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Water Quality Monitoring Robot based on Wireless Sensor System

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Abstract: A good quality of water is an important to human health and aquatic ecosystem. Providing a continuous way to monitor the water quality can help the environment protection and prevent the water from contaminated. In this paper, the water quality monitoring system was designed based on a wireless sensor system by implemented with the three type of sensors that mounted into a mobile robot. These sensors are pH sensor, turbidity sensor, and temperature sensor. Then, the parameters involve are pH level (pH), turbidity (NTU) and temperature (^{o}C). Meanwhile, the data from sensors was sent to an Arduino microcontroller. This Arduino UNO was used as an interface between input and microcontroller to process the data that received from the sensors in real time and sent to the base station via wireless system. A reliable monitoring system can be established with appropriate calibration and precaution to get more accurate measurement of data. This was permitted the user to constantly monitor the quality of water accurately and to maintain the surveillance over extended period of time. The limitation of this wireless sensor is limited below 1000 m range from the base station. There are five (5) samples of water had been taken from the river and lake in Selangor area. The results show that all wireless sensors are capable to monitor the quality of water.

Keywords: Arduino microcontroller, control system, smart sensors, quality water, wireless system.

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1. INTRODUCTION

Water quality monitoring is an essential to control the suitability of water for a particular purpose based on selected physical, chemical, and biological characteristics [1]. Most of scientist measure and analyse the water quality by measuring and classification of their characteristics such as temperature, chemical composition, bacteria, and dissolved mineral content [2]. The characteristics of the water quality are compared with the numeric standard and guidelines from agency of Department of Environment (DOE) to decide either it safe or not to use for daily activities.

In fact, the water quality is a complex subject because the water is a complex medium. There are many ways can contribute in water pollution. Industrial and commercial activities such as manufacturing, mining, construction, and transport are a major cause of water pollution [3]. Contaminants that may be in untreated water include microorganisms such as viruses, protozoa, and bacteria [4]. The drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk [5].

In urbanized areas around the world, water purification technology is used in municipal water systems to remove contaminants from the source of water before it is distributed to homes, businesses, schools, and other users [6]. Water drawn directly from a stream, lake, or aquifer and that has no treatment will be of uncertain quality.

Therefore, the water quality by using the sensors can be monitored in real time in order to get early warnings before the water getting worse. The water quality monitoring can help with the water pollution early detection by analysing using typical parameter include temperature, acidity (pH), dissolve oxygen, connectivity, and turbidity [7]. The water sensor ought to have the characteristic of autonomous, inexpensive, reliable, flexible, intelligent network allowing a well-coordinated and continuous monitoring of surface waters. By using wireless sensor based on mobile robot, it also can reduce the reliance on manpower on site as well as reducing cost. The use of multiple wireless sensor networks as a device to detect the water quality level that are able to continuously collect the data and send to wireless base station for local processing within in a remote area with limited access.

In this paper will focus on the designing of wireless water monitoring in Section 3, meanwhile in Section 4 is about the mobile robot based with the electronic system then followed by the results and discussion. However, in Section 2 is discussed about the water pollution and also water quality monitoring.

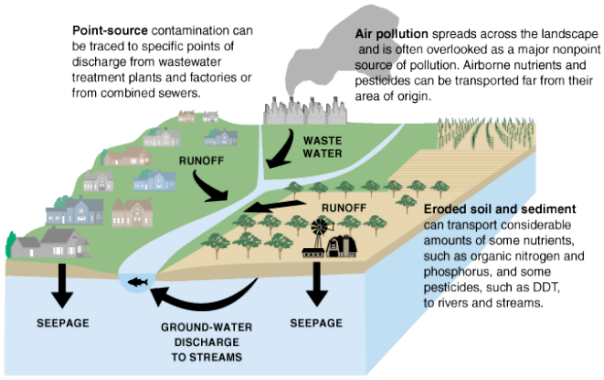
2. LITERATURE REVIEW

2.1 Water Pollution

Water pollution is the contamination upon the water bodies caused by human activities [8]. This form of environmental degradation occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. The major contaminated that affected to the water source such as surface water and ground water which are the major source for drinking water [9]. The water pollution affects the entire plants and organisms living in water bodies. The effect of water pollution is damaging not only to individual species and population, but also to the natural biological communities. There exist two main types of water pollution: point pollution and diffuse pollution.

2.1.1 Point Pollution

Most of point source pollution are pipe discharges, industrial outflows, tributaries, or wastewater treatment plant outflows that relatively easy to define and regulate as seen in Figure 1. The main point pollution discharges are the industrial loads and the loads coming from wastewater treatment plants (WWTPs) [10]. However, there is still pollution coming from unconnected households. The large point pollution sources are most often well-known due to the regular measurements. The emissions of smaller industries are often just estimated based on average values of water discharge per sector. Meanwhile, unconnected households are also estimated with an average pollution load per inhabitant. Figure 1 shows the point source pollution.



. Figure 1. The point source pollution [10]

2.1.2 Diffuse Pollution

Diffuse pollution also refers to as non-point pollution results from the release of a variety of substances in many different situations. It includes the nutrients such as nitrogen and phosphorus from fertilisers and manures. It also come from the livestock and badly connected drainage systems. Other examples of diffuse pollution are soil particles from livestock farming, erosion, forestry, urban areas and construction and demolition sites. Pesticides, veterinary medicines and biocides from industrial, municipal, and agricultural use, poor storage, and handling can be the diffuse pollution. Metals, including iron, acidifying pollutants, and chemicals from atmospheric deposition, abandoned mines and industrial processes [11].

Most agricultural activities are considered to be non-point sources such as organic wastes, oil and hydrocarbons from car maintenance, disposal of waste oils, spills from storage and handling, road, and industrial run-off. This is not the case for the large number of animals are kept and raised in confined areas. The feed is here generally brought to the animals, rather than that the animals are grazing or otherwise seeking feed in pastures, fields, or rangeland [12]. Those activities are treated in a similar manner to other industrial sources of pollution. Whereas point source pollution can be measured by monitoring the discharge and the water quality, diffuse pollution sources are very difficult to monitor because the sources are distributed along the river as shown in Figure 2.

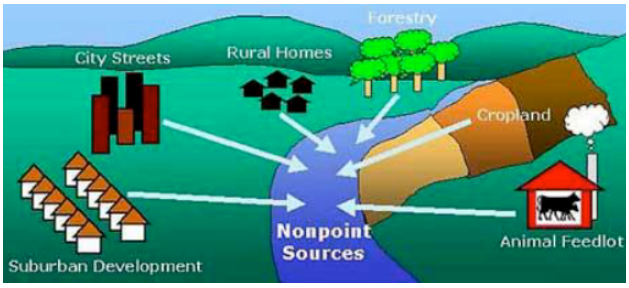


Figure 2. The source of diffuse pollution [12]

2.2 Water Quality Monitoring

Water quality monitoring can be used to protect the water source by identifying the pollutant levels and locations. Water quality monitoring is commonly done multiple times a year because water quality may change with season and with weather events. The water quality can be monitored by measuring physical, chemical, or biological based on the characteristics of the water.

Physical measurements consist of the measuring the temperature, flow, specific conductance, turbidity, and the condition of stream or the water. Physical characteristics are almost related to chemical parameters. For example, eroding stream banks may be the cause of high suspended solids or low flow may be the cause of low dissolved oxygen content [13]. Two measurable physical parameters that were measured in this study include temperature, and turbidity.

Temperatures can change significantly over the course of rivers due to the physical changes in channel configuration and altitude (air temperature), and in response to inflow from tributaries and ground water [14]. Moreover, biological water quality may vary with temperature due to vary species survival rates in different temperatures. Therefore, the temperature is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen and other material in the water column [15].

Meanwhile, turbidity is a measure of the number of suspended solids in surface water. The suspended solids include soil particles, algae, and microbes. The grater the number of suspended solids in the water, the cloudier it

appears and the higher the measured turbidity [16]. The major source of higher turbidity is in open water zone like lakes cause by phytoplankton but closer to shore may cause by clays and slits from shoreline erosion. Turbidity in water is also affected by the weather, which means it increases when the water flow or currents increases due to rain or wind.

The other method can be used in monitoring the quality of water is by applying pH sensor that measure of the concentration of free H+ ions, is affected by acid rain, surrounding rock formations, and certain wastewater discharges [17]. Most freshwater aquatic species prefer a pH range of 5.5 to 8.0 depend on the types of organisms that found in surface water. A low pH can also allow toxic elements and compounds to become mobile and available for uptake by organisms [18]. One reason of pH change in water is photosynthesis which the process that absorbs carbon dioxide from the water and uses sun energy to convert it into simple organic carbon compound and produce oxygen.

3. DESIGN OF MONITORING SYSTEM

On this project, the water monitoring systems include the study of fluctuations in pH, temperature, and turbidity. The sensor data need to continuously gather to the base station via wirelessly so that it can be easily observed. The monitoring database analyses and process the quality parameters, give an alarm for emergency like water contamination. The hardware design for wireless sensor nodes requires the sensor unit and wireless module.

3.1 Sensor Unit

Basically, the sensor unit consists of several types of sensor to predetermine the quality of water which are pH, temperature and turbidity sensor use in this project. The pH sensor is to sense the acidity and alkalinity of the water. Meanwhile, the temperature sensor uses to detect the temperature of water and the turbidity sensor is to detect the cloudiness or haziness of the water caused by large numbers of individual particles that are generally invisible to the naked eye which is similar to smoke in air. The entire sensor powered by battery that connects to the microcontroller. The data from the sensors will convert into an electrical signal through signal amplification circuit then passed to the microcontroller as shown in Figure 3.

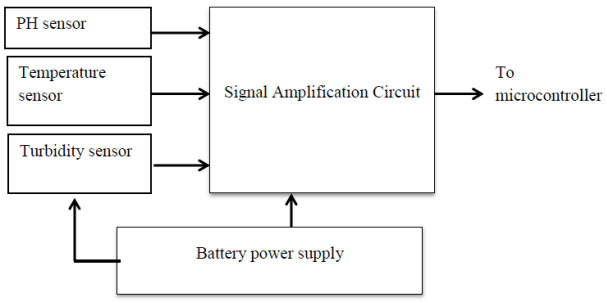


Figure 3. Sensor unit block diagram

3.2 Wireless Sensor Nodes

Wireless sensor network consists of sensor unit, microcontroller, and wireless module. A microcontroller is a self-contained system with peripherals, memory and a processor that can be used as an embedded system. Arduino Uno is used as an interface in order to receive and process data in this project. Arduino Uno also is an open source product, inexpensive, light and provide sufficient digital and analog pin. The wireless modules are embedded solutions providing wireless end-point connectivity to devices. In this project, XBee-PRO 802.15.4 OEM RF modules had been used as the wireless connection to the base station. These wireless modules are ideal for low-power, low-cost applications. From the Figure 4, the data from the sensor been processed through Arduino then the information will be sent to the base station using wireless network.

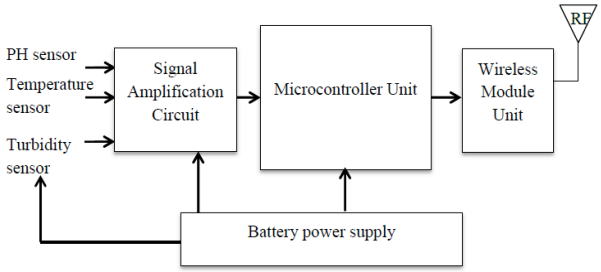


Figure 4. Block diagram of sensor unit and wireless module

From the Figure 4, the monitoring system the wireless sensor nodes can be set for end device or router device. The end device and only can communicate to the router or coordinator to process the data receives form the sensor probe. The router also can be used as input device for wireless sensor node and the end device can connect to router to extend the coverage. Only one coordinator is on the base station that will receive the data either from the router or end device.

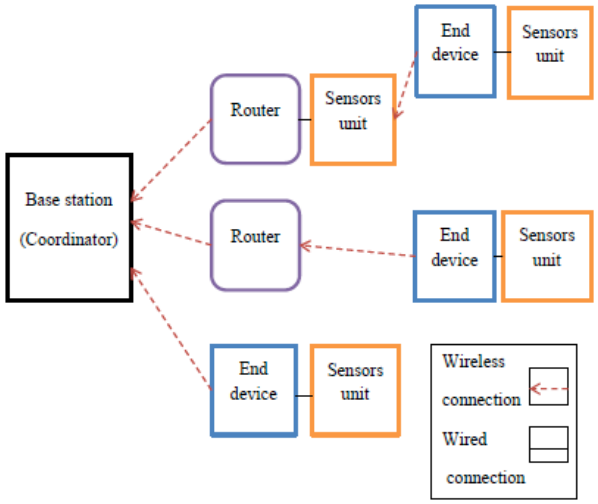


Figure 4. Block diagram of monitoring system

3.3 Mobile Sensor System

Mobile sensor system for collection of water quality data has many advantages over geographically fixed sensor. Some advantages are able to monitor at difficult location for fixed sensor, able to change quickly the location and also can be remotely control multiple mobile robot sensor. Figure 5 shows the mobile robot requires wireless sensor unit mounted on the mobile robot. The concept of this mobile robot is same as hovercraft which ability to move on land and water surface controlled by remote. To minimize the cost and development of time the body of this mobile robot made from layers Styrofoam to make it simple and light. Two propellers mounted on the mobile robot for easily control to maneuver left or right. Brushless motor been used to pump up the air cushion of the mobile robot. A robot arm powered by two servos which to move the sensor from the mobile robot deck to the surface of water. Customization to the mobile robot keeps to minimum with the primary focus on the wireless sensor.

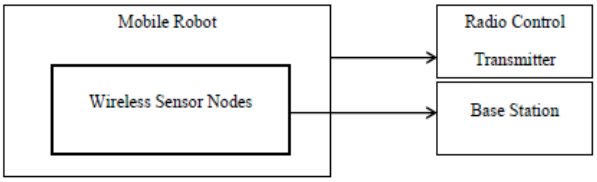


Figure 5. Mobile sensor block diagram

3.4 Base Station Monitoring

The base station in this project consist the same XBEE-PRO that programmed as coordinator that receives the data from the sensor nodes via wirelessly. The XBEE-PRO is connected to computer using XBEE Explorer USB Dongle as shown on Figure.6. The data received continuously and displayed using XCTU application which is a free multi-platform application to enable interacts with XBEE using graphic interface.

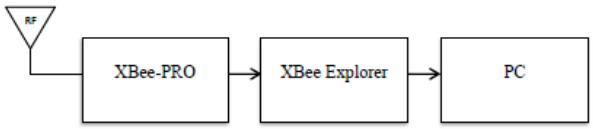


Figure 6. Base station block diagram

4. WATER QUALITY MONITORING BASED MOBILE ROBOT SYSTEM

4.1 Designing Mobile Robot

The mobile robot used to collect the water quality data that fixed with three sensors: - pH, turbidity, and temperature sensors. approach. This robot can used in both land and water. This is because of the concept of designing this robot by using a hovercraft approach model. Figure 7 shows the model of mobile robot by using CATIA V5.

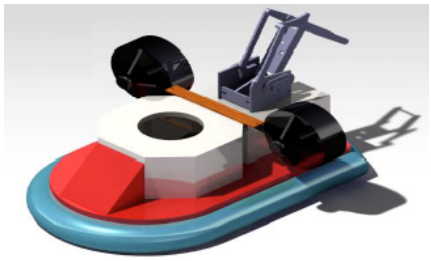


Figure 7. Designing the mobile robot by CATIA

Meanwhile, Figure 8 expressions the prototype of the mobile robot. This mobile robot consists of several main part such as thrust fan, lift fan, fan tower, air cushion and robot arm. The unique of this robot is it has a simple robotic arm. The sensors will be attached to this arm.

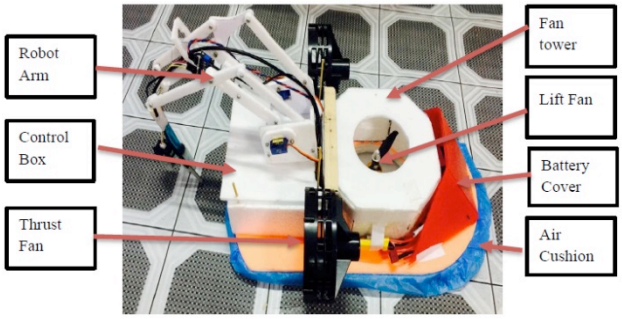


Figure 8. Prototype of mobile robot

The main component of this robot is air cushion. It will make the robot can float on the surface of the water. There are three fans will be used; - thrust fan, lift fan and tower fan. Each fan has its function in movement the water mobile robot. The summary of each component of robot is explained in Table 1.

Table 1. Summary of each components

Component	Function
Air cushion	Also known as flexible skirt which contained the air. The escaping air from where the skirt touches the ground and create a frictionless cushion of air.
Thrust fan	Move forward, backward and turn left and right.
Lift fan	Lift the mobile robot body by sucking large volume of air from outside and blow into air cushion that slightly above atmospheric pressure.
Fan tower	The fan tower use to protect the motor and the propeller inside the fan tower by providing large amount of air trapped inside it.
Robot arm	Used to lift and down the sensor mounted on it.
Control box	Act as protection for the microcontroller from water
Battery cover	To cover the battery

4.2 Controlling Mobile Robot

In term of controlling the robot, it includes the combination circuit of sensors and other components, the algorithm of the system. Figure 9 shows the system operation of the water monitoring system. The monitoring nodes use three types of sensor which are pH sensor, turbidity sensor and temperature sensor. The wireless sensor node is mounted on the mobile robot that can move on the land and water. Then, the sensor node mounted on the rear of the robot which control by robot arm to move the sensor upward and downward from the surface of water. The data from sensor node will be received by computer using XBEE Dongle Explorer module. The data will be shown on the serial monitor using XCTU program. The monitoring system will automatically collect pH, turbidity, and temperature data for every second for five minutes.

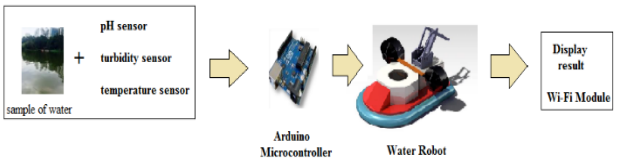


Figure 9. System operation of the water monitor system

Figure 10 shows the actual water monitoring wireless sensor nodes. This system will be mounted to the mobile robot for water monitoring experiment. It consists of sensor unit which include pH sensor, turbidity sensor and temperature sensor. To transfer data via wirelessly, a wireless module (XBEE) was mount together with microcontroller (Arduino UNO). This system consumes only 5V power supply.

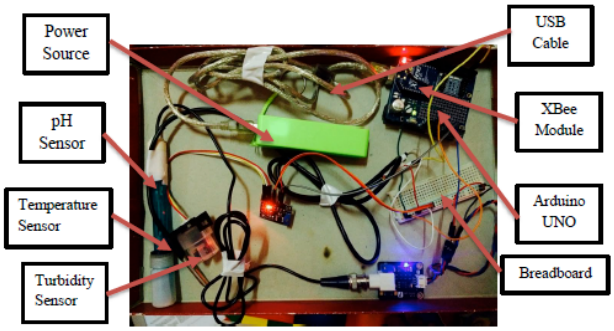


Figure 10. Wireless system nodes

In the other hand, Figure 11 shows the algorithm of water quality system. This system is start when all the sensor submerged into the water after the robot arm move downward. When the system is on, the serial monitor will show the word "Water Quality Experiment" via wirelessly. The pH, turbidity and temperature sensor will read the value and will display on serial monitor using wireless module. The data from the sensor will be analyse by plotting the graph and compared from the standard value.

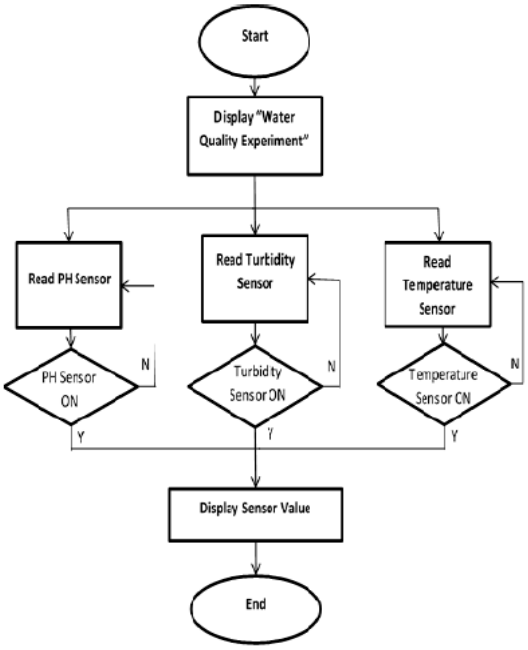


Figure 11. The algorithm of the system

5. RESULTS AND DISCUSSIONS

5.1 pH, Turbidity and Temperature sensors Reading

For this project, there are five samples of water had identified around river or lake at Selangor region. All the sample will be compared with the tap water quality.

a) Tap water (reference) (TW): Shah Alam
b) Klang Gate River (KGR): Taman Melawati
c) Sendat River (SR): Ulu Yam Bahru
d) Seksyen 7 Lake (S7L): Shah Alam
e) Seksyen 14 Lake (S14L): Shah Alam

During the testing, the sensors will submerge into the water for five minutes for each sample of the water. Therefore, there are three experiments had been conducted: using pH sensor, turbidity sensor and temperature sensor. All the data values collected by the sensor units had been transferred to base station via XBEE communication module.

Table 2 illustrates the results from all sample with. From the Figure 5.1, all the location shows the pH values in the range of pH 5.5 to pH 9. The pH sensor can measure from pH 0 up to the pH 14 with accuracy of ± 0.1. These values of pH are accepted for recommended values for raw water in Malaysia. However, the standard pH value for drinking water is pH 6.5 to pH 9.0 which means that the pH value for Klang Gate River is not safe to drink.

Table 2. pH readings

Water sample	Reading					
	1st	2nd	3rd	4th	5th	Average
TW	6.05	6.50	6.56	6.60	6.63	6.47
KGR	6.87	6.17	5.95	5.80	5.8	6.12
SR	7.23	7.17	7.11	7.04	7.00	7.11
S7L	6.83	6.92	7.01	7.11	7.13	7.00
S14L	7.54	7.13	6.88	6.73	6.62	6.98

Table 3 shows the results of turbidity value for all the samples. The turbidity value in water is the value of cloudiness in water. Since the turbidity sensor type is for dishwasher used, the turbidity value is in term of absorbance (AU) which is the common logarithm of the ratio of incident to transmitted spectral radiant power through a material. The value of absorbance can be determined using this formula

$$A = 2 - \log 10\ \%T \quad (1)$$

This value will be programmed in Arduino. A is Absorbance value in AU while %T is transmittance percentage which is the percentage of the water turbidity. From the table, the value of absorbance for all location is more than 70% which means the water is still safe from pollution.

Table 3. Turbidity values

Water sample	Reading					
	1st	2nd	3rd	4th	5th	Average
TW	0.12	0.12	0.12	0.12	0.12	0.12
KGR	0.13	0.12	0.12	0.12	0.12	0.12
SR	0.13	0.13	0.13	0.13	0.13	0.13
S7L	0.15	0.13	0.13	0.13	0.13	0.13
S14L	0.12	0.12	0.12	0.12	0.12	0.12

Table 4 shows the result of temperature reading for five samples of water. This experiment is done to determine the effect of temperature to the water quality. The temperature value for each location is affected by the surrounding temperature. However, none of samples can harm human. This temperature is normal for average water temperature in Malaysia. This temperature sensor can read from range of -10°C to + 85°C with accuracy of ±0.5°C.

Table 4. Temperature readings

Water sample	Reading					
	1st	2nd	3rd	4th	5th	Average
TW	28.70	28.68	28.67	28.65	28.63	28.66
KGR	29.58	29.58	29.59	29.60	29.60	29.59
SR	24.10	24.00	24.00	24.00	24.00	24.02
S7L	30.09	30.12	30.12	30.12	30.12	30.11
S14L	30.69	30.62	30.51	30.50	30.50	30.56

5.2 Water Quality

Based on the results, the overall of quality water samples were stated in Table 5. Most of the samples of water quality still in good condition except for Klang Gate River. This is maybe in that area of Klang Gate River had been contaminated because the pH level is below than pH 6.5. Thus, there are still many people who use the water from the river for their daily purpose used which are they did not mention the condition of that the river. It can cause the decease without good treatment to the river.

Table 5. The overall of water monitoring

Water sample	Type of sensor		
	pH	Turbidity	Temperature
TW	√	√	√
KGR	X	√	√
SR	√	√	√
S7L	√	√	√
S14L	√	√	√

Figure 12 shows the combination of the averaged value for three sensors in measuring and controlling in water monitoring. It is a good idea to know the quality of water in order to have the safety environment.

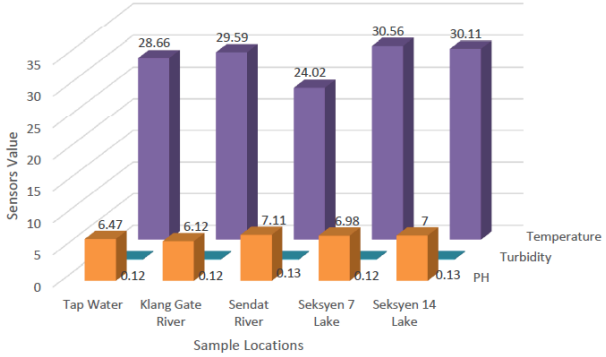


Figure 12. The readings of three sensors: pH, turbidity, and temperature

6. CONCLUSION

As a conclusion, the objectives of this project are achieved. The wireless sensor system is able to test the quality of water and collect data from pH, turbidity and temperature sensor by either using or not using mobile robot. By using mobile robot, it presents useful features such as large monitoring range, easy to maneuverer, flexible configuration, low power consumption and relatively low cost.

Based on analysis, this project can help to tackle the lack of practical environment monitoring system. It can be implemented for real time collection of water quality data at locations that inaccessible to other fixed sensors and able to quickly change monitoring location. For future, the project can be improved and utilized by using graphic user interface (GUI). By using this method, the data can process and plotting in a faster and more systematically. The other way, it also can be used GPS system on mobile robot, so that it can improve the exact location of water quality monitoring and can set the location of mobile robot autonomously for a period of time.

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