Remote Multisensor System for Environmental Quality (Water and Air) Monitoring Applications in Aquaculture Environments Based on the Internet of Things

Muhammad Iqbal [1,*]
[1] Universitas Pendidikan Indonesia, Bandung, Indonesia
* Corresponding Author

ARTICLE INFO

Article history:

Received July 28, 2021
Revised August 28, 2021
Accepted September 28, 2021

Keywords:

Multisensor System;
Water Quality Monitoring;
Internet of Things;
Aquaculture

ABSTRACT

Water quality monitoring in the aquaculture environment is often carried out by cultivators of aquatic organisms in order to monitor the health and suitability of the water. The usual way is done by laboratory tests that take a long time. In the last decade, researchers have developed water quality monitoring systems in aquaculture environments by utilizing sensors and other electronic devices to quickly determine water quality. A water quality monitoring system has been developed in aquaculture environment using PT-100 sensor, DHT-22 sensor, TDS sensor and turbidity sensor. Each sensor is connected to the ATmega328p microcontroller to be able to transmit water quality readings. The atmega328p microcontroller is connected to the Raspberry pi gateway to be able to transmit the reading data to the internet network using the MQTT protocol. The MQTT protocol allows telemetry systems to transmit data quickly and in real time. The reading data can be displayed on a website page that can be accessed using the internet network in real time and can be accessed within a distance of more than 1,000 km from the monitoring site.

Cite Article:

F. Author and S. Author, "Remote Multisensor System for Environmental Quality (Water and Air) Monitoring Applications in Aquaculture Environments Based on the Internet of Things," *Journal of Science in Agrotechnology*, vol. 1, no. 1, pp. xx-xx, 2022, doi: .

1. INTRODUCTION

Ponds have an important role in the survival of aquaculture organisms, so it is necessary to carry out routine monitoring of the suitability of the aquaculture environment. One of the important things in managing the aquaculture environment is managing the water used. If the water is managed well, the organisms living in the pond will be healthy, but if the water management in the pond is poor, it will result in the death of the organisms living there. In general, the causes of death of aquaculture organisms to date are caused by poor water quality and infection by disease. Poor water quality in ponds will trigger the emergence of various diseases such as White Spot Syndrome Virus, Infectious Myonecrosis Virus, and White Feces Diseases. Poor water quality also directly affects the health of aquaculture organisms and causes a decline in the quality of organisms in the aquaculture environment.

Water quality has been studied by previous researchers. Investigation of Groundwater Quality for Drinking Use in Kifri District (Iraq) using the NPI and WQI Index was researched by Abdulmutalib Raafat Sarhat [1]. The study of the relationship between landscape patterns and water quality in the Qingshanzui Reservoir District was researched by YI [2]. Chemometry Applied in the Development of a Water Quality Indicator System in the Brazilian Amazon was researched by da Costa [3].

Interval type-2 fuzzy ontological model: Predicting water quality from sensory data was researched by [4]. Variability of Surface Water Quality in Post-Mining Degraded Areas in Bytom was studied by Czajkowska [5]. An intelligent water quality monitoring method based on image processing and the RVFL-GMDH model was researched by Chen [6].

California Trichoptera museum records: potentially useful information to provide larval-adult associations to improve water quality surveys researched by [7]. The influence of the Przebędowo Reservoir on the Water Quality of the Trojanka River in the First Years of Its Function was studied by Waligórski [8]. A new dynamic multi-criteria ensemble selection mechanism applied to beverage beverage quality anomaly detection A new dynamic multi-criteria ensemble selection mechanism applied to beverage beverage quality anomaly detection was researched by Alves [9].

Spray water quality and herbicide performance: a review researched by [10]. Conversion of Páramo to Pasture in Mountain Watersheds: Its Effect on Water Quality and Quantity was studied by Matovelle [11]. The effect of heavy metal pollution on river water quality due to industrial waste disposal was studied by Mokarram [12].

Spatial and temporal variations in river mercury in the Mackenzie River Basin, Canada, from community-based water quality monitoring data were studied by [13]. MODELING AND ASSESSMENT OF THE IMPACT OF LAND USE IN THE WEST RIF REGION, MOROCCO, ON WATER QUALITY was researched by Fattah [14]. Monitoring groundwater quality before and after the rainy season in the north-eastern region of Haryana using GIS was researched by Ravish [15].

Operational monitoring of water quality with Do-It-Yourself modular instruments was researched by [16]. Drinking Water Quality Assessment in Various Areas of Tehsil Isa Khel, Mianwali, Punjab, Pakistan was researched by Khan [17]. The Performance of Satellite-Based Rainfall Products in Simulating River Flow and Water Quality During Hydrometeorological Extremes was researched by Solakian [18].

The study of simulating water quality and capacity of dynamic water environment in the third drainage channel of Helan County in Ningxia was researched by Yang [19]. Low Cost IoT Based Automatic Water Quality Monitoring System for Textile Industry was researched by Das Gupta [20]. Long-term trends in water quality and the influence of water recharge and climate on the water quality of brackish water lakes: A case study of Shahu Lake was researched by Tian [21].

The spatiotemporal characteristics of groundwater quality and health risk assessment in the Jinghe River Basin, Loess Plateau of China were studied by Li [22]. Monitoring sea water quality in Muara Kali Porong as a disposal site for Lapindo mud using Google Earth Engine was researched by Bioresita [23]. Characterizing water quality and microbial communities in various zones of a recirculating aquaculture system using biofloc biofilters was researched by Liu [24].

Assessment of the impact of reforestation on soil, river bank sediments and river water quality based on polyaromatic hydrocarbon pollutants was studied by [25]. The effect of different fish diets on water quality and growth of crucian carp (Carassius carassius) in the presence and absence of prometrin was studied by Yang [26]. The influence of water quality on caddis flies (Trichoptera) in the Kallada River, Kerala, India was studied by Benchamin [27].

Integrated water quality modeling in river-reservoir systems to support river basin management was researched by Ferreira [28]. Development of a Water Quality Discrimination System for Water Color Images Based on the LM Neural Network Optimization Algorithm was researched by Ni [29]. Exploring the application of soft computing techniques for spatial evaluation of groundwater quality variables was researched by Esmaeilbeiki [30].

It is important for pond managers to be able to know the value of each parameter that influences the water quality in ponds. One of the usual ways to find out water quality is through a lab test process which is quite long and takes time to find out the results. However, in the last few decades many researchers have tested water quality in ponds in various ways, one of which is by implementing instrumentation systems in ponds. Through electronic sensors, now pond managers can save time in finding out the values of various water parameters.

Based on this background explanation, the researcher formulated the research title "Remote Multisensor System for Environmental Quality Monitoring Applications (Water and Air) in Aquaculture Environments Based on the Internet of Things". This research includes creating a multisensor system that can detect water quality parameters such as environmental conditions (air humidity and air temperature), turbidity (turbidity) values, TDS (Total Dissolved Solid) levels and also water temperature values using sensors that can detect these parameters. The system that researchers use uses an Arduino Uno microcontroller as a reader and sensor data processor. Data from Arduino is sent via serial communication to the Raspberry single-board computer as a database and network gateway. Then the data is transmitted to the internet network using the

MQTT (MQ Telemetry Transport) protocol and sent to the cloud server. Processed water quality monitoring data can be accessed without being limited by space and time.

2. METHODS

Aquaculture is an activity of cultivating aquatic biota, both animals and plants that live in fresh water, sea water and brackish water, involving social and economic activities in it [5]. Aquaculture activities are often found in Indonesia because of the favorable geographical conditions so that many people carry out aquaculture activities to support their families and daily lives. In practice, aquaculture activities use the application of appropriate technology and scientific knowledge so that they can control the sustainability of aquaculture activities and obtain more profits. Apart from that, understanding in managing aquaculture activities also affects the life of the biota that is maintained. The better the understanding, the better the management will be and the living aquaculture biota will be healthier.

A multisensor system was created to be able to determine parameter values and water quality from an aquaculture environment using sensors connected to a microcontroller. The multisensor system that will be designed uses a DHT11 sensor, salinity sensor, water temperature sensor and turbidity sensor.

The sensor block (node) in Figure 1 has an important role because it makes direct contact with the aquaculture environment. The sensor block also gets a voltage supply from the microcontroller so that it can activate the sensor's operation. Each sensor will measure parameters of the aquaculture environment due to changes in voltage when immersed in water, then the voltage change data obtained from the sensor is sent via serial communication to the microcontroller which is then converted using an ADC (Analog to Digital Converter).

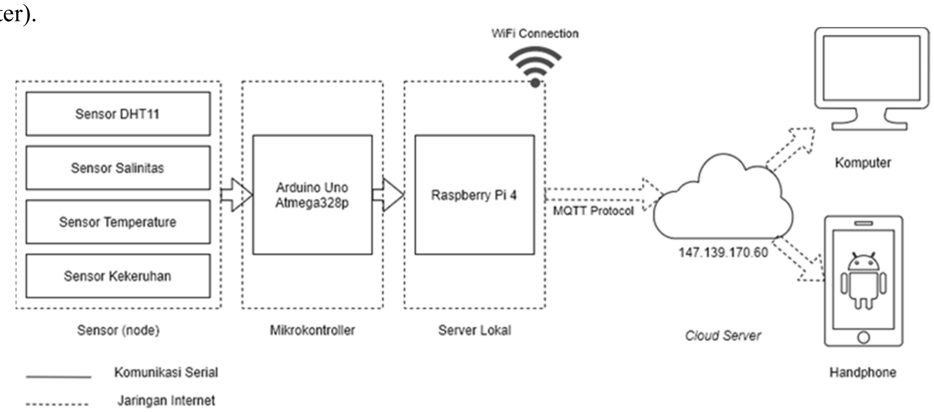


Fig. 1. Block Diagram of Multisensor System for Remote Monitoring

The microcontroller block as the control center for sensor activity acts as the head that controls sensor performance, sending instructions and commands to the sensor and receiving data from the sensor. The microcontroller also functions as a tool that facilitates communication with the Raspberry Pi as a local server which will store reading data in a database.

The local server block functions to store data from sensor readings using serial communication between the Raspberry and Arduino. Next, the reading data will be saved via the node-red application in .csv format, which will make it easier to carry out further analysis. This block also functions as a connector to the internet network using WiFi communication with the MQTT protocol. WiFi is used to connect to the internet network, and MQTT is used as a communication protocol for sending data to the cloud server 147.139.170.60 so that the reading data can be accessed via the internet network.

The cloud server block receives data transmitted by the local server block using the MQTT protocol which contains the results of data readings from embedded sensors. This block can be accessed by entering the url http://147.139.170.60:1880/ in the browser on your cellphone or laptop. 147.139.170.60 is the IP address of the server used, and 1880 is the port to address the Node-red application that has been installed on the server. In the Node-red application there is a flow program as the main part for reading and displaying reading results. To access the sensor reading dashboard, you can visit the address http://147.139.170.60:1880/ui to be able to see the program reading results in the form of visualizations in graphs and numbers.

2.1. Hardware Circuit Planning and Design

The hardware system implemented in this research consists of 2 large parts, namely a sensor reading system where Arduino as a microcontroller is connected to RTD, DHT22, Turbidity, and TDS sensors. Then the second part is a data retrieval and storage system using SBC (Single-board Computer) Raspberry pi 2 model B+, where the Raspberry can run the Linux OS system so that various applications can be installed to store data locally and connect it to the internet.

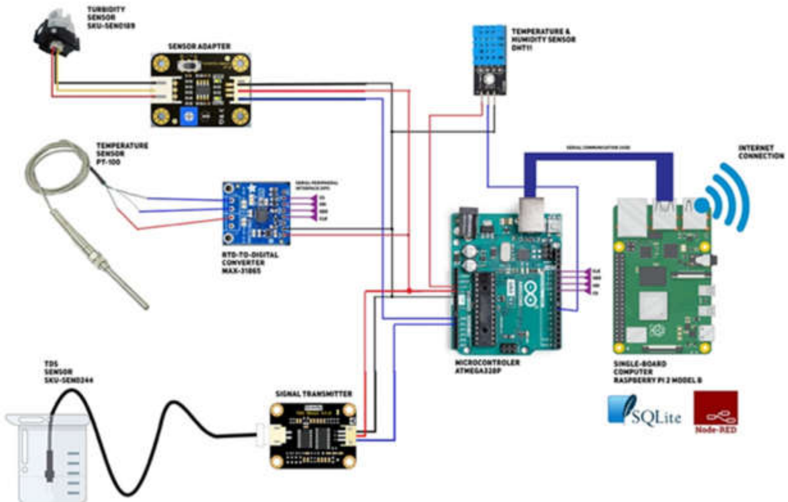


Fig. 2. Remote Multisensor Hardware System Suite

Figure 2 is a series of connections between the sensor used and the Arduino microcontroller as well as the Raspberry pi. The sensor is connected via the I/O pin on the Arduino so that the reading results can be processed digitally via the Arduino microcontroller.

Table 1. Configure I/O pins for sensor components on Arduino

Component	Pin Komponen	Pin Arduino Uno
SEN0189 Water Turbidity Sensor	VCC	5V
	GND	GND
	Output	A0
Water TDS Sensor SEN0244	VCC	5V
	GND	GND
	Output	A1
DHT22 Sensor	VCC	3.3V
	GND	GND
	Output	D7
RTD PT-100	Vin	5V
	GND	GND
	CS (*chip select*)	D10
	SDI (*slave input*)	D11
	SDO (*slave output*)	D12
	CLK (*clock*)	D13

Table 1 shows the pin configuration used by each sensor on the Arduino where there are 3 working voltages, namely 5V used for the PT-100, Turbidity and TDS sensors, while the working voltage of 3.3 V is used for the DHT22 sensor. The PT-100 sensor uses SPI (serial peripheral interface) communication, which is a synchronous type of communication that connects the PT-100 and Arduino using 4 pins as communication lines. SDI is the pin for sending data from the PT-100 (Master) to the Arduino (Slave), while SDO is the pin for sending data in the reverse direction. CLK is a pin that regulates the output clock as the time to send data. Meanwhile, CS is a pin that determines when the direction of the data flow is changed or not [6].

2.2. Programming Flow Planning and Design

The data flow starts from collecting data in the aquaculture environment by sensors, which is sent to the Arduino in the form of a voltage output by following commands or flows that have been programmed using the C++ language on the Arduino.

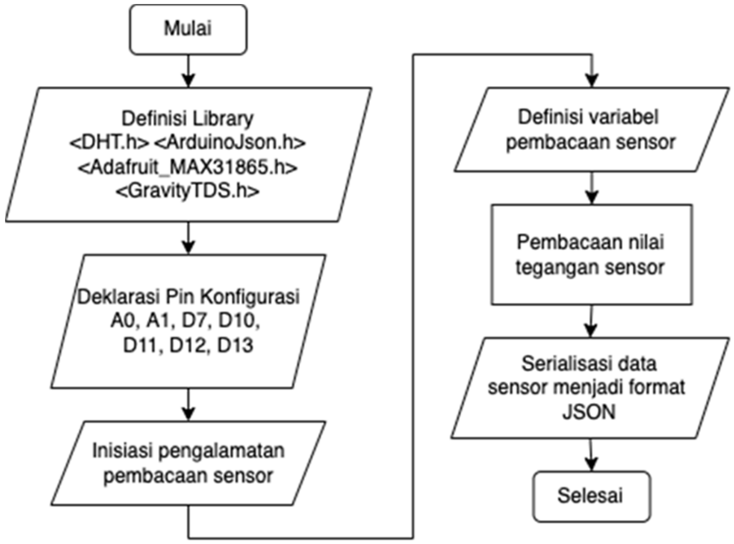


Fig. 3. Flowchart of programming the sensor reading system on Arduino

The programming flow on Arduino is explained in Figure 3 starting from defining the library used/needed in the water quality reading program, the DHT.h library is used to read the DHT22 sensor, Adafruit_MAX31865.h, namely the library for reading the output of the PT-100 sensor reading driver, GravityTDS.h is used to read the TDS sensor, and ArduinoJson.h is used to call the JSON data conversion function.

The analog pin A0 is used to read analog signals from the Turbidity sensor, while the analog pin A1 is used to read analog signals from the TDS sensor. Digital pin D7 is used to read the output of the DHT22 sensor, where the output of this sensor contains 2 values, namely environmental temperature and environmental humidity. Pins D10, D11, D12, D13 are pin configurations for SPI (serial peripheral interface) communication to read the output from the PT-100 sensor.

The next flow is to initiate addressing of sensor readings using functions from the library used. And also set the pin configuration used to be able to read the output voltage value received. This program uses a serial data reading speed of 115200 bit/s, which means the microcontroller will work to be able to read the voltage value received from the sensor of 115200 bits in one second. Then the results of the sensor readings will be stored in variables to facilitate the mathematical operations to be carried out.

After the sensor reading data is stored in certain variables, the variables are converted into JSON (Javascript Object Notation) format, which is a data format in object form to make it easier to read the data because it uses an object format, where in this format each data exchange can contain 2 parts. namely "key" which is the definition or identity of a value sent, and "value" which is a value in the form of a number. So the data that has been converted into JSON format is sent through a serialization process, so that it can be sent via serial communication using USB. So the Raspberry Pi can read data from Arduino sensors via serial communication using USB and can send 5 types of data in one sent object.

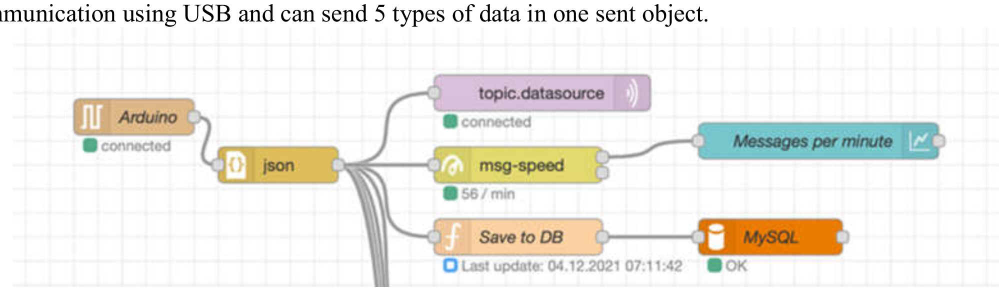


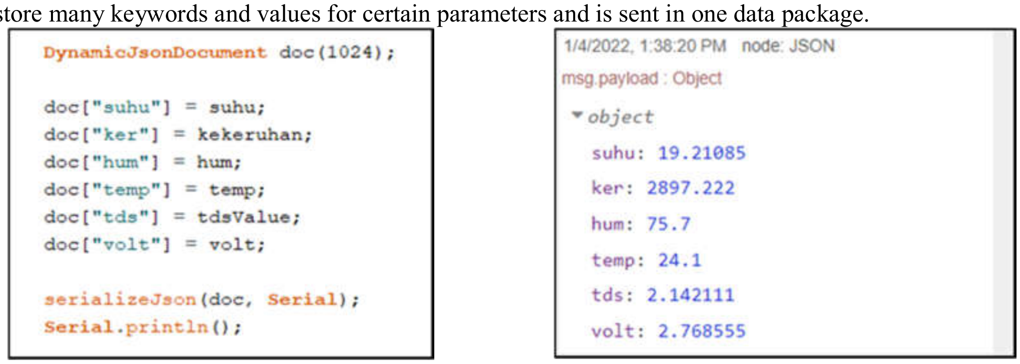
Fig. 4. Flow of reading data from Arduino

Figure 4 is the program flow on the Rapberry pi using the Node red application, where the Arduino block is a function for reading the port on the Raspberry which has a USB connected to the Arduino. So data transferred via serial communication using USB can be read using the Arduino block function. Then the next json block is a block to be able to read the function of the object that was sent, because previously the Arduino data had been converted using JSON so it needed a block that functioned to read the JSON data.

Data received via the Arduino block is sent to the internet network using the MQTT topic.datasource block. Data transmission is carried out using the MQTT protocol with a level connected to the cloud server with IP Address 147.139.170.60 with port address 1880. The data delivery concept used by MQTT uses the ¬publish-subscribe principle where a component can publish data according to the desired topic and the client or The recipient of the data subscribes the published data topic. This process can save time and speed up data transfer between machines (Machine to Machine) because the transfer is light and the delivery is in accordance with the topic being followed (subscribe).

3. RESULTS AND DISCUSSION

System implementation is carried out by creating a remote multisensor system consisting of environmental sensor components, water temperature sensors, TDS sensors and turbidity sensors to read water quality data in the aquaculture environment. The data received from each sensor is forwarded to the Arduino via serial communication, then the results of reading the voltage changes can be saved in JSON (Javascript object notation) format. The JSON (Javascript object notation) data format is a data format that can store many keywords and values for certain parameters and is sent in one data package.



(a) (b)

Fig. 5. The JSON data package contains the sensor reading results, a. Program on Arduino, b. Data packets received by the database

In the Arduino library there is a function that can change the data format to JSON, so that the sensor reading results have their own keywords and are stored in one data package containing many parameters as shown in Figure 5.a. This data package will be sent to the database via raspberry with serial communication. Raspberry will read the data sent via serial communication using the Serial block, then the user selects the port connected to the Arduino serial.

Overall testing of the remote multisensor system was carried out in a fish pond located in the Isola Building, Indonesian University of Education. Implementation was carried out on December 29 2021 at 16.20 to 17.41 with an environmental temperature of 25.60 □C and relative humidity of 74.20 %RH.

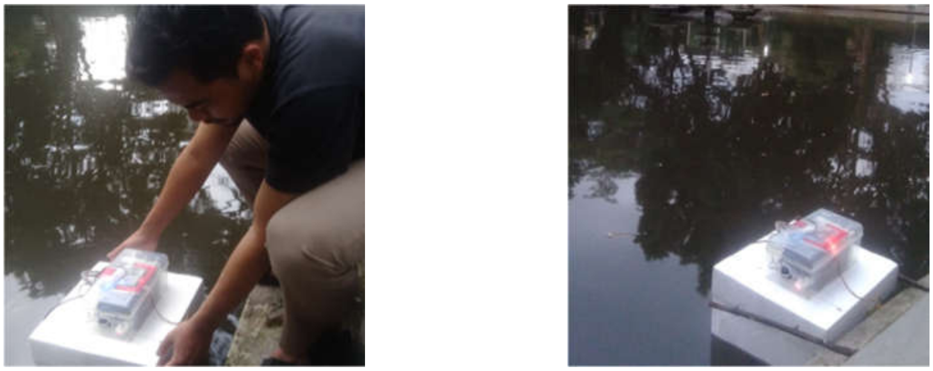


Fig. 6. Implementation of tools in an aquaculture environment

The tool is left for one hour and stored in a place that is easy to reach and ensured that it does not move around, this is done so that you can access the tool easily. Then ensure that the TDS sensor, RTD temperature sensor and turbidity sensor have been immersed in the water and can read the water parameters. For turbidity sensors, because they cannot be completely submerged, adhesive is used on the cable and attached to the container, so that the sensor is not completely submerged.

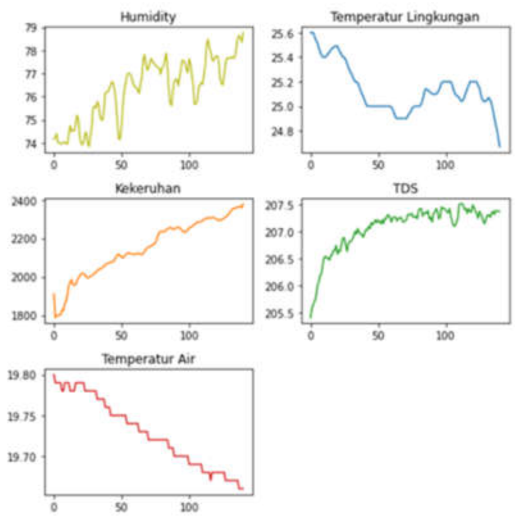


Fig. 7. Graph of sensor parameter readings for 1 hour

It can be seen in Figure 4.17, a graph of the results of sensor readings that were left for 1 hour to read the water quality in the Isola pool, UPI. The air humidity parameter has a fluctuating graph but has a slowly increasing trend, this is because the sensor is in an open space so the air flow changes at any time and takes time to stabilize. The environmental temperature parameter also has a fluctuating graph but has a slowly decreasing trend, this is because the test was carried out in the afternoon towards evening, so the air temperature decreased over time. Changes in humidity and temperature values have an inverse relationship with each other, this is because when the humidity level increases it means the air has a lot of water content which reduces the temperature of the surrounding air, likewise when the humidity has a low value it means the air does not contain much water which can raise the air temperature.

In the graph, the parameters of turbidity and TDS have a linear relationship with each other, both have graphs that increase slowly. This is because what both measure is the solids contained in the water, turbidity detects solids that are not dissolved in the water so they can scatter light and the TDS value measures the solids dissolved in the water. So these two parameters have a linear relationship with each other and increase slowly.

The water temperature parameter produces a graph that decreases due to the cold water temperature and slowly reduces the temperature of the resistor on the sensor, which causes the sensor to read a slow decrease in temperature. However, the temperature drop value is not too far in the range of 0.05, it can be concluded that the water temperature has a relatively constant value, it's just that the temperature sensor adapts to the water environment so that it has a graph that decreases slowly.

In Figure 8 you can see a web page that has been successfully created on the IoT system, where the web page can display graphs and also real-time measurement results. So in this test the data can be transmitted using the internet network, and can be accessed anywhere using an internet network connection. The next test is testing access to the IoT web page so that it can be accessed from various places, where respondents are given a web link so they can access the web page and see the measurement values in real time.

Fig. 8. Real-time display of interface pages

The measurement tool was placed in the Isola pool, UPI in the Lembang area, Bandung. Respondents were asked to be able to access a web page containing monitoring data transmitted by devices located in Lembang, Bandung. So testing the access distance to web pages is carried out remotely where respondents are spread across several areas, then send their location using the Google Maps feature to find out the distance between the respondent and the device.

Table 2. Distribution of respondents' locations to access IoT web pages

Respondents	Place	Distance Difference (km)
1.	Sukasari, Bandung City	1.2
2.	Coblong, Bandung City	6.6
3.	Cisarua, Bandung Regency	13.6
4.	Cibiru, Bandung City	21.2
5.	Babelan, Bekasi Regency	135
6.	Tamansari, Tasikmalaya Regency	140
7.	Kesambi, Cirebon City	151
8.	Sleman, Sleman Regency	481
9.	Handsome, Pekanbaru City Riau	1395
10.	Al-Khor, Qatar	7066

Table 2 contains the distribution of respondents' locations for accessing the IoT web page that has been created, namely by accessing the web page via the following link http://147.139.170.60:1880/ui/ . It was found that the distribution of respondents' locations was spread across several districts in Indonesia, such as Bandung Regency and City, they could be accessed smoothly and were around 1 - 56 km from the tool. Other districts, namely Cianjur, Bekasi, Karawang and Tasikmalaya, can access it at a distance of 65 – 150 km from the equipment. Outside West Java, there are 2 respondents who are in Sleman Regency and Pekanbaru City, Riau, who can access it with a distance of 481 and 1395 respectively. There are also respondents who are in the State of Qatar, in the Al-khor community area with a distance of 7066 km.

4. CONCLUSION

Based on the results presented in the previous chapter regarding results and discussion, there are several conclusions and work that researchers have carried out, namely a remote multisensor system for monitoring water quality that has been created and can read 5 parameters related to water quality, namely measuring environmental parameters (temperature). air and air humidity) using the DHT-22 sensor, measuring water temperature parameters using the PT-100 RTD sensor, measuring TDS parameters using the SEN0244 TDS sensor probe and measuring turbidity parameters using the SEN0189 turbidity sensor. The Internet of Things system that has been created can be accessed at the link http://147.139.170.60:1880/ui/ has several features such as graphs for the last 1 hour, graphs of recapitulation of all sensors for 12 hours as well as a menu to find out the IP address and internet speed on servers and clients. The IoT system can be accessed by respondents at varying distances including 1 km – 1000 km around Indonesia and can reach as far as the State of Qatar which is 7000 km away. So the IoT system that has been created can also be accessed anywhere and at any time using an internet connection.

There are several recommendations to improve further research, including: Direct research can be carried out longer in order to see changes in each parameter over a long period of time and analyze the correlation between the parameters. Make sure that further research can be implemented in ponds that are specifically used for cultivating aquatic animals, such as shrimp ponds on the coast or freshwater fish ponds. Using more sensors such as pH sensors and dissolved oxygen sensors can determine the quality of other water parameters and is more useful for pond farmers.

DECLARATION

Author Contribution

Aquaculture is an activity of cultivating aquatic biota, both animals and plants that live in fresh water, sea water and brackish water, involving social and economic activities in it.

Funding

Please add: “This research received no external funding” or “This research was funded by NAME OF FUNDER, grant number XXX” and “The APC was funded by XXX”.

Acknowledgments

In this section, you can acknowledge any support given which is not covered by the author con-tribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

Conflict of Interest

[1] Abdulmutalib Raafat Sarhat, Muhammad Mohsin, and Aram Hassan Mohammed, “Investigation of Groundwater Quality for Drinking Usage in Kifri District (Iraq) by using NPI and WQI Indices,” Proc. Pakistan Acad. Sci. A. Phys. Comput. Sci., vol. 59, no. 4, pp. 67–77, Dec. 2022.
[2] J. YI and Q. XU, “Study on the relationship between landscape pattern and water quality in Qingshanzui Reservoir District,” in Proceedings of the 2021 4th International Conference on E-Business, Information Management and Computer Science, 2021, pp. 144–149.
[3] H. C. da Costa et al., “Chemometrics Applied in the Development of a Water Quality Indicator System for the Brazilian Amazon,” ACS Omega, vol. 5, no. 51, pp. 32899–32906, Dec. 2020.
[4] D. Hooda and R. Rani, “An interval type-2 fuzzy ontological model: Predicting water quality from sensory data,” Concurr. Comput. Pract. Exp., vol. 34, no. 28, Dec. 2022.
[5] A. Czajkowska and Ł. Gawor, “Variabilities of Surface Water Quality of Degraded Post-mining Areas in Bytom,” Rocz. Ochr. Środowiska, vol. 23, pp. 318–331, 2021.
[6] J. Chen, D. Zhang, S. Yang, and Y. A. Nanehkaran, “Intelligent monitoring method of water quality based on image processing and RVFL-GMDH model,” IET Image Process., vol. 14, no. 17, pp. 4646–4656, Dec. 2020.
[7] V. H. Resh and P. K. Mendez, “Museum records of California Trichoptera: potentially useful information to provide larval-adult associations for improving water quality surveys,” Pan-Pac. Entomol., vol. 98, no. 4, Dec. 2022.
[8] B. Waligórski and E. Janicka, “The Influence of the Przebędowo Reservoir on the Water Quality of the Trojanka River in the First Years of its Functioning,” Rocz. Ochr. Środowiska, vol. 23, pp. 151–167, 2021.
[9] V. H. Alves Ribeiro, S. Moritz, F. Rehbach, and G. Reynoso-Meza, “A novel dynamic multi-criteria ensemble selection mechanism applied to drinking wacater quality anomaly detection,” Sci. Total Environ., vol. 749, p. 142368, Dec. 2020.
[10] O. S. Daramola, W. G. Johnson, D. L. Jordan, G. S. Chahal, and P. Devkota, “Spray water quality and herbicide performance: a review,” Weed Technol., vol. 36, no. 6, pp. 758–767, Dec. 2022.
[11] C. Matovelle, “Páramo to Pasture Conversion in a Mountain Watershed: Effects on Water Quality and Quantity,” Mt. Res. Dev., vol. 41, no. 4, Dec. 2021.
[12] M. Mokarram, A. Saber, and V. Sheykhi, “Effects of heavy metal contamination on river water quality due to release of industrial effluents,” J. Clean. Prod., vol. 277, p. 123380, Dec. 2020.

[13] S. Åkerblom, C. Zdanowicz, A. Campeau, A. L. Soerensen, and J. Hewitt, "Spatial and temporal variations in riverine mercury in the Mackenzie River Basin, Canada, from community-based water quality monitoring data," Sci. Total Environ., vol. 853, p. 158674, Dec. 2022.
[14] G. Fattah, F. Ghrissi, J. Mabrouki, and N. Al-Jadabi, "MODELING AND ASSESSMENT OF THE IMPACT OF LAND USE IN THE WESTERN RIF REGION, MOROCCO, ON WATER QUALITY," Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., vol. XLVI-4/W5-, pp. 225–230, Dec. 2021.
[15] S. Ravish, B. Setia, and S. Deswal, "Monitoring of pre- and post-monsoon groundwater quality of north-eastern Haryana region using GIS," Environ. Technol., vol. 41, no. 28, pp. 3695–3721, Dec. 2020.
[16] C. Rodero, R. Bardaji, E. Olmedo, and J. Piera, "Operational monitoring of water quality with a Do-It-Yourself modular instrument," Front. Mar. Sci., vol. 9, Dec. 2022.
[17] H. Khan, M. N. Khan, M. Sirajuddin, S. M. Salman, and M. Bilal, "Assessment of Drinking Water Quality of Different Areas in Tehsil Isa Khel, Mianwali, Punjab, Pakistan," Pakistan J. Anal. Environ. Chem., vol. 22, no. 2, pp. 376–387, Dec. 2021.
[18] J. Solakian, V. Maggioni, and A. N. Godrej, "On the Performance of Satellite-Based Precipitation Products in Simulating Streamflow and Water Quality During Hydrometeorological Extremes," Front. Environ. Sci., vol. 8, Dec. 2020.
[19] C. Yang, L. Zheng, Z. Zhang, and M. Feng, "Study on water quality simulation and dynamic water environment capacity of Helan County section of the third drainage ditch in Ningxia," Front. Ecol. Evol., vol. 10, Dec. 2022.
[20] A. Das Gupta, Z. Sadek, M. H. R. Bhuiyan, M. G. Kibria, T. R. Toha, and S. M. M. Alam, "A Low-Cost IoT Based Automatic Water Quality Monitoring System for Textile Industry," in 8th International Conference on Networking, Systems and Security, 2021, pp. 65–76.
[21] L. Tian, X. Zhu, L. Wang, P. Du, F. Peng, and Q. Pang, "Long-term trends in water quality and influence of water recharge and climate on the water quality of brackish-water lakes: A case study of Shahu Lake," J. Environ. Manage., vol. 276, p. 111290, Dec. 2020.
[22] Z. Li, Q. Yang, C. Xie, H. Wang, and Y. Wang, "Spatiotemporal characteristics of groundwater quality and health risk assessment in Jinghe River Basin, Chinese Loess Plateau," Ecotoxicol. Environ. Saf., vol. 248, p. 114278, Dec. 2022.
[23] F. Bioresita, M. H. Ummah, M. Wulansari, and N. A. Putri, "Monitoring Seawater Quality in the Kali Porong Estuary as an Area for Lapindo Mud Disposal leveraging Google Earth Engine," IOP Conf. Ser. Earth Environ. Sci., vol. 936, no. 1, p. 012011, Dec. 2021.
[24] W. Liu et al., "Characterizing the water quality and microbial communities in different zones of a recirculating aquaculture system using biofloc biofilters," Aquaculture, vol. 529, p. 735624, Dec. 2020.
[25] V. Pillay and B. Moodley, "Assessment of the impact of reforestation on soil, riparian sediment and river water quality based on polyaromatic hydrocarbon pollutants," J. Environ. Manage., vol. 324, p. 116331, Dec. 2022.
[26] Z. Yang et al., "Effect of different fish feeds on water quality and growth of crucian carp (Carassius carassius) in the presence and absence of prometryn," Ecotoxicol. Environ. Saf., vol. 227, p. 112914, Dec. 2021.
[27] D. Benchamin, R. Sreejai, and B. S. Kurup, "Effect of Water Quality on Caddisflies (Trichoptera) in Kallada River, Kerala, India," Curr. Sci., vol. 119, no. 11, p. 1845, Dec. 2020.
[28] D. M. Ferreira and C. V. S. Fernandes, "Integrated water quality modeling in a river-reservoir system to support watershed management," J. Environ. Manage., vol. 324, p. 116447, Dec. 2022.
[29] Y. Ni, N. Xie, G. Yang, and W. Chen, "Development of Water Quality Discrimination System for Water Color Image Based on LM Neural Network Optimization Algorithm," in 2021 International Conference on Aviation Safety and Information Technology, 2021, pp. 578–582.
[30] F. Esmaeilbeiki, M. R. Nikpour, V. K. Singh, O. Kisi, P. Sihag, and H. Sanikhani, "Exploring the application of soft computing techniques for spatial evaluation of groundwater quality variables," J. Clean. Prod., vol. 276, p. 124206, Dec. 2020.