทั้งยังเป็นแนวทางต้นแบบสำหรับการใช้ระบบภายในครัวเรือนเพื่อให้สามารถปลูกพืชไว้บริโภคและจำหน่ายได้

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ABSTRACT

This research aims to develop a model to predict plant growth in hydroponics using machine learning. Sensors are developed for measuring environmental factors such as temperature, humidity, temperature. Water, pH and EC by using the ESP 32 microcontroller board, receive data from sensors to send data to MySQL database. In system development, use C and C# for programming onto microcontroller boards, use PHP, Java Script and AJAX languages for web development and dashboard design, use Python for data analysis and prediction using algorithms. Machine learning algorithms include logistic regression, K-NN, random forest, decision tree, and bayesian network, and determine which model has the most accuracy for this dataset. The data stored in the database contains information that measures factors affecting plant growth, including temperature, humidity, water temperature, pH and EC. Light intensity uses artificial incandescent light with an appropriate range of light. plant The data to be stored in the database will store time based on the actual measurement, which is collected every 20 minutes.

The results showed that the random forest model was the most accurate by using two precision measurement methods: split test and cross validation test, both of which used logistic regression model, K-NN, random forest, decision tree. and the Bayesian network. In the performance test, the most accurate model for this test dataset was the random forest with an accuracy of approximately 98%. The accuracy of these predictions depends on the data used. In addition, the sensor display is also available through the web page, which displays data in numerical, graph and table formats so that users can get the measurement data of the hydroponic environment which can be viewed. from any device connected to the Internet. This research aids in user decision making for growing in hydroponics systems and is able to effectively control crop yields and is also a model guideline for using the system. within the household to be able to grow crops for consumption and sale.

ACKNOWLEDGMENT

I would like to express my sincere thanks to my thesis advisor, Asst. Prof. Dr.Supaporn Chai-Arayalert and Co-advisor, Asst. Prof. Dr.Nathaphon Boonnam for their teaching, support, help, suggestion, and constant encouragement. This thesis may not be completed without all support from them throughout the course of this research.

I appreciate my parents' assistance and suggestions. They are my greatest source of inspiration and unwavering support. My parents have been a major motivating force up to this point, and this thesis would not have been completed without their unwavering support throughout the research process.

I would like to thank all the teachers in Master of Science in Applied Mathematics and Computing Science for their support, offering me guidance, assistance, and suggestions. In addition, I would like to thank all the seniors, juniors, and friends in my class in this course who have always encouraged me and helped me.

I would like to thank Prince of Songkla University This research and innovation activity was funded by the National Research Council of Thailand (NRCT) and funded by Prince of Songkla University. Surat Thani Campus, Thailand. The author would like to thank Assoc. Prof. Dr. Seppo Carrila and the Publishing Clinic. Research and Development Office Prince of Songkla University for assistance in preparing the manuscript.

Wrintorn Booneua

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LIST OF ABBREVIATIONS AND SYMBOLS

%RH	= Relative Humidity
°C	= Degrees Celsius
ADC	= Analog-to-digital converter
DHT 22	= Digital Humidity and Temperature Sensor
DNNs	= Deep Neural Networks
EC	= Electrical Conductivity
GPIO	= General Purpose Input/Output
I2C	= Inter-Integrated Circuit
I2S	= Inter-IC Sound
IoT	= Internet of Things
K-NN	= K-Nearest Neighbour Algorithm
mS/cm	= millisiemens per centimeter
ML	= Machine Lerning
NFT	= Nutrient Film Technique
NO_3	= Nitrate
Node MCU	= Microcontroller Unit
pH	= potential of the Hydrogen ions
RF	= Random forest
SPI/HSPI	= Serial Peripheral Interface
SVR	= Support vector regression
UART	= Universal Asynchronous Receiver Transmitter
XGB	= Acceleration gradient Intensive colors

LIST OF PAPER AND PROCEEDINGS

1. W. Boonneua, S. Chai-Arayalert, and N. Boonnam, “Automated Hydroponics Notification System Using IOT”, Int. J. Interact. Mob. Technol., vol. 16, no. 06, pp. 206–220, Mar. 2022.

CHAPTER 1

INTRODUCTION

1.1 Rationale

Farming is an important part of driving the country's economy as well as a country is being developed or developing countries. The transport of agricultural goods is part of the country's mobility. Not only every region can produce enough crops to be profitable, but also it must be an area having the fertility and minerals necessary for plants. Plants Climate is also a factor in plant growth and plant species. Each plant has different needs for each species.

Rapid urbanization and industrialization include global warming by 2050. The arable land is greatly reduced. Soil fertility and crop yields are deteriorating, and in some areas, arid conditions are unsuitable for cultivation due to the instability of the climate with higher temperatures. Pollution from factories and rivers. Poor water management affects the productivity and demands of the population in the future. The future goal is to create a hydroponics culture to avoid these problems (Mamta D. Sardare & Shraddha V. Admane, 2013).

For this reason, the rapidly changing climate in recent years has had an impact on crop yields. Traditional agriculture and soil horticulture have many limitations in the cultivation which yields an area of cultivation. In the changing climate conditions, many crops die in large numbers. Few plants thrive in this situation and are often not grown in hydroponics. It can grow plants in any climate regardless of the weather outside, and it can also grow many types of crops. The system can be automated using sensors and controlled through the Internet of Things network using the Internet to control the system operation problems (Vaibhav Palande et al., 2018). By detecting sensors with huge amounts of data in the database, the application of artificial intelligence to the Internet of Things is an innovation for today. Artificial Intelligence of Things (AIoT) is the Internet of Things that uses intelligent control and AI. This is the processing of information through various algorithms which can effectively improve the efficiency of agriculture (Shu-Ching Wang et al., 2021).

In this thesis, we are interested in factors affecting plant soilless growth with artificial light. We attached importance to the factors of interest and impact on plant growth, such as temperature, humidity, water temperature, pH, electrical conductivity, and light. The data were analyzed using different algorithms in processing, such as simple linear regression, multiple linear regression, logistic regression, K-nearest neighbor, decision tree, random forest, and Bayesian network. By comparing the efficiency of the algorithm in each stage of plant growth analyzes the effects of factors affecting the results and controls the automation of the system. In addition, we have developed a website page for displaying information through the dashboard and manual control of the system for use in the event of a sensor device failure or in the final stage of plant growth that does not require much control over the operation of the system. On the dashboard, users can view the data from any device over the Internet.

1.2 Objectives

1. To review the factors that influence plant growth
2. To analyze the accuracy for suitable growth using machine learning
3. To develop the system to be able to track the system through the website on all devices connected to the Internet

1.3 Outcome

1. Apply the data of factors affecting plant growth to control the environment in the system.
2. Implement the best algorithm for hydroponics cropping for all crops.
3. Show the cropping system with website.

1.4 Scope of Research

This development uses data from sensors such as temperature, humidity, water temperature, light, pH and electrical conductivity. The data were analyzed using artificial intelligence to analyze the data in this research work. The crops were planted in 3 types as shown in Table 1.

Table 1 Duration of Hydroponic Planting

Type of plant	Duration of planting
Red Amaranth, Green Amaranth	30 Days per crop
Red Oak, Green Oak	
Lettuce, Red Lettuce	

The scope of research can be defined as follows:

1. Use sensor data to identify factors that influence plant growth.
2. Establish a monitoring and management system to control plant growth factors to meet the optimum needs of plants.
3. Apply sensor data to automate tasks that would otherwise require human intervention.
4. Display the website to show sensor data.
5. Perform a statistical analysis to synthesize a suitable algorithm for the processing of plant data.

1.5 Research Methodology

We have a process of analyzing and designing systems through the System Development Life Cycle (SDLC) with prototyping methods as shown in Figure 1.

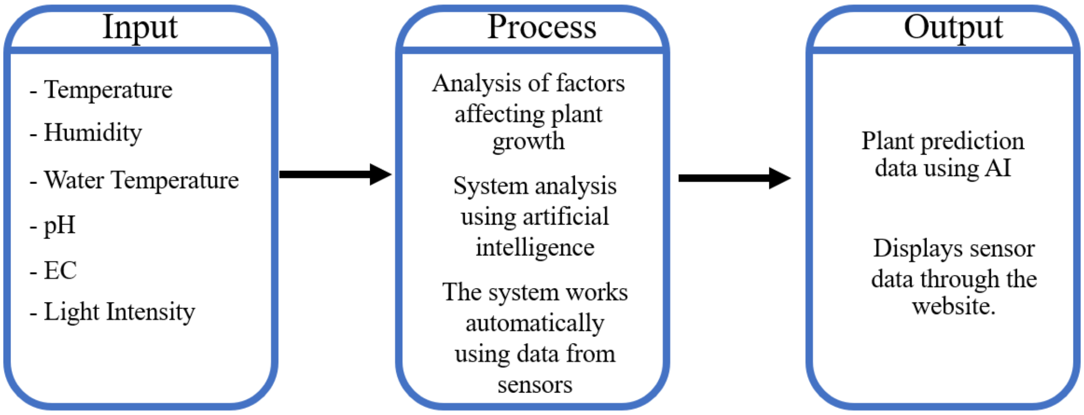


Figure 1. Overview of Research

1.5.1 Define the Research Problem

Hydroponics mainly focuses on growing only one type of crop, not a variety which sometimes may result in an insufficient demand for consumer demand. Plant growth factor regulation is essential for hydroponics. This feature of hydroponic systems has been solved by climate change and uncontrollable problems. Factors affect plant growth indirectly, such as temperature, humidity, water temperature, pH, EC, light intensity, and other factors. The data of the sensors connects to the internet continuously. This is a problem that must be solved in the system.

1.5.2 Review the Literature

Study of factors affecting plants appropriately and meet the needs of plants in the system including the introduction of artificial intelligence as part of the data analysis together with the connection of sensors by the Internet of Things to predict the factors affecting plant growth and the optimal period to maintain crops for better yields. If the value that the sensor measures are not within the desired range of the plant, the parameters will be adjusted to optimize the plant's growth. We have made the automatic and manual systems to prevent any possible technical failures of the sensors. We collect data from sensors without human intervention in the data collection process to prevent data discrepancies.

1.5.3 Formulate Hypotheses

Each data set consists of different data received from the sensors put in the hydroponics system. Temperature, humidity, light, and other environmental variables may all influence plant development. In hydroponics, according to Suhan M. et al. noticed that hydroponics is simple to set up and can help plants grow faster and yield more than traditional planting. Sensor readings of temperature, humidity, and pH are important components of plant development for controlling hydroponics (Dingyi Lin et al., 2019).

1.5.4 System Design

Plant growth factors are determined using sensors for temperature, humidity, water temperature, pH, and conductivity. The sensors are then measured to display information that contributes to plant growth using this data. It is used to analyze data in terms of conditions. The water pump in the system is turned on by the sensor. The microcontroller processes this automatically, and the system learns on its own when new data is received from the sensor. If these sensors are self-learning, it will be automated without human involvement in hydroponics to obtain factors affecting plant growth. Three plants are used together: short-term, medium-term, and long-term. Each crop has a different growth stage when we harvest a short crop. We added new ones to get trending information and make the system smarter. It allows the machine or system to learn by itself from the data measured by the sensor based on the information received from the sensor. By obtaining this model, the system is so intelligent that humans wait to collect vegetables from only the system. The system architecture design consists of four layers as follows:

- Sensor Layer: used to obtain information from the sensors that are factors in plant growth. The data obtained includes the data measured by the sensor, temperature, humidity, water temperature, pH, EC, and light intensity. The resulting data will be forwarded to the next layer.
- Network Layer: responsible for transmitting data received from sensors to hardware, using WIFI to communicate between microcontrollers and to send data to the cloud.
- Data Processing Layer: the layer for receiving data from sensors and processing it using algorithms appropriate for the data. The data value used in the system's operation is the value obtained from the data after processing.
- Application Layer: in charge of command control by receiving data from the processing layer and storing the resulting value in the form of a controlled label to manipulate the system's operation as shown in Figure 2.

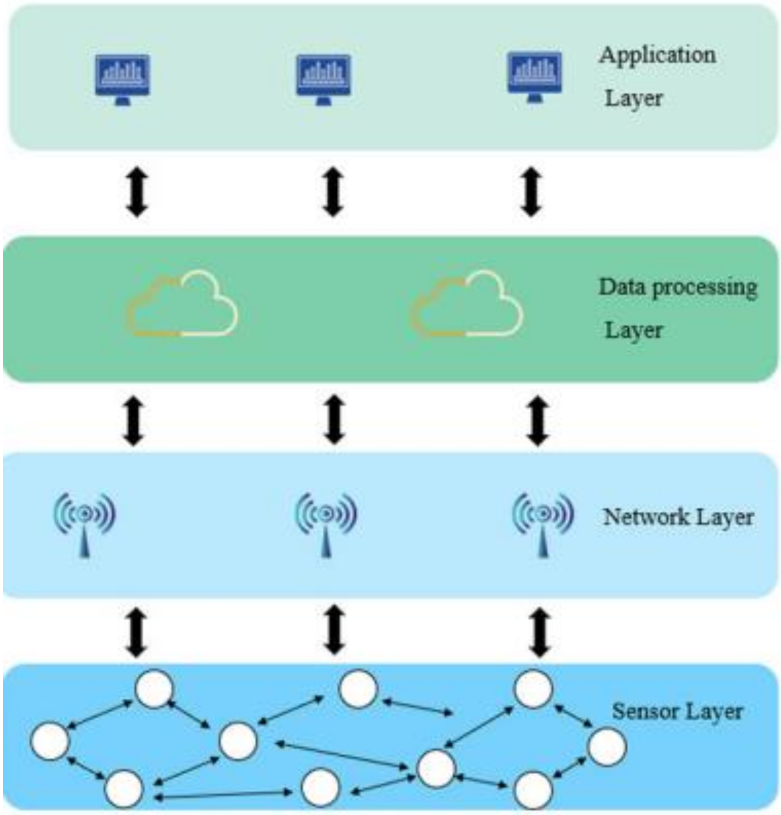


Figure 2. The four-layer architecture of a sensor network

1.5.5 System Development

We used the ESP32 board as a microcontroller board that connects to environmental sensors in a hydroponics system. We use conditions for controlling the system. to program using sensor data in accordance with the appropriate environment the program used is the Arduino IDE. In order for it to work, we stored the data in the database by writing the connection code in the PHP language through the Visual Studio program and upload it to the server so that the data can be viewed over the internet.

1.5.6 Analyze Data

We compared all the data obtained from the internal sensors to measure the effectiveness of the predictive data. The derived data models were used to predict data in systems such as logistic regression, K-NN, decision tree, random forest, and Bayesian network.

1.5.7 Thesis Preparation, Defense and Improvement

A summary of the factors affecting plant growth the device used to monitor the values from the sensors is installed and analyzes the data using artificial intelligence to control water, light, etc. Factors affecting plant growth that must be automated finally, we prepared a thesis document for the examination defense exam.

CHAPTER 2
RELATED WORKS

In this chapter, we discuss various research studies. This is the starting point for researching hydroponics and plant growth factors. As well as how to use algorithms to predict data, process the data, and find the best model to analyze it.

2.1 Background

Soilless cultivation is also known as hydroponics. Hydroponics is a crop where the roots are immersed in water mixed with a fertilizer containing essential plant nutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K), which depends on the area and use. By planting, each type will be planted differently. Hydroponics was officially introduced in 1699 when John Woodward learned of the solid and liquid soil particles that are essential for the growth of plants. They have experimented with various soil particles dissolved in water to test the plant growth. Later, Julius von Sachs who was the first German botanist pioneered the modern scientific method of hydroponics between 1860 and 1865, inventing a standardized nutrient solution. After that, there have been many scientists. Researchers who invented formulas for nutrient solutions, especially Wilhelm Knop, a German scientist, whose nutrient solution formula that he invented in 1865 is still used today. In 1920s, William F. Gericke from the University of California developed aeration techniques in water until the cultivation of plants with the method of hydroponics could be used in business, causing this professor to be regarded as the Father of modern hydroponics technology (John Woodard, accessed on 24 June 2021). There are several types of hydroponic cropping patterns, Sabale Snehal & Shirkande Aparna Shrinivas (2019) presented the following types of hydroponic crops:

- Wick system

The wick system is the easiest to install and maintain of the basic hydroponics systems as it does not require electricity and does not require changing nutrients. In this way, water is added to the planted container and left. The water in the container evaporates through the wick to allow the plants to absorb the nutrients from the solution mixed in the water as shown in Figure 3.

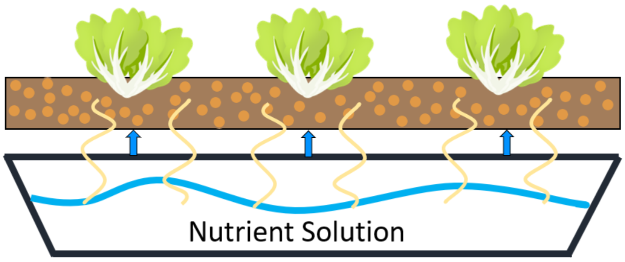


Figure 3. Wick System

- Deep Water Culture System

The deep water culture system is a system commonly used for long-rooted crops. The operation of the system is to add water to the nutrient solution. The roots of the planted plants are constantly immersed in water, where oxygen is supplied to the roots as shown in Figure 4.

Figure 4. Deep Water Culture System

- Ebb and Flow System

This system uses a pump to absorb water that is mixed with nutrients to be locked in a planting container until almost full, then let the water out completely. This system provides the plants with nutrients to retain water and oxygen when the water is released as shown in Figure 5.

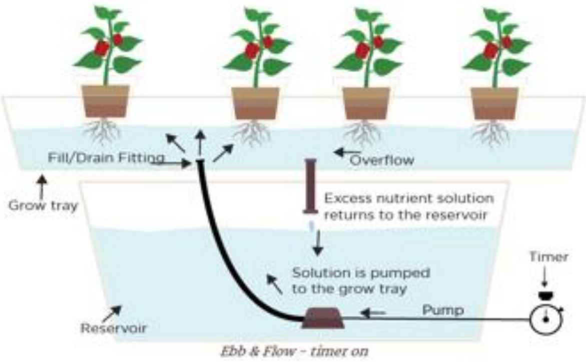


Figure 5. Ebb and Flow System (Snehal, S. & Shrinivas, S. A., 2019)

- Drip System

The drip irrigation system is probably one of the more commonly used systems. In a typical planting system, a timer is used to allow the pump to suck up the water and the nutrient solution to be transported to the plants, where water is dripped onto the base of each plant as tiny droplets. The way the drip system works simply drop a nutrient solution onto the roots to keep them hydrated. For the most part, plants grown in drip systems are useful for larger plants that take up a lot of space. With the functioning of a drip irrigation system that ensures sufficient humidity for the plant. This system therefore uses very little water, as shown in Figure 6.

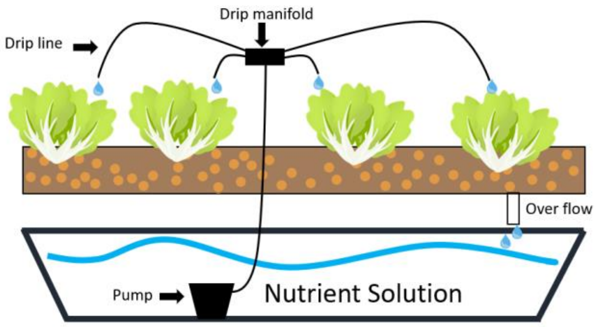


Figure 6. Drip System

- Nutrient Film Technique System

The system works with a continuous flow of nutrients, so there is no need for a timer. The NFT (Food Film Technique) system is popular in farmhouses. NFT Hydroponics growers often grow fast-growing crops such as lettuce. Commercial gardeners can grow herbs and grasses in addition to lettuce. The nutrients will be expelled from the reservoir into the pipes. by connecting large pipes with many smaller pipes. Cultivation with the Nutrient Film Technique System can also be applied to a variety of system functions. Because the Nutrient Film Technique System has a continuous flow of water, it is not necessary to visit all the time when planting as illustrated in Figure 7.

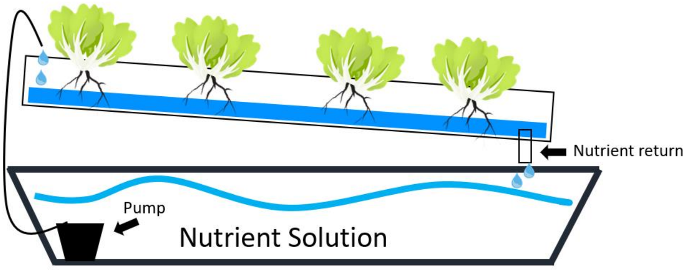


Figure 7. Nutrient Film Technique System

- Aeroponics System

Aeroponics is a state-of-the-art technology for growing advanced hydroponics plants. The concept of system aerobics is quite simple. It is the best technique among all types of hydroponics systems. Aeroponics also uses less water than other hydroponics systems. Nutrient transport uses a pump to spray micro-nutrient aerosols into the roots, where the roots of the plant will immediately absorb the nutrients. Aeroponics systems receive more nutrients and oxygen than other methods, allowing plants to grow faster than in traditional system plantings as shown in Figure 8.

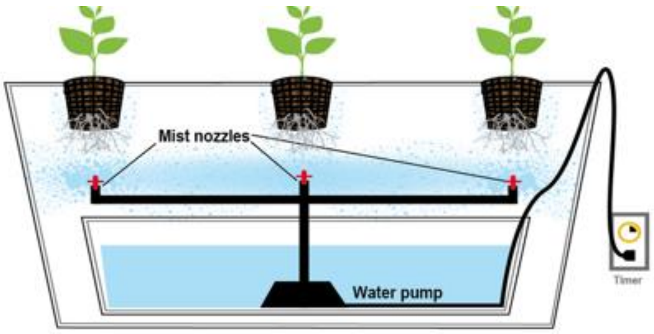


Figure 8. Aeroponics System (Snehal, S. & Shrinivas, S. A., 2019)

The medium of this growth is air, which is produced by the aerosol. (also known as a fog machine) (from 5-30 mm) because the tiny droplets (mist) stimulate more than the absorption of nutrients. The resulting mist sends water and nutrients to the roots of plants. Fogponics is better than aeroponics. Compared, mist also reaches plant roots and nutrient deficiencies allow better monitoring of plants (Falmata Modu et al., 2020)

Jinghua Guo et al. (2019) investigated the quality control techniques of vegetables and nutrients as assessed by estimating the amount of NO_3, vitamin C, and soluble sugars in plant hydroponics to reduce NO_3

accumulation and quickly increase the nutritional value, value, and yield of some hydroponics vegetables High levels of nitrate accumulation from hydroponics were able to be carried out by discontinuing the solution to reduce the residues by using the planting water not mixed AB for 3-5 days, the nitrate content in vegetables decreased by 30%.

There are important environmental factors that affect the cultivation of plants in hydroponics, such as light, temperature, and air humidity. relative humidity, light intensity, pH, and EC. Regulated plant growth rates generally have faster growth rates. Temperature is one of the most important factors for growth. How well vegetables grow is temperature dependent, as some plants may not be suitable for temperatures that are too hot or too cold. Humidity is the most difficult environmental factor to control. There are many ways to control relative humidity in cold climates. The most effective way to control humidity is to open a window so that the humidity in the room can be vented to control the humidity. (Fraz Ahmad Khan et al., 2018). Using Artificial Lighting (Super Bright LEDs) for Hydroponics Growing To compare the growth of plants grown in natural light. Light control (LED light) is on for 16 hours a day. The temperature is maintained at less than or equal to 30°C. Red and blue light with a ratio of 3:1 was used. In the growth test, the amount of light, temperature, and humidity data were collected. The study found that artificial lighting (LED) showed better growth than Natural light (Luechai Promratrak., 2017). Maintaining nutrient and pH levels in hydroponics systems is critical if these parameters are influenced by unfavorable environmental conditions which can damage the plant or stop its growth. Controlling the environment allows the plant to grow fast and produce quality yields. Several growth factors It depends on electrical conductivity, pH, temperature, and humidity, which are fundamental factors for all types of crops (J. R. N. Felizardo et al., 2015; Shin Jong Hwa & Son Jung Eek, 2015).

2.2 Internet of Things of Agriculture

The Internet of things over the past decade has been widely used in agriculture. Environmental detection and plant control weather are important for making accurate decisions. Productivity and quality are improving. Growing plants in greenhouses show that climate change affects crop yields. To increase the efficiency of growing plants in the greenhouse, more accuracy in terms of monitoring and control is required (Antonis Tzounis et al., 2017). The Internet of Things (IoT) is connecting things. and connecting devices to communicate via the Internet (Luigi Atzori et al., 2010). In agriculture, the Internet of Things enables communication with devices and storing data. from remote areas via the Internet And can make us perceive data with graphs, numbers, or different data. through the interface (Boonneua Wrintorn. et al., 2022). In addition, the connection with the Internet of Things allows farmers to automatically grow crops with hydroponics and monitor the environment. and control various factors that affect plant growth This makes it possible to control temperature, humidity, light, pH, and EC according to plant needs and make vegetables grow quickly (Manav Mehra et al., 2018).

Chanya Peuchpanngarm et al. (2016) developed a sensor-based hydroponics system automatically controlled via a mobile application. It uses different types of sensors. To provide automatic environmental control for hydroponics. Including temperature and humidity sensors and light intensity sensors to provide optimum control for crops. where harvest data is used to plan hydroponics for the next planting.

Arif Supriyanto & Fathurrahmani (2019) studied greenhouse humidity control and monitored the condition of hydroponics plants in real time using technology to track the water quality of hydroponics plants and provide farmers. They can control and view plant information through the web. Under the experimental conditions, the temperature was limited to 35 °C, which is the temperature at which plants were able to grow.

2.3 Artificial Intelligence of Things

Traditional farming is not enough to meet human food demands, adopting an Internet of Things with automation and data collection capabilities. Exchange and interact with the environment Applied to smart decisions that reduce human intervention. The combination of the Internet of Things and artificial intelligence results in a more efficient farming system in terms of accuracy (A. Subeesh & C. R. Mehta, 2021). Artificial intelligence is not the only enhancement of smart farming systems. It also optimizes the Internet of Things for more accurate computing by taking data from this sensor installation stored in the cloud and applying artificial intelligence algorithmic models to its processing. for best results Then the results will be displayed and notified to the farmers via the website or the interface as shown in Figure 9.

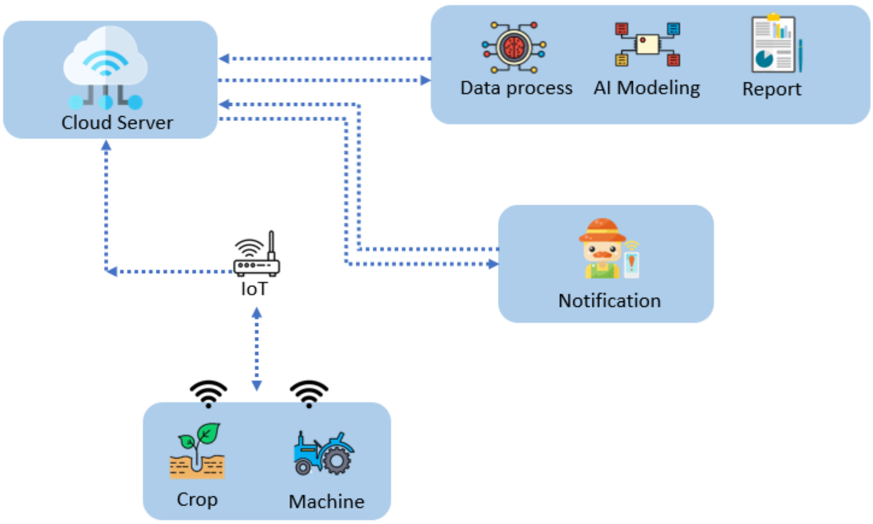


Figure 9. Work Flow of AIoT

Artificial intelligence It's an imitation of the human brain. which uses historical data to learn Compared to humans is learning from past experiences (Enzo Grossi & Massimo Buscema, 2008) . Artificial intelligence is widely used in medicine, industry and most importantly agriculture. Many researchers have applied artificial intelligence to increase the efficiency of agricultural products.

Ramesh & Vishnu Vardhan (2015) predicted the harvest using multiple linear regression (MLR) and density clustering techniques. Problems in forecasting productivity to predict the outcomes from production variables, year, rainfall, sowing area, yield, fertilizer (nitrogen, phosphorus, and potassium), and yield were used as forecast parameters.

Herman et al. (2019). Planting without soil, which uses nutrients, and minerals as a nutrient solution for plant growth can control acidity or alkalinity (pH), conductivity (EC), and temperature. Using only a few sensors to work. Lettuce was used as the target of the experiment and the K-NN (k-Nearest Neighbor) algorithm was chosen as the predictive algorithm for how classifying nutrients. The prediction results are used to send commands to the microcontroller turning on or off. The controller and actuator by K-NN research accuracy was 93.3%. When k = 5 was used, the accuracy was increased.

An understanding of the system and climate change allows the system to make accurate decisions by learning from experience. This method of crop prediction is often used for the detection of various parameters. Many environmental sensors such as pH, nitrogen, phosphate, potassium, organic carbon, calcium, including temperature, rainfall, humidity are often rationally programmed (Ngozi Clara Eli-Chukwu, 2019). There are various algorithms for predicting agricultural productivity Each model has its advantages and disadvantages. The performance of the model depends on the amount of data to be predicted.

Ali Mokhtar et al. (2022) predicted crop yields by studying lettuce crops using four different machine learning (ML) models: Support Vector Regression (SVR), Acceleration gradient Intensive colors (XGB), Random Forests (RF), and Deep Neural Networks (DNNs) were grown in three hydroponics systems (e.g., suspension nutrient film technique), Aeroponic Pyramid System and Aeroponic Tower). The greenhouse environment was controlled during the 2018 and 2019 growing seasons). The dataset was divided into 70% for training the four ML models (RF, XGB, SVR, and DNN). And 30% of the remaining data was used for model testing. The SVR nutrient film technique was the most efficient, followed by DNN and XGB for in-plant cultivation, the Aeroponic Pyramid, and the Aeroponic Tower.

2.4 Model Analysis

The choice of model for prediction is based on the use and data of the prediction. We are interested in the prediction model. The five models are logistic regression, decision tree, random forest, K-NN, and Bayesian network.

2.4.1 Logistic Regression

Logistic regression is a type of regression model used to make predictions in category models. The dependent variable depends on the predictor. A logistic regression model was used to determine the effect of independent variables. Logistic regression doesn't have to be linear. This model is often used for big data (Archana Chaudhary et al., 2013). Logistic regression capability also measures the probabilities of classes in which the variable has two probability values, 0 and 1 (Govind Kumar Jha et al., 2020).

2.4.2 Decision Tree

Decision tree Also known as a classification and regression tree (CART), it is used to categorize and predict both categorized inputs and outputs and contiguous variables. The decision tree works by following the decision tree to the leaf node. Figure 9 shows a tree method with the root node at the top. Conditions in the predicted tree the values are compared with the trained weights. Branching shows the terms beside the branches, with X_1, X_2, X_3 and X_4 representing the independent variables and a, b, c and d representing the learned weights shown in Figure 10 (Yemeserach Mekonnen et al., 2019).

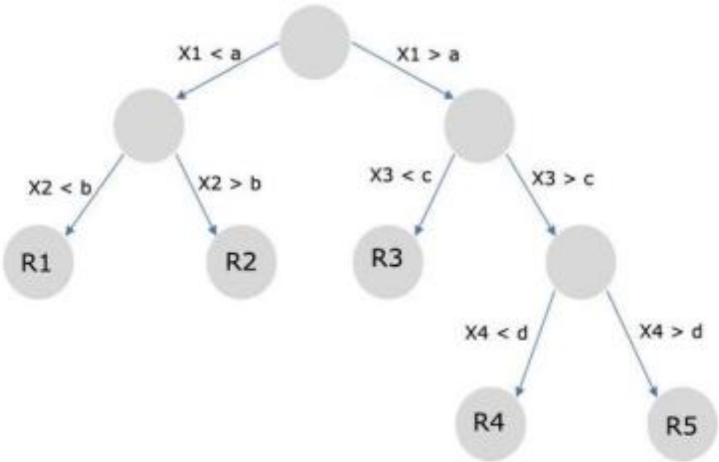


Figure 10. Decision Tree (Yemeserach Mekonnen et al., 2019)

2.4.3 Random Forest

Random forest (RF) is the most popular machine learning algorithm that can perform classification and regression by generating multiple decision trees at training time and exporting b-mode classes class (classification) or predicting the mean (regression) of each tree. The more trees in the forest, the more the more accurate the prediction will be. Decision tree habits are too good for practice sets, datasets, where the compilation of decision trees takes into account two-thirds of the records in the dataset. These decisions will be applied to the remaining records for the correct classification. The RF algorithm was used to study the performance of the dataset. The advantage of random forest algorithms is that overfitting is less problematic than Random Forests. No pruning is required (Priya et al., 2018).

2.4.4 K-nearest-neighbor

The k-nearest-neighbor (K-NN) algorithm is a classification method. Forecast and analyze from historical data. How K-NN works the most similar samples or data are considered. The k-nearest-neighbor

(K-NN) algorithm finds the closest match to the current data. Then determine the appropriate proportion of data. In the attribute area the similarity is determined using a simple Euclidean distance function based on the input vector $X = (x_1, x_2, x_3, \ldots, x_n)$.

Choosing the right value for K to select the right K for your data. We run the K-NN algorithm multiple times with different K values to minimize errors. While still delivering algorithmic results to accurately predict if it encounters never-before-seen data (Evan J. Coopersmith et al., 2014). The strength of this algorithm is simple and simple to use. There is no need to model anything. It makes more assumptions or customize multiple parameters. This algorithm also comes in a variety of shapes and sizes. They can be used for searching, classification, and regression. However, the weakness is slowness significantly when the number of samples and/or predictors/independent variables increases.

2.4.5 Bayesian Network

Bayesian network is a formal decision-making strategy analysis under unstable conditions. Probability prediction models have the theorem of Bayes is the foundation This data model mainly solves classification or regression problems. Bayesian inference uses examples to train very little data compared to other models. Bayesian theorem can be expressed as

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

where $P(A|B)$ is the probability of event A when event B has already occurred, $P(B|A)$ is the probability that we will get this information, $P(A)$ is the probability that the answer we are interested in before obtaining this information, and $P(B)$ is an opportunity for us to get this set of information. In summary, a Bayesian network is a directed graph composed of nodes (random variables) and edges. There is a conditional independence hypothesis between random variables if they are not linked (Yemeserach Mekonnen et al., 2019), (Brett Drury et al., 2017).

There is also research related to the study of environmental control in growing crops using artificial intelligence and the Internet of Things.

Srivani et al. (2021) studied different plant growth parameters. Plant growth factors have a significant influence on changes in plant growth in hydroponics. The researchers studied the growth of spinach in an aquarium to measure pH, conductivity, water temperature, system internal temperature and humidity, and the relationship between parameters was analyzed using Random Forest, Gradient Boost, K-NN, Bayesian Ridge regression model, the Random Forest model showed the most accurate predictive efficiency of 98%, concluding that pH and EC control affected the growth of significant plant as shown in Figure 11.

Table 3. Summary of regressor models' performance.

Model	Accuracy Score		RMSE	
	Plant Height	Number of Leaves	Plant Height	Number of Leaves
RFR	98.3	92.9	0.5	1.3
GBR	97.0	91.9	0.6	1.4
KNR	95.6	92.8	0.7	1.3
BRR	85.8	65.6	1.3	2.9

Figure 11. Summary of Regressor Models' Performance (Srivani et al., 2019)

Rashmi Bhardwaj et al. (2021) study decision-making systems based on climate analysis. It uses machine learning to predict performance which uses algorithms to analyze both, KNN XG Boost, Random Forest. Each algorithm's accuracy results have different results. Forrest sampling is the most accurate at 99.95 %, while the KNN network has the highest accuracy. Accuracy at k = 1 is 97.5% and at k = 10 it is 95% and at XG Boost, 99.81%.

From the study of predictive models, seven popular prediction models were simple linear regression, random forest, decision, multiple linear regression, K-NN and Bayesian network. which is the main model for prediction Each model has different advantages and disadvantages. The accuracy of each model depends on the data obtained in the predictions. The implementation of the model should take into account the data. Type of information and appropriateness in this study We considered a suitable and interesting model for predictive control of five closed hydroponics systems: logistic regression, random forest, decision tree, K-NN, and Bayesian network.

2.5 Related Sensor Devices

The operation of the sensor is controlled by ESP32 microcontroller in this system. Based on Espressif, ESP-WROOM-32 module, based on chips and modules from Espressif Espressif Systems, is an ESP32 microcontroller that supports Wireless LAN and Bluetooth Low Energy compliant wireless communication. Following the release of the ESP8266EX, Tensilica L106 Diamond series 32-bit architecture microcontroller chips are now very successful and well known among developers. The most interesting feature is that it supports 2.4GHz Wi-Fi frequency, allowing developers to create devices that can instantly connect wirelessly. With a GPIO interface for connecting additional devices as needed, including Digital Input/Output, ADC, UART, I2C, I2S, SPI/HSPI, SDIO, etc., for example, and modularizing the ESP-WROOM-02 as shown in Figure 12.

Figure 12. ESP32

The DHT22 sensor is used to measure air temperature in enclosed rooms equipped with hydroponics systems. The DHT22 is a highly accurate sensor. The sensor's measurement range is - 40 °C to 80 °C, with an accuracy of ± 0 5 °C. Measuring the temperature inside a hydroponics room is one of the most important factors in growing plants. if the temperature is correct plants will flourish, the climate in the room can be controlled by ventilating the room. Humidity is the actual quantity of water vapor involved in the storage of water vapor in the air provided that the air reaches a certain temperature. Relative humidity is expressed in terms of pressure or density. Like steam, relative humidity is often referred to as RH and is expressed as a percentage (%) as a percentage between 0%RH and 100% RH as shown in Figure 13.

Figure 13. DHT22

We use the DS18B20 sensor to measure the temperature of the water. The sensor is in range Temperature range: -55 °C to 125 °C with 2°C accuracy on the water temperature sensor. Water temperature is measured every 20 minutes, as shown in Figure 14.

Figure 14. Waterproof Temperature (DS18B20)

Plant pH is essential for plant growth. Sensor pH is measured in the range of 1-14, generally if the resulting value is less. 7 is acidic if more than 7 is alkaline. The accuracy of the pH sensor is ±0.1 pH at a constant temperature of 25 °C, and the optimal values for plants in the range of pH 5.5-7.2 are shown in the Figure 15.

Figure 15. pH Probe

The conductivity of water helps to determine the purity of the water. In hydroponics, conductivity is a measure of conductivity in a nutrient solution. The measuring range of the conductivity sensor is 0-20 µS/cm However, conductivity measurements do not require a large measuring range due to the high cost of sensors to measure conductivity. A range of 0-10 µS/cm is sufficient to measure conductivity. The optimum value for plant growth in the sensor conductivity was 1.1-1.8 µS/cm, as shown in the Figure 16.

Figure 16. EC Probe

CHAPTER 3

Installation of NFT Hydroponics Multi cropping

Various environmental factors affecting plant growth It is an important part of keeping our plant environment undamaged. Sensor system in hydroponics for collecting data from various sensor devices and monitoring plant growth factors. various environmental factors It is an important part to solve the problem of keeping our plant environment from being damaged, making it interesting to study. Controlling these factors with the Internet of Things and Artificial Intelligence.

This chapter discusses the installation of NFT Hydroponics system, device, and Sensor using and communicating datasets to the database as follows: section 3.1 describes the components of the sensor device, 3.2 overview of the sensor devices, 3.3 display data with a dashboard, and 3.4 data preparation for analysis.

3.1 Components of Sensor Devices

The connection between pH, water temperature, DHT22 and EC is connected to the microcontroller board. We can wire and ground all the sensors from the microcontroller board to the breadboard. It is also known as the board for testing the electronic circuit of the DHT22 sensor, it is connected in the box to transmit data with the digital pin and other sensors are connected by analog pins as shown in the Figure 17.

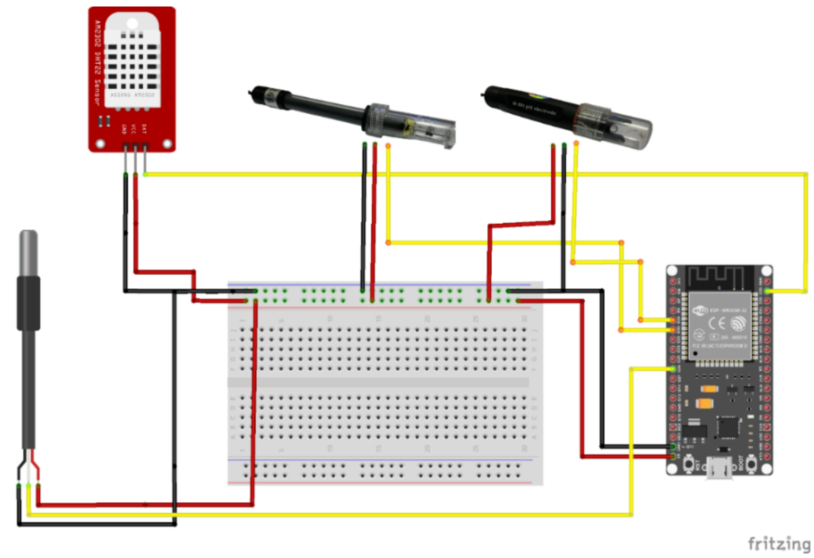


Figure 17. Circuit diagram for hydroponics system

In this hydroponics crop of this study, the sensor specifications are described in detail as shown in Table 2.

Table 2. Sensor Specifications

Parameter	Sensor	Voltage	Range Value	Accuracy
Node MCU	ESPino32	2.3-3.6V	-	-
Temperature	DHT22	3.3-3.6V	- 40 °C to 80 °C	± 5
Humidity	DHT22	3.3-3.6V	0 % RH to 100 % RH	-
Water Temperature	DS18B20	5V	-55 °C to 125°C	± 2
pH	pH probe DFROBOT	5V	0-14	± 0.1
EC	EC probe DFROBOT	5V	0-20	-

All sensor specifications are put into this system. All temperature and humidity sensors are mounted in a waterproof case system for the device. In the water tank placed water temperature, pH and EC sensors. Each sensor in the system. It sends data to the database via WIFI, so users can view detailed information through the dashboard. For programming development, we use the Arduino IDE. These devices are developed for use with the Arduino IDE programming system and consist of C or C++ commands and libraries. existing and use data analysis with model's logistic regression, K-NN, decision trees, random forest, and Bayesian networks.

3.2 Device Overview

Device operation with sensors installed in hydroponics include a DHT22 sensor, temperature, waterproof, pH and conductivity. We studied the factors affecting plant growth before installing these sensors. All sensors are essential for environmental control and plant growth in hydroponics. We measured the state of the system with sensors in the reservoir. Nutrient solution AB is mixed with water in a container. The sensors in the water tank include temperature, waterproof, pH and conductivity sensors. The system was repeated retrieving the data every 20 minutes, sending results to the control box. Then it automatically managed the water pump control after receiving the processing value. The control box has a light sensor for measuring temperature and humidity inside the system room when data from the sensor is directed to the control box. It sends the data to the MySQL database, which displays the measured sensor values to the user through the website as well as the measurement values along with a data graph. Users can choose to control the system by themselves as shown in Figure 18.

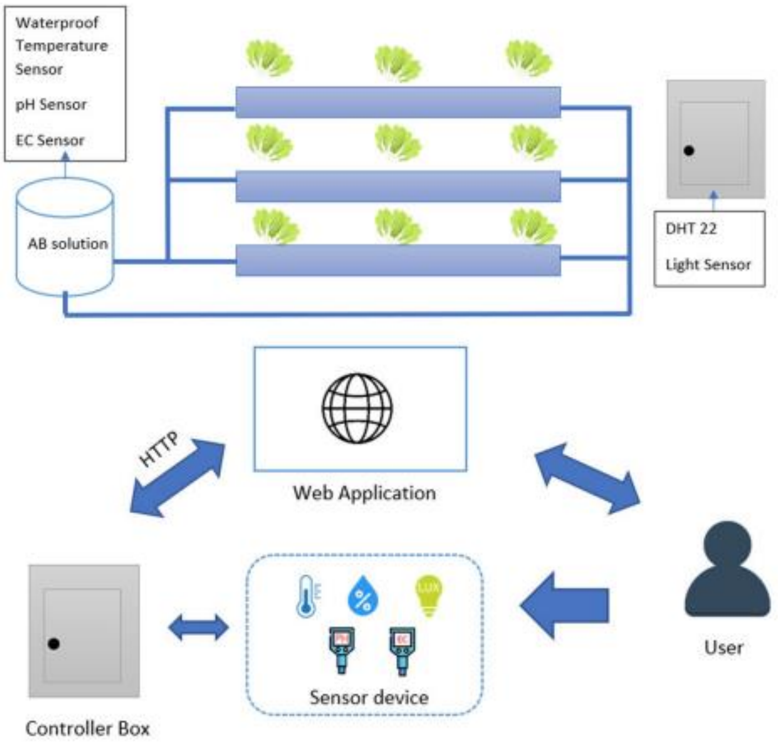


Figure 18. Overview System

3.3 Displaying Data with a Dashboard

Once the data from the sensor has been sent to the database. Extracting large amounts of data from a database is important to keep users informed and to be able to view the data in real time and view historical data in operation before it is recorded in the database. A data table is created to store the data for the installed sensors. which we have used SQL language to create tables by creating in phpMyAdmin host as shown in the Figure 19.

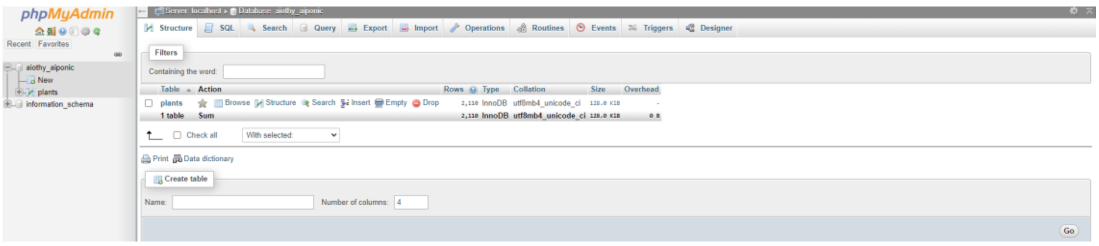


Figure 19. phpMyAdmin

Once the database has been created. The next step is to program the sensor to send data to the database. You can use the Arduino IDE to write the data to the microcontroller board, shown in the Figure 20.

Figure 20. Arduino IDE Program

Once we have received the data from the database Coming to the process of creating a web page to display information, we use Visual studio to write a website to display. which uses the language of PHP, java script and AJAX for writing up to the host to view online information on the Internet as shown in the Figure 21.

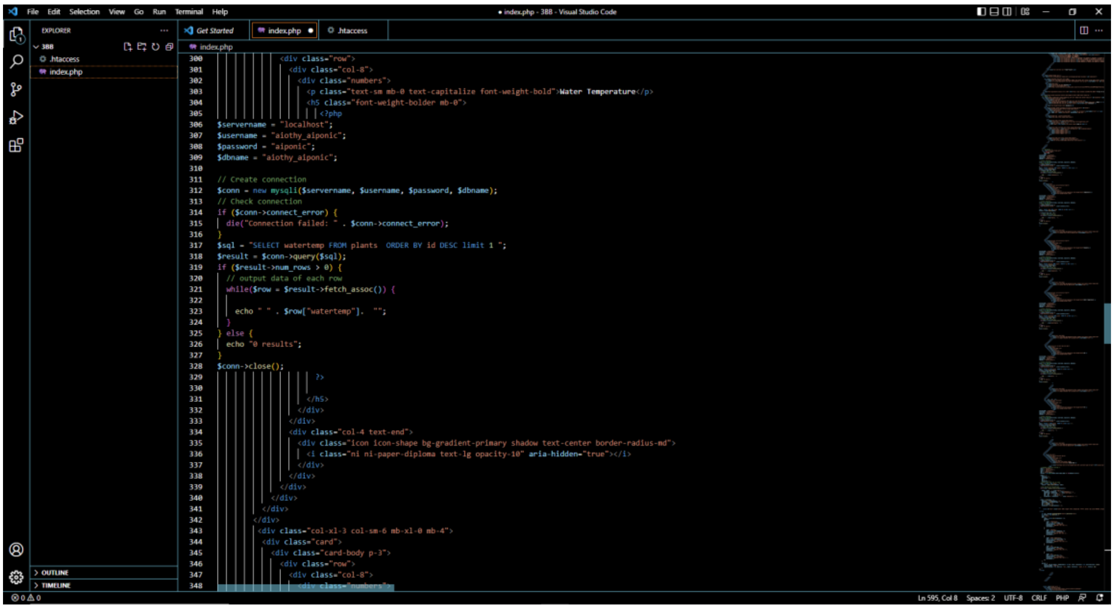


Figure 21. Visual Studio Program

3.4 Data Preparation for Analysis

3.4.1 Train and Test Data

Usually, we divide the data for training and testing into 2 parts: Training Set and Test Set by dividing this data into three main methods: self-consistency testing; split testing and cross validation testing.

3.4.2 Self Consistency Test

Self-Consistency Test testing is the simplest method for simulated testing using the same dataset in both practice and testing. The performance can be very high due to the original data set. which is not suitable for use but it's more suitable for looking at trends in data. The self-consistency test method is shown in Figure 22.

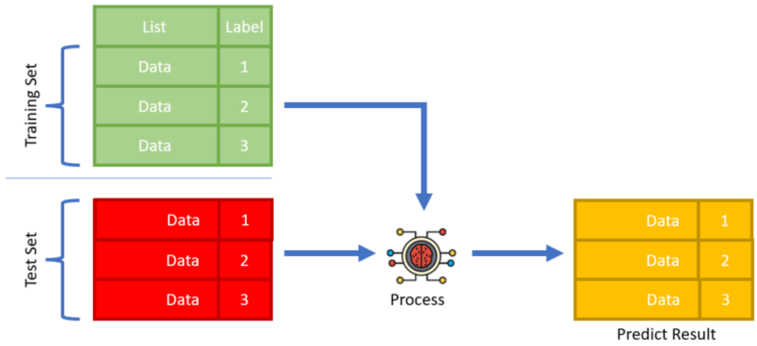


Figure 22. Self-Consistency Test

3.4.3 Split Test

Split Test This method is popular for splitting data. There are usually two types of information. The division of 70% training data, 30% testing data, and 80% training data, 20% testing data, randomize both of them only once. The advantages of this method are It takes less processing time and is ideal for big data as shown in Figure 23.

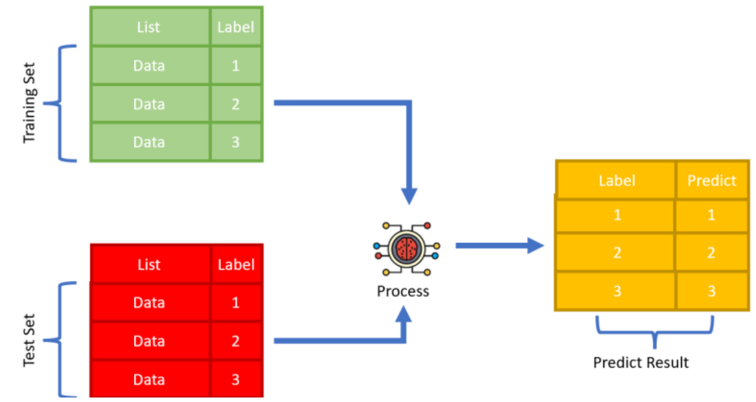


Figure 23. Split test

3.4.4 Cross Validation

Cross validation is one popular method for modeling and research. This method divides the data into multiple parts, using the value k to divide it. For example, a 4-segment cross validation is 4 segments, or, as is heard in 10-fold cross validation, is a 10-fold cross validation. Examples of validation methods are shown in Figures 24-26.

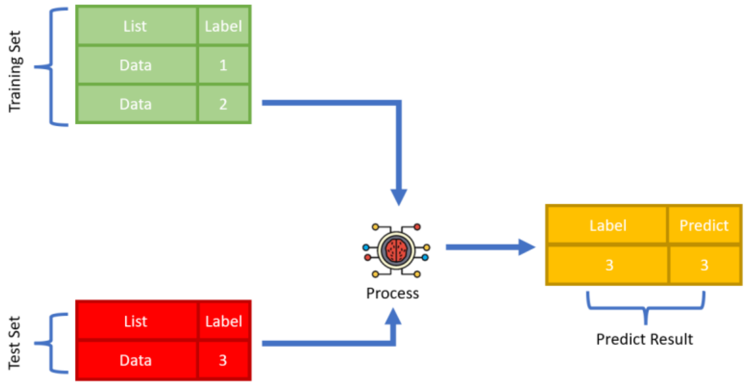


Figure 24. Cross Validation in Round 1

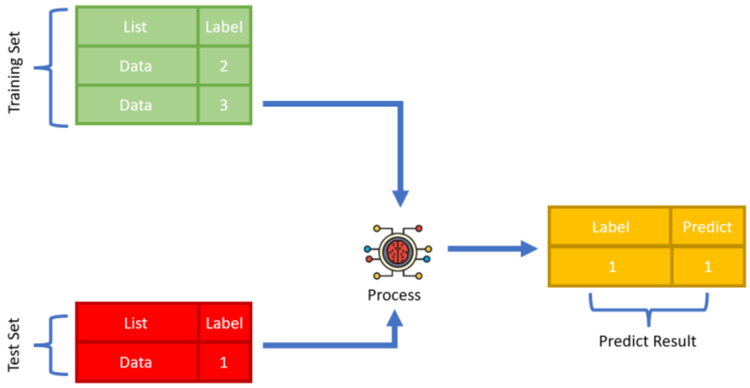


Figure 25. Cross Validation in Round 2

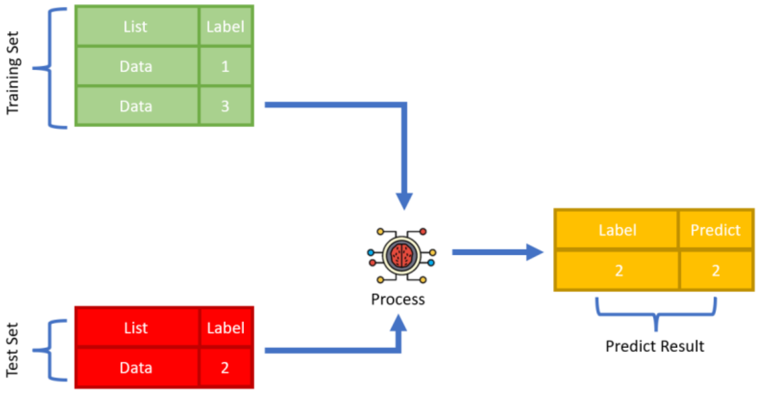


Figure 26. Cross Validation in Round 3

CHAPTER 4
RESULT AND DISCUSSION

In the chapter, we describe about device sensors. Hydroponics equipment design and device-to-database communication. This chapter focuses on the information obtained by installing environmental monitoring equipment in a closed hydroponics system in a control room. This study examined environmental factors affecting plant growth. Hydroponics system alert and predictive analysis using logistic regression model, K-NN, random forest, decision tree. and Bayesian networks

4.1 Hardware Installation

After completing the installation of the device, we installed it at Faculty of Industrial Science and Technology, Prince of Songkla University, Surat Thani Campus to measure and store environmental factors in a closed hydroponics system for study, analysis and forecasting to control the operation of a hydroponic system as shown in Figure 27.

Figure 27. Location installs hydroponics system

Inside the lab, three layers of steel planting rails are installed as well as a water conduit, and three levels of artificial lighting are installed to illuminate the plants in the system. Which has a pipe from the water pump to transport the nutrient solution to all the vegetable crops as shown in Figure 28.

Figure 28. Inside hydroponics system

This study used plant growth factors (temperature, humidity, water temperature, pH and EC) from a hydroponics system installed at the Faculty of Science and Technology, Prince of Songkla University, Surat Thani Campus. The collected data was collected from April 2022 to July 2022 and the database we used was phpMyAdmin. The analytics model used Google Colab to analyze and predict results in hydroponics.

4.2 Comparison Standard value

The most suitable factors for plant growth are those that need to be controlled to ensure good growth and yield. The range of factors required by plants is shown in Table 3.

Table 3. Standard Factor Value

Factor	Boundary Condition
Temperature	15–30°C
Humidity	50–70 RH%
Water temperature	22–28°C
pH	5.5–7.2
Electrical conductivity	1.1–1.8 mS/cm

For the control, we have set the conditions for the operation of the system specified as a Label. Each label is derived from a standard plant growth factor that forms a conditional rule for plant control in hydroponics. as shown in Table 4.

Table 4. Conditions for Controlling the System

Label	Action
0	No action
1	Open fan
2	Down pH
3	Add AB nutrient
4	Open fan and Down pH
5	Open fan and Add AB nutrient
6	Down pH and Add AB nutrient
7	Open fan, Down pH and Add AB nutrient

By working data when receiving data from the sensor, This was conditionally analyzed to identify the label for managing the control of hydroponics systems as shown in Figure 29.

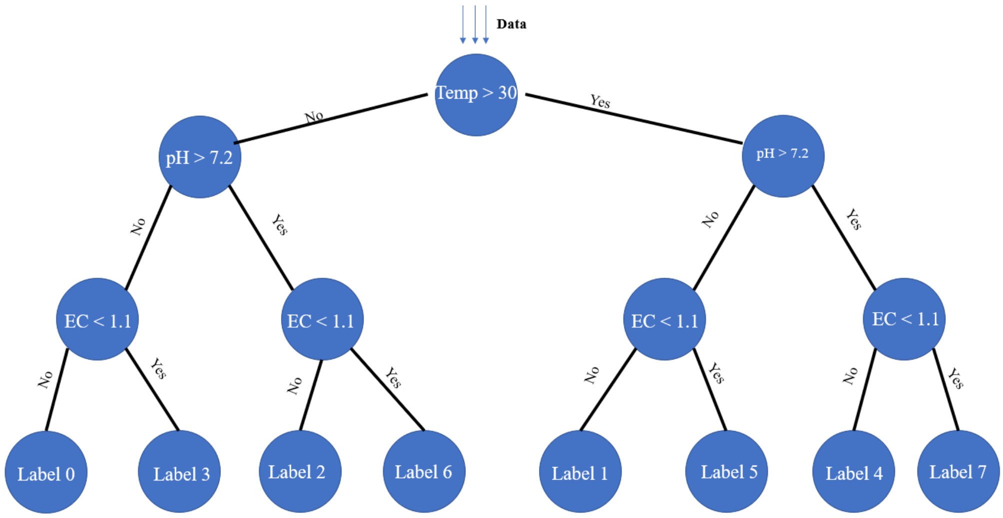


Figure 29. System Conditions of Decision Tree

Comparison of measured sensor data with standard data ranges the measurement data from the hydroponics system was compared with the optimal range for plant growth. We measure temperature, humidity, water temperature, pH and conductivity. We do not measure the range of light because we use artificial light to grow plants, which is the range the plants need. We compare the crops of three crops together. temperature comparison as shown in Figure 30.

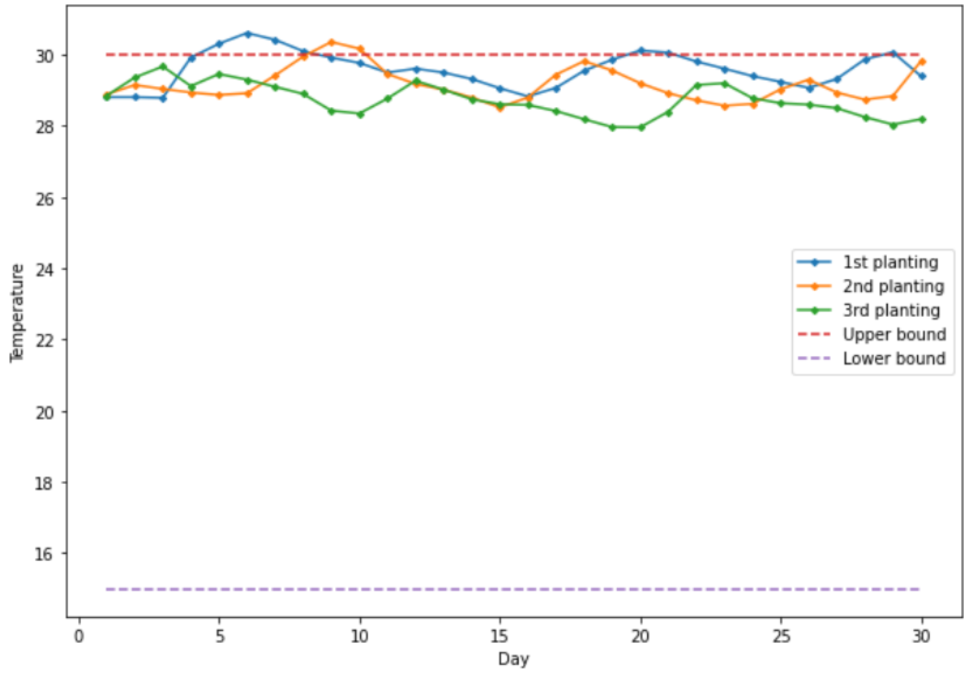


Figure 30. Comparison in Temperature Data

Humidity measurement, which from the graph can be seen that in the 2[nd] and 3[rd] planting cycles, the humidity is still controlled to be within the range that is not harmful to the plants as shown in Figure 31.

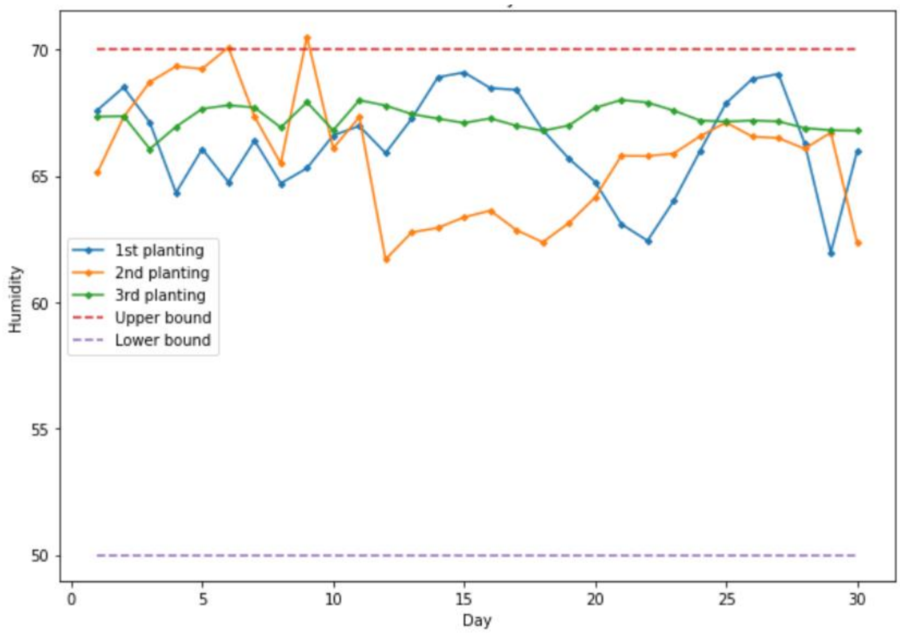


Figure 31. Comparison in Humidity Data

Automated hydroponics using IoT to transport nutrients to plants. Water temperature is something that can damage crops in a short time if not controlled. Research has shown that when temperature is controlled, water is within the desired range of plants, shown in Figure 32.

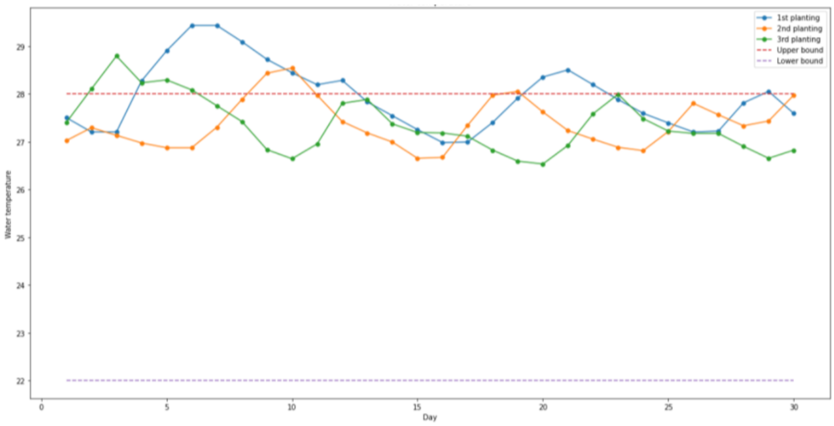


Figure 32. Comparison in Water Temperature Data

pH is very important for growing plants. It can be seen that during the first 3 cycles of planting the pH is still within the standard range. But there are some values that are higher than normal due to board signal transmission fault. This mistake can destroy plants from acidic water, shown in Figure 33.

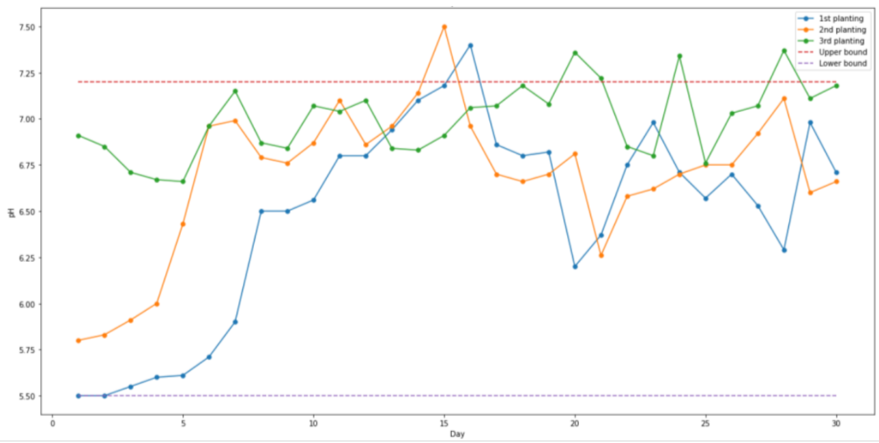


Figure 33. Comparison in pH Data

In addition to measuring the electrical conductivity of plants It is a measure of the rate of residual solution. whether it is sufficient for the use of plants or not which the system is able to make notifications various abnormalities. To allow users to fill the nutrient solution in the container that supplies water to the plants as shown in Figure 34.

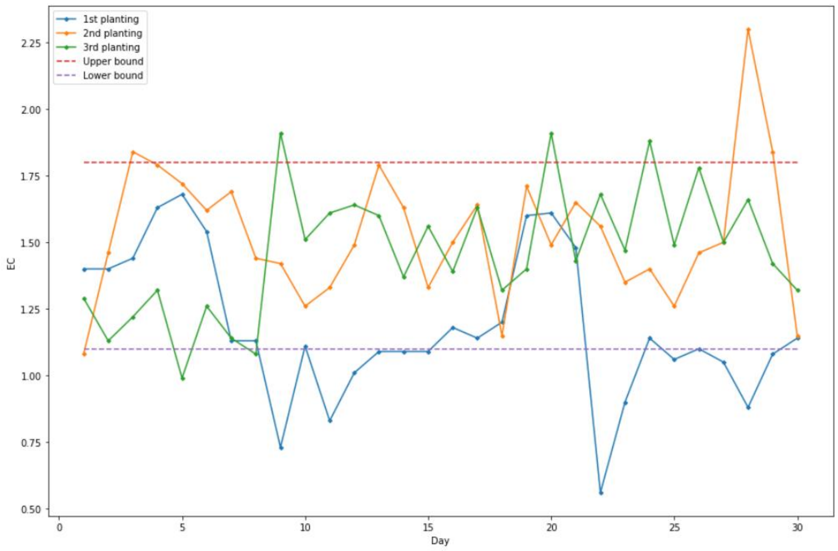


Figure 34. Comparison in EC Data

We can see that the conductivity of the plants during each growing cycle is very fluctuating. This may be caused by the measuring device being used for a long time.

4.3 Model Performance

To bring the data for training and testing to measure the performance of a suitable model for this hydroponic growing system. We have tested Using a split test and cross validation test, from k=2 to k=10 to test the performance to be more accurate. The logistic regression, K-NN, random forest, decision tree, Bayesian network were used to test the data. From 3 round of planting during 30 days using all 30 days of data to test.

4.3.1 Split Test Performance

We divided the data into 70% training data and 30% testing data. from all three rounds. The wild random model is the most efficient. which is 100% accurate. The forecast was based on a logistic regression model with an accuracy of 96.6%, indicating that the latter, if more and more data is available. Model predictions will be more accurate. The logistics model is shown in Figure 35.

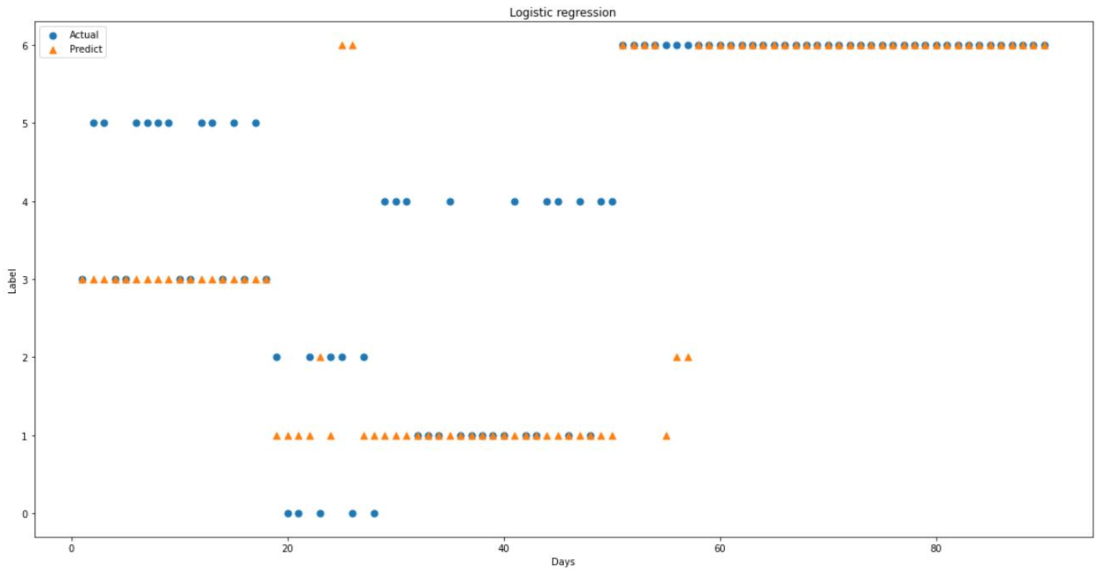


Figure 35. Logistic Regression Model

The prediction using K-NN was higher than the logistic regression model. It has a prediction accuracy of 98.5%. The K-NN test model is shown in the Figure 36.

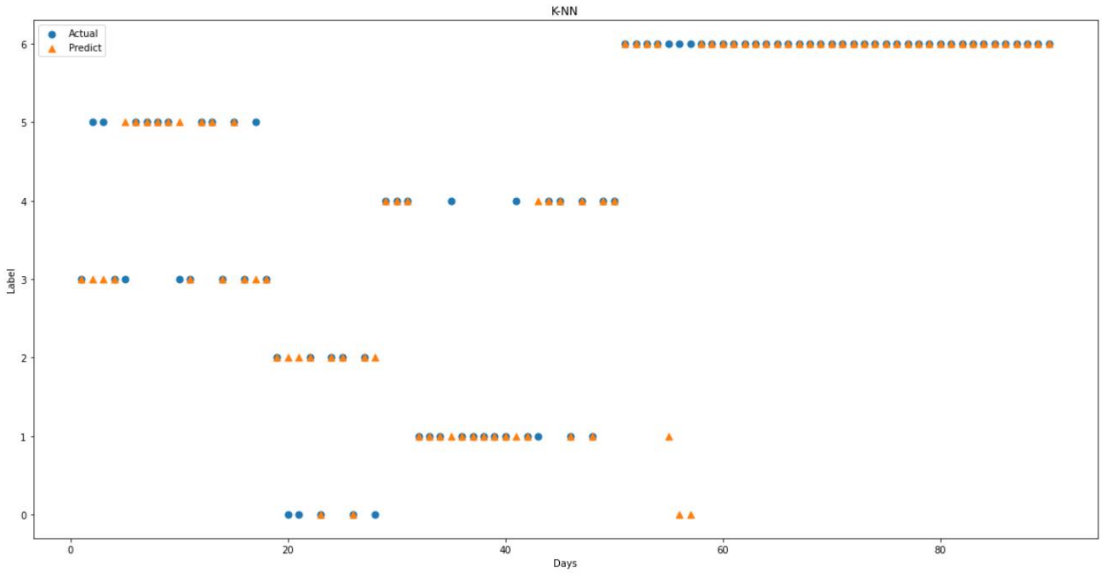


Figure 36. K-NN Model

The random forest model can be seen that the model's predictions were accurate with no errors at all, either due to insufficient data or due to untestable training data as shown in Figure 37.

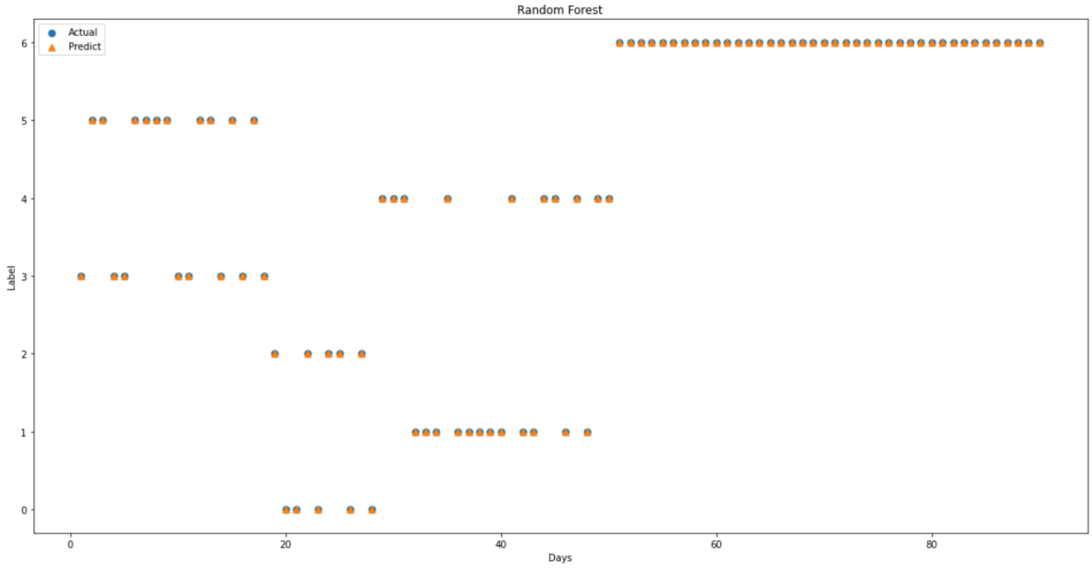


Figure 37. Random Forest Model

The decision tree model when compared to the decision tree model's accuracy, it is considered to be a usable precision. The prediction accuracy of the decision tree model was 99.04% as shown in Figure 38.

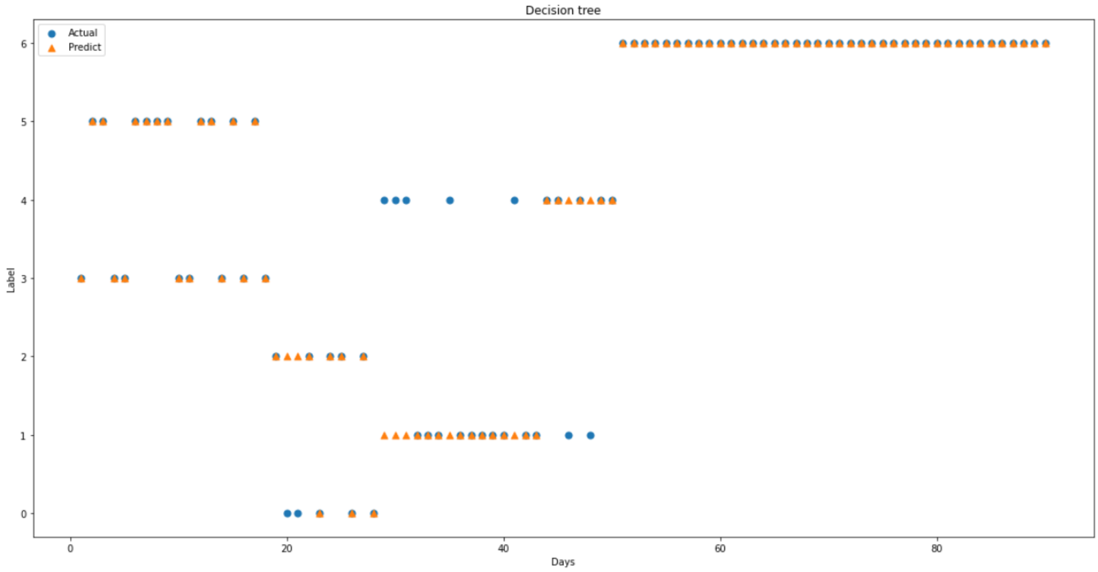


Figure 38. Decision Tree Model

The Bayesian network model are 99.26% accurate, which is a high accuracy value. We can see from the data of every model that during the first month All models will have a few prediction errors. But after a month or more, these models learned more from the data, resulting in better prediction accuracy. These models learn from new information received from automated sensors.is shown in Figure 39.

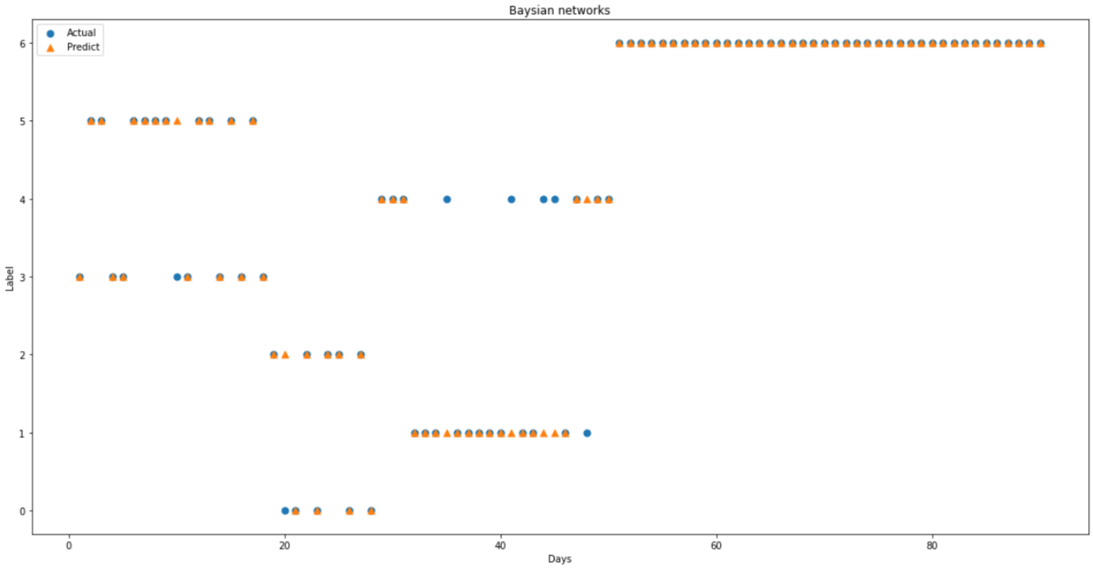


Figure 39. Bayesian Network Model

4.3.2 Cross Validation Performance

In this study, a cross validation method was used by dividing the data into 2 to 10 parts to test the model to see which k-value was the most accurate in each model processing. Logistic regress k=2 was the most accurate. For K-NN, Random forest, Decision tree, and Bayesian network, the best k values for prediction were 4, 4, 6 and 7, respectively, as shown in Figure 40 and Table 5.

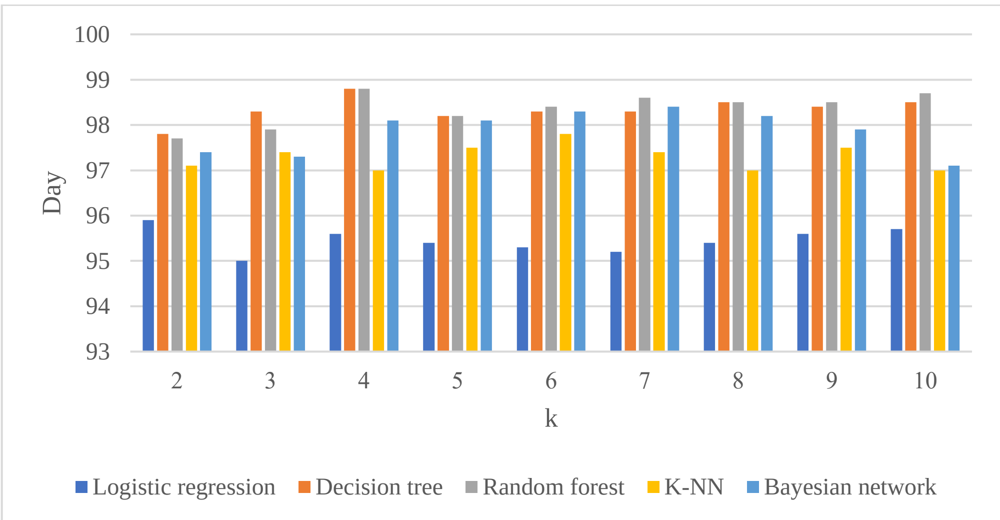


Figure 40. Cross Validation

Table 5. Performance cross validation

	k								
Model	2	3	4	5	6	7	8	9	10
Logistic regression	95.9	95	95.6	95.4	95.3	95.2	95.4	95.6	95.7
Decision tree	97.8	98.3	98.8	98.2	98.3	98.3	98.5	98.4	98.5
Random forest	97.7	97.9	98.8	98.2	98.4	98.6	98.5	98.5	98.7
K-NN	97.1	97.4	97	97.5	97.8	97.4	97	97.5	97
Bayesian network	97.4	97.3	98.1	98.1	98.3	98.4	98.2	97.9	97.1

4.4 Display dashboard

After studying environmental factors affecting plant growth. We therefore create accessibility and usability. Through the dashboard has been developed to display sensor data and system alerts. If the system has a problem or the machine has a problem We can go in and fix it so that our factory won't be damaged. It also makes it easy to use the data for reporting.

The dashboard display is divided into two sections: the home page and the tabular data page.

Main page:

• Homepage: This is an overview of all with information on temperature, humidity, water temperature, pH and EC, as well as data graphs. with the last data shown in Figure 41.

• The table page is the part that shows the data in the database. which the user can press to delete the data as shown in Figure 42.

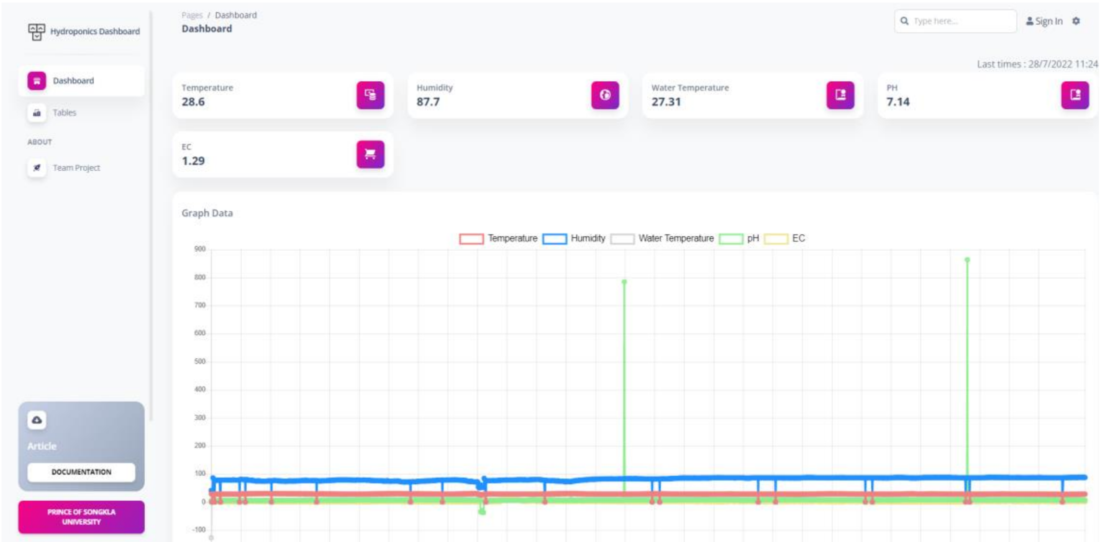
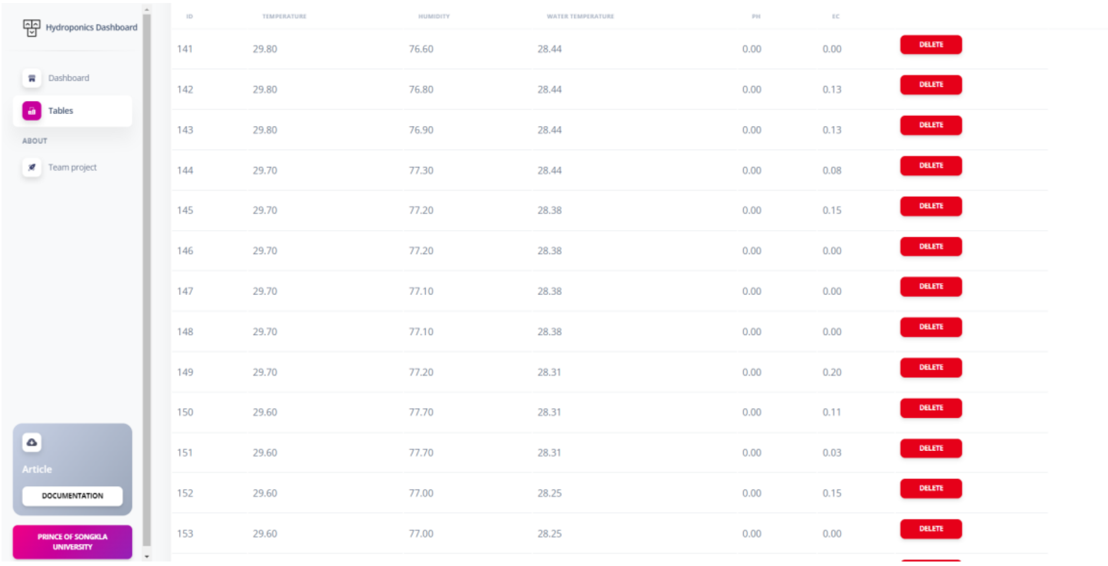


Figure 41. Home



ID	TEMPERATURE	HUMIDITY	WATER TEMPERATURE	PH	EC	
141	29.80	76.60	28.44	0.00	0.00	DELETE
142	29.80	76.80	28.44	0.00	0.13	DELETE
143	29.80	76.90	28.44	0.00	0.13	DELETE
144	29.70	77.30	28.44	0.00	0.08	DELETE
145	29.70	77.20	28.38	0.00	0.15	DELETE
146	29.70	77.20	28.38	0.00	0.00	DELETE
147	29.70	77.10	28.38	0.00	0.00	DELETE
148	29.70	77.10	28.38	0.00	0.00	DELETE
149	29.70	77.20	28.31	0.00	0.20	DELETE
150	29.60	77.70	28.31	0.00	0.11	DELETE
151	29.60	77.70	28.31	0.00	0.03	DELETE
152	29.60	77.00	28.25	0.00	0.15	DELETE
153	29.60	77.00	28.25	0.00	0.00	DELETE

Figure 42. Table data

In addition, the system is able to notify the system operation to the user via e-mail. Users are able to recognize the abnormalities of each part of the system through alerts as shown in the Figures 43 and 44.

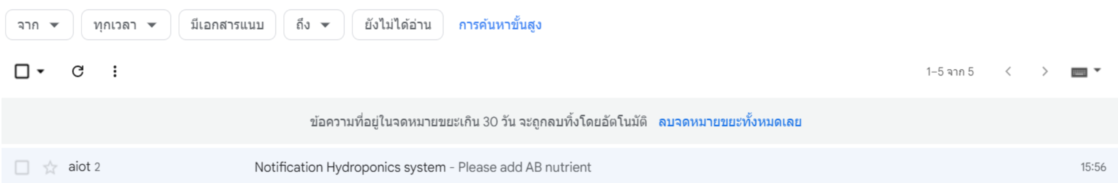


Figure 43. Notification system

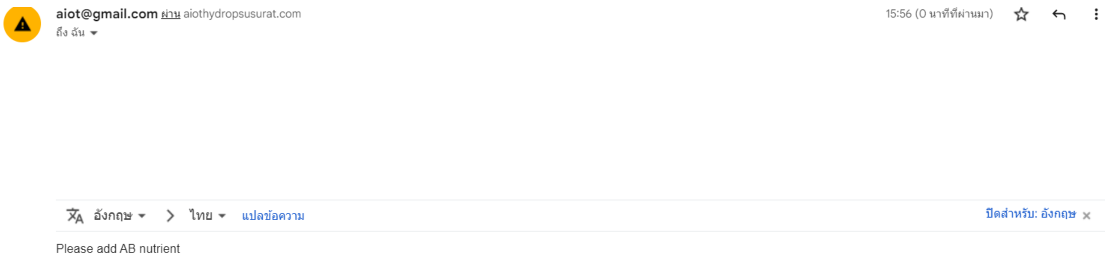


Figure 44. Notification details

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter summarizes the research and findings after studying environmental factors affecting plant growth in hydroponics. Focuses on measurement data from sensor system models for predictive control of hydroponics systems. and notifications including display on the dashboard Future research is as follows. in terms of the accuracy of the machine There are various options. Choose according to your budget for sensor usage. The system used as an alternative for those with low budget but effective that can be used in practice.

5.1 Conclusion

For the measurement of the environment in hydroponics systems, the research on plant growth factor control was taken from research and the factor was used as a factor for this research. Set up sensors to control plant growth factors in the system including temperature, humidity, water temperature, pH and conductivity. The data is transmitted by the sensor and stored in the MySQL database using a WiFi router to transmit data from the sensor. The sensors are connected to the ESP32 microcontroller board. The data contained in the database; users can choose to view the data through any device connected to the Internet through the website created. In the sensor measurement, if the sensor has an incorrect value, it also sends a notification to the system administrator to take care of the plants in a timely manner.

From the plant growth factors studied from research and measurements from the system check. We tested the predicted data using models for logistic regression prediction, K-NN, random forest, decision tree, and the Bayesian network. The accuracy of each model produces different results depending on the data set used. Predictive data types and trends of data that measure the environment within the hydroponics system in which direction. The optimum environmental factors for plants (temperature, humidity, water temperature, pH, and EC) are controlled in this enclosed room. It can be seen that the predicted sensor data. The most suitable model is a random forest, which can be applied to conventional hydroponics. We also offer system communication through web pages that can be controlled and viewed in real time through any Internet-connected device. It shows the environmental factor dataset. Our trend graphs are measured over the real time, being detected every 20 minutes which can alert users when there is a problem in the system. This allows users to resolve the system before the plant is damaged. Getting more accurate information, sensors also need to be more efficient to make predictions more efficient due to the higher quality of the sensor the price will be higher. It is more accurate than the sensor used, which is a part that needs to be developed and may require applications that support both iOS and Android systems to facilitate users as well.

5.2 Future works

In the future, we can grow all kinds of vegetables. in hydroponics and let the system automatically calculate plant needs using machine learning through models. It collects data through sensors and records it in a database. The system will then automatically extract the data to make predictions against existing models in the system. and select the most accurate model to control the cropping system. to be in the appropriate range of plant needs. When both the IoT and AI functions work together, the IoT is responsible for sending the data to compute. The AI is responsible for analyzing the received data to make predictions and using the prediction results to control the actuators in hydroponics automation without human intervention. get involved and may be connected to a harvesting robot. that can automatically harvest crops and grow them for humans in the future. The development of a precision system depends on the sensor element, the high cost and efficiency of the sensor adoption will improve the accuracy of the system, and the industrialization of the sensor makes the system more efficient. More accuracy than the prototype system by applying the application of this prototype system can be used in the agricultural sector from small to large scale to increase productivity and increase income. This increase in productivity, if the sensor is used for accurate measurements, will result in a more efficient output.

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APPENDIX

APPENDIX A: Publication at the International Journal of Interactive Mobile Technologies (iJIM), 16(06), pp. 206-220. https://doi.org/10.3991/ijim.v16i06.27959

Automated Hydroponics Notification System Using IOT

https://doi.org/10.3991/ijim.v16i06.27959

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Abstract—This research was conducted to increase the productivity of farmers and to plan the planting of crops by farmers when using a hydroponics system that controls various environmental conditions, in which plant growth factors such as temperature, humidity, water temperature, pH and electrical conductivity are important factors for hydroponics. The Internet of Things control and notifications enabling farmers to quickly modify and improve their crop treatment. This research focuses on use of the Internet of Things to control plant growth factors. Displays and alerts are communicated to the user through a web application where, when comparing plants with controlled growth factors and unregulated systems, it can be seen controlled plant growth factors are in the desired range of the plant, whereas in uncontrolled systems there are unwanted values range of plant, which can cause the plant to not fully grow or even to wither. In this system, farmers are able to view plant growth factor data and can retrospectively view graphs displayed on the web application by this controlled system when the measuring sensors in the system are in range that plants do not want it will alert farmers to the crops they are planting, to assisting farmers to prevent crop malnutrition damage of plant. Monitoring of environments using IoT, including alert allow them to fix the system quickly and with minimal damage to crops.

Keywords—hydroponics, internet of things, notification, automated

1 Introduction

Rural people everywhere are moving to the cities to pursue a better life, abandoning their former occupations in agriculture, and in Thailand this has caused a significant shortage of agricultural products. From the results of previous research, it was predicted that there would be a lack of resources by 2050. The growth in the current worldwide population of 7.9 million people has motivated studies on how to address these concerns [1].

Planting in soil has limitations since it causes plants to grow poorly. Poor drainage is caused by deterioration of the soil, and cultivating plants in the soil requires a lot of cultivation space and is labor intensive. For the above reasons, hydroponics was created [2]. Hydroponics is the cultivation of plants in a nutrient solution specifically so that the roots float in a nutrient solution [3]. Without sufficient nutrient solution, hydroponic plants may not grow well [4]. One of the hydroponics cultivation techniques is NFT

APPENDIX A: Publication at the International Journal of Interactive Mobile Technologies (iJIM) (Cont.)

hydroponics, which is a good technique for farmers. In this hydroponics system, special care is required to control the water temperature, acidity, and nutrient solution [5].

In terms of environment control, it allows plants to grow faster depending on temperature, humidity, pH and electrical conductivity, which are indispensable factors in plant growth in a hydroponics system [6]. The optimal environmental conditions are managed by regulating the conductivity and pH of the nutrient solution; in this case, pH is essential in controlling the growth of plants during each growing period, and nutrient control supports the rapid growth of plants [7]. However, plants require light for photosynthesis, which is part of their natural cycle [8].

Crops can be cultivated with hydroponic systems using the Internet of Things, which allows farmers to automate hydroponics and monitor the system's environment [9]. The Internet of Things (IoT) is a technology that uses the internet to connect everything without involving humans. To put it another way, the Internet of Things can be perceived and connected to the environment via the internet, allowing humans to be aware and connected [10]. The Internet of Things helps with communication and storage data in remote areas, and can make us aware of information through an interface. Furthermore, these automation systems have the potential to improve agricultural efficiency [11].

In agriculture, the Internet of Things has been utilized to control the environment of cultivated plants. Due to unexpected climate change caused by humans or nature, plants are affected and have low yields. As a result, maintaining an optimal climate by controlling humidity and temperature is essential for plant growth in hydroponics system [12]. The Internet of Things is more applied in intelligent farming [13]. Hydroponics has enabled the growth rate of hydroponic cultivation using the Internet of Things-controlled environment is up to 50% higher than that of soil cultivation [14].

In this paper, we develop a hydroponic system based on the Internet of Things. Sensors are connected to a WIFI module for connectivity and monitoring the plant environment [15]. The wireless sensor node becomes a tiny device with limited battery resources. Processing and memory are cut down as well. It is now possible to collect environmental data with accurate sensors and send those data to the control station with high efficiency [16]. Therefore, optimization by using the Internet of Things and data analysis to help simulate and manage plant growth by controlling plant growth factors improving agricultural efficiency and increasing productivity for users. Furthermore, this work aims to increase yield efficiency and accelerate plant growth by controlling plant growth factors, reducing fertilizer residue in plants, and allowing users to automatically control the watering without measuring the data all the time.

2 Experimental design

2.1 Hydroponic cultivation

One of the significant issues in agriculture is environmental problems. The fertile areas are declining due to environmental pollution, and farmers are escaping to residential life [17]. In agriculture, climate is an unforeseeable factor over which we have no control. It is crucial for growing crops as inclement weather may make the cultivated area no longer fertile due to pollution or residue problems [18]. Currently,

APPENDIX A: Publication at the International Journal of Interactive Mobile Technologies (iJIM) (Cont.)

approximately 3.5% of the global area is cultivated in greenhouses using soilless cultivation techniques with nutrient solutions [19]. There are several types of hydroponics today, but the most popular is NFT hydroponics, which has roots directly immersed in a nutrient solution by nutrient solution that flows through piping as a 1–3 mm thin film. The slurry flows continuously and is pumped with circulation back to the storage tank. NFT Hydroponics shows the flow of the water acquisition system from the water storage to transport the nutrient-rich water to the plants grown in layers 1 and 2, and after that water will flow back to the reservoir again. This method can save water for the farmers as shown in Figure 1.

The advantage of NFT hydroponics is that there is no need to control the irrigation as due to the constant supply of water. By to the continuous water supply, this approach prevents and eliminates various plant pathogens. In addition, hydroponic crops are also there is empowering agriculture with automated technology and decision making to improve productivity with quality, and high yield [20]. Many related factors affecting the growth of plants are being studied: temperature, humidity, light, pH, and electrical conductivity. This is done by adopting Artificial Intelligence to help in the analysis and control of plant growth factors. Revathi Nukala et al and Xiaotao Ding et al have studied the growth of tomatoes with light, temperature, and humidity controls. They applied a Bayesian optimization close to the result of the actual values of the crops. In general, controlling the environmental factors temperature, humidity, and light is sufficient for good growth. However, it has been found that other essential plant growth factors include pH and electrical conductivity. The former should be 5.5–6.5 while electrical conductivity should be 1.8–4.8 [21], [22].

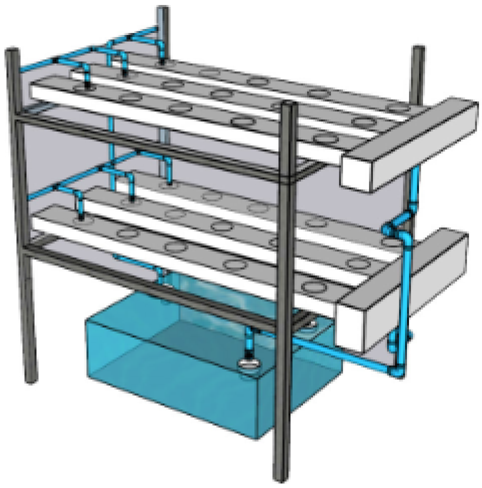

Fig. 1. Prototype design of NFT hydroponics system
(This figure is provided by authors)

Hydroponic cultivation requires that the factors Temperature, Humidity, Water temperature, light intensity, pH and electrical conductivity are controlled for the plants to

APPENDIX A: Publication at the International Journal of Interactive Mobile Technologies (iJIM) (Cont.)

grow correctly, and hydroponics is an alternative way for farmers to grow crops instead of in soil, to avoid residues or herbicides. This hydroponic cultivation, therefore, meets the needs of farmers and consumers for clean and organic vegetables. Typically, in hydroponics, sensors are installed in a hydroponics system including a DHT22 sensor, waterproof temperature, pH, electrical conductivity, and light sensors. We studied factors affecting plant growth prior to the installation of these sensor. All sensors installed are crucial for controlling the environment and plant growth in hydroponics. We measure the system status with sensors in the water reservoir. The AB nutrient solution is mixed into the water in the container. The sensors in the water storage tank consist of waterproof temperature, pH, and electrical conductivity sensors. They perform measurement every 5 minutes, sending results to the control box, it then manages to control the water pump automatically after receiving the value for processing. The control box contains a light sensor for measuring temperature and humidity inside the system room. When the data from sensors is taken to the control box, it sends the data to a database, which shows the sensor value that has been measured to the user through the website, including the value from measurement along with data graph visualizations. The user can choose to control manually the system, as shown in Figure 2.

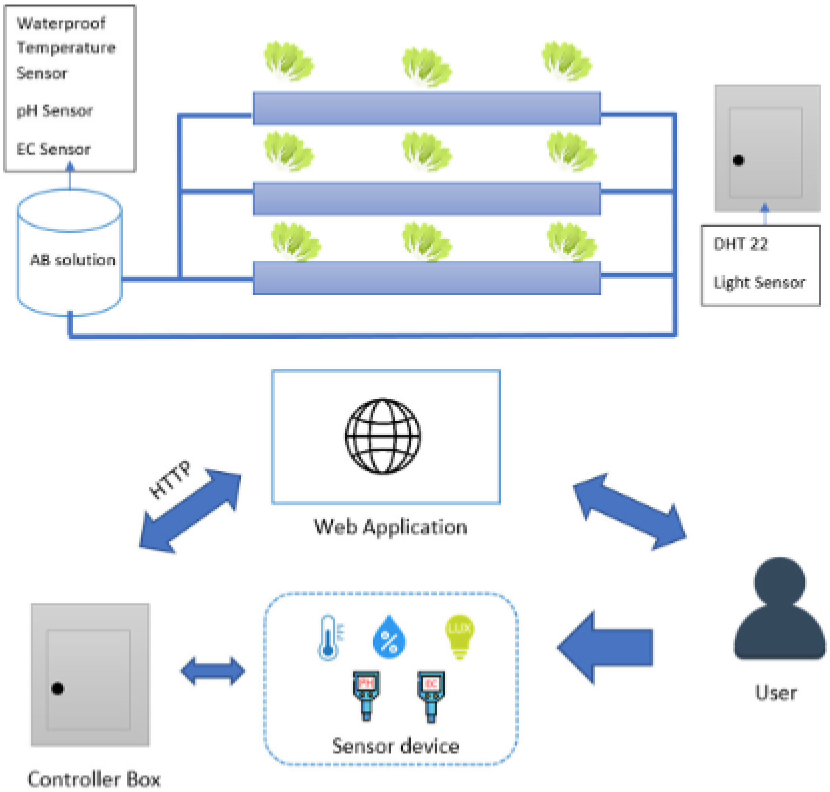

Fig. 2. Common sensors in hydroponics systems

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Our work aims to design and install a sensor system in a limited area and manage data using a smartphone or a computer with a website to control the system. The principle of the working system is to receive data from the sensor layer with various sensors installed. The measured signals consist of temperature and humidity, light, pH, and conductivity. When data from the sensor layer is received, it is forwarded to processing in the processing layer. The measured signals pass through Internet intermediary or network layer transfers to the processing layer. After the data are processed, results are displayed to the user through the dashboard shown in Figure 3.

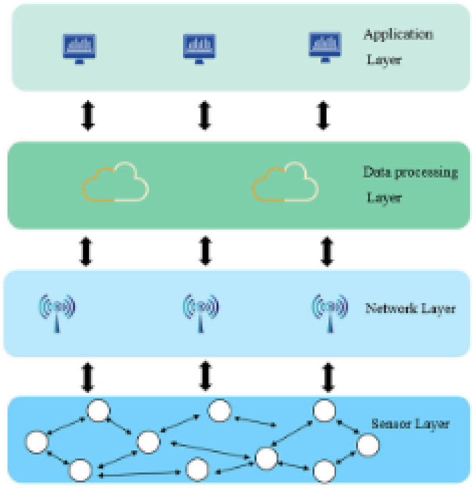

Fig. 3. Four-layer architecture of a sensor network

2.2 System specification

We use sensors to measure the environment in the hydroponics system, as shown in Table 1.

Table 1. Hardware specification

Parameter	Sensor	Voltage
Node MCU	ESPINO 32	2.3–3.6V
Temperature	DHT22	3.3–3.6V
Humidity	DHT22	3.3–3.6V
Water temperature	DS18B20	5V
pH	pH sensor	5V
Electrical conductivity	EC sensor	5V

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The most influential factors for growing plants in a closed hydroponics system are the following: water temperature, closed room temperature, relative humidity, light intensity, pH, and electrical conductivity. We controlled the growth factors to within an optimal range for plant growth. The selected ranges used in this experiment intended for the plants to grow best are shown in Table 2.

Table 2. Sensor threshold values

Sensor	Condition
Temperature	15–30°C
Humidity	50–70 RH%
Water temperature	22–28°C
pH	5.5–7.2
Electrical conductivity	1.1–1.8 mS/cm

The efficiency of the system depends on the selection of individual sensors for suitability and for low cost as well. This system is very flexible for users.

Temperature. Temperature control is therefore important for growing plants in hydroponics. DHT 22 sensor is used to measure the air temperature in a closed room equipped with this hydroponics system. The DHT22 is a high-precision sensor. The measurement range of the sensor is from –40°C to 80°C with an accuracy of ±0.5°C. The DHT22 sensor sends a signal to the microcontroller board in order to receive the temperature values in the area where the sensor is installed. The operation of the device is based on the programming written in the Arduino IDE.

Humidity. Humidity is another key factor for control in hydroponics. Humidity informs about the fraction of water vapor in the air, and the relative humidity depends on the temperature. Relative humidity can be expressed in terms of pressure, or as mass fraction. Relative humidity is often referred as RH and as a percentage between 0% and 100% RH, and gives the amount of water in proportion to saturation level. We use the DHT 22 to measure humidity in the area where the sensor is installed. The function of the sensor works as the temperature measurement signal which is sent to the microcontroller board.

Temperature of water. Hydroponics requires to monitor the water temperature to keep the temperature from getting too high or too low. We utilize a DS18B20 sensor to measure the temperature of the water. The measurement range of the water temperature sensor is from –55°C to 125°C, with a 2°C accuracy. The water temperature is measured every 10 minutes. We use alerts to the system to manage the temperature. The function of the water temperature sensor measures the temperature of the water in the immersed part of the sensor and transmits the temperature data as a digital signal to the microcontroller board for display.

pH. The pH is very important for the growth of plants. It is measured in the range 1–14. In general, if the pH is less than 7, the solution is acidic, while pH 7 and over is alkaline. The accuracy of the pH sensor is ±0.1 pH units. At a constant temperature of 25°C and with acidity, the optimum range for plants is 5.5–7.2 pH, for good plant growth. The pH monitoring is necessary in hydroponics on a frequent basis to maintain

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plants in optimal condition. This is accomplished by immersing the probe in the area to be measured. The sensor then transmits the data as an analog signal to the microcontroller board. pH sensor applications Calibration is required for use to ensure accurate and accurate sensor measurements.

Electrical conductivity. EC stands for electrical conductivity, which means the conductivity of water that depends on purity of the water. In hydroponics, EC is measured for the nutrient solution and the pH measurement complements the EC value. The electrical conductivity can indicate the amount of nutrients available in solution. The measurement range of the electrical conductivity sensor is 0–20 mS/cm. However, the electrical conductivity measurement does not need a large measuring range, which would increase the cost of sensors, instead the range 0–10 mS/cm is sufficient in our context. The optimum electrical conductivity is 1.1–1.8 mS/cm for maximal plant growth. The EC sensor transmits analog data to the microcontroller board which can be easily connected the probe to the sensor module. The EC value indicates the water quality in the crops. The calibration of EC sensor is required at least once a month to ensure measurement accuracy and reduce errors in the analyzed data.

Light intensity. A light intensity sensor is a device that changes the resistance value when light hits it to measure data. 0–65535 Lux. Inside the sensor there is an analog-to-digital converter circuit so that the data can be used without having to go through mathematical methods. The color range of light required by plants is from blue to red, so the wavelengths suitable for growing plants are in the range 400–700 nm, and when the light intensity falls below 4.31 Lux, plants will stop photosynthesis. Therefore, hydroponics provides the optimal range of light, which enables plants grow faster.

3 Results

To evaluate and compare the crop efficiency in the closed-room NFT hydroponics system, we used the data from sensors for both the environmental and non-environmentally controlled plant growth systems. We used 5-day plant growth data to determine the optimum plant growth efficiency. More effectively, we compared the controlled environmental factors with the natural plant growth without control of the growth factors.

3.1 Comparison of analyzed sensor data

Comparison of the sensor data measured was done against standard data ranges. Measurement data from control systems of hydroponics and unregulated hydroponics systems were compared with the appropriate ranges for plant growth, for temperature, humidity, water temperature, pH and electrical conductivity. We do not measure photoperiod because we use artificial light for plant growth in the range that the plants need. The humidity was not included in our part of the project, and the humidity effects on plant growth will be studied in future work. The uncontrolled crops were all damaged, probably because the pH of water. Temperature in the controlled hydroponics system is shown in Figure 4.

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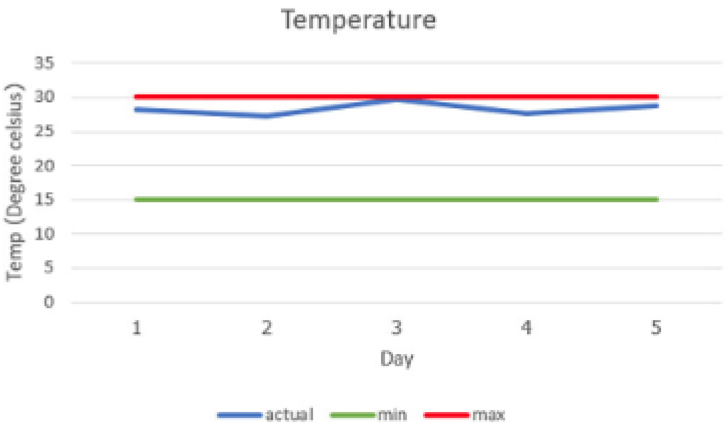

Fig. 4. Temperature in controlled case

The optimum temperature for plants for a controlled hydroponics system shows that the average intraday value is within the optimum range. There will be some days when the graph goes up to the highest value because of the heat from the artificial lights that we have turned on as shown in Figure 5. However, the duration of light received by the plant may be insufficient for photosynthesis. Water temperature, in addition to room temperature, is required for plant growth.

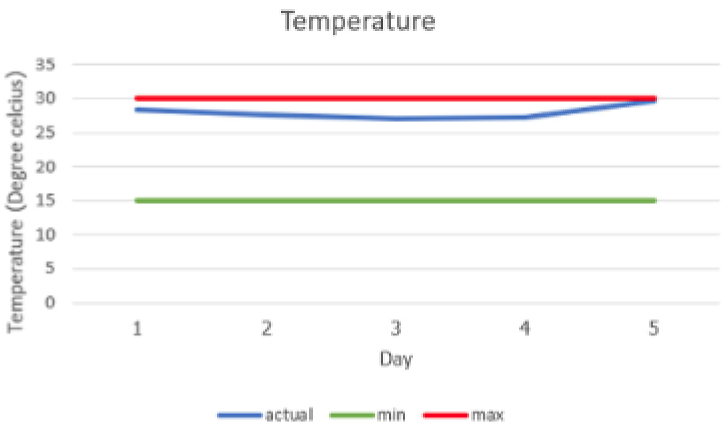

Fig. 5. Temperature in case without control

Hydroponics is the cultivation of plants without soil. The transport of water to plants is extremely important. Sensors in regulated and unregulated systems had temperatures higher than the room temperature, caused by the water pump running all the time and

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heating the water by input of energy. The resulting water temperatures were still within the optimum range for plant growth as shown in Figures 6 and 7.

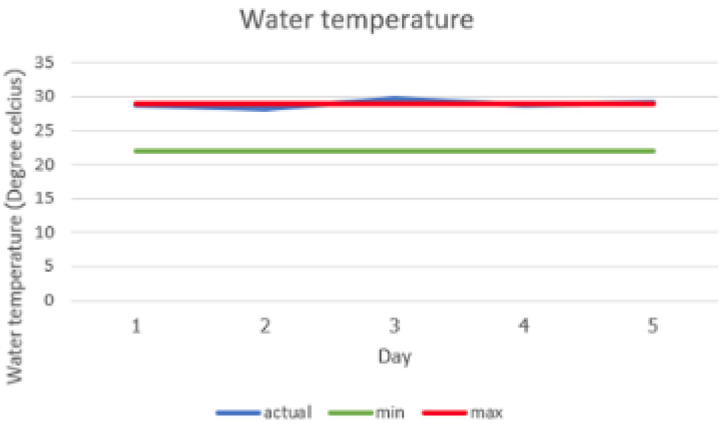

Fig. 6. Water temperature in controlled case

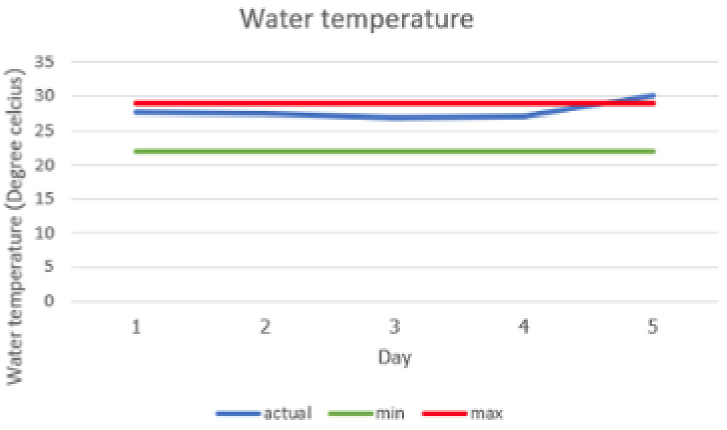

Fig. 7. Water temperature in case without control

pH is very important for growing plants. It can be seen that the plants cultivated without control had high pH, although within the optimum range. This may have damaged plants in the uncontrolled system. The pH data are shown in Figures 8 and 9.

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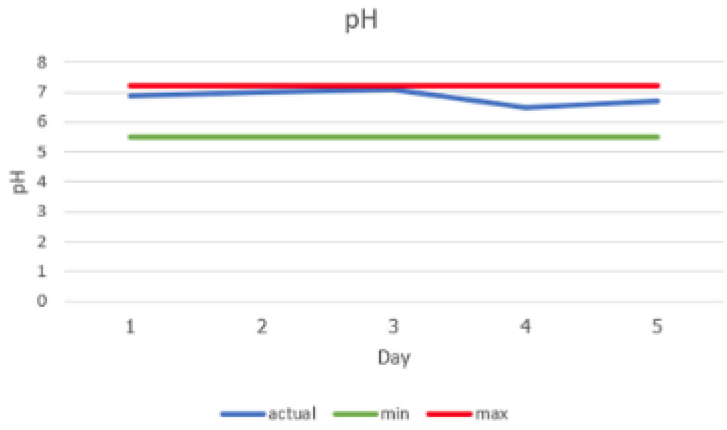

Fig. 8. pH in controlled case

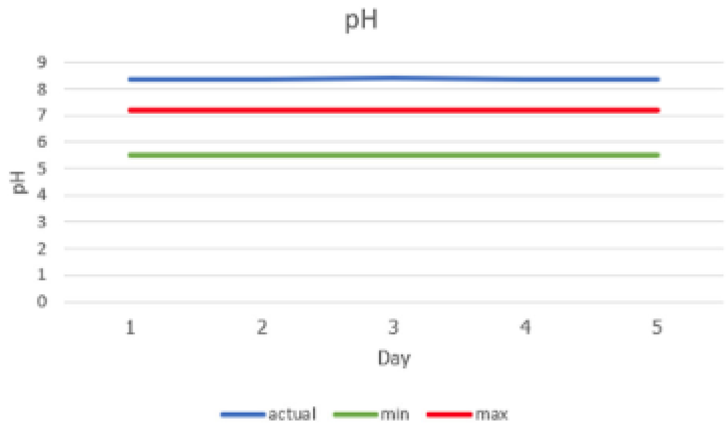

Fig. 9. pH in case without control

In addition to the above factors, we measured the electrical conductivity of the water to compare with the range required by the plants. The measurements from the controlled system are shown in Figure 10. The electrical conductivity was more suitable for the crop than in the not controlled system. The pH may have affected the electrical conductivity in the system without control, shown in Figure 11.

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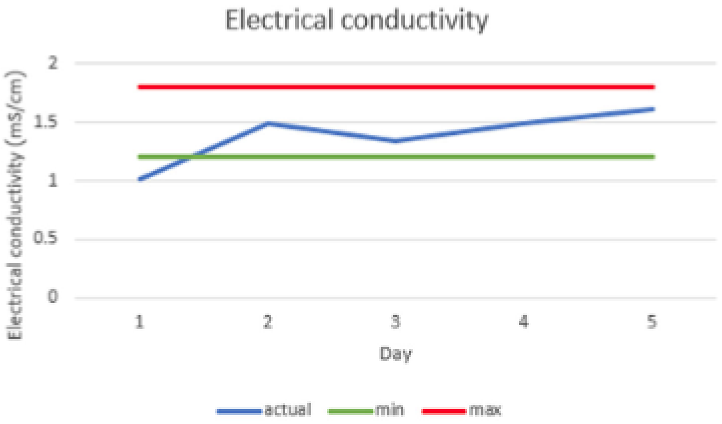

Fig. 10. Electrical conductivity in controlled case

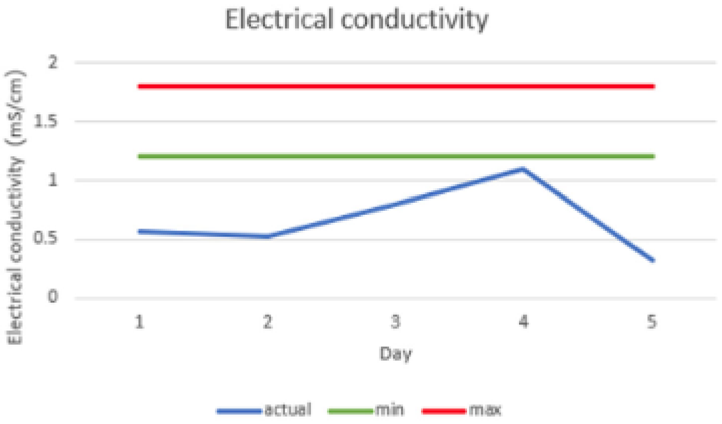

Fig. 11. Electrical conductivity in case without control

The system will display the results on the web. The farmers are able to access sensor data from their mobile devices, which gives farmers convenience and ability to view sensor data for use in planning and crop management. When the system has a malfunction, such as a power outage or sensor failure, the installed system has a will have a notification to the farmer. The data page in the dashboard displays data from the sensors used to measure the environment in the system. The displayed data includes temperature, humidity, water temperature, pH and EC. The displayed data is the latest data obtained from the sensors stored in the base. data through measurements of sensors in the system as shown in Figure 12.

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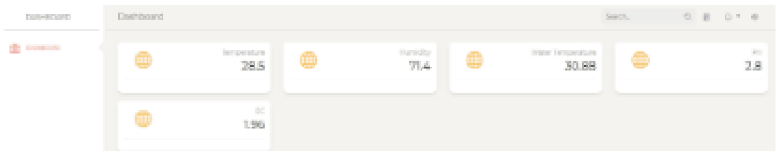

Fig. 12. Data display in the dashboard

The data obtained from the sensors are collected in real time and can be shown to farmers as a result of the sensor installation for further analysis. In the dashboard, in addition to displaying data, it can also be displayed in graphs, so farmers can view historical data for decision-making in system management. The display section can be automated where users can choose to view only the data they want or they can view all of the data through the graph display in the dashboard as shown in Figure 13.

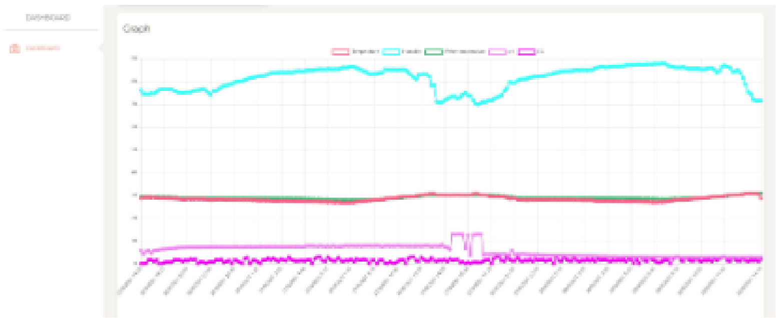

Fig. 13. Graph from sensor

3.2 Conclusion

This study applied the Internet of Things to manage an NFT hydroponic system in a closed laboratory room. Plants in hydroponic cultivation combined with remote monitoring in this intelligent agriculture system had efficient growth. The system also allows farmers to monitor crop growth and assists them in making decisions, about production planning and planting, and the interface can be tailored to the needs of farmers. By adjusting the appropriate parameters for the plants, this system provides automation.

3.3 Discussion

A simulation of the system demonstrates that it accurately guides farmers to make the right decisions to reduce mistakes and avoid damage to crop, which help farmer manage their crops and increase their productivity. Farmers will be able to boost their yields and manage their crops more efficiently as a result of this developed system.

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The farmers can obtain information for decision-making and interact with the control system both manually and automatically. The approach demonstrated can be altered and applied to other plants. Furthermore, the data records can be used for long-term data analysis and decision-making, which meets the needs for effective resource allocation. Machine learning and forecasting are used in the last stages of development to improve the system's efficiency.

In future work, the plant moisture study and use of algorithms to predict crop yields, and to apply control with greater accuracy, may allow us to grow multiple crops in the same system instead of planting only one type of crop in the system. The algorithm does not need to be adjusted because it learns by itself and makes the system intelligent using popular adaptive algorithms including artificial intelligence, neural networks, and deep neural networks. More complex algorithms allow the system to learn innovatively and make faster decisions to increase crop yields. In addition, it is interesting to use a learning algorithm that performs a comparative analysis of optimal performance for the system.

4 Acknowledgments

The authors are deeply grateful to the Prince of Songkla University, Surat Thani campus, Thailand, and to the National Research Council of Thailand (NRCT). This research and innovation activity is funded by National Research of Thailand (NRCT) (Grant no. 960749) and financially supported by Prince of Songkla University, Surat Thani campus, Thailand. The authors would like to express their gratitude to Assoc. Prof. Dr. Seppo Karrila and Publication Clinic, Research and Development Office, Prince of Songkla University, for help in manuscript preparation.

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Article submitted 2021-10-31. Resubmitted 2022-01-06. Final acceptance 2022-01-16. Final version published as submitted by the authors.

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2. Graduate school funding fiscal year 2020 from National Research Council of Thailand

.

List of Publication and Proceeding

Boonneua, W., Chai-Arayalert, S., & Boonnam, N. (2022). Automated Hydroponics Notification System Using IOT. International Journal of Interactive Mobile Technologies (iJIM), 16(06), pp. 206–220. https://doi.org/10.3991/ijim.v16i06.27959