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Design and Implementation of IOT-Based Monitoring System on Nanobubble-Based Hydroponics Farming

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ABSTRACT

Maintaining Dissolved Oxygen (DO) levels in the hydroponic plant nutrient solutions can be done using nanobubble technology. Manual monitoring can be time-consuming and measurement results are less accurate. Therefore, a monitoring system is needed to monitor air temperature, air humidity, water temperature, water pH, nutrient concentrations, and DO levels. Several stages in this research are preparation, design, sensor calibration, and monitoring system implementation. Air temperature and humidity conditions can be measured with the DHT22 sensor, water temperature can be measured with the DS18B20 sensor, water pH can be measured with the Analog pH Meter Pro, nutrient density can be measured with the Analog TDS sensor, and DO levels can be measured with the Dissolved Oxygen Sensor. Based on the measurement results monitored by the monitoring system, the parameters that affect the ignition of the nanobubble generator are DO values and water temperature. The system can also visualize sensor data on monitors and online, and can store sensor data locally and IoT so that this system has the potential to monitor hydroponics, especially nanobubble-based hydroponics.

1. INTRODUCTION

Hydroponics is one of the fastest growing technologies in agriculture. According to Kilmanun & Ndaru (2020), vegetables produced from hydroponic cultivation have the potential for a growing market such as restaurants, supermarkets and cafes and have great opportunities for export. According to Ismail & Syam (2019), hydroponic cultivation is also a farming business that has adaptive technology to innovation which can provide relatively large profits. Hydroponics has several advantages such as higher plant production, more secure plants free from pests and diseases, more efficient use of water and fertilizer, easy to replace new plants without disturbing the growth of other plants, has better quality plants, the planting process is not depending on environmental conditions, and does not require large areas of land (Susilawati, 2019; Anika & Putra, 2020). The many advantages that exist in hydroponics can increase business opportunities in agriculture. This is also supported by the level of community demand for vegetables. Vegetables are a product that is widely consumed by people from the agricultural sector (Sulistyowati & Nurhasanah, 2021).

Plants in hydroponics need oxygen to take nutrients by plant roots so that the dissolved oxygen (DO) level in the nutrient solution must be maintained to be sufficient. According to Yuliantari *et al*. (2021), DO is an indicator for determining water quality, namely the better the quality of the water, the higher the DO content in it. For plants, DO is needed in the combustion process with oxygen in organic plants and aerobic processes in inorganic plants. Giving oxygen so that DO levels remain sufficient can be done in several ways, one of which is by giving air bubbles to the nutrient solution (Susilawati, 2019). In this study, the addition of these bubbles will be carried out using nanobubble technology. Nanobubble technology is a technology that can increase DO in water in the form of bubbles that are <200 nm in size so that these bubbles can last a long time in water (Alam *et al*., 2021). Nanobubbles can last longer in the water because the internal pressure of the nanobubbles in the liquid is higher than the environment which can accelerate the dissolution of the gas into the liquid (Ljunggren & Eriksson, 1997) and also because the surface of the nanobubble is negatively charged (zeta potential), different from macrobubbles. which will increase in size then rise rapidly and break up on the surface of the water (Matsuki *et al*., 2012). Based on the results of research that has been done (Liu *et al*., 2016), water nanobubbles with different amounts of density will have different effects on the seed germination process in spinach and carrots. Water nanobubble with a high density will result in a faster final germination rate in spinach seeds but not in carrot seeds, so the density of nanobubble water must be lowered so as not to inhibit germination. Therefore, it is necessary to know the DO level when the nanobubble is applied to hydroponics so that it can determine the condition of the hydroponic plants. In this research, hydroponics has applied nanobubble technology using the same type of nanobubble generator as in the research conducted by Alam *et al*. (2022) namely the swirling-flow nanobubble generator type.

Hydroponics does not depend on environmental conditions so it requires a controlled environment in order to avoid a decrease in plant quality. Based on this, it is not only monitoring DO conditions but also monitoring as a whole. This monitoring also aims to determine the effectiveness of nanobubble technology in hydroponics. However, if this monitoring is carried out using measuring instruments manually, it can be time-consuming and if you want to get accurate measurement results, of course, you have to make measurements properly. Therefore, a monitoring system is needed that is supported by the Internet of Things (IoT) to monitor plant conditions. According to Burange & Misalkar (2015), IoT is able to move data using a network, namely source to destination or human-computer interaction so that it no longer requires two-way traffic between humans and humans. IoT has had a great impact on agriculture in examining various problems in agriculture. One way is to create a wireless sensor network that can help collect sensor data. Through sensor data, it can provide information about environmental conditions or plant productivity and then send the data to the main server so that it can evaluate factors that can affect plant conditions (Farooq *et al*., 2019).

There are several studies related to monitoring systems in hydroponics. Research conducted by Doni & Rahman (2020) regarding an IoT-based hydroponic plant monitoring system using the NodeMCU ESP8266 with data obtained related to water level, temperature and humidity with the output results appearing in the Android application. Another study by Pamungkas *et al*. (2021) regarding the design of a monitoring system for IoT-based NFT hydroponics using Arduino Mega and NodeMCU ESP8266 with parameters regarding dissolved nutrient content, pH level, and water temperature level then these data can be accessed on an Android mobile. While research conducted by Assa *et al*. (2022), namely regarding the design of an IoT-based monitoring system using ESP32 which provides information regarding pH levels, nutrient concentrations, water levels, temperature, and air humidity with the output results being stored in the OVoRD (Online Value of Real Time Data) platform and displayed in web form. Other research related to aeration monitoring using the dissolved oxygen parameter was carried out by Salim *et al*. (2016) regarding the design and implementation of water quality monitoring in eel aquaculture using microbubble aeration for changes in dissolved oxygen, temperature, and acidity.

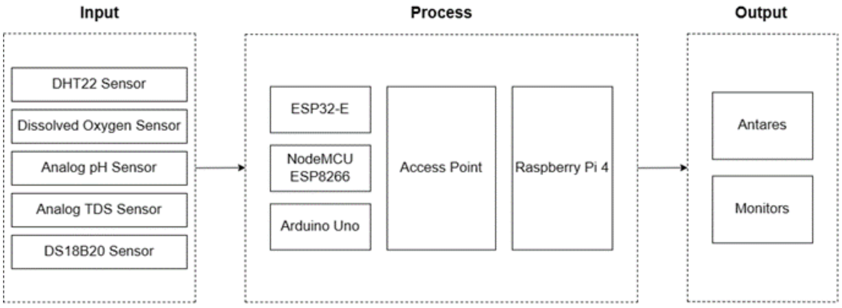
This study aims to design a hydroponic monitoring system that has implemented nanobubble technology with a system based on the Internet of Things (IoT). Therefore, hydroponics will install a DS18B20 sensor to measure water temperature, a TDS sensor to measure nutrient concentrations, a DHT22 sensor to measure air temperature and humidity, a pH sensor to measure water pH, and a Dissolved Oxygen Sensor to measure water DO levels. These sensors are installed in the system so that they can assist in measuring parameters that can affect hydroponic plants. When compared with previous studies, in this study there was research development on the monitoring system, namely the addition of the Dissolved Oxygen Sensor so that it can assist in monitoring hydroponics which is already based on nanobubbles. This monitoring system is also supported by the Internet of Things (IoT) to make monitoring easier. Through the data from the sensors that have been obtained it will help to find out the conditions of hydroponics through 2 options, namely from the user interface display on the NodeRED dashboard which is a browser used to create IoT applications (Mulyono *et al*., 2018) which will appear on a monitor and the second option which can also be accessed online through the Antares database. In addition, this monitoring system can also help in knowing how much influence nanobubble technology has on hydroponic plants.

2. MATERIALS AND METHODS

The tools and materials used in this study include: (1) laptops (Arduino IDE already installed), (2) sensors (Atlas Scientific Dissolved Oxygen, Analog TDS Sensor, Analog pH Meter Pro, DHT22 sensor, and DS18B20 sensor), (3) microcontroller (Arduino Uno R3, ESP32-E, NodeMCU ESP8266), (4) Raspberry Pi 4 (NodeRED has been installed), (5) Monitor, and (6) Router. This research was conducted from September to November which is located at BRIN (LIPI Bandung Area) Jl. Sangkuriang, Dago, Coblong District, Bandung City, West Java 40135.

2.1. System Block Diagram

Based on the monitoring system block diagram (Figure 1), the sensors used act as system input. The results of sensor readings consist of data related to air temperature, humidity, dissolved oxygen levels, pH levels, nutrient concentrations, and temperature in nutrient water. Furthermore, the data will be processed through the microcontroller to be sent to the Raspberry Pi via the access point. On the Raspberry Pi, sensor data will be stored locally and displayed on the dashboard user interface in NodeRED. This sensor data will also be stored online through the Antares database so that the data can also be accessed online or remotely. Therefore, the output of this system can be seen directly on the monitor and can also be viewed online via Antares.



Figur 1. Block diagram for monitoring system

2.2. Hardware Design

In hardware design, each sensor was connected to a different microcontrollers except for the DS18B20 sensor which was installed for each sensor as temperature compensation. Dissolved Oxygen (DO) sensor and sensor DS18B20 were connected to Arduino Uno and NodeMCU ESP8266 to assist in sending data to the access point. The Analog TDS sensor and sensor DS18B20 were also connected to Arduino Uno and NodeMCU ESP8266 for the same purpose. Analog pH Meter Pro and sensor DS18B20 were connected to the ESP32-E then the results of the sensor data were sent directly to the access point. Similarly, the DHT22 sensor was also connected to the ESP32-E. The DHT 22 sensor and Analog pH Meter Pro used a different microcontroller because the position of this sensor was different from the other sensors and the choice of ESP32-E as the microcontroller is due to lower voltage as compared to that of Arduino Uno. Other sensors used Arduino Uno due to the presence of one sensor, namely Analog DO which is stable only when used at an input voltage of 5V. Previously, researchers had designed all sensors using one microcontroller (except DHT22), but in fact all sensors generate voltage. Separation of VCC on each sensor still makes the ground on each sensor should be combined with the microcontroller. If the ground was separated, it failed to read the sensor on the microcontroller. If using a relay it will produce sensor readings sequentially so that the data obtained is not at the same time. Therefore, each sensor uses a different microcontroller. All data from sensor readings sent to the access point was sent to NodeRED already installed on the Raspberry Pi. These data were displayed on the user interface display on the NodeRED dashboard. Figure 2 shows the hardware design of the monitoring system.

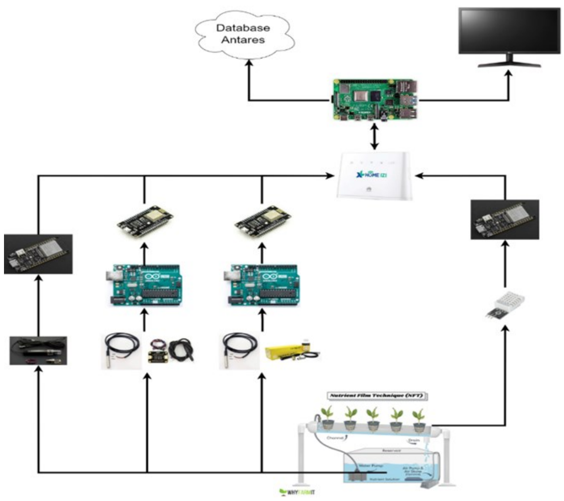


Figure 2. Design of hardware for monitoring system

2.3. Software Design

In the software design, all programs on Arduino Uno, ESP8266, and ESP32-E were made using the Arduino IDE. The program on Arduino Uno was designed to take readings from the DO sensor, Analog TDS sensor, and DS18B20 sensor. These data were sent to NodeMCU ESP8266 in which a program has been created to receive data from Arduino Uno and then send the data to NodeRED using MQTT (Message Queue Telemetry Transport) via the access point network. In the program in ESP32-E, a program was also created so that it can take readings from the Analog pH Meter Pro and DHT22 sensors, then the data were sent directly to NodeRED using MQTT. Next, a program was created on NodeRED already installed on the Raspberry Pi to receive the data. The received data were then stored and processed to be displayed in the user interface on the NodeRED dashboard which can be seen on the monitor. At NodeRED, data were stored with 2 storages, namely local storage and IoT storage. The received data from sensors were stored on the Raspberry Pi called local storage. For IoT storage, the data were sent to an Antares database to be accessed online. Figure 3 depicts the monitoring system software design.

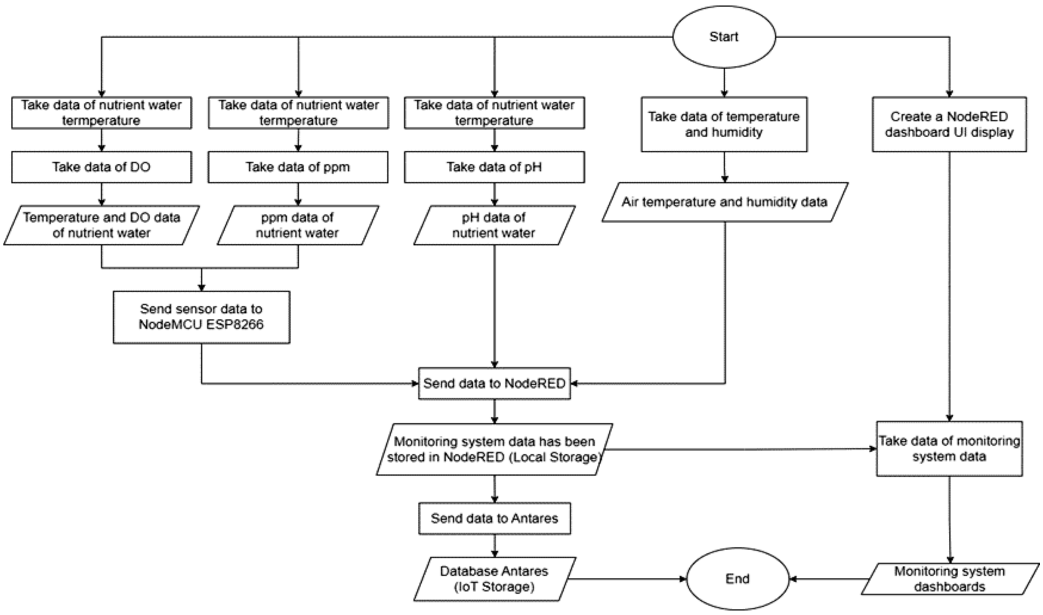


Figure 3. Flowchart for software monitoring system design

2.4. Sensor Calibration

Calibration aims to obtain accuracy from the measurement results of measuring instruments or sensors and maintain the conformity of measurement results with international units (Nasarudin *et al*., 2020). All sensors used in this study must be calibrated beforehand. The DS18B20 and DHT22 sensors had been calibrated from the factory. Calibration of the Analog TDS sensor, Analog pH Meter Pro, and Dissolved Oxygen sensor was carried through automatic calibration using a solution provided for each sensor brand. The sensor probe was dipped into the calibration solution and then followed the command input on the Serial Monitor found on the Arduino IDE to perform the automatic calibration.

Calibration begun with compiling the program via the Arduino IDE and inserted the TDS probe into the TDS calibration solution. Then gave the command "enter" to enter calibration mode and in this mode select the command "cal: tds value" to calibrate the sensor automatically. Because this study used a 500 ppm TDS calibration solution, the command "cal: 500" was given so that the results of the TDS sensor readings will appear which are more stable and in accordance with the TDS calibration solution and the calibration mode was ended by giving the "exit" command. After automatic calibration, the sensor is ready to use. The TDS sensor had been compensated for temperature, the data of which comes from the readings of the DS18B20 sensor so that the readings from the TDS sensor are more precise.

To enter calibration mode of the Analog pH Meter Pro, the command "enterph" was selected and continued by inserting the probe into the buffer solution. In this study, 3 types of buffer solutions were used, namely pH 4.01, pH 7.00 and pH 10.01. Next, the command "calp" was given to start the calibration. However, the feature of DFRobot only requires 2 types of buffer solution to perform automatic calibration, namely pH 4.01 and pH 7.00 so that each time probe was dipped in a different buffer solution, the "calp" command must be given. Meanwhile, the pH 10.01 buffer solution is used as a material to test the readings of the Analog pH Meter Pro. After performing calibration, calibration mode can be ended by giving the command "exitph". This Analog pH Meter Pro has also been compensated with the temperature obtained from the DS18B20 sensor.

The automatic calibration performed on the Dissolved Oxygen Sensor was carried out using air and zero calibration solution. Calibration was initiated using air, when the sensor has been placed in free air then gave the command "Cal" to perform automatic calibration of air. The next calibration was with zero calibration solution: when the sensor probe has been dipped into the solution, give the command "Cal, 0" to perform automatic calibration of the zero calibration solution. Atlas Scientific Dissolved Oxygen has also been compensated for temperature whose data comes from the readings of the DS18B20 sensor.

2.5. System Implementation in Greenhouses

The implementation of the monitoring system is carried out in the greenhouse owned by Blessing Farm I (Ciwaruga, Parongpong, West Bandung Regency, West Java: -6.845729 S, 107.585765 E). The system runs for 2 days from 08:00 – 16:00. On the first day, the nanobubble generator was not turned on, then on the second day, the nanobubble generator was turned on. This is done in order to know the changes in the values of the parameters measured when the nanobubble generator is turned on.

3. RESULTS AND DISCUSSION

3.1. Sensor Calibration

3.1.1. Analog TDS Sensor Calibration

Based on the calibration results, with the help of Microsoft Excel, it can be seen that the average error of the Analog TDS sensor is 3.22 with a standard deviation of 3.89. The average error value is still in accordance with the sensor specifications which have a measurement accuracy of ±10%. Based on the readings from this sensor, a boxplot as shown in Figure 4 is made to visualize the sensor data obtained. Based on the boxplot, it can be seen that the Analog TDS sensor readings have a minimum value of 493, Q1 (lower quartile) of 497, Q2 (median) of 501, Q3 (upper quartile) of 503, maximum value of 508, and the average average value of 499.98.

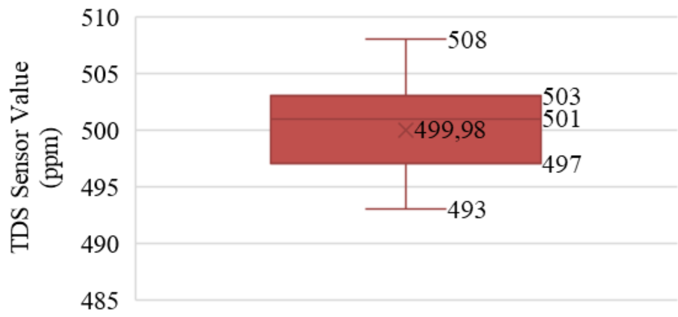


Figure 4. Bloxpot of Analog TDS sensor readings

3.1.2. Calibration of Analog pH Meter Pro

Based on the calibration that has been carried out, the average error obtained from this sensor is 0.1106, 0.0628, and 0.0444 and a standard deviation of 0.119, 0.068 and 0.073, repectively for pH buffer solution of 4.01, 7.00, and 10.01. These values are still in accordance with the specifications of the sensor which has a measurement accuracy of ±0.1. The boxplots presented in Figure 5, it can be observed that readings for a buffer solution pH 4.01 have a minimum value of 3.72, Q1 (lower quartile) of 3.8375, Q2 (median) of 3.94, Q3 (upper quartile) is 4.01, the maximum value is 4.2, and has an average value of 3.9342. Readings at buffer solution pH 7.00 have a minimum value of 6.87, Q1 (lower quartile) of 6.9275, Q2 (median) of 6.96, Q3 (upper quartile) of 7, maximum value of 7.09 , and has an average value of 6.9644. However, in this boxplot there is an upper outlier value of 7.11 and a lower outlier value of 6.76. Based on the boxplot resulted from readings at buffer solution pH 10.01, it can be seen that it has a minimum value of 9.92, Q1 (lower quartile) of 9.9775, Q2 (median) of 10, Q3 (upper quartile) of 10.0225, maximum value of 10.08 , and has an average value of 9.9908. In this boxplot there is also an upper outlier value of 10.09, a lower outlier value of 9.91, and there are 2 lower extreme values of 9.74 and 9.67.

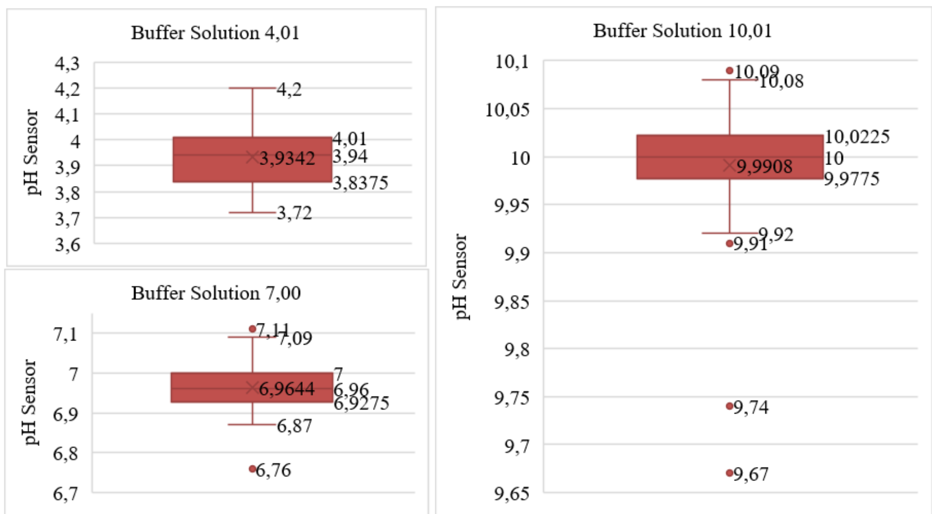


Figure 5. Three boxplots based on readings from Analog pH Meter Pro

3.1.3. Calibration of Atlas Scientific Dissolved Oxygen

Based on the calibration that has been carried out, a standard deviation of 0 is obtained for calibration with zero calibration solution and 0.005 for calibration with air.

There are 2 boxplots that can be made as shown in Figure 6. Based on the boxplot on the results of DO readings in the zero calibration solution, there is no minimum value, Q1 (lower quartile), Q2 (median), Q3 (upper quartile), maximum value, or average. value because there is only 1 data value that is read, namely 0. Based on the boxplot on the results of DO readings in air, it can be seen that it has a minimum value of 8.51, Q1 (lower quartile) of 8.52, Q2 (median) of 8.52, Q3 (quartile above) is 8.53, the maximum value is 8.53, and has an average value of 8.5228.

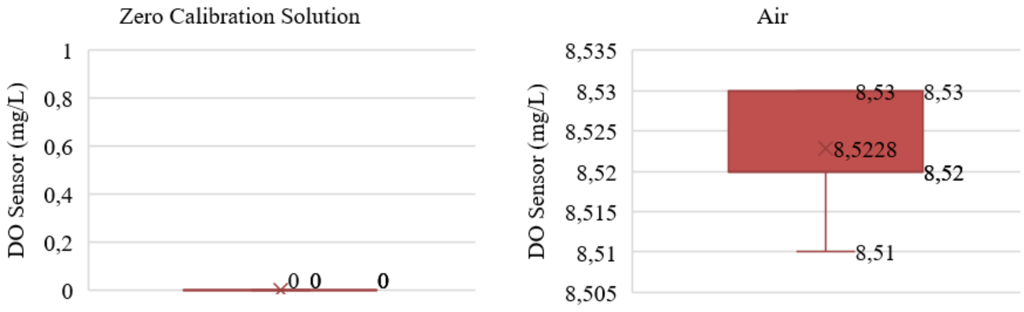


Figure 6. Two boxplots based on readings of DO sensor

3.2. Local Communications and IoT

The protocol used for local and IoT communications is MQTT. The use of this protocol is capable of sending data with little electricity consumption, light bandwidth, and very high connectivity (Susanto *et al*., 2018). In this study, MQTT is used to send sensor data from the microcontroller to NodeRED and send sensor data in NodeRED to the Antares database. In local communication and IoT, there are 2 mechanisms, namely a data recording mechanism that is intended for local data storage and a data delivery mechanism that is intended for IoT data storage. Local storage and IoT storage are intended so that data can be easily accessed online, but if there is a problem with the internet network, local data can be used as a backup so that data loss does not occur.

3.2.1. Mechanism of Data Recording

Data recording is done by receiving all sensor data that has been sent by the microcontroller using MQTT over the network from the access point. The microcontroller and Raspberry Pi have previously been connected to the same access point so that they can process data sending and receiving using MQTT. The data that has been entered into NodeRED will then be stored locally on the Raspberry Pi in a csv file format which can later be accessed using Microsoft Excel. Before the data is entered into the file, the data is first arranged in the "function" node so that the incoming data can be organized and easy to understand. To create a csv file, you can add a "csv" node and manage the storage of the file using the "write file" node. The interval for recording data is 15 seconds so that data will be entered into local storage every 15 seconds. This interval can be set on the “timestamp” node. The following is a design for recording data locally on NodeRED as shown in Figure 8 and the results can be seen in Figure 9.

Figure 8. Mechanism of local data recording

tanggal	waktu	hum	temp	tempw	ph	do	tds
2/12/2022	14:42	62.2	28.7	26.19	6.68	28.50324	1067.75
2/12/2022	14:42	61.8	28.7	26.19	6.64	27.32936	1067.75
2/12/2022	14:42	59.5	28.6	26.25	6.65	30.3032	1067.75
2/12/2022	14:42	59.2	28.6	26.19	6.64	28.34672	1071.79
2/12/2022	14:43	59	28.6	26.19	6.52	27.87717	1067.75
2/12/2022	14:43	59.4	28.5	26.19	6.6	27.87717	1067.75
2/12/2022	14:43	60.2	28.4	26.25	6.5	27.48587	1071.79
2/12/2022	14:43	60.4	28.3	26.25	6.62	27.48587	1067.75
2/12/2022	14:44	60.6	28.3	26.19	6.55	28.73802	1071.79
2/12/2022	14:44	61.2	28.3	26.25	6.52	27.32936	1071.79
2/12/2022	14:44	62.6	28.4	26.25	6.66	27.32936	1071.79
2/12/2022	14:44	61.6	28.4	26.25	6.51	28.73802	1067.75
2/12/2022	14:45	62	28.4	26.25	6.6	27.79891	1067.75
2/12/2022	14:45	63.4	28.4	26.25	6.56	29.05105	1071.79
2/12/2022	14:45	63	28.4	26.19	6.52	29.44235	1067.75
2/12/2022	14:45	62.7	28.3	26.19	6.52	29.44235	1067.75
2/12/2022	14:46	61.8	28.3	26.19	6.6	28.34672	1063.72
2/12/2022	14:46	61.6	28.2	26.19	6.5	29.12931	1067.75
2/12/2022	14:46	61.3	28.2	26.25	6.52	28.89454	1063.72
2/12/2022	14:46	61.2	28.2	26.19	6.66	29.59887	1067.75

Data Monitoring Terbaru

Figure 9. Results of local data recording on 2/12/2022 from 14:42 to 14:46 in Bahas Indonesia (tanggal = date; waktu = time)

3.2.2. Data Transfer Mechanism

Data transmission is carried out by sending data that has been received on NodeRED to the Antares database storage. Sending this data also uses MQTT. The interval for sending data is 1 minute so that not too much data is sent to the database. This interval can be set on the “timestamp” node. However, before the data is sent to the database, the data also needs to be arranged so that it can be read clearly in the database using the "function" node. Then the data will be sent to the destination Antares database address using MQTT with the "mqtt out" node. The following is a design for sending IoT data on NodeRED as shown in Figure 10 and the results can be seen in Figure 11. Data that has been entered into the Antares database storage can also be visualized on the dashboard provided by Antares.id as shown in Figure 12.

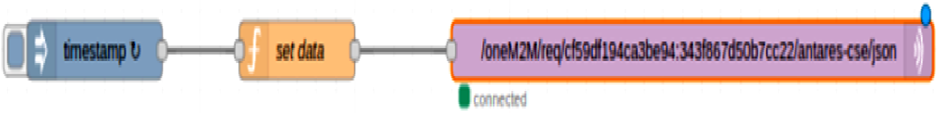


Figure 10. Mechanism of transferring data using IoT

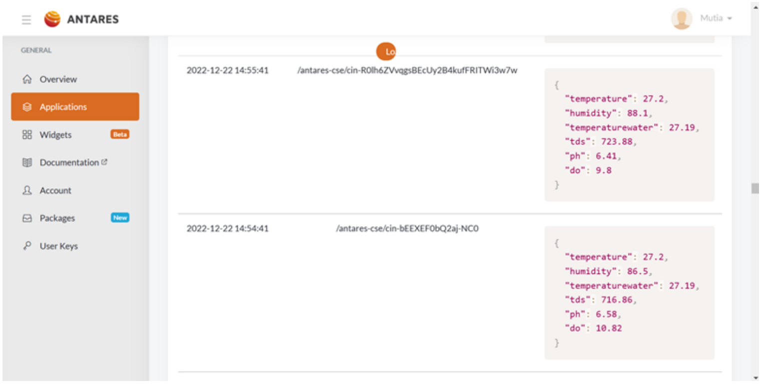


Figure 11. Features of database Antares.id

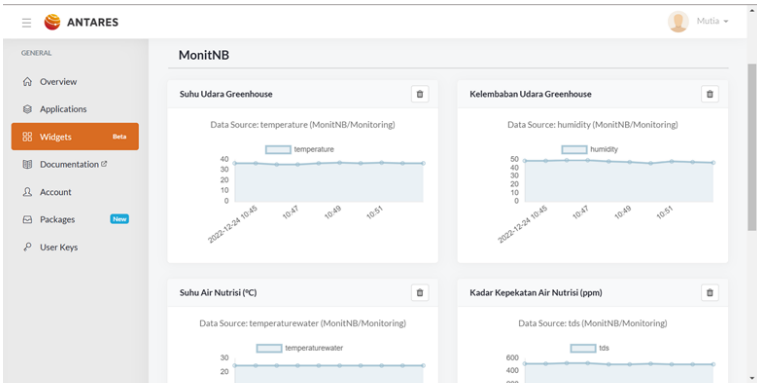


Figure 12. Dashboard of Antares.id

3.3. Dashboard User Interface

Making the user interface on the NodeRED dashboard is used to display data from sensor readings that can be seen from the monitor. All data that has been received via MQTT will then be visualized into a gauge display with a level type. The choice of this display is due to the fact that these data can be more easily understood when viewed on a monitor. The following is a design for creating a dashboard user interface on NodeRED as shown in Figure 13. Based on the figure, it can be seen that some of the data received by NodeRED is still in the form of aggregated data, namely dissolved oxygen data with water temperature and ppm with water temperature so it is necessary to separate the data by using "split" nodes. The separated data is then converted into String data using the "change" node. These data will then be sent to each gauge that has been provided using a "switch" node. The "function" node is added in order to store the separated data so that it can be reused if needed. The results of the NodeRED dashboard user interface are as shown in Figure 14.

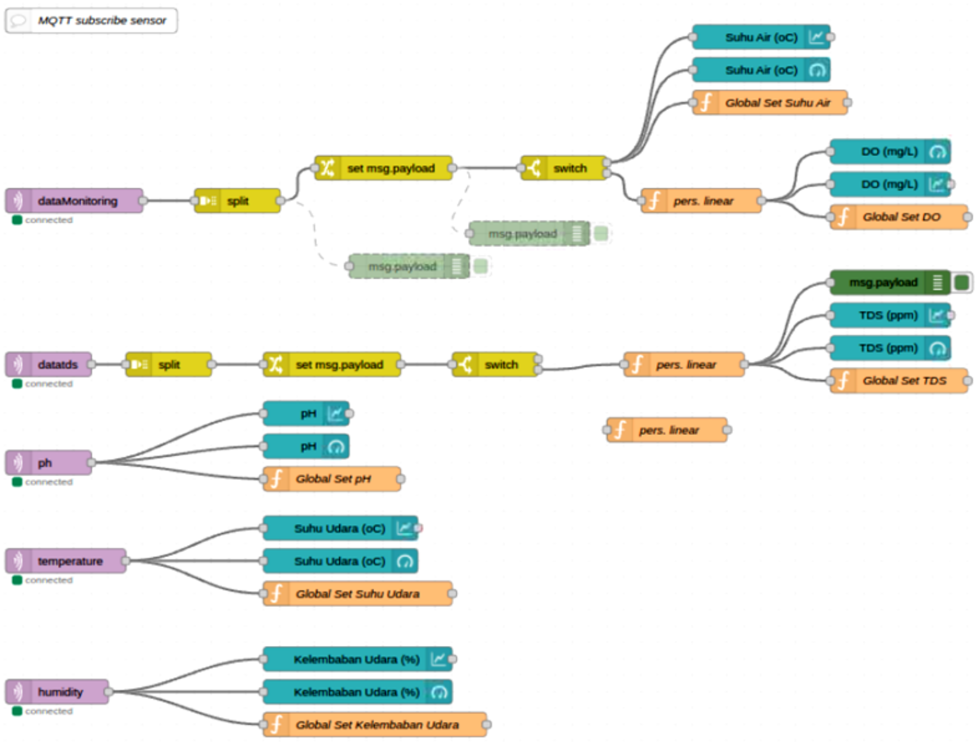


Figure 13. Preparation of user interface dashboard NodeRED (suhu udara = air temperature; kelembaban udara = relative humidity)

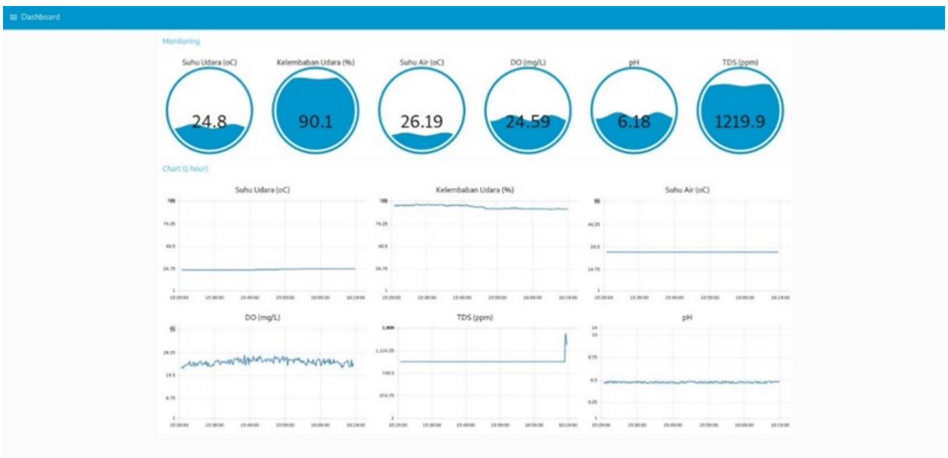


Figure 14. User interface dashabord NodeRED (suhu udara = air temperature; kelembaban udara = relative humidity)

3.4. System Implementation

The graphs of the results of the monitoring system obtained are shown in Figures 15, 16, 17 and 18. During this measurement, on the second day, the nanobubble generator was turned on from morning to noon. Based on the graph obtained, it can be seen that the parameters that affect the ignition of the nanobubble generator are DO values and water temperature.

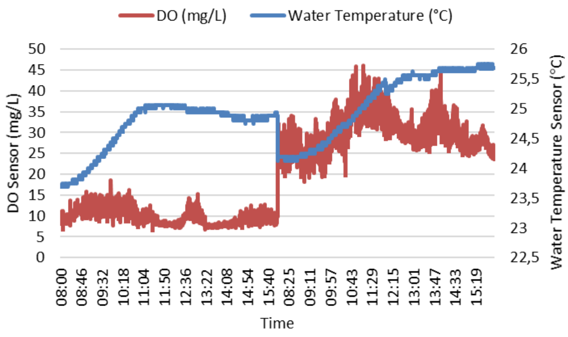


Figure 15. Graph of DO sensor and water temperature sensor readings

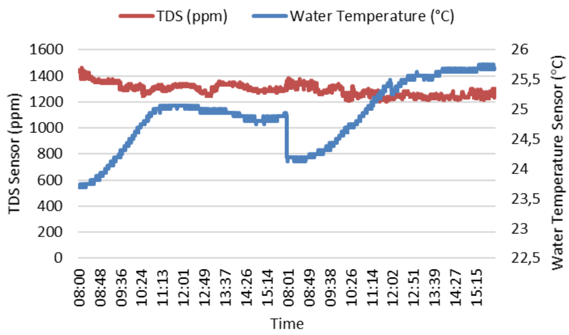


Figure 16. Graph of TDS and water temperature sensors readings

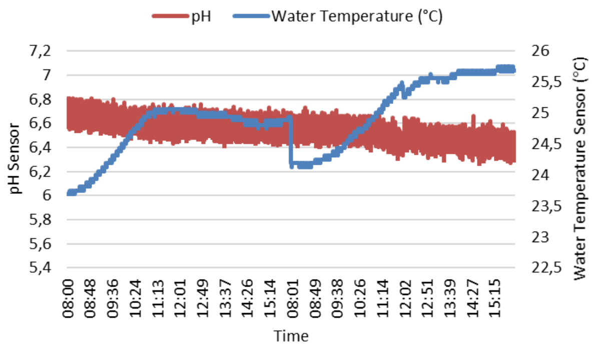


Figure 17. Graph of pH sensor and water temperature sensor readings

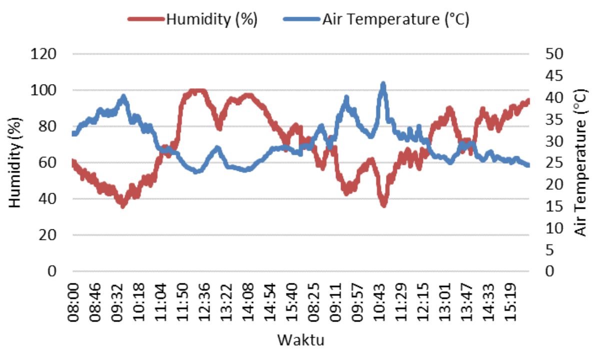


Figure 18. Graph of air temperature and humidity sensors readings

In Figure 15 it can be seen that on the second day from morning to noon there was an increase in DO values and water temperature. This is in accordance where at that time the nanobubble generator was being turned on for 30 minutes on, 1 hour stopped, and 30 minutes on again. Turning on the nanobubble generator can increase the temperature of the water so that after the nanobubble generator is not turned on again, it can be seen in the graph that the DO value drops again. This is still according to the theory according to Saputri *et al*. (2014) regarding increasing water temperature can make DO values decrease and vice versa. Therefore, when the nanobubble generator is turned off, the DO value decreases due to increased water temperature. Based on the graphs in Figures 16 and 17, the values of the TDS sensor and pH sensor have no effect as a result of turning on the nanobubble generator, while the values of the temperature and humidity sensors in Figure 18 are due to being outside the nutrient reservoir so they have no effect as a result of turning on the nanobubble generator.

4. CONCLUSIONS AND SUGGESTIONS

This research resulted in an IoT-based monitoring system design that can be applied to nanobubble-based hydroponic farming. Based on the results obtained, all sensor readings used in this system are quite stable. Therefore, this monitoring system is able to assist in monitoring nanobubble-based hydroponics, especially Dissolved Oxygen Sensors which can assist in knowing how much influence nanobubble technology has on hydroponic plants by measuring dissolved oxygen levels in nutrients. This system is also capable of sending data using the MQTT protocol so that it can display data on a monitor and store data both locally and IoT. The interval for sending data between local storage and IoT is also different so that not too much data is sent to the database but still has quite complete data in the local storage section. The suggestion for further research is to add a control system so that it can meet some of the measurable parameters that are still lacking, especially the control system for dissolved oxygen levels in nutrient water.

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