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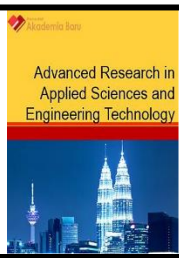

A Review on Water Quality Monitoring Methods Based on Electronics and Optical Sensing

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ABSTRACT

Water pollution is a detrimental issue that can affect health, economy, society, flora, and fauna. Monitoring water quality is important to mitigate water pollution issues. The purpose of this research is to investigate several water quality monitoring methods based on electronics and optical sensing. Electronics and optical sensing are among common and popular methods used to monitor water quality. The smart platform is used to work together with electronics and optical sensors to assist users in controlling the system. Both methods have their own benefit such as electronics sensing being portable and easy to handle whereas optical sensing does not affect the water sample, leading to higher accuracy results. Thus, the selection of the suitable method depends on the consumer's requirement, cost, budget, and time.

Keywords:
Low-cost; real-time; portable; water quality monitoring system; water pollution

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1. Introduction

Water is a crucial resource for every life on earth in order to survive. Malaysia's primary water supply sources are surface water and groundwater[1]. Human needs water for drinking, hygiene and sanitation while other different key sectors like industrial, manufacturing and agriculture use water for purposes like removing and watering down waste, growing food and transportation [2]. Despite enormous water resources in Malaysia, the rapid pace of current industrialization and population has given impact on water quality [1]. Pollution in water sources becomes a huge problem in Malaysia with the main sources of pollution come from domestic sewage, garbage, and discharge from agriculture and manufacturing businesses [3]. Arsenic, iron, lead, and other heavy metals are commonly found in groundwater sources in agricultural areas, radioactive waste landfills, municipal water supply sources, and garbage dumps [3,4]. Water pollution rises with economic progress, result

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in the important of detecting water pollutants. Covid-19, a pandemic concern, also affects water quality when non-essential services, such as development project work, are halted while the demand of clean water is intensified for hygiene and sanitation [5].

Water quality management in Malaysia with about 488 water treatment plant requires all surface water and groundwater to be treated before distributed and supplied to users [6]. Rapid growth of human population, urbanization and industrialization cause the emerging of new contaminants and pollutants, worsening the pollution impact on the nature. However, some water management companies in Malaysia stayed with conventional water treatment system which is outdated to remove these pollutants [7].

Water also can be contaminated during and even after treatment when being supplied to consumers, not only limited to be polluted at the sources. Chemicals are used in water treatment to remove heavy metals in water. Aluminum sulfate (Alum) is widely used to reduce the amount of phosphorus in water for water clarification process when Ab Razak *et al*., claimed that Alum has also become the source of water pollution [8]. Pipelines in Malaysia nowadays are made of plastic, stainless steel, ductile iron and mild steel pipes which replace galvanized iron pipe that is used in the past due to the corrosion that occurs inside the pipes [6]. Despite that, galvanized iron pipes are still being used and yet to be replaced because of the limited budget and the pipes' condition are still good, result in the risk of consumers having water polluted with corrosion. With the advancement of technologies nowadays, most households have their own water filtration system. Improper maintenance of the system can lead to discharging of heavy metals like nickels, chromium and aluminum [6]. Thus, there are needs for better improvement in water quality monitoring systems and the water monitoring process should be done consistently and properly.

Water quality can be accessed through parameters which include chemical, physical and biological properties. These parameters can be monitored and tested according to the concerned water. The persistent and key parameters which are monitored and tested as the indicator to determine the quality of the water are dissolved oxygen (DO), turbidity, temperature, pH, bioindicators and nitrate chemicals. Turbidity and temperature parameters are the physical properties of the water whereby turbidity is important to measure the cloudiness and murkiness of the water [9]. DO, pH and nitrate chemicals parameters are the chemical properties of the water. DO is the amount of oxygen available in the water while pH tells the acidity and alkalinity of the water. Nitrates chemical parameter measure the amount of nitrogen in the water. Biological properties of the water can be represented through bioindicators parameters. Bioindicators are the organic and natural indicators like plants, planktons, microbes and algae which are used to determine the health of the water [10].

Here, we review many techniques on water quality monitoring system based on electronics and optical sensing. Both electronics and optical sensing have benefits and weaknesses. The consumers can opt for the best solution depending on the project and situation requirement.

2. Electronics Sensor-Based Water Monitoring

Electronics sensors for water quality monitoring have been widely developed, improved and used to detect and analyze water parameters like pH, turbidity, conductivity, dissolved oxygen and so on [11]. Water pollutions occur during distribution process cause the development of electronic sensors for water monitoring. This is because the sensors have low production cost, real-time and continuous water monitoring, and portability.

Alam *et al*., [12] built a multi-parameter water quality monitoring system (MWQMS) that monitors water pH, free chlorine concentration, temperature and bisphenol A (BPA). The system allows monitoring through user-friendly smartphone application using wireless connection without the needs of skilled personnel. The sensors allow real-time detection of pH, temperature and fast detection of free chlorine concentration and BPA. A smart water quality monitoring (WQM) was developed to monitor temperature, pH level, water level, carbon dioxide (CO_2) level by interfacing transducers with sensors network. The sensors outputs were sent to web server by using Internet of Things (IoT) technologies. Thus, monitoring can be done at anytime and anywhere in real-time [13]. Demetillo *et al*., [14] developed a low cost and real-time water quality monitoring system that was used for monitoring quality of lakes, rivers and other water resources. The system consisted of microcontroller and electrochemical sensors which are pH sensors, dissolved oxygen (DO) sensors, and temperature sensors. The system was attached to a customized buoy that floated on water. The monitoring was done in pre-determined and programmed time interval and the results were observed over web server using wireless communication system. The developed system can monitor the quality of water resources in real-time and continuously. Types of microcontrollers are also considered in developing electronics water quality monitoring system due to factors like, cost, power supply, robustness, durability and complexity. Anuradha *et al*., [15] developed a cost-effective system for monitoring the quality of water in real-time. The system monitored pH, temperature, turbidity and Total Dissolved Solids (TDS) of water by using different types of sensors. Raspberry Pi microcontroller was used to process the output of the water sensors and ThingSpeak, an internet application programming interface was used as the user interface. The system used low power and portable. Main issue of a laboratory-based water monitoring system is the need of workers to collect samples from each water sources which lower the accuracy of the data as the information obtained are not in real-time and continuous. Johar *et al*., [16] built a tank water quality monitoring and controlling system using IoT. pH and temperature of water were obtained using electronic sensors which were integrated with NodeMCU EP8266 for the readings. The readings will be sent to Blynk application through internet. Blynk is an application that allows users to monitor the quality of tank water.

However, electronics-based water monitoring systems have drawback such as limited water contaminants can be detected by sensors due to low sensitivity of electronic sensors when the contaminants are in low concentration. This results in low accuracy of data obtained [17,18].

3. Water Quality Monitoring using Optics

Water quality monitoring systems using optics are systems that manipulate the characteristic of light including transmission, absorption and fluorescence spectrum to measure and identify the concentration or characteristics of a chemical species [19]. Water parameters that can be determined by using optical sensing water quality monitoring systems are concentration of suspended solid, size of contaminants, presence of chemicals and concentration and characteristics of dissolved organic matter [20]. Transmission, absorption and reflectance spectra of light in water allow determination of turbidity of water, size of particles, and concentration of contaminants in water. Spectroscopy techniques are the examples of classic optical techniques to monitor water quality that are still relevant till today. Systems using spectroscopy are very reliable, accurate, sensitive, fast response time, low maintenance costs, non-intrusive and non-invasive techniques for water quality monitoring. However, the technique has weaknesses like complicated to use, discrete samples collected weekly, laboratory based, require expert to handle and delay in time due to analyses of results. The weaknesses limit the ability of the systems using spectroscopy technique [21] and have led to the innovation of water quality monitoring system using optical sensors including optoelectronic sensors [22]. Overall, systems using optics benefit water quality monitoring by allowing more accurate, non-intrusive and non-invasive with detection of more water quality parameters.

3.1 Spectroscopic Techniques

Spectroscopic technique is the utilization of light to interact with matter. The interactions allow probing of certain properties of a sample to gain an understanding on the structure or consistency of the matter [23]. The spectrometry method was first discovered by Newton when he studied the radiation of white light that split up into various shadings while going through a crystal [24]. Various types of spectrometers are invented to measure the wavelength and frequency of light include mass spectrometers, optical spectrometers, electron spectrometers, and magnetic spectrometers [25]. There are many distinct types of spectrometers, each with its own set of variants and alterations that are tailored to certain uses. X-ray, UV-VIS (Ultraviolet–Visible), IR (Infra-Red), and microwave are the regions of the electromagnetic wave spectra that have traditionally been utilised.

In water monitoring, spectroscopic technique uses the interaction between scattered light and water samples to gain knowledge on the chemical and biological components in the water [26,27]. Due to its non-invasive and non-intrusive testing, minimum preparation of samples and rapid response, spectroscopic technique that is more precise and environmentally compatible like vibrational spectroscopy has been widely explored and studied. Later, the conservative water analytical techniques like gas chromatography (GC) are gradually replaced. Three primary types of spectroscopies used for vibrational spectroscopic technique are Raman, infrared (IR) and near-infrared (NIR) spectroscopy. As the structure and environment of a molecule affects the vibrational frequencies, experiments are done to observe the changes in vibrational states of the molecule via the spectroscopy [28].

A molecule gives a unique and different vibrational spectrum which can be used as an identification for the molecule. This has led to the development and advancement of vibrational spectroscopy for the purpose of water quality monitoring [21]. The structure of water consists of tiny molecule. The structure is susceptible to changes in surrounding area due to the molecules having strong potential for hydrogen bonding. Accordingly, vibrational spectroscopies have been used to study water structure, such as Raman and NIR spectroscopy [29]. Near-Infrared has a wavelength between 700nm to 1200nm. NIR spectroscopy has been widely used for identification of some physical and chemical characteristic of water body. Lin and Brown [30] have shown the potential of NIR spectroscopy to determine and measure water parameters like density, vapor pressure and dielectric constant. Their research elaborated various reactions of electrolytes on water structure. Dabakk *et al.*, [31] used NIR spectroscopy to obtain reflectance spectrum of measured lake water. The reflectance spectrum differs the quality of the lake water according to the presence of algae. Water quality parameters measured in the study were total of organic carbon, total of phosphorus, colour and pH of the lake water.

3.2 Optical Sensors

In order to improve current detection and monitoring methods of water quality, optical water sensors are developed as there is a growing demand for low-cost, multiparameter, real-time, and continuous-monitoring approaches with improved temporal and spatial resolution. This is due to their unique characteristics, such as high throughput, small footprint, and low power consumption. Examples of optical water sensors include optical density-probes, optical biosensors, fibre-optic sensors, in-situ microscopes, near-infrared sensors, fluorescence sensors, refractometers and ultraviolet sensors [32-34]. Daraigan *et al*., [20] had constructed an optical sensor to monitor the transmitted light through water samples in order to retrieve total suspended solids (TSS) concentrations. Light emitting diodes (LEDs) are used in the proposed optical system to transmit light through total suspended particles in water samples. Physical variables such as particle size, shape, suspended solids concentration (SSC), and composition, as well as chemical properties such as the presence of NIR-absorbing dissolved materials, determine light transmission through a water sample. The values of transmitted radiation were calculated using the optical detector's output, voltage readings. Meanwhile, the TSS concentrations in the samples are associated with the voltage values. The link between these two characteristics was determined using a custom algorithm, which the radiation levels and total suspended solids TSS concentrations have a good association, according to the findings. An experiment was conducted by Hojris *et al*., [35] using a novel bacteria monitor to investigate its capability on identifying four different types of pollution: wastewater intrusion, rainwater runoff, resuspension of drinking water sediments, and bird droppings entering the distribution system. The results of the experiments showed a significant link between the bacterium signal from the sensor and total direct cell counts done in the lab. The sensor's ability to detect various simulated pollution events was demonstrated to be equivalent to laboratory-based total direct cell counts, and the pollution was detected at concentrations one half to two decades lower than the turbidity detection limit. On the other hand, oil in wastewater had been able to be measured through the findings of Jiang *et al*., [36] with the optical fibre surface plasmon resonance (SPR) sensor. The optical sensor was designed based on the principle of SPR that may observe the interactions of biological molecules in real time, without the need for labelling, separation, or purification. As the designed optical fibre SPR sensor system was put to the test in greasy wastewater at various concentrations, it is proven through the experimental results that the method achieved on-line monitoring and increased the real-time of detection. The operation was assisted by measuring the oil in wastewater with high accuracy, speed, and stability. Besides that, the optical fibre SPR sensor is designed to be tiny and portable, making it ideal for remote monitoring while able to test a variety of indicators simultaneously, such as water pollution levels, water temperature, and turbidity. The device also can be used in wide range of applications in environmental monitoring and protection, as well as industrial safety, and it can generate significant economic and social benefits.

4. Conclusions

This research reviews on water monitoring techniques and systems based on electronics and optics. Water contaminant detection techniques used by water companies in Malaysia are nationally standardized and usually are done in laboratory. The water monitoring systems involve the practice of both concepts but mainly optics. Water contaminant detection done by these companies need to be highly accurate in order to precisely manage the quality of water sources. Water monitoring using optics systems give better accuracy given that the number of samples and testing are much larger compared to when using electronics devices. However, the systems taking longer time to analyse the results and higher cost for all the testing. Water monitoring systems using electronics water sensors and devices are usually developed in portable kits to allow water to be monitored in real-time. They require only small amount of water samples for testing and use lower development and testing cost. Yet, they give lesser accuracy and limited detection of contaminants compared to optical water monitoring systems. Electronics and optics systems give great benefits and contributions to water monitoring technologies although both methods have some weaknesses. With rapid and arising growth in technology, the development and improvement of water monitoring systems nowadays must be up to date with current issues of water pollution. The systems should not only be able to detect but also quantify and classify new contaminants that come into existence. Fast and reliable responses are to be expected from current monitoring systems to allow water to be monitored continuously and detection is done at the early stage.

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References

[1] Bao, J. L. K. "Water quality study and its relationship with high tide and low tide at Kuantan River." *Universiti Malaysia Pahang, Pekan* (2010).
[2] Gleick, Peter H. "Basic water requirements for human activities: meeting basic needs." *Water international* 21, no. 2 (1996): 83-92.
[3] bin Khalit, Ahmad Rizal. "Current State of Water Environment in Malaysia." (2005).
[4] Bilal, Hamza, Abdul Ghafoor, and Anjum Munir. "Desalination of brackish water using dual acting solar still." *Journal of Engineering Research* 4, no. 4 (2016).
[5] Najah, A., F. Y. Teo, M. F. Chow, Y. F. Huang, S. D. Latif, S. Abdullah, M. Ismail, and A. El-Shafie. "Surface water quality status and prediction during movement control operation order under COVID-19 pandemic: Case studies in Malaysia." *International Journal of Environmental Science and Technology* 18, no. 4 (2021): 1009-1018.
[6] Ab Razak, Nurul Hafiza, Sarva Mangala Praveena, Ahmad Zaharin Aris, and Zailina Hashim. "Drinking water studies: A review on heavy metal, application of biomarker and health risk assessment (a special focus in Malaysia)." *Journal of epidemiology and global health* 5, no. 4 (2015): 297-310.
[7] Department of Environment, “Environmental Quality Report,” Putrajaya, 2020.
[8] Ab Razak, N. H., S. M. Praveena, A. Z. Aris, and Z. Hashim. "Quality of Kelantan drinking water and knowledge, attitude and practice among the population of Pasir Mas, Malaysia." *Public Health* 131 (2016): 103-111.
[9] N. Hassan Omer, “Water Quality Parameters,” in *Water Quality - Science, Assessments and Policy*, IntechOpen, 2020. doi: 10.5772/intechopen.89657.
[10] Parmar, Trishala K., Deepak Rawtani, and Y. K. Agrawal. "Bioindicators: the natural indicator of environmental pollution." *Frontiers in life science* 9, no. 2 (2016): 110-118.
[11] Lambrou, Theofanis P., Christos C. Anastasiou, Christos G. Panayiotou, and Marios M. Polycarpou. "A low-cost sensor network for real-time monitoring and contamination detection in drinking water distribution systems." *IEEE sensors journal* 14, no. 8 (2014): 2765-2772.
[12] Alam, Arif Ul, Dennis Clyne, and M. Jamal Deen. "A low-cost multi-parameter water quality monitoring system." *Sensors* 21, no. 11 (2021): 3775.
[13] Madhavireddy, Vennam, and B. Koteswarrao. "Smart water quality monitoring system using Iot technology." *International Journal of Engineering & Technology* 7, no. 4.36 (2018): 636.
[14] Demetillo, Alexander T., Michelle V. Japitana, and Evelyn B. Taboada. "A system for monitoring water quality in a large aquatic area using wireless sensor network technology." *Sustainable Environment Research* 29, no. 1 (2019): 1-9.
[15] Anuradha, T., Chaitra R. Bhakti, and D. Pooja. "IoT based low cost system for monitoring of water quality in real time." *Int. Res. J. Eng. Technol.(IRJET)* 5, no. 5 (2018).
[16] Johar, Haziq Lukman, Shamsul Mohamad, Shaharil Mohd Shah, and Rafizah Mohd Hanifa. "Water Quality Monitoring and Controlling Using IoT." *Journal of Electronic Voltage and Application* 2, no. 1 (2021): 20-25.
[17] de Winter, Casper, Venkata Reddy Palleti, Daniel Worm, and Robert Kooij. "Optimal placement of imperfect water quality sensors in water distribution networks." *Computers & Chemical Engineering* 121 (2019): 200-211.
[18] Du, Zengfeng, Jing Chen, Wangquan Ye, Jinjia Guo, Xin Zhang, and Ronger Zheng. "Investigation of two novel approaches for detection of sulfate ion and methane dissolved in sediment pore water using Raman spectroscopy." *Sensors* 15, no. 6 (2015): 12377-12388.

[19] Scully, P. "Optical techniques for water monitoring." In *Monitoring of Water Quality*, pp. 15-35. Elsevier Science BV, 1998.

[20] Daraigan, Sami Gumaan, Mohd Zubir Matjafri, Khiruddin Abdullah, Lim Hwee San, and Syahril Amin Hashim. "Water pollution monitoring using optical sensor based on transmitted light." In *Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense V*, vol. 6201, p. 62010U. International Society for Optics and Photonics, 2006.

[21] Gowen, A. A., R. Tsenkova, Michael Bruen, and C. O'donnell. "Vibrational spectroscopy for analysis of water for human use and in aquatic ecosystems." *Critical reviews in environmental science and technology* 42, no. 23 (2012): 2546-2573.

[22] B. Karlberg, P. Worsfold, and J. E. T. Andersen, "European Analytical Column," *TrAC Trends in Analytical Chemistry*, vol. 29, no. 6, pp. 447–451, Jun. 2010, doi: 10.1016/j.trac.2010.04.005.

[23] Andreas, H. "Spectroscopic Techniques: I Spectrophotometric Techniques." *K. Wilson, J. Walker,* (2010).

[24] Bakar, Norazhar Abu, Huize Cui, Ahmed Abu-Siada, and Shengtao Li. "A review of spectroscopy technology applications in transformer condition monitoring." In *2016 International Conference on Condition Monitoring and Diagnosis (CMD)*, pp. 372-375. IEEE, 2016.

[25] P. McIntosh, "Types of Spectrometers," *Sciencing.Com*, 2017. https://sciencing.com/atomic-absorption-spectrometer-work-6326899.html (accessed Jul. 20, 2020).

[26] Singh, Keisham S., Mahesh S. Majik, and Supriya Tilvi. "Vibrational spectroscopy for structural characterization of bioactive compounds." In *Comprehensive analytical chemistry*, vol. 65, pp. 115-148. Elsevier, 2014.

[27] H. W. Siesler, "Vibrational Spectroscopy," in *Reference Module in Materials Science and Materials Engineering*, Elsevier, 2016. doi: 10.1016/B978-0-12-803581-8.01318-7.

[28] V. P. Gupta, "Vibrational Frequencies and Intensities," in *Principles and Applications of Quantum Chemistry*, Elsevier, 2016, pp. 247–289. doi: 10.1016/B978-0-12-803478-1.00008-X.

[29] Bakker, H. J., and J. L. Skinner. "Vibrational spectroscopy as a probe of structure and dynamics in liquid water." *Chemical reviews* 110, no. 3 (2010): 1498-1517.

[30] Lin, Jie, and Chris W. Brown. "Novel applications of near-infrared spectroscopy of water and aqueous solutions from physical chemistry to analytical chemistry." *TrAC Trends in Analytical Chemistry* 13, no. 8 (1994): 320-326.

[31] Dåbakk, Eigil, Mats Nilsson, Paul Geladi, Svante Wold, and Ingemar Renberg. "Inferring lake water chemistry from filtered seston using NIR spectrometry." *Water research* 34, no. 5 (2000): 1666-1672.

[32] Kim, Chihoon, Joo Beom Eom, Soyoun Jung, and Taeksoo Ji. "Detection of organic compounds in water by an optical absorbance method." *Sensors* 16, no. 1 (2016): 61.

[33] Marose, Stefan, Carsten Lindemann, Roland Ulber, and Thomas Scheper. "Optical sensor systems for bioprocess monitoring." *Trends in Biotechnology* 17, no. 1 (1999): 30-34.

[34] Tengesdal, Ø. A., B. L. Hauge, and L. E. Helseth. "Electromagnetic and optical methods for measurements of salt concentration of water." *Journal of Electromagnetic Analysis and Applications* 6, no. 06 (2014): 130.

[35] Højris, B., S. N. Kornholt, S. C. B. Christensen, H-J. Albrechtsen, and L. S. Olesen. "Detection of drinking water contamination by an optical real-time bacteria sensor." *H2Open Journal* 1, no. 2 (2018): 160-168.

[36] Jiang, Xuehua, and Qingmin Meng. "Design of optical fiber SPR sensing system for water quality monitoring." In *International Conference on Computational Science and Engineering (ICCSE 2015); July*, pp. 20-21. 2015.