

Development of Hydroponic IoT-based Monitoring System and Automatic Nutrition Control using KNN

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Abstract— Hydroponic farming is limited by inefficient monitoring and maintenance, which can affect plant growth and yield. This paper proposes using IoT technology, specifically a combination of STM32 microcontroller and sensors with 4G connection to cloud, to automate the monitoring and maintenance of hydroponic plants. The system monitors water and air temperature, pH, and TDS, and controls the hydroponics by adding nutrient in the form of AB mix. An automatic decision maker is built using KNN with an accuracy of 92.86% based on Euclidean distance algorithm. This technology could optimize the growth of hydroponic plants, as it provides continuous monitoring and maintenance.

Keywords—hydroponic, internet of things, monitoring, automation

I. INTRODUCTION

Population growth in cities has become a major phenomenon resulting in a lack of land for agriculture, especially to meet the nutritional needs of the community. This causes an imbalance of food production with population growth [1]. Hydroponics is a method of farming without using soil media so that it can be applied to a variety of environments. The hydroponic farming method uses air media with the help of other materials to support the roots [2]. However, hydroponic systems alone are not enough, innovation is needed to meet these needs by using new methods that do not rely on conventional methods by utilizing Internet of Things technology.

Internet of Things or also known as IoT[3] is a concept where objects have an exclusive identity with the ability to transfer data over a network without the need for human intervention and utilize smart sensors and smart devices that can work together over the internet [4]. IoT is a development area of internet technology and other communication media. IoT allows humans to be able to manage and optimize electronics and electrical equipment connected to the internet. In the application of IoT itself, it can identify, find, track, unite objects, and trigger related events automatically and in real time. Internet and information technology can have an impact

on economic management, production operations, social management, and even personal life [5].

The combination of IoT and agriculture produces Smart Farming [6]. The use of hydroponic techniques in industry 4.0 can include smart agriculture, scalable agriculture, and biotechnology. Smart agriculture is farming or anything that is sustainable in carrying out creative, efficient and effective agriculture. This is done instead of achieving greater profits at lower costs. Smart farming can help or even replace the task of farmers in doing routine things such as fertilizing, watering, and applying pesticides through technology [7].

Furthermore, Smart Farming is carried out on plants that can be grown hydroponically, namely lettuce. Hydroponics itself has many advantages when compared to conventional planting methods on soil, because hydroponics uses water media, so it can be done on limited land. So that hydroponics can be easily done by anyone. Then coupled with the application of IoT in hydroponic systems, it can help hydroponic actors monitor and help care for their hydroponic plants.

The addition of Artificial Intelligent (AI) to smart farming [8] can improve the quality of agriculture in any form. Furthermore, AI can maximize and streamline agriculture and reduce production costs by automating and predicting Actions that must be performed manually in advance [6]. AI is an intelligence that is made in such a way as to meet four definitions, namely: human thinking, rational thinking, acting humanely and acting rationally [9]. There are various types of AI, generally they can be grouped into two groups based on the algorithm used, namely Machine Learning (ML) [10] and Deep Learning (DL) [11].

ML is a complex process that allows the system to learn from the data given rather than explicit logical programming. ML utilizes various algorithms that can develop and learn iteratively based on data given to improve the accuracy of understanding and predictions generated [12]. In ML, there are various algorithms that can be used, one of the simplest is KNN (K-Nearest Neighbor). KNN is an algorithm used to perform classification by matching the test data and the data

that has been studied. With a certain K value, the algorithm can take as many as K neighboring data to further determine the class of data being tested.

Therefore, this paper will rather be focused on the usage of KNN for automatic decision making on hydroponic system on controlling its nutritional value. This paper also aimed for the continuation of development for real time monitoring of IoT-based hydroponic system. The author hopes that the corresponding design and algorithm result can be used for integration with existing or new system available, so that it can help to reduce the maintenance needs to grow hydroponic plants.

II. LITERATURE REVIEW

In this section, the author presents previous studies related to this research.

Research conducted by Adidrana et al. [13]. using Arduino Leonardo to take sensor readings, ESP8288 to transmit Arduino readings to Thingspeak, NodeMCU to control actuators in the form of pumps based on commands given from the local KNN server. Tested on hydroponics with the NFT method of growing Watercress.

Research conducted by Samuel Jason et al. [14]. utilizing the Robodyn Arduino UNO equipped with ESP8266 to read sensors and send data to a cloud server via MQTT whose results can be monitored on an Android-based application. Tested on hydroponics with the Wick method of growing Watercress.

Research conducted by Shubhashree et al. [15]. using Arduino Mega to control exhaust fans, nutrient pumps, and buzzers, as well as monitor sensors that are sent via ESP8266 to the Blynk server so that they can be monitored remotely.

Research conducted by Putra et al. [16]. using Arduino Mega 2560 to read sensors and control pumps to be able to maintain pH automatically using Fuzzy Logic. Tested on hydroponics with the NFT method of growing spinach.

Research conducted by Taufik et al. [17]. using Arduino Uno to control pumps and sensor readings which will be sent to the MQTT server via the NodeMCU ESP8266 whose data results can be seen in an Android-based application. Tested on hydroponics with the NFT method of growing red spinach.

TABLE I. RESEARCH REFERENCES

References	Result
[13]	Backend using KNN can evaluate data sets in real-time with 25-minute intervals, with an accuracy rate of 93.3% with $k = 5$ regarding decision making to control nutrition.
[14]	The system can monitor plant conditions in real time and can provide notifications if it exceeds certain limits through an Android application.
[15]	The system can be monitored using the Blynk application and maintains the pH with simple logic.
[16]	The tool can maintain the pH in the range of 6.6-7.6 with growth results as high as 24.8cm and has thirteen leaves for 14 days. Spinach is susceptible to moisture.
[17]	The pH sensor readings were classified as accurate with an error percentage of 0.0017% and the TDS sensor readings with an error percentage of 0.025%. In addition, controlling pH and TDS levels and the early warning system worked successfully.

The author's research has differences from the previous research conducted (Table I. Research References). This paper will conduct a limited scope for growing watercress

with Wick hydroponic system that equipped with IoT system using STM32 microcontroller and automatic decision making using KNN to control nutritional value. By only testing to control one variable rather than multiple variables at once, it will test partial control of the system, to reduce the upfront cost of gradually automating hydroponic system, therefore making hydroponic automation more accessible.

The research will also aim the target of ideal condition of hydroponic nutrition based on pH around 6.0 and ppm around 800.

III. METHODOLOGY

A. Research Methodology

The author uses a research methodology by utilizing quantitative research methods using benchmark generated from the research. The research will go through several stages. Starting from data collection that's going to be analyzed. After that, the research can move into application design and IoT schemes / solution creation, implementation / development of applications and systems, up to the final stage of testing systems, tools, and ML.

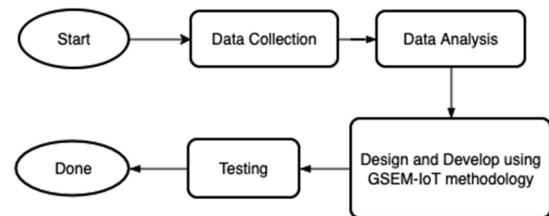


Fig. 1. Research Framework's Flowchart

Fig. 1. shows where research begins by collecting data either through surveys or by looking for appropriate theories. Then proceed with analyzing the data which is then outlined in a system design plan using the GSEM-IoT development framework. After the design is realized, testing will then be carried out to determine the success of the design that was previously carried out.

B. Data Collection Process

The author utilizes a data collection strategy by collecting it through the system attached to hydroponic system that collects sensor variables i.e., pH, TDS, water temperature, air temperature, and air humidity. This will later also be utilized for hydroponic system monitoring that will be shown at web application dashboard.

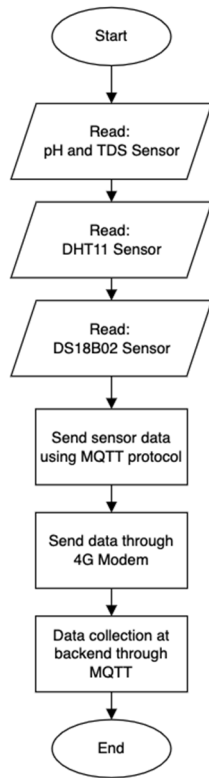


Fig. 2. Data Collection Flow

Fig. 2. shows the data are being collected from the pH and TDS sensor, DHT11 temperature and moisture sensor, DS18B02 water temperature sensor, then the data sent to the backend server through MQTT protocol using 4G modem.

C. Data Analysis Process

After the author collects data using the data received from the node. The author analyzes and select random data from the readings especially near the time when it is the time to add ab mix to increase its water nutrition value. The variables that monitored are pH and TDS value because these two variables are affected by ab nutrition solution.

After random samples had been collected, then the author labels the data using predefined label/classification at Table III and solution needed to adjust the value of the system's nutrition. The purpose of dataset labeling is to be used as a reference dataset to build KNN model using previous labeled condition to make future decisions that will be used later for creating automatic decision for the system.

IV. RESULT

A. System Design

The author designs the system based on experiments to build a system which could control and monitor hydroponics plants remotely using IoT technology. The design then turns into prototype. The prototype will be implemented on a pilot scale hydroponics and the authors collect data from multiple sensors such as pH, TDS, water temperature, air temperature and humidity.

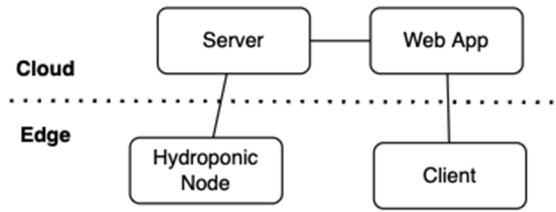


Fig. 3. IoT System Infrastructure Design

Fig. 3. shows a system diagram in terms of infrastructure where there are three main parts, namely the hydroponic edge node which consists of a set of sensors, a microcontroller, a 4G modem and a battery as a power supply. Cloud servers that run server applications that are made, and client devices that are system access devices and can be smartphones or computers.

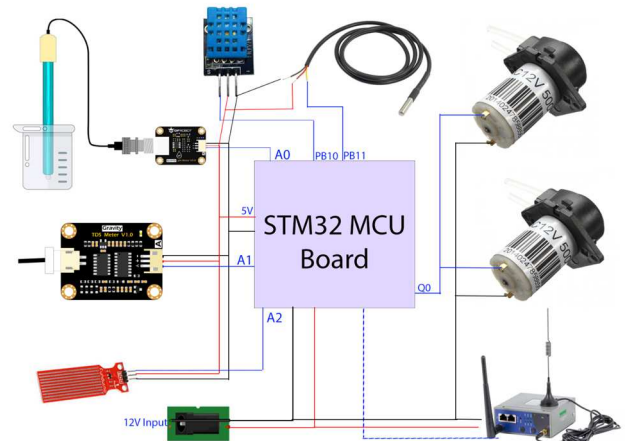


Fig. 4. IoT Node Block Diagram with its connected module/sensor

Fig. 4. is a developed IoT node block diagram. Consists of various sensors and a control board based on the STM32 microcontroller and a 4G modem to send and receive data to and from the cloud.

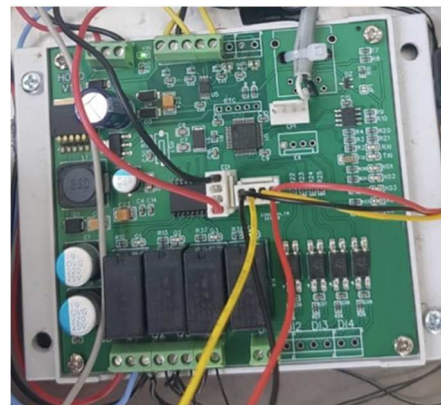


Fig. 5. STM32 MCU Custom Board

Fig. 5. is a custom board for STM32 microcontroller unit to customize its I/O for attaching sensors and electricity management to power the edge unit.



Fig. 6. Prototype of the IoT hydroponic system.

Fig. 6. is a prototype of the IoT hydroponic system that using Wick method and Watercress as the plant of choice. This prototype is being utilized for testing real-time monitoring as data source for the web application and testing automatic decision when deciding whether the system need to add more nutrition or not using selected KNN Model. This prototype also used for determining how long the pump need to be turned on to add certain amount of nutrition needed for the plants.

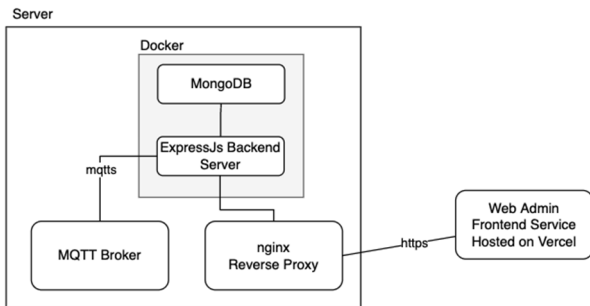


Fig. 7. Cloud layer detail of IoT System Infrastructure Design

Fig. 7. shows a part of the Fig 3 diagram showing the detail inside the cloud layer consists of backend system which includes Docker containers that stores MongoDB and ExpressJs-based backend server, Nginx reverse-proxy, and MQTT broker. And a web application that was built using React that is hosted on Vercel PaaS.

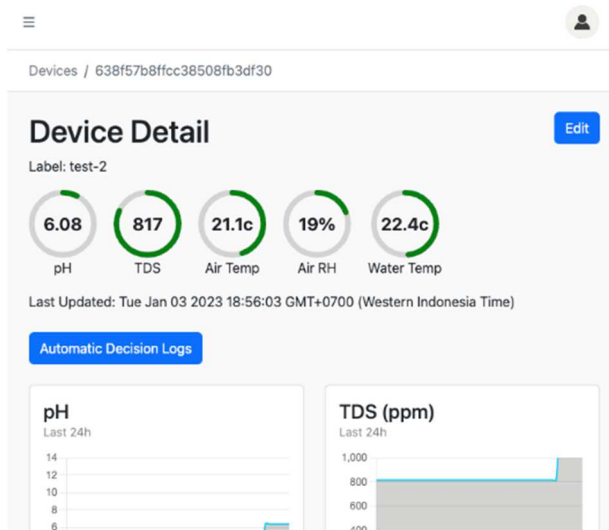


Fig. 8. Web Application Dashboard User Interface

Fig. 8. shows a web application user interface where users can view sensor readings in real time and find out historical data on sensor readings and decisions taken.

TABLE II. CLASSIFICATION/LABELLING FOR DATASET

Label	Condition	Solution
1	Enough ppm and pH	Nutrition pump off
2	Low ppm or pH	Nutrition pump on for 10 seconds.
3	Extremely low ppm or pH	Nutrition pump on for 15 seconds.
4	High ppm or pH	Nutrition pump off, indicating high concentration of nutrition.

Table II above is a label that will be used for labeling the classification model along with its decision result and conditions.

TABLE III. EXAMPLE DATASET FOR KNN-MODEL

pH	TDS	Label
5.5	753	2
6.1	833	1
5.7	736	2
6.7	926	4
6.3	811	1
5.0	653	3

Table III above, is a sample dataset that is being labeled manually based on label classified at Table II for ML model reference.

KNN-model generated is evaluated and visualized using Confusion Matrix which is a tool for predictive analysis in machine learning. Confusion matrix is used to examine the performance of a classification-based machine learning model. With a form of an $N \times N$ matrix to evaluate the performance of a classification model, where N is the number of target classes or label used and can calculate model accuracy by observing its diagonal values to measure the number of accurate classifications made [18].

ML testing was carried out using the confusion matrix method in the form of a table created to link the classification results with the data obtained that also including f1-score and prediction accuracy.

Accuracy (1) is a metric that can describe how the model works on all types of existing classifications. This method of measuring accuracy is useful when all classes are of equal weight or importance.

$$Accuracy = \frac{True_{positive} + True_{negative}}{True_{positive} + True_{negative} + False_{positive} + False_{negative}} \quad (1)$$

Precision (2) is the ratio value between the classification with true positive results to the total positive prediction results, either wrong or right. Precision can help describe how reliable an ML model is in classifying a sample as a positive value [19].

$$Precision = \frac{True_{positive}}{True_{positive} + False_{positive}} \quad (2)$$

Recall (3) is the ratio value between the classification with true positive results and the number of true positive and false negative predictions. If the recall value is high, the model can accurately classify positive values [19].

$$Recall = \frac{True_{positive}}{True_{positive} + False_{negative}} \quad (3)$$

F1-score (4) is a value that combines precision and recall by calculating the harmonic mean value of the two values. The formula below applies to binary classification [20].

$$F1score = \frac{2 \times (precision + recall)}{precision + recall} \quad (4)$$

In the classification of more than two possibilities, each type of classification is calculated by its f1-score first and then the average is taken.

B. Testing KNN

The research will test the decision-making aspect of the system and find the best hyperparameter for the KNN model. The test is conducted using Euclidian and Manhattan distance algorithm combined with k value from 1 until 8.

The following table will show KNN Model testing result with descending / y-axis value shows the predicted results while horizontally / x-axis shows the actual value.

TABLE IV. KNN WITH MANHATTAN DISTANCE FUNCTION TESTING USING CONFUSION MATRIX

Confusion Matrix Manhattan k=4, f1-score=0.9273 accuracy=92.86%				
	1	2	3	4
1	5	0	0	0
2	0	3	0	0
3	0	0	3	0
4	1	0	0	2

TABLE V. KNN WITH EUCLIDIAN DISTANCE FUNCTION USING CONFUSION MATRIX

Confusion Matrix Euclidian k=4, f1-score=0.9273 accuracy=92.86%				
	1	2	3	4
1	5	0	0	0
2	0	3	0	0
3	0	0	3	0
4	1	0	0	2

Table IV and Table V above shows the example result of KNN Model testing that was shown in Confusion Matrix form, that also includes its corresponding f1-score and prediction accuracy, From the test, the author can choose the highest score and take the hyperparameter i.e., distance algorithm and k value to be chosen for main KNN model at the backend server.

TABLE VI. COMPARISON TABLE OF F1-SCORE

k	euclidian	manhattan
1	0.6530	0.6530
2	0.8583	0.8583
3	0.6530	0.6530
4	0.9273	0.9273
5	0.8583	0.8583
6	0.7673	0.7673
7	0.7673	0.7673
8	0.7673	0.7673

Table VI above compares f1-score values based on k values (1-8) and the algorithm used (Euclidian, Manhattan), values are rounded up to four decimal places.

TABLE VII. COMPARISON OF THE PERCENTAGE OF ACCURACY

k	euclidian	manhattan
1	64.29%	64.29%
2	85.71%	85.71%
3	64.29%	64.29%
4	92.86%	92.86%
5	85.71%	85.71%
6	78.57%	78.57%
7	78.57%	78.57%
8	78.57%	78.57%

Table VII above compares prediction accuracy percentage based on k values (1-8) and the algorithm used (Euclidian, Manhattan), values are rounded up to two decimal places.

It can be seen from the results above, that KNN uses hyperparameters with the Manhattan and Euclidian distance functions at a value of k = 4 which has the best results with an f1-score of 0.9273 and an accuracy of 92.98%. In this case the Euclidian and Manhattan distance formulas do not have different results for each value of k, because not many dimensions/data features are used in the function formula. To perform classification with few data features, the Euclidian distance formula is chosen.

C. Automatic Decision Correct Prediction Impact

Based on the research conducted, sensor readings processed through the KNN to determine the action needed to achieve optimal conditions with the addition of nutrients have been successfully carried out. Under hydroponic conditions with parameters pH = 5.73 and TDS = 776, the system succeeded in classifying these conditions as requiring nutrients so that the system made the decision to add nutrients until the final measurements were obtained with parameters pH = 6.03 and TDS = 817.

V. CONCLUSION

This study successfully developed an IoT-based monitoring and control system for hydroponic farming, with supporting web applications. The system design integrated sensors with an STM32 microcontroller that connected to a 4G modem to transmit data via MQTT. On the cloud side, a back-end service received data from the node via MQTT and stored it in a MongoDB non-relational database. The stored data was then used in automatic decision-making. Data visualization was achieved through a web application built using the NextJs front-end framework based on ReactJs. The KNN algorithm's evaluation was successfully carried out using the Confusion Matrix with an F1 score of 0.9273 and an

accuracy of 92.98%, using the Euclidean distance function with a k value of 4.

The results of this study demonstrate the potential of the proposed system to optimize hydroponic farming. However, there is a future scope for this system to improve its variable control and system resiliency by integrating additional sensors to monitor and control environmental factors such as temperature and lighting, in addition to nutrient levels. Incorporating redundancy and failover mechanisms would ensure uninterrupted monitoring and control of the hydroponic system, minimizing the impact of system failures.

In conclusion, this study contributes to the development of advanced hydroponic systems and presents a promising future for IoT-based smart farming. By expanding the scope of this system and improving its resilience, we can further optimize hydroponic farming and contribute to sustainable agriculture.

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