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Smart Water Monitoring System using Ultrasonic and pH Sensor with IoT Platform

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ABSTRACT

During floods and water pollution, delayed operations by corresponding authorities and communities have led to significant damage. The existing monitoring systems for flooding and water quality are inefficient because they function independently. Besides that, the conventional method of collecting information is time-consuming, and current systems do not alert people immediately. The current system must be upgraded to a real-time smart monitoring system so that people can access information immediately via their smartphones. The aim of this research is to develop a smart water monitoring system capable of monitoring water level and water quality in terms of pH level at a specific location. Both parameters can be tracked simultaneously by the proposed system. Ultrasonic and pH sensors are utilized to gather data. The microprocessor processed the data before sending it to the system's outputs, which include ThingSpeak as the IoT platform, which can be accessed via a smartphone. The results show that the JSN-SR04T is the best ultrasonic sensor to use for detecting water level because its percentage of error is only 1.38% and it can also reduce the system's power consumption by 13.89%. Furthermore, due to its low percentage of error 2.72%, the analog pH metre SKU: SEN 0161 is the appropriate pH sensor to detect a relatively correct pH level. Hence, by incorporating both sensors, a reliable system can be developed.

Keywords:
Ultrasonic sensor; digital pH meter; analog pH meter; internet of Things (IoT); monitoring System

1. Introduction

Water is a crucial element of life as living things need it to stay alive. Dhillon *et al.,* in [1] stated that oceans, rivers, lakes, underground sources, springs, and wetlands are all examples of water resources and about 71% of the Earth’s surface is covered by water. Malaysia is a country surrounded by the sea. Thus, Malaysia really takes advantage of this by making it a water supply for drinking, farming, and other essential uses. However, this geographic location also has a negative implication. Humanity does not want to deal with natural disasters such as floods and water pollution. Statistical

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analysis by Ali *et al.,* [2] in recent years have shown that the floods in Kelantan and Selangor have done great damage to human life and, even worse, they have also caused death . Other than that, floods also cause diseases for victims, such as cholera due to bacteria from the flood and shortage of medicine reported by Bernama [3]. Meanwhile, water pollution in Johor Bahru also caused serious illnesses such as shortness of breath, nausea and vomiting disclosed by Palansamy *et al.,* [4]. Flooding, water pollution, and degraded water supplies resulted from the rapid growth of civilization and various human activities such as deforestation, domestic sewage, and dumping chemical waste into the river as mentioned by authors in [5,6].

Assessment and monitoring of natural disasters have become significant issues that require an appropriate response to the danger as it will not occur daily and will also ensure the protection of the ecological system. Ajayi *et al.,* [7] stated that the traditional technique to monitor a natural disaster and inform the corresponding authorities and communities is time-consuming. Furthermore, that particular approach to monitoring water quality must be conducted through laboratory-based tests using collected water samples. Additionally, a laboratory-based test using the samples can take up to a few days to achieve results and may show less accuracy of the parameter due to a change in the sampling water highlighted by Abdul Kadir *et. al.,* [8]. In Malaysia, a flood monitoring system has been developed to assist the Department of Irrigation and Drainage Malaysia (DID) in monitoring the real-time water level. Leman *et. al.,* [9] added that the information can also be accessed through the InfoBanjir website. The established system is a web-based application that requires users to browse the link to the InfoBanjir website in order to get information. Indeed, it is a good monitoring system. However, if a flood occurs, the website does not notify the communities directly. It could be improved by sending the data to any IoT platforms. Thus, the communities can easily access the information by using any IoT application software, such as ThingSpeak.

People nowadays live in a technological age where they can access any information they want. The traditional method must be replaced with a Wireless Sensor Networks (WSN) system that is more cost-effective and time-efficient by incorporating IoT into the monitoring system so that all people are always aware of the river environment. The continuous collection of water level and pH level, along with the real-time monitoring system, can be used to track the condition of the river environment. This approach is to establish patterns and also determine the details related to event detection [8]. As a result, this can be used as a preventative measure for people to prepare more physically and mentally before experiencing a natural disaster.

Authors in [10,11] created a water monitoring system that tracks pH, temperature, and dissolved solids in water contaminated by industrial waste dumping. The concentrations of inorganic salts and organics in the water solution were measured. The Arduino microcontroller handles both systems, and alert messages are sent via GSM. Sheikameer *et al.,* [12] implemented the same microcontroller, but they enhance their water monitoring system by including attributes for potential study to use. The data collected will be stored in a data set (ORACLE/SQL/MS Excel). Researchers for paper [13] proposed an IoT-GSM smart water system to minimize water waste, leakage, and water contamination. The proposed system has impressive outcomes and can be easily used in residential areas.

The goal of this research is to create a monitoring system that can evaluate both the water level and the pH level of water at the same time. The other objective of this research is to analyze the ultrasonic and pH sensors that can reduce the power consumption of a reliable system. It is also to implement a system that can give early notification to people using IoT. An analysis was carried out based on previous research pertaining to flood and water quality monitoring systems. Researchers have conducted a comprehensive study in order to enhance the current system and ensure that the new system that will be developed is more efficient. Table 1 shows the comparison component used in the previous research. The main parameters of this research are to monitor the water level and pH level of the water. One of the differences between the system introduced by other authors in [8,14,15] system and the proposed system is the type of ultrasonic sensor. The authors used HC-SR04 while the proposed system used JSN-SR04T. Other than that, the previous research did not deliver the information through smartphones, so the communities could not obtain the information about floods and water pollution instantly. The proposed system will be very reliable since it can notify communities and corresponding authorities by using an application on a smartphone.

Table 1
Comparison Component of Research

Research Title	Ultrasonic Sensor	pH Sensor	LCD	Arduino	Raspberry Pi	Wi-Fi	Smartphone
Smart Water Quality Monitoring and Metering using LoRa for Smart Villages [14]	/	/	X	X	X	X	X
IoT Based Smart Water Quality Monitoring and Prediction System [15]	/	/	/	/	X	X	X
Smart Sensor Node of WSNs for River Water Pollution Monitoring System [8]	/	/	X	X	X	X	X
Smart Water Monitoring System using Ultrasonic and pH Sensor with IoT Platform	/	/	/	X	/	/	/

2. Methodology

This section is divided into two parts: the hardware and software components of the system.

2.1 Hardware Part

Figure 1 shows the block diagram of the system. Those devices are used to construct the hardware part. The ultrasonic sensor and pH sensor are the system's inputs. As for the outputs, they are the LCD, buzzer, and smartphone. The system starts with solar energy, which supplies power to the Raspberry Pi (Raspi). When the Raspi gained sufficient power, it transferred the instructions that had been coded in it to the sensors. Right after the sensors obtained the data, the Raspi processed it and sent it to the LCD, cloud, and buzzer. The LCD is used to display the data, while the cloud also does the same thing. Although the function is the same, the LCD could not store the data throughout the system's operation, but the cloud could. People could get the data and notifications from the ThingSpeak application on their smartphones. Lastly, the buzzer is triggered and produces a "beep" sound when the data has exceeded its threshold alert (water level < 60 cm and pH < 6.5).

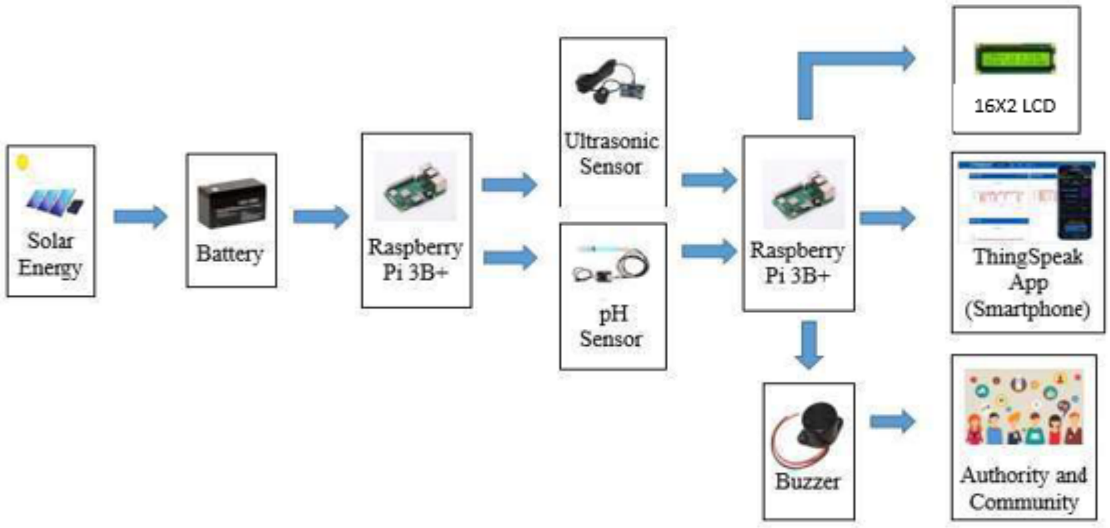

Fig. 1. Block diagram of the system

Figure 2 is the complete schematic diagram of the system. Fritzing software is used for circuit designation. All components are connected to the RasPi to receive signals from the microprocessor and function as the system has been programmed. The microprocessor sent the instruction to the inputs and outputs of the system via Broadcom Mode (BCM). Only the Analog-to-Digital Converter (ADC) is attached to the specific BCM, which is known as the Serial Peripheral Interface (SPI) while others are connected to any General-Purpose Input Output (GPIO) pin on the RasPi board. Other than that, the components except the ADC required 5V input voltage to operate. Because the RasPi only has two 5V pins, a mini breadboard serves as the power supply for the components. The 5V, 3.3V and ground pins coming from the RasPi are connected to the mini breadboard so that all components can get the power supply.

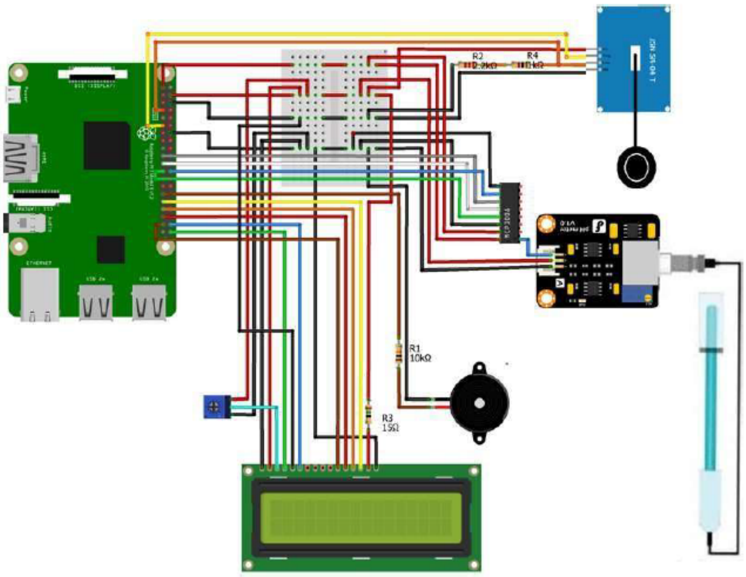

Fig. 2. Schematic diagram of the system

The prototype of the research is depicted in Figure 3. The prototype is placed near the water resource, which enables the sensors to acquire the data. In order to obtain the pH value, the pH sensor is immersed in the water, while the ultrasonic sensor is hung in the air (as in Figure 3) to measure the increases in water level.

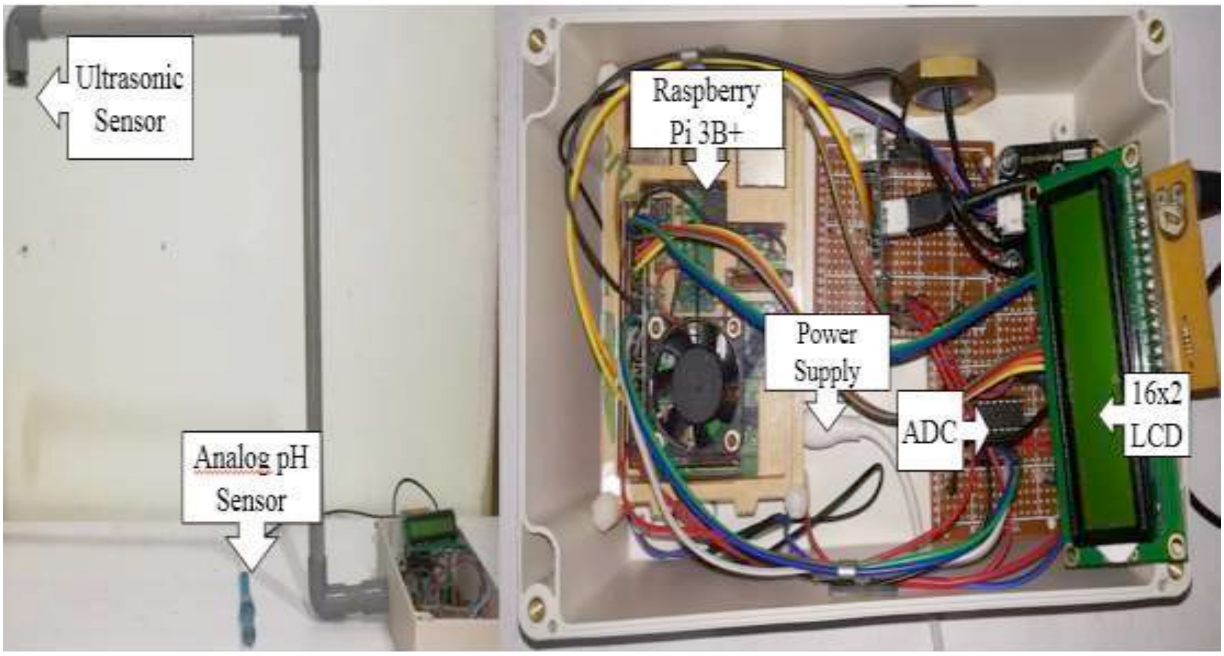

Fig. 3. Research prototype

2.1.1 Components Description

An ultrasonic sensor is used to measure the water level. In this research, there are two types of ultrasonic sensors that have been tested, which are JSN-SR04T and HC-SR04. JSN-SR04T has only one ultrasonic transducer, which acts as both a transmitter and receiver of the ultrasonic waves. Furthermore, unlike the HC-SR04 ultrasonic sensor, it is designed to be waterproof. The JSN-SR04T sensor is chosen by Rahman *et al.,* [16] as the input of the system due to its high accuracy compared to the HC-SR04 ultrasonic sensor . Assessment did not happen if the energy obtained by the receiver was insufficient due to the angle of the ultrasonic waves and also because the inconsistency of water surfaces affected the reflected wave away from the receiver remarks by Heys *et al.,* [17]. Sometimes the surface of the river is inconsistent; therefore, a pipe with a hole is made to ensure the water that enters the pipe is flat and stationary. Kruger *et al.,* [18] placed the sensor at the upper end of the pipe, and measurement of the water level is done in the pipe. This method is the implementation concept for streamflow measurement by the United States Geological Survey (USGS).

An analog pH meter is a sensor that measures pH to check the acidity level of water. It is a built-in, simple, convenient, and practical connection. The input voltage for this sensor is between 3.3V~5.0V. The sensor only reads an analogue input, and the conversion of data into digital value is needed due to the incompetency of the microprocessor to read the analog input. Thus, the sensor is connected to the Analog to Digital Converter (ADC). A commercial digital pH meter is used to compare with the analog pH meter. The portable digital pH sensor was powered by a 3V battery. Before performing the testing, both pH metres are calibrated. The goal of this comparison is to see which metre is more accurate in terms of error percentage. In order to verify the water is acidic, the reading must be < 6.5 pH since the standard neutral range of the pH value of water is between 6.5 ~ 8.5 noted by Kamidi *et al.,* [15] in their research.

2.2 Software Part

2.2.1 ThingSpeak

The system utilizes ThingSpeak as the IoT platform. ThingSpeak is an IoT analytic software application that enables the analysis and visualization of live data streams in the cloud [8]. It is suitable to be used as a monitoring platform. This is an easily accessible platform where anyone can retrieve the live data through the ThingSpeak website or ThingSpeak application on their smartphone. Other than that, ThingSpeak can also connect directly to MATLAB and social media sites such as Twitter. Figure 4 shows the data that has been sent to the ThingSpeak application on the smartphone. According to the diagram below, the colour of the data will be white if no data has exceeded its own threshold value. Otherwise, the colour will be red, and a warning notification will appear on the smartphone.

IoT ThingSpeak Monitor Widget
Warning for pH Level (pH)
Current value: 5.3

Fig. 4. ThingSpeak application in smartphone

2.2.2. Flowchart of The System

Figure 5 shows the flowchart of the system. The solar system absorbs sunlight to charge the battery. At the same time, the battery is used to power up the Raspi. After the Raspi received power from the battery, it initialised to distribute the instructions to each component in the system. Then, the sensors, which are ultrasonic and pH sensors, began to measure the water level and acidity, respectively. The data is sent to the Raspi to be analysed and used to make a decision about whether the data meets the system's conditions. If the input data meets any of the conditions, the buzzer is triggered, and the LCD displays the data with the status. On the other hand, if the water level and pH do not meet the conditions, the buzzer will not trigger, but the data will still be displayed on the LCD. At the same time, Raspi also sent the data into the cloud by using the built-in Wi-Fi module. The data is stored in ThingSpeak, and people could see the data through the ThingSpeak application on their smartphones.

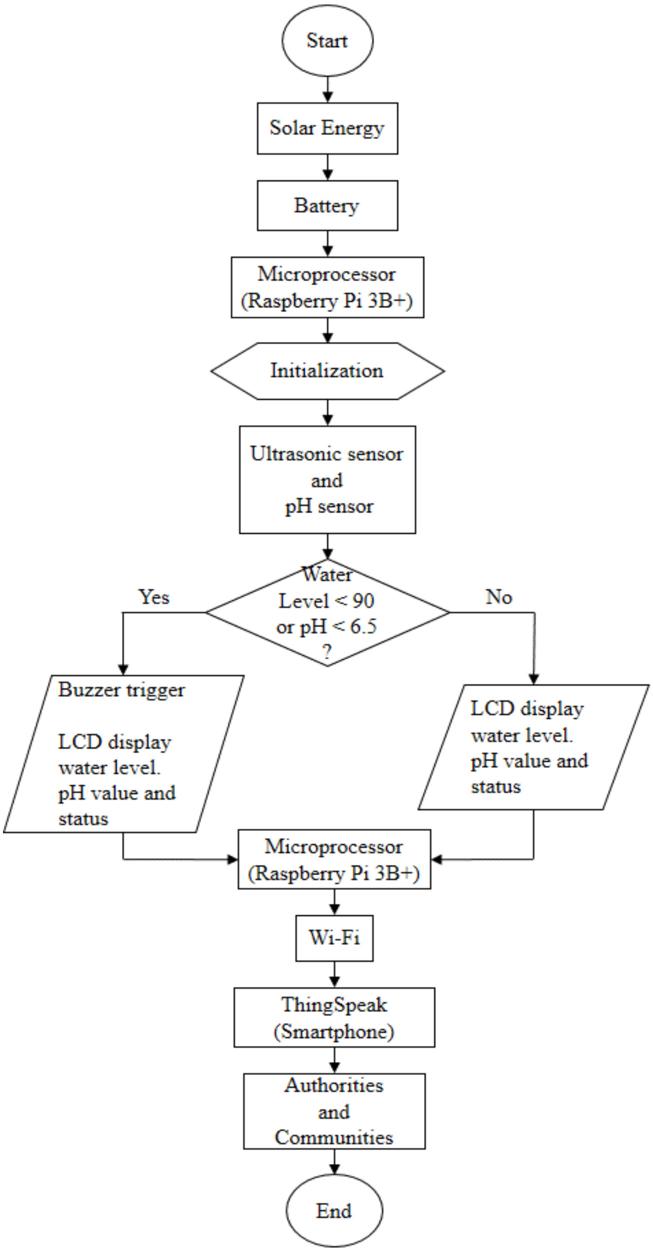

Fig.5. Flowchart of the system

3. Results and Discussion

3.1 Smart Water Monitoring System

Table 2 and Table 3 below show the water level condition and pH level condition that have been applied to this monitoring system.

The water level condition is classified into three levels: Level 1, Level 2, and Level 3 to indicate the status Safe, Alert, and Danger, respectively. Each level has its own range of water level, as stated in the table above. The range in the table is the distance between the water's surface and the ultrasonic sensor. When the water level reaches any point within the specified range, the data is processed by the microprocessor and sent to the LCD as well as the cloud to be displayed for future reference. The buzzer is triggered when the water level is between level 2 and level 3.

Table 2
Water Level Condition for Klang River [19]

Water Level	Range of Water Level (m)	Status
Level 1	≥ 1.3	Safe
Level 2	≥ 0.8 & 1.3 <	Alert
Level 3	< 0.8	Danger

Other than that, pH level conditions are also separated into 3 types, which are Neutral, Acidic and Alkaline/Base. When the pH sensor detects a particular range of the pH of the river, the LCD displays the range and also the status. Furthermore, the data will be sent to the cloud and can be monitored on a smartphone through the application. Also, the buzzer is triggered when an acidic or alkaline pH level is detected.

Table 3
pH Level Condition

pH Level	Status
≥ 6.5 & 8.5 ≤	Neutral
< 6.5	Acidic
> 8.5	Alkaline/Base

3.2 Comparison of Ultrasonic Sensor

Table 4 below shows the accuracy test results of both ultrasonic sensors. An ultrasonic sensor is used to detect any malfunctioning instrument that is buried underground. The sensor is highly sensitive, rugged, and has low power consumption, which provides many advantages over conventional hydrological sensors. The test is carried out to determine which type of ultrasonic sensor is suitable for the system in terms of accuracy. Since this is a real-time water level detection, the selection of sensor types to measure the distance between the surface of the water level and the sensor is very crucial. According to Table 4 below, ultrasonic sensor type HC- SR04 has a higher percentage of error compared to JSN-SR04T. The average percentage of error for JSN-SR04T and HC-SR04 is 1.38% and 2.17% respectively. The reduction of the percentage of error from 2.17% to 1.38% could increase the performance of the system. Furthermore, JSN-SR04T is more suitable to use in the system than HC-SR04. JSN-SR04T has only one ultrasonic transducer, which acts as both a transmitter and receiver of the ultrasonic waves. This is because, JSN-SR04T is designed with water protection, which is able to get through in hot and rainy weather mentioned by Rahman *et al.*, [16].

Table 4
Percentage of Error for the Sensor

Water Level (m)	Result			
	JSN-SR04T	Percentage of Error (%)	HC-SR04	Percentage of Error (%)
0.2	0.198	1.00	0.204	2.00
0.3	0.291	3.00	0.309	3.00
0.4	0.393	1.75	0.425	6.25
0.5	0.491	1.80	0.500	0.00
0.6	0.592	1.33	0.590	1.67
0.7	0.691	1.29	0.687	1.86
0.8	0.797	0.38	0.786	1.75
0.9	0.892	0.89	0.879	2.33
1.0	0.991	0.90	0.991	0.90
1.1	1.087	1.18	1.078	2.00
1.2	1.183	1.42	1.173	2.25
1.5	1.479	1.40	1.464	2.40
2.0	1.967	1.65	1.964	1.80

3.3 Comparison of Power Consumption of The System

Table 5 shows a comparison of power consumption when the system is tested with different types of ultrasonic sensors. It shows that, when the system used the JSN-SR04T as the ultrasonic sensor, the energy consumption of the system was much lower compared to a system with the HC-SR04 sensor. The energy consumption performance is 13.89% lower than the system with HC-SR04. JSN-SR04T produced the best performance in accuracy for the water level detection, resulting in a more reliable system. Furthermore, power consumption for both systems is less than 5W which was sufficient for the solar panel used to supply power to the whole system. According to the calculation, the required battery capacity is 12.96Ah and 14.76Ah for both systems, respectively. On the other hand, the capacity of the battery that has been applied is 8.2Ah and the lifetime of the battery is less than 24 hours. Rotunno *et al.*,[20] clarified that since the solar energy acts as the backup power supply to the battery, a 8.2 Ah battery could make the system operate accordingly.

Table 5
Power Consumption of The System

Parameter		Type of Ultrasonic Sensor	
		JSN-SR04T	HC-SR04
System Voltage, Vsys	(V)	12	12
System Current, Isys	(A)	0.36	0.41
System Power, Psys	(W)	4.32	4.92
System Energy, Esys	(Wh)	103.68	118.08
Capacity Battery Required	(Ah)	12.96	14.76
Capacity Battery Used (Lead Acid)	(Ah)	8.2	8.2
Battery Lifetime	(h)	22.78	20

3.4 Comparison of pH Sensor

The sensor that has been proposed to be used as an input to this research hardware is an analog pH meter SKU: SEN0161. The solutions for calibration, buffers 4.0 pH and 7.0 pH have been used to indicate acidic and neutral, respectively. The result of the calibration is shown in Table 6 below. Both sensors have been calibrated with a calibration solution. The purpose was to compare and determine which one of the sensors has high accuracy in detecting the pH value. According to Table 6 below, an analog pH meter has a low percentage of error, with an average of 2.72%. While digital pH meter recorded a high percentage of error with an average of 21.68%. This shows that an analog pH meter is the best pH meter because it has 18.96% less error compared to a digital pH meter. Since the accuracy is high, the analog pH meter could measure a relatively correct pH level proved by Pakpahan *et al.,* [21].

Table 6
Calibration Testing of pH Sensor

pH Scale	pH Level		
	Calibrating Solution	Digital pH meter	Analog pH meter
Acidic	4.00	2.86	4.12
Neutral	7.00	5.96	6.83

3.5 Comparison of Battery Lifetime

Battery lifetime is an indicator of battery performance and reliability. It is important to select the right type of battery to energise the system. Besides that, the capacity and lifetime need to be high in order to ensure the power and energy of the system are sustainable. Referring to Table 7, it shows that Laptop batteries are not suitable to be implemented in the system because their lifetime is too short while the system needs to operate for more than 12 hours. When comparing the two types of batteries, the Power Bank has a longer battery life than the Lead Acid battery. Although the power bank has the longest lifespan, it is not suitable for the system. The system is using solar energy to sustain the power; therefore, the most suitable rechargeable battery to be used is the Lead Acid battery. During daylight, while the battery is supplying power to the system, the solar panel is charging the battery. While at night, the system 100% relies on the battery, and based on the battery's lifetime, it can survive all night long.

Table 7
Comparison on lifetime of different type of battery

Battery Type	Capacity (Ah)	Voltage (V)	Time (hours)	Size (mm)
Lead Acid	8.2	12	22.78	151x65x95
Power Bank	10	5	27.78	108x72x22
Laptop (LiPo)	4.61	7.6	11.25	198.15x93.16x6.4

4. Conclusions

The objective of this research is to develop a smart water monitoring system that can monitor both the water level and the pH level at the same time. Based on the outcome, it met the objective of constructing a monitoring system that can immediately notify people using IoT. Furthermore, the JSN-SR04T is the best ultrasonic sensor with 1.38% error and has the potential to reduce power consumption by 13.89%. Analog pH meter SKU: SEN 0161 is the suitable pH sensor to use due to its small percentage of error of 2.72%, which is able to detect a relatively correct pH level.

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