A Low Cost Nephelometric Turbidity Sensor for Continual Domestic Water Quality Monitoring System

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***Abstract*—This paper focuses on the design and development of a low cost nephelometric turbidity sensor for the continuity of domestic monitoring of water quality. The electronic turbidity sensor operates based on the scattered light intensity with regards to light scattering in solids and liquids. The electronic turbidity sensor used Light Emitting Diode (LED) as light transmitter, Light Dependent Resistor (LDR) as receiver, PIC 16F777 as a main processor and RS232 module for the integrated sensor communication between the computer. Laboratory experiments have been done by comparing the self-developed sensor with commercial turbidity meter (Hach 2100P) output of NTU. The advantages of the electronic turbidity sensor are lightweight, user friendly, low-power consumption, easy to monitor and low cost. Conclusively, the electronic turbidity sensor can be used as part of a low-cost sensor to provide continuous turbidity information of water quality directly to consumer. Laboratory tests are conducted and proven that the proposed devices produced a comparable NTU reading as commercial turbidity sensor. Moreover, with a low development cost of RM196.95, has been savings money compared to commercial turbidity sensor. Therefore, the development of this device can save cost and benefited to consumer by providing the water quality reading instantaneously.**

Keywords- Turbidity measurement, turbidity sensor, water quality, NTU, light scattering sensor.

I. INTRODUCTION

The fundamental of water quality parameter are essential in preventing the water-borne diseases. The laboratory testing is the most common method in analyzing the water quality. The use of electronic sensors penetrates the analysis due to cost and time effectiveness. In addition, the manual sampling process reduces and provides an accurate information directly to the investigated location without any laboratory testing. Due to these factors, the use of sensors are more preferable [1]. Turbidity is defined by the cloudiness or haziness of a fluid caused by suspended solids that are not normally visible to the eye. A standard has been outlined by World Health Organization (WHO) to determine the water quality parameter (WQP) for each water usage [2]. The significant parameters in water purification studies are temperature, turbidity, pH, total dissolve solid (TDS), bacteria oxygen demand (BOD) and heavy metal [3]. The turbidity is the most highlighted parameter and the best turbidity level for drinking water is below 1 NTU [4]. In Malaysia, the turbidity level is set below than 5 NTU in accordance to Ministry of Health standard [5].

There are variety of different particle sizes and shapes in the water known as suspended solids. Some of these particles are lightweight and easily floating, whilst the heavy particles precipitate to the bottom. These particles cause the water to appear cloudy or turbid especially the transparent solid such as glass and plastic. The suspended solids also contain the biological origins like zooplankton, phytoplankton and other organic particles. Sizes of particles are also play an important role, wherein the particle size that less than 0.45μm are harmless, however the particles attenuate, scatter and reflect light [6]. Consequently, the turbidity level indicates a variety of situations such as epidemics and pollution. The suspended sediments also cause damages to the environment such as irritation of fish gills and transporting of absorbed contaminants. These sediments affect the photosynthesis process by blocking the light source [7]. The spread of light can be used to measure turbidity at specific angle and wavelengths, usually 90º [8]. This paper is organized as follows; Section II presents a short resume of turbidity measurement technique followed by the development of electronic turbidity sensor in Section III. Section IV illustrates the sensor calibrations and laboratory testing followed by the results and discussions in Section V. Finally, the paper is concluded in Section VI.

II. TURBIDITY MEASUREMENT TECHNIQUE

Turbidity level is measured by determining the clarity of the water based on the amount of light passing through the impurities in the water. The impurities include particles (clay, silt and sand), algae, plankton, microbes and other substances. The sizes of the particles ranged from 0.004 mm (clay) to 1.0 mm (sand) [9]. However, to ensure the effectiveness of disinfection, turbidity level preferably less than 1 NTU [4]. In water purification, it causes impurities to coagulate into larger particles and filtered out with the addition of coagulant. This process is called coagulation or flocculation. Turbidity is measured by Nephelometric turbidity units (NTU) and observed with visual observation up to 20 NTU. Turbidity is the optical property in water, and hardly to measure. The cloudy or turbid of water is a subjective measurement [10]. Based on the measurement methods, different units are defined to standardize the level of turbidity and allowed a comparison. It can be measured relative to water clarity or directly by the instrument as turbidity meter or turbidity sensor.

Nowadays, there are three (3) modern methods for measuring turbidity, and two (2) methods measuring the amount of suspended solids [11]. These methods are developed to measure the turbidity measurement from a basic object visibility test. However, each method has its limitations and advantages [12]. Secchi disk is referred as a turbidity meter, where the disk is sunk in the water to examine the water clarity. This method is considered fast and cheap, but inaccurate readings with NTU [13]. Thus, the turbidity meter using nephelometry (90 degrees dispersion) or other optical scattering detection techniques are preferable in turbidity measurement on water samples. These turbidity sensors used optical technologies that can be placed directly in the investigated water to measure water turbidity. In addition, the turbidity sensor can be used for a continuous turbidity measurement [14].

III. Sensor Design and Development

Fig.1 shows the flowchart of electronic turbidity sensor development in measuring the turbidity level of water quality. The flowchart elaborates the operation of electronic turbidity sensor in details with LCD display. The electronic turbidity sensor utilizes the PIC 16F777 as the microcontroller which turns on the LED light and measures the brightness of the LED using LDR. The brightness of the light received by the LDR is processed by the microcontroller and displayed in the form of voltage and NTU on the LCD screen. In addition, the electronic turbidity sensor displays an output to the computer via USB cable from RS232 module. The sensor block diagram is shown in Fig.2.

The processing core of the electronic turbidity sensor is controlled by a PIC 16F777. There is a major component used to ensure that the electronic sensor operates effectively; i.e. LED as a transmitter of light, LDR as a receiver of light, the LCD displays the measured voltage and NTU value and RS232 module is to integrate between the sensor and computer through a USB cable. The electronic turbidity sensor circuit diagram is shown in Fig.3. In addition, this sensor can be connected to Matlab software as a data collection tools for displaying the output graph.

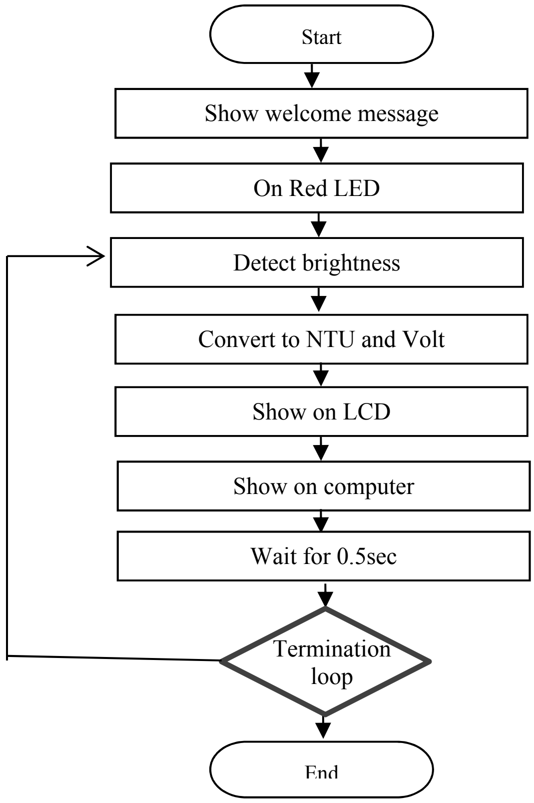

Fig. 1. Turbidity sensor operation flowchart.

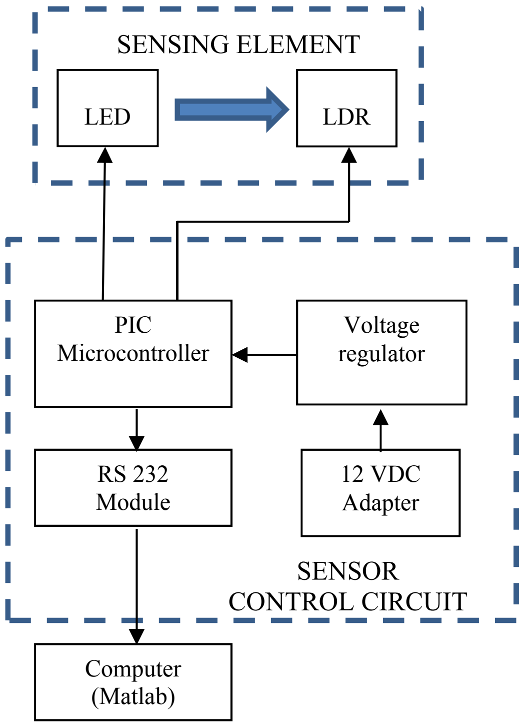

Fig.2. Turbidity sensor block diagram.

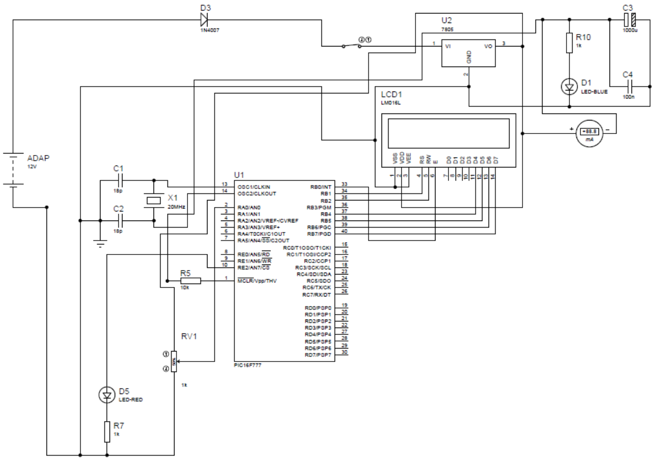

Fig.3. Turbidity sensor schematic circuit diagram

A. *Turbidity sensor cost*

The electronic components of the electronic turbidity sensor can be found in any of electronic component store. The estimated cost of an electronic turbidity sensor without the sensor housing is about RM 196.95. The development of the electronic turbidity sensor is cheaper than the available turbidity sensor/meter in the market. A complete electronic turbidity sensor consists of several electronic components as shown in Table 1.

TABLE 1: Total electronic component prize list.

Description	Value	Quantity	Unit Price (RM)
Microcontroller	PIC16F777	1	27.00
IC Socket	40 pin	2	1.00
Crystal	20MHz	1	1.20
Capacitor	18pF	2	0.30
Voltage Regulator	LM7805	1	1.20
Capacitor	0.1uF, 50V	1	0.30
Capacitor	1000uF, 16V	1	1.00
LED	5mm	1	0.20
Resistor	1KR	1	0.05
Diode	1N4007	1	0.20
Switch	On/Off	1	2.00
Photo PCB	300mm*150mm	1	28.00
Etching Powder	1Kg	1	20.00
PCB Developer	50g	1	8.00
Adapter	12VDC	1	30.00
LCD	2x16, Blue	1	40.00
Resistor	1KR	2	0.05
LED	5mm	1	0.20
Resistor	10KR, 1/4W, 5%	3	0.05
LDR	5mm diameter	1	1.50
Voltage Converter	Max232	1	4.00
Capacitor	1uF, 35V	4	0.70
RS232 converter	USB to Serial	1	30.00
Total			**196.95**

IV. Sensor Calibration and Testing

An indirect method for calibrating the electronic turbidity sensor is conducted. This calibration is to avoid the use of expensive chemicals which a common practice for a calibration [15]. For the calibration process, a stable water-clay mixture is prepared. 10 g clay powder is mixed with 200 ml distilled water as shown in Fig.4. Ten (10) water samples are prepared from a mixture of clay powder with different turbidity values.

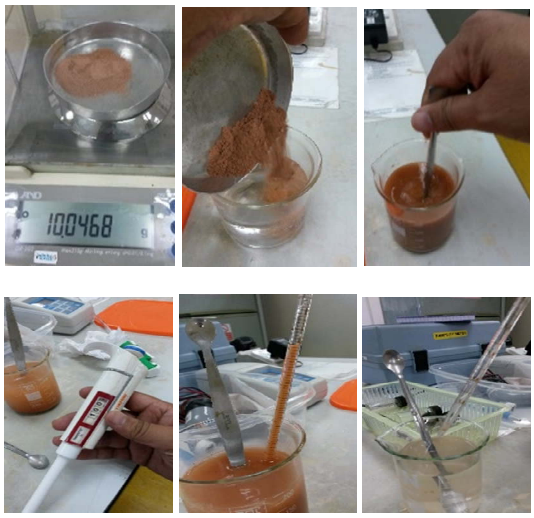

Fig.4. Clay water preparation for various (10 sample) turbidity water level.

The calibration procedures are as follows: A number of 10 samples are prepared by diluted a small volumetric value (mL) of clay water into 150ml of distilled water using a volumetric pipette. The turbidity of each sample is measured with the self-developed turbidity sensor and a commercial turbidity meter (Hach 2100P). Ten (10) water samples are prepared ranging from 0.1ml to 1.0ml for this experiment as shown in Fig.4. Each turbid water sample is measured using the self-developed turbidity sensor for voltage value as shown in Fig.5 (voltage measurement demonstration using the self-developed turbidity sensor). The same turbid water sample is measured by 2100P turbidity meter for NTU value (refer Fig.6 as the NTU measurement by commercial turbidity meter).

Fig.5. Voltage measurement demonstration for the self-developed turbidity sensor

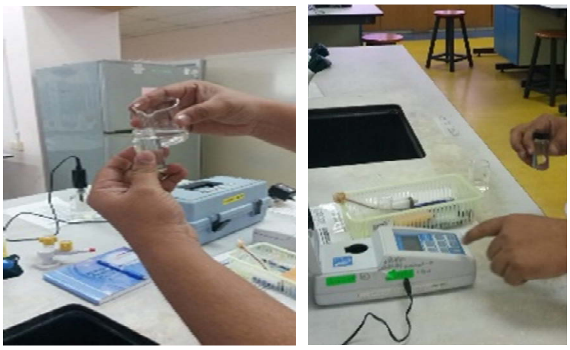

Fig.6. NTU measurement demonstration using commercial turbidity meter

V. Results and Discussions

The development of the electronic turbidity sensor is based on the water-clay mixture with different turbidity level. Ten (10) samples are prepared and analysed using the linear regression method for both apparatus (commercial turbidity meter and self-developed electronic turbidity sensor). The results and discussion for each method (self-developed turbidity sensor and commercial turbidity meter) are as follows:

A. Results of the self-developed sensor

The self-developed turbidity sensor indicates a linear increase with respect to the variation of turbid water samples. This sensor used voltage reading as the indicator. The voltages are regulated from 2.864Volt to 3.533Volt depending on the water turbidity. From the conducted experiment, the result shows that less turbid water would give a lower voltage reading. For example, the 0.1mL clay water gives 2.864Volt, whilst the 1.0mL clay water with 3.533Volt. This scenario indicates that less turbid water gives a less voltage value than more turbid water. The illustration of the result is shown in Fig.7.

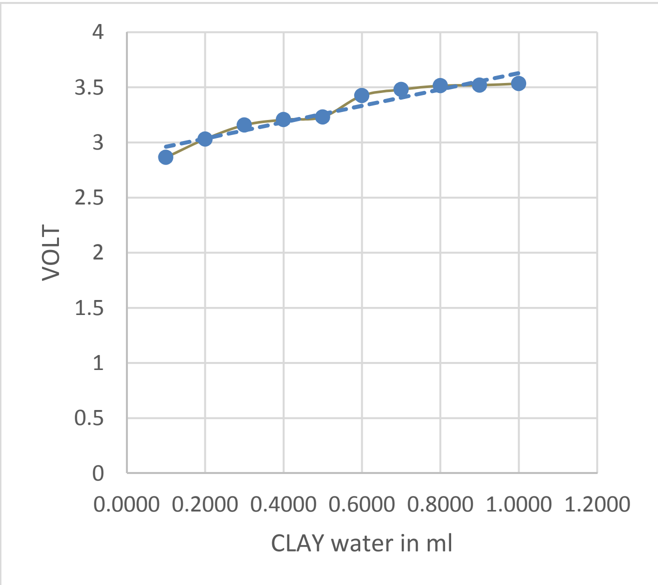

Fig.7. Turbidity sensor voltage graph

The linear regression relationship for self-developed turbidity sensor is shown in Eq. 1

$$V_o = 2.91927 + 0.74197\,X; \quad R^2 = 0.90397. \qquad \text{(Eq. 1)}$$

where V_o defines as voltage.

B. Results of the commercial turbidity meter

The commercial turbidity meter shows an increment with the variation of clay-water mixture. The commercial turbidity meter uses the NTU as an indicator. The NTU increases from 9.7NTU to 84.9NTU depending on the turbidity of water. From the conducted experiment, it is observed that less turbid water would give a lower NTU reading. It is obtained that 0.1mL clay water shows 9.7NTU, unlike the 1.0mL clay water with 84.9NTU. This indicates that less turbid water has a less NTU than more turbid water. The illustration of the experiment result is shown in Fig.8.

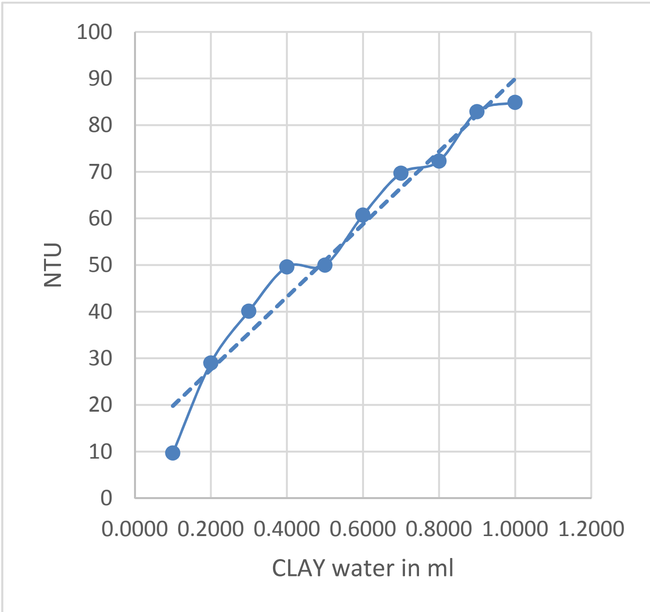

Fig.8. Commercial turbidity meter measurements graph

The linear regression relationship for commercial turbidity meter is given by Eq. 2

$$T = 12.48 + 77.9455\,X; \quad R^2 = 0.959. \qquad \text{(Eq.2)}$$

Using linear regression, the relationship between the V_o, of the self-developed turbidity sensor and the mL of the clay water with 150ml of distilled water (represented by x) is given by; $V_o = 2.91927 + 0.74197$ X. Consequently, the relationship between turbidity measurements, T (in NTU) of the commercial turbidity meter and the mL of the clay water into 150ml of distilled water is given by; T = 12.48 + 77.9455 X. The simplification of above equations (Eq.1 and Eq.2) gives the relationship between turbidity, T (in NTU) and the V_o (in volt) of the self-developed electronic turbidity sensor as in Eq. 3

$$T = 105.0518\,V_o - 294.1945. \qquad \text{(Eq. 3)}$$

With respect to the relationship of the aforementioned results, the programming of the sensor has been modified according to Eq. 3 (for the self-developed sensor to measured NTU value). The same samples of clay water are used to repeat the experiment using a self-developed sensor and the results are shown in Table 2. It is concluded that the difference of voltage reading between the self-developed turbidity sensor and commercial turbidity meter is less than 10%. The comparison of these methods is depicted in Fig.9. In light of this, the self-developed turbidity sensor is a reliable tool in monitoring the water quality.

TABLE 2. A comparison between commercial turbidity meter and sensor values with respect to the clay content

Clay	Meter	Sensor	% diff
0.10	9.70	8.70	10.31
0.20	29.00	26.00	10.34
0.30	40.10	37.00	7.73
0.40	49.60	44.80	9.68
0.50	50.00	45.00	10.00
0.60	60.70	66.00	-8.73
0.70	69.70	71.00	-1.87
0.80	72.30	75.00	-3.73
0.90	82.90	76.00	8.32
1.00	84.90	77.00	9.31

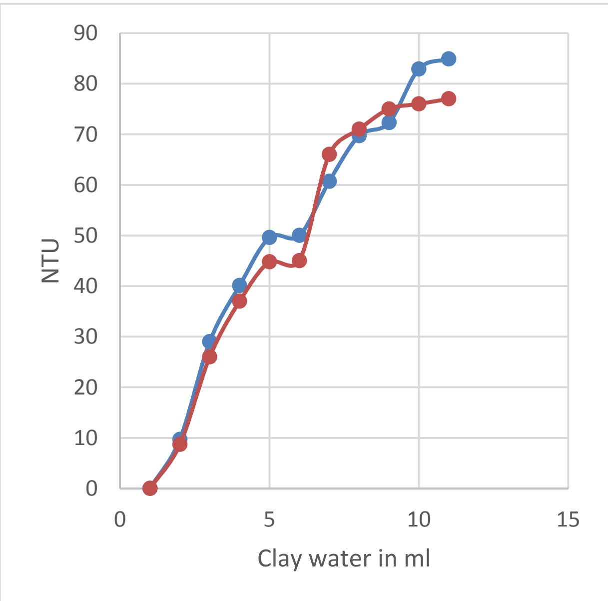

Fig.9. The comparison of NTU readings between the commercial turbidity meter and self-developed turbidity sensor.

VI. Conclusion

From the conducted experiment, it is proven that the self-developed sensor can be used to provide a comparable NTU readings as compared to commercial turbidity meter (Hach 2100P). It is found that the difference between the two methods with respect to the clay content is about 10%. Moreover, with a sensor circuit development cost of RM196.95, has brought savings money compared with commercial turbidity sensor. Therefore, the development of this device can save cost and benefited to consumer by providing the water quality reading instantaneously

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References

[1] S. Sendra, L. Parra, V. Ortuño, J. Lloret, and U. P. De Valencia, "A Low Cost Turbidity Sensor Development," *SENSORCOMM 2013 Seventh Int. Conf. Sens. Technol. Appl.*, no. c, pp. 260–265, 2013.

[2] I. A. A. Ahmad Aftas Azman, Mohd Hezri Fazalul Rahiman, Norbaya Sidek, "Water Quality Parameter : A Review On Dissolve Oxygen (DO) Control Method," *Int. J. Tech. Res. Appl. e-ISSN 2320-8163*, vol. 28, no. 28, pp. 98–102, 2015.

[3] S. N. Shamsudin, A. A. Azman, N. Ismail, and Mara, "Review on Significant Parameters and Techniques in Water Quality Assessments," *2015 6th IEEE Control Syst. Grad. Res. Colloq. (ICSGRC 2015*, pp. 1–6, 2015.

[4] W. H. Organization, "Guidelines for Drinking-water Quality," no. FOURTH EDITION, 2011.

[5] "Drinking Water Quality Surveillance Programme - Ministry of Health." [Online]. Available: http://kmam.moh.gov.my/public-user/drinking-water-quality-standard.html. [Accessed: 04-Oct-2015].

[6] World Population Prospects and T. 2010 Revision, "Directive 2001/42/EC of the European Parliament and o fthe Council on the assessment of the effects of certain plans and programmes on the environment," *Off. J. Eur. Communities*, vol. 197, pp. 1–3, 2001.

[7] J. P. G. Minella, G. H. Merten, J. M. Reichert, and R. T. Clarke, "Estimating suspended sediment concentrations from turbidity measurements and the calibration problem," *Hydrol. Process.*, vol. 22, no. 12, pp. 1819–1830, 2008.

[8] T. P. Lambrou, C. C. Anastasiou, and C. G. Panayiotou, "A nephelometric turbidity system for monitoring residential drinking water quality," *Lect. Notes Inst. Comput. Sci. Soc. Telecommun. Eng.*, vol. 29 LNICST, pp. 43–55, 2010.

[9] O. US EPA, "Turbidity," *http://water.epa.gov/type/rsl/monitoring/vms55.cfm*.

[10] R. G. Wetzel, *Limnology: Lake and River Ecosystems*, vol. 37. 2001.

[11] "Measuring Turbidity, TSS, and Water Clarity - Environmental Measurement Systems." [Online]. Available: http://www.fondriest.com/environmental-measurements/equipment/measuring-water-quality/turbidity-sensors-meters-and-methods/#TurbidMM1. [Accessed: 29-Aug-2016].

[12] T. N. Williamson and C. G. Crawford, "Estimation of

suspended-sediment concentration from total suspended solids and turbidity data for Kentucky, 1978-1995," *J. Am. Water Resour. Assoc.*, vol. 47, no. 4, pp. 739–749, 2011.

[13] R. W. Preisendorfer, "Secchi disk science: Visual optics of natural waters," *Limnol. Oceanogr.*, vol. 31, no. 5, pp. 909–926, 1986.

[14] A. F. Bin Omar and M. Z. Bin MatJafri, "Turbidimeter design and analysis: A review on optical fiber sensors for the measurement of water turbidity," *Sensors*, vol. 9, no. 10, pp. 8311–8335, 2009.

[15] D. M. Lawler, "SPECTROPHOTOMETRY | Turbidimetry and Nephelometry," in *Encyclopedia of Analytical Science*, 2005, pp. 343–351.