WATERWAY CONTINUOUS MONITORING USING FIBER OPTIC SENSING SYSTEM

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Abstract – This project presents a waterway monitoring system using fiber optic sensing approach that can monitor certain parameters of water. The optical fiber based system can continuously monitor and alert the authorities if sudden changes in parameters happen. The problem with the existing system is that the system is either labour intensive or requires data connection. The objective of this project is to develop a continuously monitoring system that can detect the changes in parameters along waterway such as river which also will be focused throughout development of this project. The scope of work for this project are to design a system that cover long distance monitoring and allow detection of changes in different parameter such as oil detection, water level and pH of water. The methodology for this project is the information will be transmitted by light information through the optical fiber. The information will be fed to a detector that converts light to difference in voltage signal and optical analyzing tools that communicate to a PC and microcontroller. As a findings for this project, the functionality of this project can be illustrate by considering situation when there is change in parameters along the river such as changes of pH from pH 10 (alkaline) to pH 4 (acidic) ; the difference in output voltage signal of the electronic pH sensor will be converted into light signal and cause shifting of central wavelength. This information regarding the exact location of the situation will be sent to the authorities for further action. The benefit of this project is to ensure fast action from authorities in case any hazardous condition happens.

Keywords-Fiber Bragg Grating; Optical fiber sensing system

I. INTRODUCTION

This projects presents waterway monitoring system using fiber optic sensing approach which provides continuous monitoring on environmental factor including water quality control for waterway such as rivers. This system can be implemented to any waterway which becomes major water resources for the country. The importance of ensuring the continuous monitoring on waterway is because of water is one of the important aspects in human life as well as other live forms such as plant and animal [1]. Any activities associated with agriculture and industry also need continuous supply of water. The demand of fresh water continues to increase from time to time due to the development of agriculture and industrial activities as well as increase in human population [2].

In Malaysia, waterway such as rivers has become the major supplier in fresh water. There are about 1800 rivers in Malaysia with the total length of the rivers are estimated to be 38,000 km. There are also about 30 dam in Malaysia which purposely for harvesting hydroelectric energy and fresh water resources [3]. Between the large numbers of river in Malaysia, 30 of the river have become main reservoirs which contribute to the 97% of water supply throughout Malaysia and responsible to satisfied the needs of almost 25 million of people currently living in Malaysia [3]. Even though the statistics has shown the importance of the rivers as the main resource for water supply, many of the rivers today has been polluted with industrial waste and most of the illegal activities involving industrial waste dumping has been done in remote areas due to the lack of supervision from the authorities at those areas [4]. Besides that, based on the data collected by agencies in Malaysia, it shows that only 50% of rivers in Malaysia remain clean while the other half are polluted from several factor [5].

The problem with the current situation is the river or water reservoir is unattended. The existing system also requires data connection and workers to continuously monitor the river. This is not a practical solution due to the fact that the area of river network in Malaysia is very large [3]. Therefore, the needs to develop a more reliable monitoring system has become the main objective of this project to develop systems that can monitor by detecting the changes in parameters of the waterway and the information will be transmitted by light information through the optical fiber [6]. The scope of this project is the development of Fiber Bragg Grating (FBG) signal detection using Agilent VEE, development of sensing mechanism and reaction system for hazardous condition. The foundation for this monitoring system is a technology developed in the 70s and 80s known as a Fiber Bragg grating (FBG) optical fiber. The FBG optical fiber is sensitive to both temperature and strain which serve as excellent choice of medium for this system [7]. The FBG will act as the main medium for transportation of information by reflecting narrow spectra of light whose wavelengths shift due to temperature/strain variation [8].

The significance of this project is to solve the problem with existing system which either require data connection or labour intensive. The system also being develops to enable long distance monitoring without having to hired more workers to constantly monitor the waterway from pollution and hazardous condition.

II. Methodology

Methodology section for this project will be divided into three section which are conceptual framework, monitoring and information processing and fiber optic system. Fiber optic system will be further divided into three more section which are optical fiber system, Fiber Bragg grating sensing and sensor interfacing.

A. Conceptual Framework

Multiple FBG can be connected along the fiber optic line which allows integration of multiple electronic sensors for different purpose [9]. The parameters that are chosen are oil spill detection, pH of water, water level and water flow rate. The hardware for this project also needs to be set up to replicate the actual surrounding environment where this system will be implemented. The equipment used for the tasks are microcontroller, optical fiber, wavelength meter, light source and electronic sensor. Wireless module is used for transmitting data wirelessly within the system. To illustrate the functionality, we consider one of the analyses which are pH detection. When there has a changes pH in the water, the voltage signal will be converted to light signal and then it will shift to maximum wavelength. The wavelength meter is used to detect the wavelength and the data analysis is expected to interface using Agilent VEE. The wavelength will be measured by wavelength meter and process the analysis data using Agilent VEE. The microcontroller is used to trigger reaction system which is in the form of light indicator and message alert when monitoring site has any hazardous condition. The location of the exact location of the parameters changes detected will be displayed on Agilent VEE and will notify the authorities for further action.

Different electronic sensor can be used to detect any desired parameter. FBG can be attached anywhere along the river such as shown in fig. 1. FBG at site 1 attached at km A, FBG at site 2 attached at km B and FBG at site 3 attached at km C. Those FBGs will detect the changes of the wavelength cause by the pressure inducer. The information data from the value of changes wavelength is send to monitoring station and process into graphical display. A real-time situation can be monitored at the monitoring station such as oil detection at site 1, pH sensing at site 2 and water level at site 3. The data also will trigger action system such as GSM alert and other notification to alert authorities if there is any hazardous condition happen and protect water reservoir from pollution.

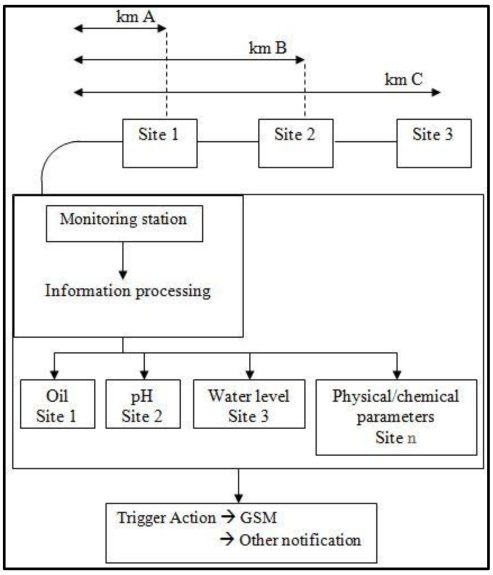


Figure 1. The framework of the project.

Fig. 2 shows the overall system architecture of the project. There are three sensing site which is site 1, site 2 and site 3 along the optical fiber network. The entire sensing site is situated at different kilometer from the monitoring station. Each sensing site can be attached to a different electronic sensor in order to sense changes of different parameter such as pH of water, oil spill detection, water level and water flow. This information will be process at monitoring station and the location for any parameter changes can be detected using this system.

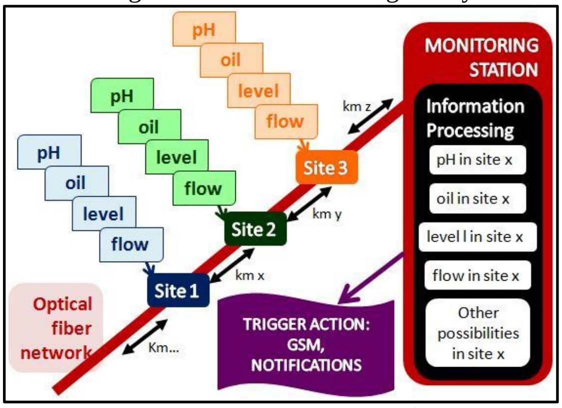


Figure 2. The overall system architecture of the project.

B. Monitoring and Information Processing

The system will turn on and start detect if there are any changes in wavelength from any site of FBG. If there are changes the system will process and trigger the alert signal and at the same time the system will continue to detect if there are any changes in wavelength again for continuous monitoring. This monitoring algorithm as shown in fig. 3 will sent information to the wavelength meter and the wavelength meter will sent the information to Agilent VEE software. This software will process the information and display it in the form of graphical display for monitoring purposes.

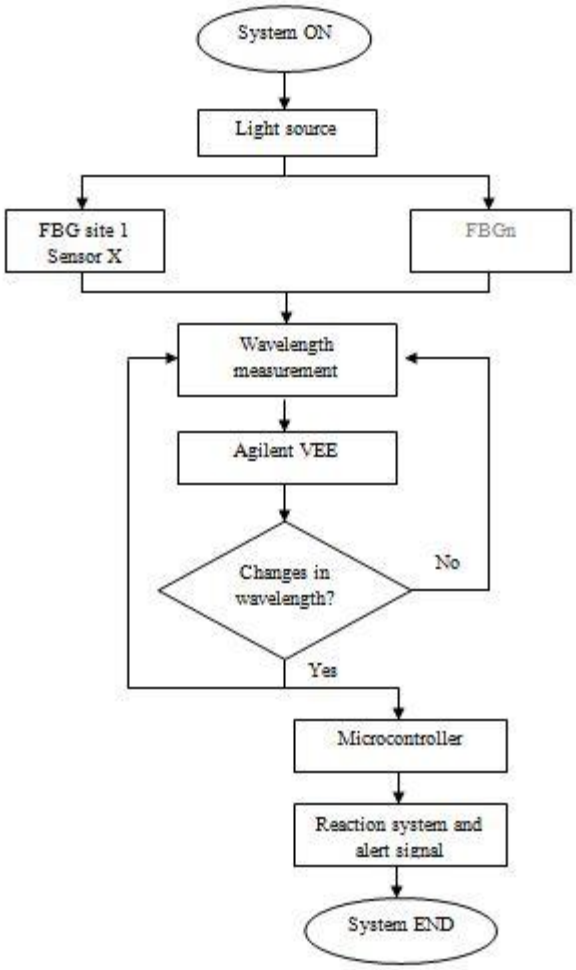


Figure 3. The flow chart of waterway monitoring system using fiber optic sensing approach.

C. *Fiber Optic System*

Fig. 4 shows the overview of optical fiber network along the rivers in Malaysia. For physical sensing, physical properties like temperature and stress can be measured while for chemical sensing; chemical properties such as pH measurement and gas analysis can be measured. Chemical or physical sensing using standard sensor can be attached at a specific point along the river such as at site 1 for sensor x and site 2 for sensor y. If there is sudden pH change, the information will be sent to the monitoring station houses the Agilent VEE processing and can send out alert signal to authorities for further action.

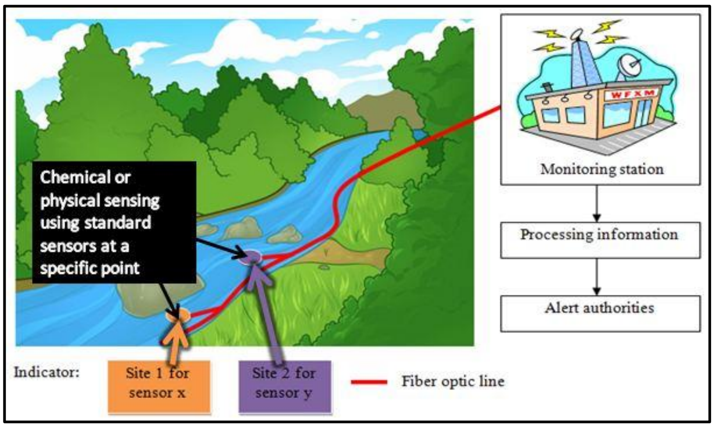


Figure 4. Environmental water quality monitoring illustration.

1) *Optical Fiber System*

Fig. 5 shows basic fiber optic system set up consist of light source, detector and optical fiber. Light source emits light signal into the optical fiber line which represent by red line. The light signal in the fiber will be detected by the detector. This is the basic working principle of fiber optic system used in this project.

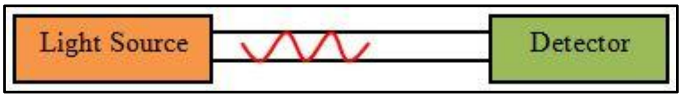


Figure 5. Basic fiber optic system set up.

Fig. 6 shows fiber optic sensing system set up used as the backbone of this project. This set up consist of light source, detector, coupler, optical fiber and FBG sensor. In this case, there will be three sites along the optical fiber line spliced with FBG sensor which is FBG at site 1, site 2 and site 3. Light source emit light signal into the optical fiber line. Coupler is needed to copy information in the optical fiber line to the detector. FBG sensor will cause shifting in wavelength when pressure inducer induces different pressure to it [10]. This differences in induce pressure is cause by the different in output voltage of electronics sensor attached at that particular sensing site. The FBG at each site will reflect different wavelength and this information will be couple to the detector by the coupler and will further analyze at the monitoring station.

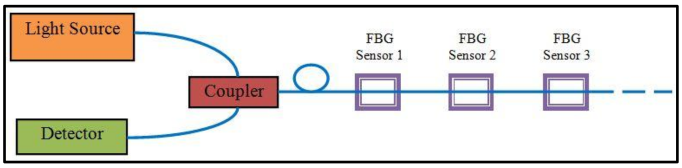


Figure 6. Fiber optic sensing system set up.

Fig. 7 shows fiber optic sensing system architecture used for this project. The system consists of pressure inducer to induce pressure to FBG according to output voltage of sensor. If hazardous condition occurs, the system will trigger reaction system and alert message to alert authorities and saving water resources from contamination.

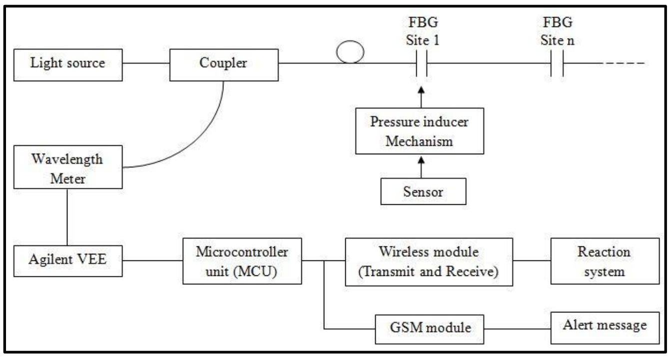


Figure 7. Fiber optic sensing system architecture.

2) *Fiber Bragg Grating Sensing*

Fig. 8,9,10 and 11 shows fiber Bragg grating sensing principle used for this project. Light signal emitted by light source will go into the optical fiber line and will pass through each FBG. Frequency (wavelength) which is in phase with that particular grating of any FBG will be blocked (reflected) while the rest allowed to pass. The remaining light signals will pass through another FBG and whichever wavelength in phase with that particular FBG will also be reflected back [11]. All of the reflected wavelength will be detected by the detector and analyze at monitoring station.

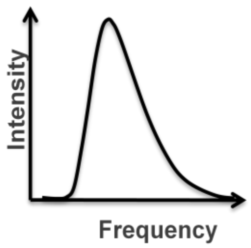


Figure 8. Wavelength of injected light signal by light source into optical fiber.

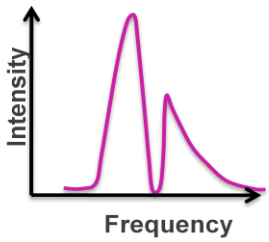


Figure 9. Wavelength of remaining light signal in optical fiber after passing through FBG.

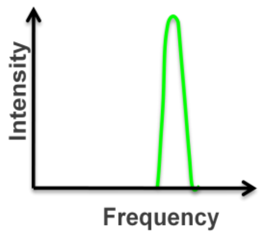


Figure 10. Wavelength of reflected light signal back to detector in optical fiber after passing through FBG.

Figure 11. Fiber Bragg grating fiber with grating represent by red line.

3) *Sensor Interfacing*

Fig. 12 shows block diagram of sensor interfacing in this project. Any type of electronic sensor for any monitored parameters can be attached to the FBG gripper and couple to the optical fiber line at any sensing site along the monitoring areas. The electronic sensor will give different output voltage during sensing changes in parameters. For example, if pH sensor detects the water pH is acidic. It will give out certain value of output voltage. This output voltage will trigger the FBG gripper to induce certain amount of pressure to the FBG along the optical fiber line. This will cause shifting of central wavelength of the FBG as shown in fig. 13. This change of information will be detected by wavelength meter at the monitoring station.

Figure 12. Block diagram of sensor interfacing.

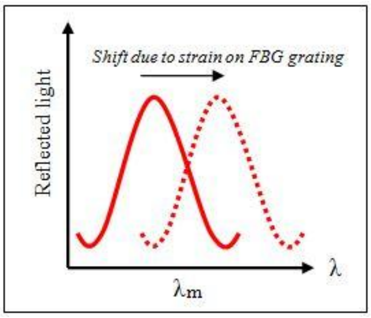


Figure 13. Shifting in wavelength due to strain induced by FBG gripper.

III. RESULT AND DISCUSSION

There are 3 parameters that were monitored using this system which are pH detection, oil detection and water level detection. The results for the whole system also will be explained in this section.

A) *Oil Detection Sensor.*

Fig. 14 shows the full set up of oil detection sensor. The electronic oil detection sensor is used as an input on this project that created the analog voltage signal. The analog voltage is feed to the microcontroller circuit to convert the analog voltage into pulse width modulation to drive a servo motor. The servo motor is coupled to FBG gripper to induce pressure on FBG. The different state of solution will created different voltage signal and resulting different level of pressure. The shifting wavelength that results from different level of pressure is measured by wavelength meter.

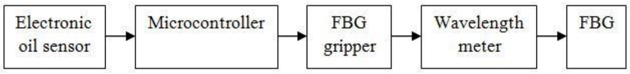


Figure 14. Full system set up of oil detection sensor.

An oil detection sensor can detect the presence of oil surrounding it. This sensor uses the two probes to pass current through the water, and then it reads that resistance of the solution. If the solution contains only water, it conducts electricity more easily (less resistance), while if the solution is a mixture of water and oil, it conducts electricity poorly (more resistance) due to the influence of oil to the conductivity of water. This difference in output voltage will be detected by microcontroller and servo motor will cause FBG gripper to induce certain pressure to FBG according to output voltage level. The result in tab. 1 shows when there is only water in the solution, the average output voltage is 2.08 V and the average shifting in wavelength is 1553.614 nm while when the solution contain water and oil, the average output voltage is 0.75 V and average shifting in wavelength is 1554.022 nm. The measurement was done using +5.90Vdc supply for servo motor and FBG central wavelength of 1553.614 nm. This difference in average shifting in wavelength detected by wavelength meter will be processed by Agilent VEE for monitoring purposes. This result also shows that an alert signal can be triggered if oil spill is detected along the river.

TABLE I. AVERAGE SHIFTED WAVELENGTH AND OUTPUT VOLTAGE MEASUREMENT OF OIL DETECTION SENSOR.

State	Average Output Voltage, (V)	Average Shifting in Wavelength, (nm)
Water	2.08	1553.614
Water + oil	0.75	1554.022

B) *Water Level Sensor*

Fig. 15 shows the full set up of water level sensor. The electronic water level sensor is used as an input on this project that created the analog voltage signal. The same set up as oil detection sensor is used to interface water level sensor to microcontroller and FBG gripper. Water level sensor can be modeled as a variable resistance. The lower the water level the higher the resistance and the higher the water level the lower the resistance. This is due to the influence of water which reduces the resistance of the metal plate inside the sensor.

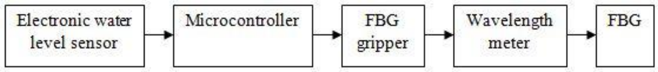


Figure 15. Full system set up of water level sensor.

Tab. 2 shows the difference in output voltage of the sensor when measured for three different water levels which are 5cm (low water level), 10cm (medium water level) and 15cm (high water level). The average shifted wavelength for three different levels also measure using wavelength meter. The results show that the sensor has high repeatability. The measurement was done using +5.90Vdc supply for servo motor and FBG central wavelength of 1553.614 nm.

TABLE II. OUTPUT VOLTAGE AND AVERAGE SHIFTED WAVELENGTH MEASUREMENT OF WATER LEVEL SENSOR.

Water Level, (cm)	Output Voltage, (V)			Shifted Wavelength, (nm)			Average Shifted Wavelength, (nm)
	Reading			*Reading*			
	1	2	3	1	2	3	
5	7.6	7.75	7.67	1553.632	1553.633	1553.633	1553.633
10	6.18	6.15	6.24	1553.807	1553.808	1553.807	1553.807
15	4.91	4.96	4.89	1553.953	1553.924	1553.924	1553.934

Fig. 16 shows the graph of average shifted wavelength from FBG gripper varies with water level. The graph shows that the linear equation is y = 0.150x + 1553 where the value of slope in the linear line indicates the sensitivity of water level sensor. The sensitivity of water level sensor is 0.150nm/cm. This difference in shifted wavelength detected by wavelength meter will also be processed by Agilent VEE for monitoring purposes and if the water level goes to high level the Agilent VEE will send signal that will trigger alert system.

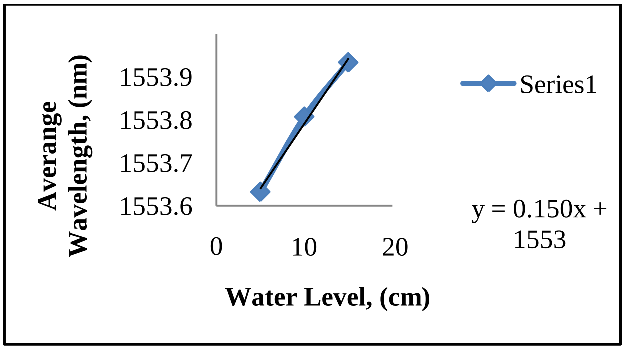
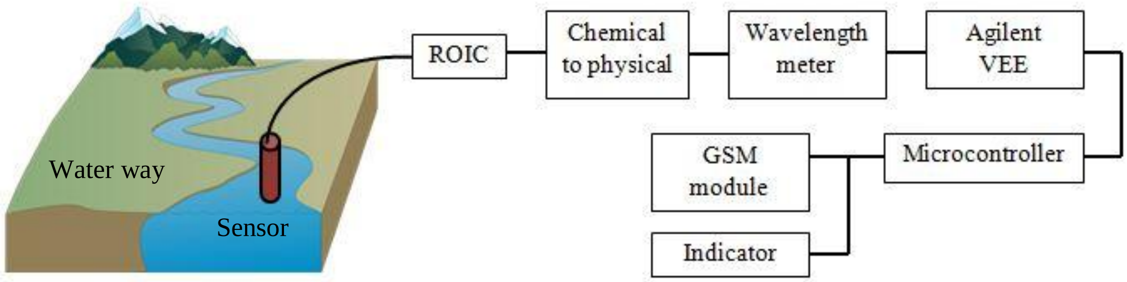
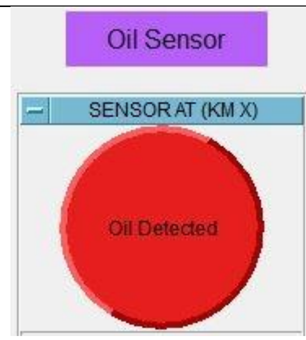


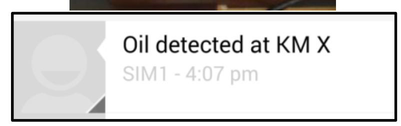
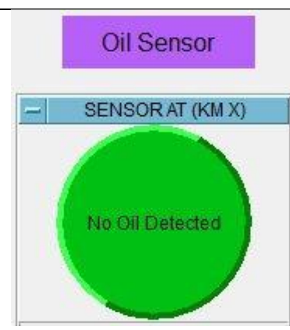
Figure 16. Graph of average shifted wavelength varies with water level.

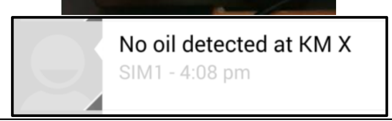
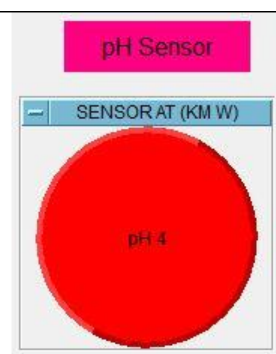
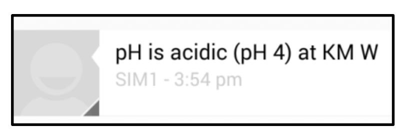
C) Results Compilation of Overall System

TABLE III. RESULTS COMPILATION OF OVERALL SYSTEM.



<table>
<tr><th colspan="2">Sensor</th><th>Wavelength</th><th>Agilent VEE (Graphical User Interface)</th><th>GSM Notification and Indicator</th></tr>
<tr><td rowspan="2">Oil Sensor</td><td>Oil detected</td><td>1553.614nm</td><td></td><td>SMS sent with red led indicator

</td></tr>
<tr><td>No oil detected</td><td>1554.022nm</td><td></td><td>SMS sent with green led indicator

</td></tr>
<tr><td>pH sensor</td><td>pH 4</td><td>1549.484nm</td><td></td><td>SMS sent
</td></tr>
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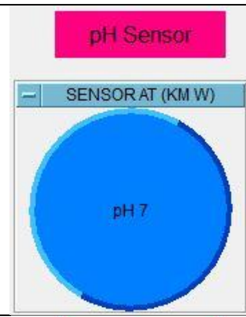
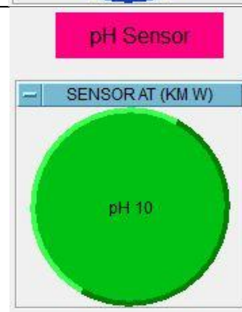
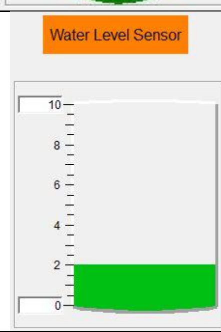
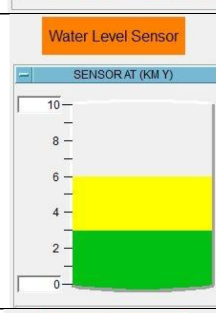
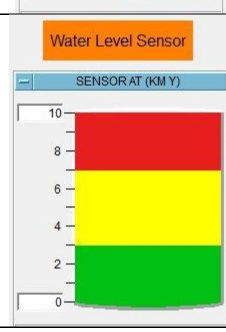
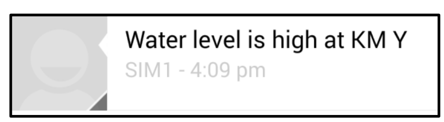
a. pH sensing was covered by student of ELE 607, Nazatul Shafinaz binti Kamal Ariff (2010282282).

pH sensor	*pH 7*	1549.598nm		SMS not sent
	pH 10	1549.803nm		SMS not sent
Water level sensor	*Low water level*	1553.63nm		SMS not sent
	Medium water level	1553.80nm		SMS not sent
	High water level	1553.93nm		SMS sent 

Tab. 3 shows the overall compilation result of the system. When there are any changes to the measured parameters, the system will display real-time data at the monitoring station. Alert signal also will be sent to authorities through SMS alert and light indicator to indicate there might be some hazardous condition happens along the monitored areas. This will ensure fast reaction from authorities to protect water resources from any hazardous condition or contamination.

V. Conclusion

The objective of this project which is to design the system that can provide continuous monitoring of water quality and properties in long distance has been achieved because by using fiber optic sensing system for monitoring purposes, long distance area can be monitor and different parameters such as oil spill detection, pH changes and water level can be observed. The benefits of this project is to ensure water resources can be monitored continuously from any pollution and labour cost also can be reduce due to the reliable system that can cover long distance of monitoring areas. The limitation for this system is the wide-spread usage of fiber optic system in Malaysia and cost consideration for the system to be implemented. This project also can further develop and equipped with more sensor and reaction system that will allow more parameters of water quality and water properties can be monitored. With this system in place, the application of this will provide a better water quality supply to the community in future.

Acknowledgement

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References

[1] F.A.Badaii, M.S. Othman, M.B. Gasim. (2013, July 21). Water Quality Assessment of the Semenyih River, Selangor, Malaysia [Online]. Available:http://www.hindawi.com/journals/jchem/2013/871056/[July.16,201].

[2] H. Don and T. Henrylito. (2011, Jul). Finding the Source: The Coming Freshwater Crisis is Already Here. *Wilson Center*.[Online] Available:http://www.wilsoncenter.org/staff/don-hinrichsen [May.18,2014].

[3] 1s1rcommunity. “What Is a River and a River Basin?,” *1s1rcommunity.net*.[Online].Available: http://www.1s1rcommunity.net/index.cfm?&menuid=4 [July.15,2013].

[4] P. Aruna. (2014, Apr). Rivers of filth and garbage[Online]. Available:http://www.thestar.com.my/News/Nation/2014/04/07/Rivers-of-filth-and-garbage-Pollution-a-contributing-factor-to-current-water-shortage/ [May.20,2014].

[5] Department of Environment (DOE).(2010). Malaysia Environmental Quality Report 2010.

[6] Theborneopost. “Real-time monitoring system to check on river pollution,” *theborneopost.com*.[Online].Available: http://www.theborneopost.com/2011/09/14/real-time-monitoring-system-to-check-on-river pollution/[July.16,2013].

[7] Jaw-Luen Tang; Jian-Neng Wang; Er-Liang Chien; Yi-Shian Wang, "Use of fiber Bragg grating sensors for fiber optic pavement monitoring system development," *Lasers and Electro-Optics, 2003. CLEO/Pacific Rim 2003. The 5th Pacific Rim Conference on* , vol.2, no., pp.571 vol.2,, 15-19 Dec. 2003.

[8] L. Meyer (2013, Sept 30). Optical Sensors Improve Railway Safety.[Online]. Available: http://www.osa.org/enus/about_osa/newsroom/newsreleases/2013/optical_sensors_improve_railway_safety/. [July.15,2013].

[9] Junjie Bai; Zhoa Damei; Zang Ziuyan .“Structural health monitoring of smart civil structures based on fiber Bragg grating sensing technology,” *Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC)*,2011,pp.635-638.

[10] M.L.H. Jose.”Optical Fiber Gratings Applications,”in *Handbook of Optical Fibre Sensing Technology*,J.Wiley,Ed.England: John Wiley &Sons,2002, pp.58-59.

[11] H.Jeff.”Specialty Fibers,”in *Understanding Fiber Optics*, 5th ed., S.E. Charles, Ed. New Jersey: Pearson Education, 2006,pp.151-172.