Pollutant Monitoring System for Mushroom Factory Liquid Waste using Arduino with 4 Sensor Integration

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Abstract - Mushroom production in mushroom processing factories produces waste from composting, where the media used include water to maintain humidity and chemical/organic fertilizers. The water used for mushroom cultivation contains hazardous substances, which if dissolved and flow into drains, water sources, or community irrigation, can cause several problems, producing liquid pollutants. The main objective and contribution of this research is to develop and implement a liquid pollutant monitoring system in liquid waste from mushroom factories based on Arduino with the integration of four sensor parameters. The 4D method used includes the stages of definition, design, development, and implementation. development of tools in the form of prototypes that are ready for implementation in the field. The results of the feasibility analysis with 20 samples have a percentage above 80% in the good category and are suitable for use. The results of implementation in the field by taking 20 samples with a distance range of 0-150 m from the mushroom waste site, namely Temperature and pH also tend to be stable without significant changes. The pH value tends to be stable in the neutral range of 7.2–7.3, which is generally still suitable for supporting the survival of aquatic organisms. Dissolved oxygen (DO) levels in the water were generally low, ranging from 2.46 to 3.01 mg/L, which is already below the standard for good water quality (generally >5 mg/L). Meanwhile, turbidity parameters indicated the presence of pollution, characterized by very high turbidity reaching 300 NTU. Then showed a drastic decrease from very high conditions at the beginning (300 NTU) to near zero after a longer distance, indicating an effective natural sedimentation process in improving water clarity.

Keywords — Liquid Pollutant, Pollutant Monitoring System, Arduino UNO, Mushroom Factory, 4 Parameter Sensors.

I. Introduction

Mushroom production carried out by industries, both large and small scale, usually uses Sengon wood sawdust as a growing medium. Sawdust is one of the substrates that meets the nutritional needs of mushrooms, one of which is sengon wood sawdust [1]. Agricultural waste that can be used as a substrate for growing button mushrooms includes corn cobs, bagasse, and straw [2]. Button mushrooms are made by composting corn cobs, bagasse, and straw. Composting begins by breaking down the organic material and then watering it with water, followed by sterilization and inoculation, [3]. During composting, microorganisms such as bacteria and fungi decompose the organic matter in the compost [4]. The decomposition process produces various organic and inorganic compounds from chemical fertilizers, including strong-smelling gases such as ammonia, sulfur, and organic acids [5]. In addition, the process also releases dyes and solid particles into the water. The accumulation of these compounds causes the water used for irrigation to turn into cloudy and highly pungent waste, which can pollute the surrounding environment if not managed properly.

Based on a review of several previous studies, it can be seen that the development of wastewater monitoring systems has been quite extensive, but each study still has certain limitations. The study conducted in system monitoring waste water only used pH and temperature sensors to design a control and monitoring prototype for wastewater processed into biogas [6]. The focus of the study was directed more towards palm oil industry wastewater, thus not addressing other aspects such as dissolved oxygen levels and turbidity levels. This resulted in the resulting information being less comprehensive in describing the overall quality of the wastewater. Another study analyzed the quality of hospital wastewater in the Brang Biji River, Sumbawa, using parameters such as temperature, pH, TDS, and TSS. This research yielded a picture of the water quality, but did not yet provide a technological solution in the form of a monitoring device [7]. Further research is underway on the development of a website-based wastewater monitoring system for the palm oil industry. This research is quite innovative, integrating it with an online system. However, the parameters used are still limited to turbidity and pH sensors, as well as palm oil wastewater sensors [8]. Further research conducted in the tofu industry in Purbalingga resulted in an Internet of Things (IoT)-based prototype with turbidity, pH, and temperature sensors [9]. This research utilized IoT technology to facilitate remote monitoring, but still left limitations in terms of measurement parameters. One major weakness was the lack of a dissolved oxygen (DO) sensor, even though this parameter is crucial for measuring the impact of liquid waste on the environment.

The research gap identified in the review above, as the main contribution of this study, lies in the development of a Pollutant Monitoring System specifically designed for mushroom factory wastewater. This study presents a more comprehensive approach by integrating four key sensors: DS18B20 temperature, pH, dissolved oxygen (DO), and turbidity. This combination of sensors enables the system to generate more comprehensive waste quality data, thus providing a complete picture of the potential environmental pollution. The combination of these parameters allows the system to provide more comprehensive information on wastewater conditions, particularly in the context of the understudied mushroom industry [10].

B. Design

After determining the objectives and the prototype/tool to be built, the prototype/tool design stage is carried out. The sensors, microcontroller, and other tool components are determined to ensure efficiency and effectiveness during use. Next, the circuit schematic is designed, as shown in Fig. 2 below.

Figure 2 shows a circuit simulation of the application to adjust the tools and programming language to be used. These adjustments include four sensors: oxygen, turbidity, temperature, and pH meters.

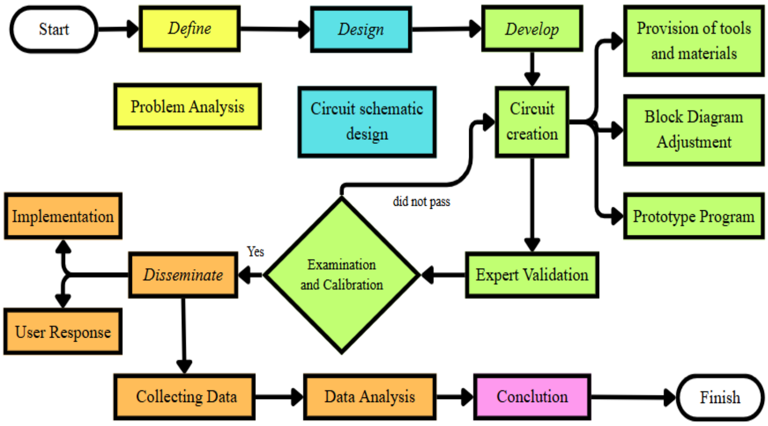

Figure 1. Research Stages

II. Research Method

The research method uses research and development with Thiagarajan's 4D stages [16], namely define, design, development, & disseminate, which are modified according to needs as in Fig. 1.

A. Define Stages

The process of analyzing the problem is that in, Paguyangan District, there is a mushroom factory whose liquid waste sometimes flows into the waterways. Research has investigated the negative impacts of mushroom waste pollutants, which are very dangerous if they flow into fields, are ingested by livestock, or reach residential areas [11]. An analysis of local residents' needs, based on observations, revealed that they lack knowledge and understanding of the impacts of this waste. After obtaining information on the negative impacts of mushroom waste pollutants, the next step was to determine several components that can detect pollutants in mushroom waste. This will allow for a more structured tool design based on the theoretical foundation presented.

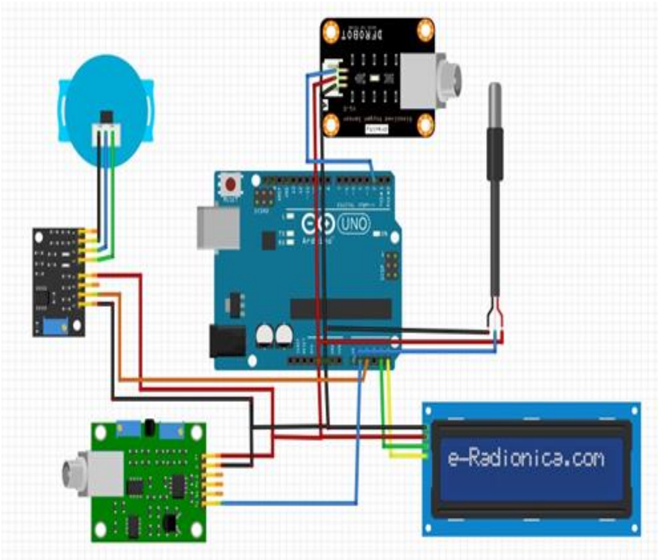

Figure 2. Wiring Diagram

C. Develop

The development process is carried out by fulfilling the tools and materials in making prototypes/tools. The main tools and materials needed are according to their function according to the following table 1.

Table 1. Experimental equipment and materials requirements

Sensor	Specification	Function
Dissolved Oxygen Sensor	Dissolved oxygen (DO) measurement range 0-20 mg/L and saturation - 100% Input voltage; 5v-12v [12]	To measure the concentration of dissolved oxygen in water
Turbidity Sensor	Measurement range: 0-400 NTU Input voltage: 5V-12V (20V) [13]	To measure the turbidity level of water
DS18B20 Temperature Sensor	Measurement Range: 55°C - +125°C Accuracy: ±0.5°C From -10°C to +125°C Voltage Input: Internal [14]	To measure the temperature of water
pH Meter	Range; 0-14 pH Accuracy; ± 0.1 pH Voltage; 5v-12v [15]	To determine the degree of acidity
Arduino	Uno; Input voltage 3v-12v	Microcontroller
LCD	I2C 16X2Inpt voltage; 3v-12v	As an indicator / output

Then adjust the block diagram for development and programming needs in the Arduino IDE.

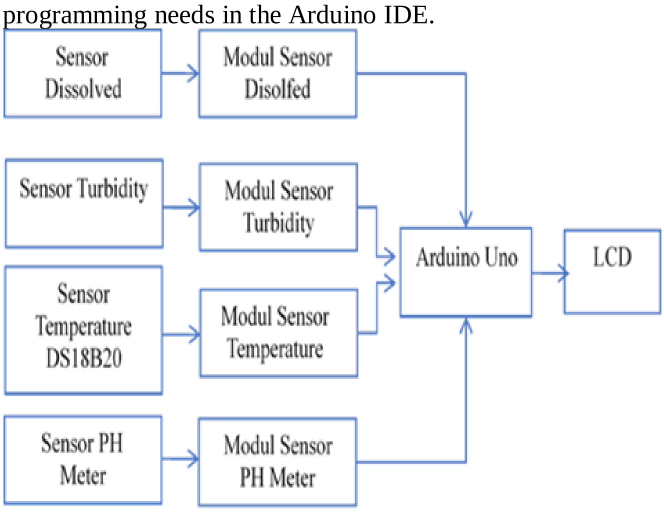

Figure 3. Block Diagram

As shown in Fig. 3 above, the installed sensors will operate according to their respective specifications. They will detect the contents of the mushroom processing plant waste and convert the input into a digital signal that is directly connected to the Arduino. The digital data received by the Arduino will then be processed into data displayed on the LCD screen.

D. Disseminate

After the development phase reaches testing, the prototype/tool is packaged in a compatible manner for implementation. The prototype is then disseminated to the Paguyangan District community using the following process. The first test was carried out on a laboratory scale by taking 20 samples from the same water source and then comparing them with a standardized measuring instrument. Then, 20 samples were taken in the field starting from the waste storage tank to the drainage channel as far as 150 m. Providing a response questionnaire to the Paguyangan District community regarding the usefulness/feasibility of the prototype or tool being developed and providing input regarding research development activities.

Field data collection location at PT Jamur Etira, Pandansari Village, Paguyangan District, Brebes Regency, Central Java.

E. Data Analysis Methods

Expert validation and community response using data collection methods through assessment questionnaires with a Likert scale of 1-5 (5 = Very Good, 4 = Good, 3 = Fair, 2 = Average, & 1 = Poor). The assessment criteria are: Utility, Beneficial for the environment and society, Ease of use, Practicality of the product, Reliability, Interesting features, Accuracy, and Durability [16]. Next, it is analyzed according to Eq. (1) [17].

$$\%N = \frac{\sum Assessment\ Score}{\sum Maximum\ score} \times 100\% \quad (1)$$

Next, component testing analysis and application of measuring tools are carried out through accuracy/error value analysis. To obtain a suitable prototype, namely having a small error value or high accuracy through Eq. (2) and Eq. (3) below .

$$\%Error = \frac{Measurement\ Result - Calibration\ Value}{Calibration\ Value} \times 100\% \quad (2)$$

$$\%Accuracy = 100\% - \%Error \quad (3)$$

This is further strengthened by RMSE (Root Mean Square Error) and MAE (Mean Absolute Error) analysis used to measure the extent of the error between the tool's results and the reference value (ground truth).

$$MAE = \frac{\sum(measure\ results - reference\ value)}{n} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum(measure\ results - reference\ value)^2}{n}} \quad (5)$$

Followed by data analysis, standard deviation is used to assess the consistency or stability of the measurement results, through how wide the spread of the data is regarding the average value. Standard deviation measurement with SPSS software

III. Results and Discussion

A. Feasibility Analysis by Experts

The Arduino-based Pollutant Monitoring System for mushroom factory wastewater uses four integrated sensors. The sensors used are the DS18B20 temperature sensor, pH sensor, dissolved oxygen (DO) sensor, and turbidity sensor, each of which serves as an indicator for determining water conditions. The following is the result of the development of the Pollutant Monitoring System for mushroom factory wastewater, shown in Fig. 4.

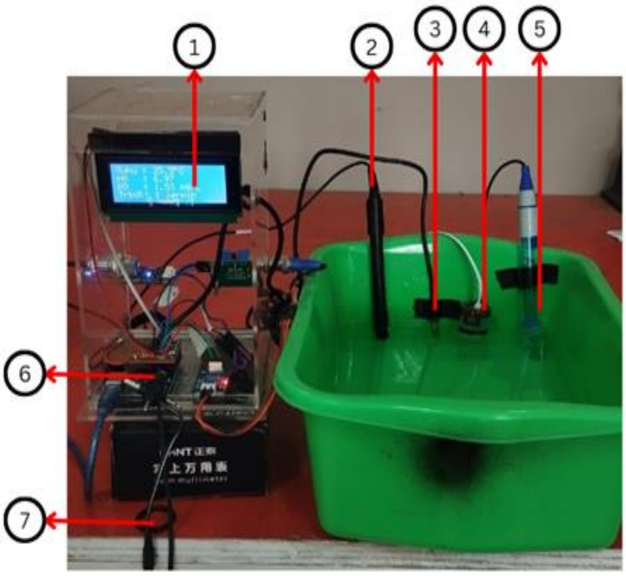

Figure 4. Pollutan Monitoring System

According to Fig 4, the components are (1) LCD, (2) pH meter sensor, (3) DS18B20 temperature sensor, (4) turbidity sensor, (5) dissolved oxygen (DO) sensor, (6) Arduino Uno, and (7) power supply. In the development process, expert validation was carried out by ensuring that the tool used was suitable for use according to the needs according to the experts. There were two microcontroller and microprocessor experts who were asked to provide validation on the tool. The following is an analysis of the results of expert validation in table 2.

Table 2. Expert Validation Results Analysis

Assessment Aspects	Expert Validation 1			Expert Validation 2		
	Score	%	Category	Score	%	Category
Utility	5	100%	Very good	5	100%	Very good
Beneficial for the environment and society	5	100%	Very good	5	100%	Very good
Ease of use	4	80%	Good	4	80%	Good
Practicality of the product	4	80%	Good	4	80%	Good
Reliability	3	60%	Fair	4	80%	Good
Interesting Feature	4	80%	Good	4	80%	Good
Accuracy	5	100%	Very good	5	100%	Very good
Durability	3	60%	Good Enough	3	60%	Good Enough
$\bar{X}$	4,14	80%	Very good	4,29	83%	Very good

In accordance with table 2, the overall average validation from experts 1 and 2 was obtained at a percentage of 80% and 83%, meaning in the "very good" criteria, indicating that the developed tool is suitable for use/valid. With aspects of usability, benefits for the environment and society, and accuracy obtaining a maximum score with a percentage of 100% from both experts, the criteria are "Very Good". This shows that the developed tool is considered truly useful, on target, and able to provide accurate measurement results. In the aspect of ease of use and practicality, both experts gave a percentage of 80% with the criteria of "Good". The assessment shows that the tool is easy to use and quite practical in its operation, although the experts noted that it could still be improved in terms of interface or system integration. The reliability aspect received varying scores, namely 60% in the “Fair” criteria from the first expert and 80% in the “Good” criteria from the second expert. The difference is due to the experts' notes that the tool has not been implemented for a long period of time, meaning there is still room for improvement, especially in the consistency of the tool's performance when used over a long period. The attractive features aspect received a score of 80% in the “Good” criteria from both experts, indicating that the tool already has relevant and useful features. The durability aspect received a score of 60% in the “Fair” category from both experts. According to expert suggestions, the material and design of the device still need to be improved so that it can be used longer, especially in conditions where the liquid waste environment tends to be extreme.

Validation with a score above 80% indicates that the instrument has met academic and practical feasibility standards. Previous research also confirmed that well-validated sensor-based devices can improve the reliability of pollutant detection and minimize potential measurement bias, [18]. The reliability of this system is highly dependent on the initial validation process, as accurate results can only be obtained from valid instruments, [19]. Another study showed that an integrated multi-sensor system is able to provide more comprehensive real-time data in monitoring water and air quality, which ultimately improves the quality of decision-making in environmental management [20]. With a “very good” validation result, the developed system can be positioned as a scientific instrument capable of providing quality data to support the sustainability of mushroom factory liquid waste processing.

B. Measurement Accuracy Testing

Each sensor was then tested using standard measuring instruments to ensure it performed according to its intended characteristics. The following table 3 shows the results of the sensor tests using water taken from the source.

Table 3. Laboratory scale accuracy test analysis results

No	Temp. Sensor (°C)	Measuring instrument (°C)	Error	pH Sensor	Measuring instrument	Error	DO Sensor (mg/L)	Measuring instrument (mg/L)	Error	Turbidity Sensor (NTU)	Measuring instrument (NTU)	Error
1	25,6	25	0,024	6,97	6,56	0,063	1,48	1,27	0,17	1	0,98	0,02
2	25,6	25	0,024	6,89	6,56	0,050	0,66	0,57	0,16	1	0,98	0,02
3	25,6	25	0,024	6,97	6,56	0,063	1,48	1,29	0,15	1	0,89	0,12
4	25,6	25	0,024	6,97	6,56	0,063	3,22	2,58	0,25	1	1	0,00
5	25,6	25	0,024	6,97	6,56	0,063	1,48	1,23	0,20	1	0,9	0,11
6	25,6	25	0,024	6,93	6,56	0,056	1,58	1,29	0,22	1	0,99	0,01
7	25,6	25	0,024	6,97	6,56	0,063	1,42	1,27	0,12	1	0,9	0,11
8	25,6	25	0,024	6,97	6,56	0,063	0,11	0,1	0,10	1	1	0,00
9	25,6	25	0,024	6,97	6,56	0,063	1,37	1,27	0,08	1	1	0,00
10	25,6	25	0,024	6,97	6,56	0,063	1,37	1,27	0,08	1	1	0,00
11	25,6	25	0,024	6,93	6,56	0,056	0,55	0,54	0,02	1	1	0,00
12	25,6	25	0,024	6,97	6,56	0,063	1,48	1,27	0,17	1	1	0,00
13	25,6	25	0,024	6,97	6,56	0,063	3,61	3,58	0,01	1	0,89	0,12
14	25,6	25	0,024	6,97	6,56	0,063	1,53	1,23	0,24	1	0,9	0,11
15	25,6	25	0,024	6,97	6,56	0,063	1,53	1,29	0,19	1	0,97	0,03
16	25,6	25	0,024	6,93	6,56	0,056	1,64	1,27	0,29	1	0,98	0,02
17	25,6	25	0,024	6,97	6,56	0,063	0,55	0,54	0,02	1	0,89	0,12
18	25,6	25	0,024	6,97	6,56	0,063	1,42	1,23	0,15	1	0,9	0,11
19	25,6	25	0,024	6,97	6,56	0,063	1,45	1,29	0,12	1	1	0,00
20	25,6	25	0,024	6,97	6,56	0,063	1,97	1,27	0,55	1	1	0,00
$\bar{X}$	25,6	25	0,024	6,96	6,56	0,061	1,50	1,28	0,16	1	0,96	0,05

Based on Table 3, it shows the results of sensor testing on water source samples from one point with a measuring instrument that was repeated 20 times for data collection to determine the error value of each sensor. In the DS18B20 temperature sensor compared with a thermometer measuring instrument, the average error value is 0,024 or if expressed as a percentage, it becomes 2,4%, meaning that the error interpretation is <10% or a very good/very accurate sensor in measuring temperature. The pH meter sensor compared with the SNI pH Meter measuring instrument obtained an average error value of 0,061 or if expressed as a percentage, it becomes 6.1%, meaning that the error interpretation is <10% or a very good/very accurate sensor in measuring pH.

Table 4. MAE and RMSE Analysis Results

	Temp. Sensor	pH Sensor	DO Sensor	Turbidity Sensor
MAE	0,6	0,4	0,213	0,042
RMSE	0,6	0,401	0,2800	0,062

The analysis results showed that all sensors had a good level of accuracy with relatively low error values, where the turbidity sensor provided the best performance (MAE 0,042; RMSE 0,062), followed by the DO sensor (MAE 0,213; RMSE 0,280) which indicated a slight variation in measurements. The pH sensor showed high consistency because the MAE and RMSE values were almost the same (0,4 and 0,401), while the temperature sensor had the largest error (MAE and RMSE 0,6) but remained stable without any indication of significant outliers. Overall, the sensor system was considered quite reliable and consistent for monitoring mushroom factory waste.

Table 5. Analysis Statistic

Statistics		Temperature	pH	DO	Turbidity
N	Valid	20	20	20	20
	Missing	0	0	0	0
Std. Deviation		0,00000	0,02200	.79974	0,00000
Variance		0,000	0,000	0,640	0,000

Table 5 shows the analysis using SPSS. The standard deviation value for the temperature and turbidity sensors shows 0,000, which indicates no variation or fluctuation in data during the measurement, so that the readings of both sensors are very stable. The pH sensor has a standard deviation of 0,022 with a variance close to zero, which indicates a small variation but is still within reasonable limits and reflects good measurement stability. Meanwhile, the DO sensor shows a higher standard deviation of 0,799 with a variance of 0,640, which indicates a greater variation in data compared to other sensors. This may be caused by the sensitivity of the DO sensor to changes in environmental conditions such as temperature, solute content, and water flow dynamics. Overall, these results indicate that most sensors have a high level of consistency, although the DO sensor requires more attention in terms of measurement stability under field conditions.

The results of the error value analysis shown from the sensor testing indicate that the designed tool has been able to work according to the expected function. The trial process carried out on a laboratory scale has provided consistent results, so that the tool can be declared to have successfully passed the verification stage and is suitable for use in mushroom factory liquid waste media. Thus, this system not only functions as a laboratory test medium, but is also ready to be applied directly to monitor liquid waste in real-time. The success of this tool's accuracy measurement proves that the design of integrating four sensors with Arduino Uno.

C. Data Analysis of Mushroom Factory Liquid Waste Pollutants

The analysis results from direct measurements at the mushroom factory site, with data collection from the factory's waste reservoir to the disposal site, 150 meters from the reservoir. The following graph displays data from each sensor based on the distance from the waste reservoir to 150 m from the reservoir.

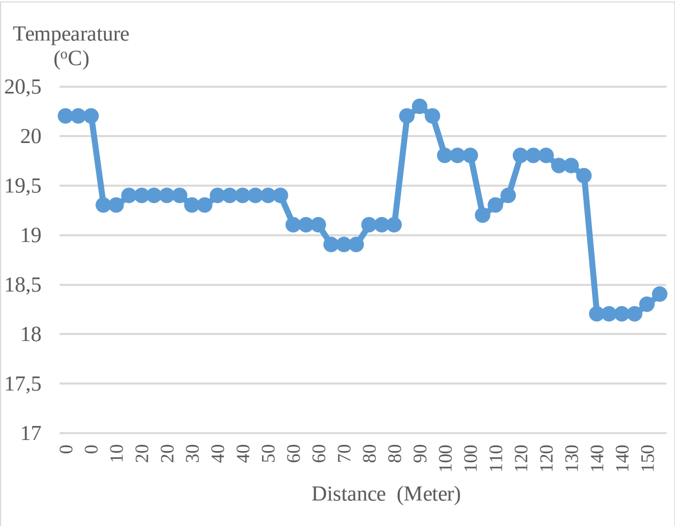

Figure 5. Temperature sensor data from the waste storage tank up to 150 meter

According to Fig. 5 , the initial graph at a distance of 0 meters or in the mushroom waste storage tank, the temperature is around 20.2 °C, then at about 10 m it immediately drops to 19.3 °C. After that, the temperature is relatively stable in the range of ± 19.3–19.4 °C until about a distance of 60 m. At around 60–80 m there is a further decrease to 18.9–19.0 °C, then the temperature rises again to approach 20–20.5 °C at around 90–100 m. After that there is a slight fluctuation, then at a distance of more than 130 m the temperature drops sharply to 18.2 °C and then rises slightly again to approach 18.4 °C. Based on the graph above, it shows that the temperature data from the storage tank to a distance of 150 meters is recorded in the range of 18–20.5 °C. These conditions are quite good for water as a medium for plants and living creatures, although slightly cooler than optimal for tropical fish, but very friendly for hydroponics and cold water organisms [21], [22].

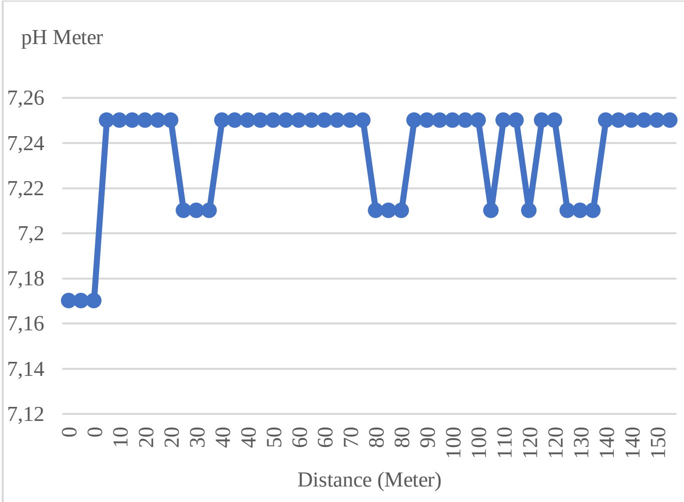

Figure 6. Water pH meter sensor data from the waste storage tank up to 150 meter

Fig. 6 shows the results of pH measurements on a graph indicating that water quality is in a relatively stable range, namely between 7.16 and 7.25. Fluctuations that occur throughout the measurement range are not too significant, only around ±0.09, which indicates that the water system has a fairly good buffer capacity.

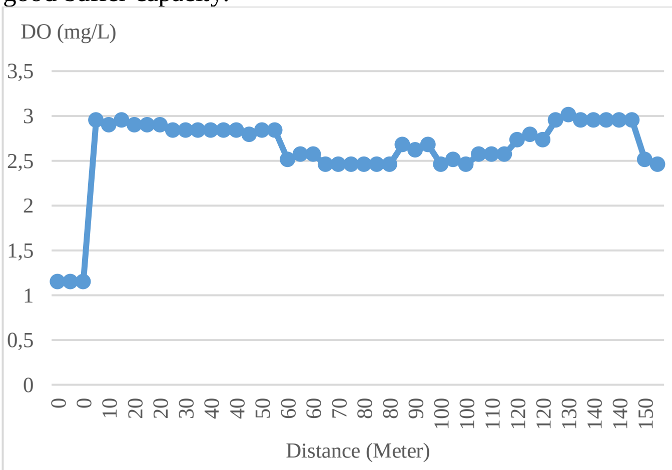

Figure 7. Dissolved oxygen sensor data from the waste storage tank up to 150 meter

Fig.7 Dissolved oxygen (DO) levels show a fairly varied pattern with values ranging from 1.1 to 3.0 mg/L from the mushroom factory waste storage tank to 150 meters. After the starting point of the factory's wastewater reservoir, there was a sharp spike, reaching 3.0 mg/L at a distance of 10–20 meters. The DO value then remained relatively stable at 2.8–3.0 mg/L for a distance of approximately 50 meters, before gradually decreasing to 2.4–2.6 mg/L between 60–100 meters. At a distance of 120–140 meters, the DO level rose again, approaching 3.0 mg/L.

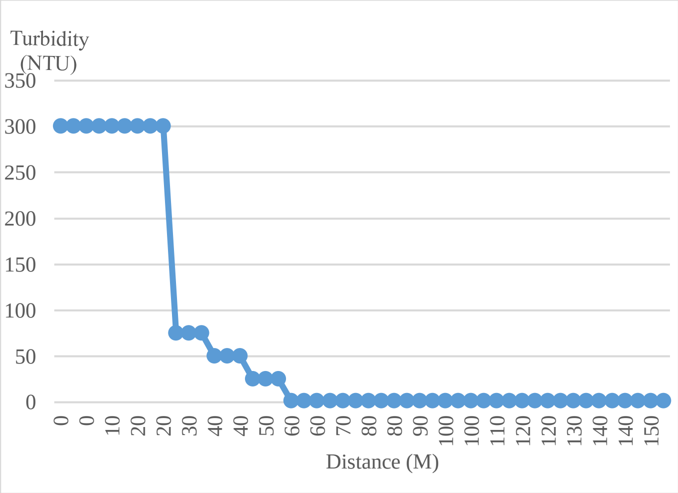

Figure 8. Turbidity sensor data from the waste storage tank up to 150 meter

Fig. 8 shows the change in water turbidity (NTU) over a distance of 0–150 meters. From the initial point up to a distance of approximately 20 meters, turbidity was recorded as very high, stable at around 300 NTU. After 20 meters, turbidity decreased drastically to around 70–80 NTU. At a distance of 60–150 meters, turbidity continued to decrease gradually to around 20–40 NTU, before finally reaching a point near 0 NTU after 60 meters until the end of the measurement at 150 meters. Data collection was carried out directly at the mushroom factory location with the data collection process from the factory waste storage tank to the disposal site, which is 150 meters from the storage tank, as shown Fig 9.

(a) Liquid waste storage tank 0 M (300 NTU)

(b) Distance 20 M (300 NTU)

(c) Distance 70 M (1 NTU)

(d) Distance 100 M (1 NTU)

(e) Distance 130 M (1 NTU)

(f) Distance 150 M (1 NTU)

Figure 9. Data collection from the liquid waste storage tank up to a distance of 150 m to the flow to the sewer/outside drain

Fig.9 shows data collection in the field taken at a single point, where 3 data were collected: temperature, soil pH, dissolved oxygen, and turbidity. The following graph shows the temperature data collected at several variations of data collection from the reservoir to 150 meters. Temperature sensor data according to Fig. 5 shows fluctuating temperature changes due to several factors from environmental conditions such as sunlight, vegetation, strong water flow and soil/water humidity. For example, at a distance of 0 meters (in the reservoir) and at a distance of 90-100 meters from the reservoir, the temperature can reach ±20.2 °C, due to direct sunlight hitting the water in the reservoir and gutter, or there is no vegetation [23]. A sharp decrease above 130 m indicates a significant environmental change, perhaps the sensor is in a condition where there is vegetation, it is more humid, more shaded, or there is a cold air flow [24].

The results of pH measurements on the Fig. 6 show that the water quality is in a relatively stable range namely between 7.16 to 7.25. Fluctuations that occur along the measurement distance are not too significant, only around ±0.09, which indicates that the water system has a fairly good buffer capacity. The graph shows the water pH between 7.16 to 7.25 with this smooth fluctuation is a fairly neutral and relatively stable condition, this value is in a safe zone for many aquatic organisms and plants (general ideal range 6.5–8.0) [25]. However, the soil pH taken in the mushroom factory waste reservoir shows 7.17 lower than data taken at other distances, meaning there is a decrease in pH due to mushroom waste. If not handled, there can be a decrease or increase in water pH that is too acidic (pH <6.5) can increase heavy metal toxicity, while water that is too alkaline (pH> 8.5) can disrupt nutrient availability and physiological balance of organisms [26].

Fig. 7 Dissolved oxygen (DO) levels show a fairly varied pattern with a range of values between 1.1 and 3.0 mg/L from the mushroom factory waste reservoir to 150 meters. At the beginning of the measurement, the DO value was around 1.1 mg/L, a figure that is considered very low and indicates water conditions with limited oxygen supply. This is due to the exact location of the mushroom factory waste reservoir, coupled with minimal water movement, high oxygen consumption by microorganisms in the process of decomposing organic matter, or the presence of sediment rich in organic matter [19, 20].

After the starting point from the factory liquid waste reservoir, there was a sharp increase to 3.0 mg/L at a distance of 10–20 meters. This increase can be associated with increased natural aeration, for example due to more open water flow or the photosynthesis process of aquatic plants and phytoplankton that produce oxygen into the water column [27]. The DO value then remained relatively stable at 2.8–3.0 mg/L up to a distance of approximately 50 meters, before gradually decreasing to 2.4–2.6 mg/L between 60–100 meters. This fluctuation indicates a balance between oxygen production through photosynthesis and oxygen consumption due to organism respiration and decomposition processes [28]. At a distance of 120–140 meters, the DO increased again to nearly 3.0 mg/L, likely influenced by the interaction of the water with the atmosphere and photosynthetic activity in the area. However, it decreased again at the end point of the measurement (150 meters) to 2.5 mg/L, indicating that the dynamics of the aquatic environment are still fluctuating. Dissolved oxygen (DO) levels in the range of 1.1 to 3.0 mg/L indicate that the dissolved oxygen conditions in the studied waters tend to be low and potentially stressful for aquatic organisms. When compared to water quality standards, the DO levels measured in this graph are still below the optimal threshold for aquatic life. Most aquatic organisms, especially fish and invertebrates, require a minimum DO level of 5 mg/L to survive normally [29].

Fig 8 shows the change in water turbidity (NTU) along a distance of 0–150 meters. From the starting point to a distance of approximately 20 meters, turbidity was recorded as very high, stable at around 300 NTU. At this distance, mushroom factory waste affects the turbidity from the reservoir to the drain at a distance of 20 meters. This value indicates turbid water conditions with very high concentrations of suspended particles, which generally originate from sediment, organic material, or waste carried by the flow [30]. After the 20 meters point, there was a drastic decrease in turbidity to reach around 70–80 NTU. This phenomenon indicates a natural sedimentation process of suspended particles along the flow. Water flowing further tends to lose most of the solid particles because gravity causes sediment to settle to the bottom of the water [31]. At a distance of 60–150 meters, turbidity continues to decrease gradually to around 20–40 NTU, before finally reaching a point approaching 1 NTU after 60 meters until the end of the measurement at 150 meters. This condition indicates that almost all suspended particles have completely settled, resulting in clear water. This pattern is common in rivers or artificial channels, where turbulence decreases with distance, allowing for optimal sedimentation [32], [33].

The analysis of the four water quality parameters shows that the observed aquatic system experienced significant changes along the measurement path. Temperature and pH also tended to remain stable without significant changes. The pH value tended to remain stable in the neutral range of 7.2–7.3, which is generally still suitable for supporting the survival of aquatic organisms. Dissolved oxygen (DO) levels in the water were generally low, ranging from 2.46 to 3.01 mg/L, which is below the standard for good water quality (generally >5 mg/L). Meanwhile, turbidity parameters indicated pollution, characterized by very high turbidity reaching 300 NTU. This then showed a drastic decrease from the initial very high 300 NTU to near zero after further distance, indicating an effective natural sedimentation process in improving water clarity

IV. Conclusions and Suggestions

A. Conclusions

1. The development results reviewed from the feasibility obtained an average overall validation from experts 1 and 2 at a percentage of 80% and 83% meaning in the criteria of "very good", indicating that the developed is suitable for use/valid.
2. Laboratory-scale sensor testing was carried out through a comparison of measuring instruments obtained from the four sensors (temperature sensor, pH meter sensor, DO sensor, and turbidity sensor) the average accuracy value is >80% in the good category.
3. The results of monitoring liquid waste from the mushroom factory, namely temperature and pH, also tend to be stable without significant changes. The pH value tends to be stable in the neutral range of 7.2–7.3, which is generally still suitable to support the survival of aquatic organisms. The dissolved oxygen (DO) levels in water are generally low, in the range of 2.46 to 3.01 mg/L, which is already below the standard for good water quality (generally >5 mg/L). Meanwhile, the turbidity parameter indicates pollution, marked by very high turbidity reaching 300 NTU. Then it shows a drastic decrease from very high conditions at the beginning of 300 NTU to approaching zero after further distance, indicating an effective natural sedimentation process in improving water clarity.
4. The limitation of the research is that the device is not integrated with the Internet of Things so that the data log is not recorded by the system. Then the power supply system is still based on a power bank so it is not good in terms of sustainable energy supply.

B. Suggestions

1. In the future, research can be expanded with additional sensors, such as heavy metal sensors and sensors for other toxic substances that can impact the environment and health.
2. Furthermore, it can be integrated with IoT and control systems in waste processing, not just in mushroom factories.

V. Acknowledgments

The authors would like to express sincere gratitude to the **Ministry of Higher Education, Science, and Technology** (**KEMDIKTISAINTEK**), **Universitas Bhamada Slawi, Universitas Peradaban**, and all parties who supported the success of this research for the invaluable support and resources provided throughout this research. This research would not have been possible without the **assistance of research grants from the Ministry of Education, Science, and Technology**, facilities, academic environment infrastructure, and encouragement from each university. This commitment is part of the contribution to developing microcontrollers and monitoring systems for waste processing.

VI. Reference

[1] Y. K. Leong, T. W. Ma, J. S. Chang, and F. C. Yang, "Recent advances and future directions on the valorization of spent mushroom substrate (SMS): A review," 2022. doi: 10.1016/j.biortech.2021.126157.

[2] Y. Geng *et al.*, "Optimization of Manure-Based Substrate Preparation to Reduce Nutrients Losses and Improve Quality for Growth of Agaricus bisporus," *Agriculture (Switzerland)*, vol. 14, no. 10, 2024, doi: 10.3390/agriculture14101833.

[3] F. Zhou, M. Hansen, T. J. Hobley, and P. R. Jensen, "Valorization of Green Biomass: Alfalfa Pulp as a Substrate for Oyster Mushroom Cultivation," *Foods*, vol. 11, no. 16, 2022, doi: 10.3390/foods11162519.

[4] A. Ghafoor and A. R. Niazi, "Mycelial Growth, Basidiocarp Production and Mineral Analysis of the Edible Lentinus squarrosulus (Agaricomycetes) from the Subtropical Part of Pakistan," *Int. J. Med. Mushrooms*, vol. 24, no. 12, 2022, doi: 10.1615/IntJMedMushrooms.2022045465.

[5] X. Liu, Z. Y. Zhou, J. L. Cui, M. L. Wang, and J. H. Wang, "Biotransformation ability of endophytic fungi: from species evolution to industrial applications," 2021. doi: 10.1007/s00253-021-11554-x.

[6] R. Chang *et al.*, "Assessment Impacts of Ozone on Salmonella Typhimurium and Escherichia coli O157:H7 in Liquid Dairy Waste," *Applied Sciences (Switzerland)*, vol. 12, no. 13, 2022, doi: 10.3390/app12136527.

[7] F. Azizoğlu and E. Ünsal, "Missing IoT Data Prediction with Machine Learning Techniques," *El-Cezeri Journal of Science and Engineering*, vol. 9, no. 4, 2022, doi: 10.31202/ecjse.1135485.

[8] Y. Rahayu, J. Wijaya, E. Safrianti, Feranita, S. Nasution, and Suwitno, "Design and development of a website-based palm oil industry liquid waste monitoring system," in *Journal of Physics: Conference Series*, 2021. doi: 10.1088/1742-6596/2049/1/012085.

[9] G. F. Arafat, A. Wijayanto, and N. A. Prasetyo, "Rancang Bangun Sistem Monitoring Pengolahan Limbah Cair Tahu Di Kabupaten Purbalingga Berbasis Internet of Things," *JURNAL MEDIA INFORMATIKA BUDIDARMA*, vol. 6, no. 3, 2022, doi: 10.30865/mib.v6i3.3863.

[10] M. Eriyadi, D. Notosudjono, H. Setiana, and M. A. A. A. Yakin, "Low-cost mobile air quality monitoring based on internet of things for factory area," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 32, no. 1, 2023, doi: 10.11591/ijeecs.v32.i1.pp545-554.

[11] A. M. L. Lee, C. F. S. Chin, J. S. S. Seelan, F. Y. Chye, H. H. Lee, and M. R. M. Rakib, "Metabolites profiling of protein enriched oyster mushroom (Pleurotus ostreatus (Jacq.) P. Kumm.) grown on oil palm empty fruit bunch substrate," *LWT*, vol. 181, 2023, doi: 10.1016/j.lwt.2023.114731.

[12] Y. Zhao, H. Zhang, Q. Jin, D. Jia, and T. Liu, "Ratiometric Optical Fiber Dissolved Oxygen Sensor Based on Fluorescence Quenching Principle," *Sensors*, vol. 22, no. 13, 2022, doi: 10.3390/s22134811.

[13] Y. Wang, S. M. S. M. Rajib, C. Collins, and B. Grieve, "Low-Cost Turbidity Sensor for Low-Power Wireless Monitoring of Fresh-Water Courses," *IEEE Sens. J.*, vol. 18, no. 11, 2018, doi: 10.1109/JSEN.2018.2826778.

[14] V. M. Patil1, "LIQUID TEMPERATURE MEASUREMENT USING ARDUINO," *International Scientific Journal of Engineering and Management*, vol. 03, no. 03, 2024, doi: 10.55041/isjem01448.

[15] L. Manjakkal, D. Szwagierczak, and R. Dahiya, "Metal oxides based electrochemical pH sensors: Current progress and future perspectives," 2020. doi: 10.1016/j.pmatsci.2019.100635.

[16] N. Fauziah and S. Ningsyih, "Eligibility of Thematic Student Worksheets Based Ethnoscience on Single Substance and Mixed Substance Materials for Elementary School," *Asian Journal of Science Education*, vol. 4, no. 2, 2022, doi: 10.24815/ajse.v4i2.28267.

[17] H. Hamzah, M. M, and H. Hasrul, "PENGEMBANGAN ALAT UKUR SUHU MENGGUNAKAN SENSOR LM35 BERBASIS ARDUINO UNO SEBAGAI MEDIA PEMBELAJARAN FISIKA," *PHYDAGOGIC Jurnal Fisika dan Pembelajarannya*, vol. 4, no. 1, 2021, doi: 10.31605/phy.v4i1.1357.

[18] S. Salehin, T. A. Meem, A. J. Islam, and N. Al Islam, "Design and Development of a Low-cost IoT-Based Water Quality Monitoring System," in *Lecture Notes in Electrical Engineering*, 2023. doi: 10.1007/978-981-19-8032-9_51.

[19] B. Yamini, M. Arthy, S. G. Priya, S. Kathiresan, J. Jeneetha Jebanazer, and G. S. Uthayakumar, "Investigation of Environmental Monitoring Based on Three IoT Wireless Sensors," in *Proceedings of the 2023 2nd International Conference on Augmented Intelligence and Sustainable Systems, ICAISS 2023*, 2023. doi: 10.1109/ICAISS58487.2023.10250596.

[20] P. M. Dinesh, K. S. Sapnaa, A. J. Kiranisha, R. S. Sabeenian, M. E. Paramasivam, and A. Manjunathan, "IOT Based Real Time River Water Quality

Monitoring and Control System," in *E3S Web of Conferences*, 2023. doi: 10.1051/e3sconf/202339904013.

[21] S. Muslimin, Y. Wijanarko, and N. A. Z. Bibrosi, "Real-time Fishpond Water Temperature Monitoring with Internet of Things (IoT) Technology," *Jurnal Teknologi Informasi dan Pendidikan*, vol. 17, no. 2, 2024, doi: 10.24036/jtip.v17i2.824.

[22] H. Volkoff and I. Rønnestad, "Effects of temperature on feeding and digestive processes in fish," 2020. doi: 10.1080/23328940.2020.1765950.

[23] M. Tagle *et al.*, "Field performance of a low-cost sensor in the monitoring of particulate matter in Santiago, Chile," *Environ. Monit. Assess.*, vol. 192, no. 3, 2020, doi: 10.1007/s10661-020-8118-4.

[24] S. S. U. H. Kazmi, Y. Y. L. Wang, Y. E. Cai, and Z. Wang, "Temperature effects in single or combined with chemicals to the aquatic organisms: An overview of thermo-chemical stress," *Ecol. Indic.*, vol. 143, 2022, doi: 10.1016/j.ecolind.2022.109354.

[25] Y. T. Chu, Y. Bao, J. Y. Huang, H. J. Kim, and P. B. Brown, "Supplemental C Addressed the pH Conundrum in Sustainable Marine Aquaponic Food Production Systems," *Foods*, vol. 12, no. 1, 2023, doi: 10.3390/foods12010069.

[26] A. Fadli, "Analysis of Clean Water Quality in the Work Area of the North Seribu Islands Health Center Based on the Regulation of the Minister of Health," *Dohara Publisher Open Access Journal*, vol. 32, no. 5, 2021.

[27] G. M. Ashley, C. B. de Wet, L. M. Houser, and J. S. Delaney, "Widespread freshwater carbonate in the Olduvai Basin, a precursor to a major eruption in the East African Rift System," *Depositional Record*, vol. 6, no. 2, 2020, doi: 10.1002/dep2.105.

[28] C. D. Querdibitty, J. Campbell, M. S. Wetherill, and A. L. Salvatore, "Geographic and social economic disparities in the risk of exposure to ambient air respiratory toxicants at Oklahoma licensed early care and education facilities," *Environ. Res.*, vol. 218, 2023, doi: 10.1016/j.envres.2022.114975.

[29] J. Trevathan, W. Read, and A. Sattar, "Implementation and Calibration of an IoT Light Attenuation Turbidity Sensor," *Internet of Things (Netherlands)*, vol. 19, 2022, doi: 10.1016/j.iot.2022.100576.

[30] X. Ren *et al.*, "The depositional characteristics of turbidity current in Manila Trench: sediment provenance, geochemical elements and organic carbon burial," *J. Asian Earth Sci.*, vol. 264, 2024, doi: 10.1016/j.jseaes.2024.106074.

[31] R. J. Davies-Colley and D. G. Smith, "Turbidity, suspended sediment, and water clarity: A review," 2001. doi: 10.1111/j.1752-1688.2001.tb03624.x.

[32] T. Kuzmanić, K. Lebar, M. Klun, and S. Rusjan, "Investigating the relationship between particle size of suspended sediments and optical sensor turbidity readings," in *EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023*, 2023.

[33] M. Bakker *et al.*, "Intercomparison of optical scattering turbidity sensors for a wide range of suspended sediment types and concentrations," *Catena (Amst).*, vol. 245, 2024, doi: 10.1016/j.catena.2024.108307.

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