OPTICAL TRANSMISSION-BASED WATER TURBIDITY MEASUREMENT SYSTEM

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ABSTRACT

An optical transmission-based system for measuring water turbidity was developed. A silicon PIN photodiode BPX65 was used for this application due to its high photosensitivity in the range of 350 nm to 1100nm. The results obtained show that the proposed turbidity measurement system gave a linear relationship between the input and the output signal of the system. Based on the random data obtained, the results given by the proposed system was comparable with the commercial turbidimeter.

Keywords: *water turbidity, optical transmission, measurement system.*

INTRODUCTION

Water pollution occurs when the quality of water is affected due to the addition of large amount of foreign particles to the water. When it is unfit for its intended use, water is considered polluted [1]. The task of identifying the compound of a polluting substance is important for the attainment of practical treatment for the municipal wastewater.

Water quality can be defined as the measurement for the suitability of a particular water system for use by human, and its suitability for providing and sustaining a pollution-free environment [2]. A qualitative measure is important to determine and describe the condition of water i.e. to determine what substances are in the water and the concentration of each substance. A standard is used to determine the quality of a particular water supply. Turbidity which falls into the physical parameter of water, apart of suspended solids, colour, taste, odour and etc., could give significant effects to both human and the ecosystem if exceeding the standard limits. Turbidity is an indicator often used to find the amount of suspended sediment in water. By cumbersome mechanical sampling, it is possible to measure the concentration of suspended solids (in mg/l) in water, but turbidity is increasingly used instead, as it is easy to use and cheaper too.

Turbidity, a measure of the degree of scattering light, is primarily determined by the amount of suspended particulate matter in water [3]. The particulate matter consists of soil, sand or mud, may include also algae, faecal matter and other organic particles. Once considered as the most aesthetic characteristic of a drinking water, significant evidence existed, proving that turbidity control is also a competent safeguard against pathogens in drinking water [4], compared to water clarity alone. Turbidity can provide food and shelter for pathogens and if not removed, turbidity can promote re-growth of pathogens in the distribution system. Although turbidity is not a direct indicator of health risk, numerous studies showed a strong relationship between the removal of turbidity and the removal of protozoa (single-celled organisms that show some characteristics associated with animals and often grouped in the kingdom Protista together with the plant-like algae), which have been known to lead to waterborne disease outbreaks, and causing significant cases of gastroenteritis throughout the world.

Furthermore, it is an ecologically important parameter as the various effects of suspended solids in aquatic ecosystems are due to their light scattering properties rather than their absolute mass. High turbidity has a number of detrimental effects on aquatic ecosystems: decrease in light penetration (limiting plant growth), fish movements and the ability of predatory fish and birds to see their prey. High turbidity means high concentration of suspended solids, which can harm fish and other aquatic fauna. These suspended solids in the process of settling down to the ocean bottom have a choking effect on bottom dwelling organisms and aquatic habitats.

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Many studies have been done related to water quality measurements. Malin Lindquist and Peter Wide, 2001 [5], have presented a paper on virtual water quality tests with an electronic tongue to fill the need of on-line monitoring of aqueous samples. The detection of environmental contaminants using time resolved laser induced breakdown spectroscopy technique has been introduced by V. Palleschi, 1996 [6]. The principle of this technique is in the avalanche ionization effect produced by an intense laser beam focused on the sample water. Method using three probe reflectometer algorithms to find the complex reflection coefficient to measure water quality at microwave frequencies has been introduced by Abdul Kadir Ermeey *et. al.* 2003 [7]. It consists of a Gunn diode source, 1 kHz modulator, attenuator, slotted line, analogue-to-digital converter and a computer.

EXPERIMENTAL SET-UP AND MEASUREMENTS

Optical Transmission-Based Measurement System Design

Optical transmission-based turbidity measurement system consists of a transmitter circuit, optical fibre optic cable, receiver circuit and a Peripheral Interface Controller (PIC), is schematically shown in Figure 1.

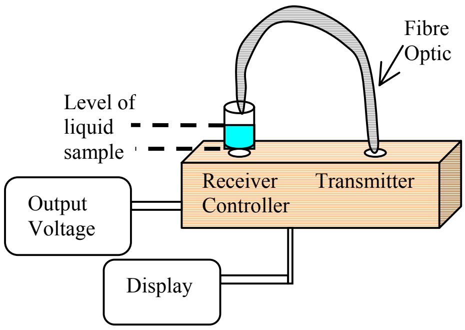


Figure 1: The Illustration of Optical Transmission-Based Measurement System

The transmitter circuit that consists of high intensity LEDs is used to transmit light through fibre optic cable. Using the transmission method, the connector is placed vertically, facing down towards the liquid sample casing. A PIN (p-type/intrinsic/n-type) photodiode is placed at the bottom of the outside of the sample casing to collect the transmitted light. PIN photodiode has been chosen as the transducer for receiver circuit because it has long lifetime, produce low noise, faster response and more sensitive than the ordinary p-n junction diodes, and hence are often used for optical communications [8]. In this study, silicon PIN photodiode BPX65 which has high photosensitivity and suitability in the applications of 350 nm to 1100 nm light range [9] was used. Besides, a current-to-voltage converter, OPA111, is used to convert small current from the sensor to voltage signal. The OPA111 is a precision monolithic dielectrically isolated FET (Difet®) operational amplifier. The outstanding performance characteristics allow its use in the most critical instrumentation applications [10].

Different turbidity value will give different amount of light penetrated through the water sample that correlates to the amount of output voltage obtained at receiver circuit. The output signal from photodiode was sent to a signal conditioning circuit before it was measured by a digital oscilloscope as the receiver's output voltage, *Vout* which will be used for both data analysis and calibration purposes.

Measurement of Samples

The output of the proposed measurement system is the output voltage, *Vout* measured from the receiver circuit. The initial voltage, *Vi* is the output voltage of the system at initial condition when no sample and casing are being placed for measurement.

A set of eleven water samples with different turbidity were prepared for this study. Nine of the samples consist of different weights (grams) of coffee powder stirred with 25 ml of distilled water and another two samples only consist of distilled water and reverse osmosis (RO) water, both having zero gram of powder weight. Table 1 describes the classification of the eleven samples.

Table 1: Samples with Different Weight of Coffee Powder

Water Sample	Powder weight (g)
Distilled water	-
RO water	-
Sample 1	0.02
Sample 2	0.04
Sample 3	0.06
Sample 4	0.08
Sample 5	0.10
Sample 6	0.12
Sample 7	0.14
Sample 8	0.16
Sample 9	0.18

The first step of this study was to find the relationship between the *Vout* and coffee powder of different weights. At the same time, the optimum setting of *Vi* at two different voltages was also determined. There is no limitation to pick different values for *Vi* setting but if higher value is to be selected, the power supplied to the transmitter need be increased to provide more light to the receiver. In this study, the particular settings were made to observe and compare the output of the measurement system between one lower and higher value i.e 2.0V and 4.17V of *Vi*. Secondly, the turbidity of the samples were measured using a commercial turbidity meter, known as turbidimeter (model HACH 2100P, HACH, Loveland, CO). This instrument operates on the nephelometric principle and its microprocessor calculates the ratio of the signals from the 90° and the transmitted light detectors [11]. The correlation on turbidity measured using turbidimeter was compared with the measurement obtained from the proposed measurement system for coffee powder samples. Combining the results from both the first and second steps, a relationship between *Vout* related to turbidity was obtained where it would be used as the standard reference data.

The following steps in the study will be implemented with *Vi*, chosen from the optimum result in step 1, and conducted to compare the *Vout* measurement of three different types of water-based samples of random (or different) weights of soluble grain. They were prepared from coffee powder mixed with distilled water, ordinary garden soil mixed with tap water and kaolin soil mixed with distilled water respectively. The purpose of choosing kaolin soil to be one of the test samples is due to the physical soil texture and its ability to distribute evenly in water without the interference of foreign materials which could impede the penetration of light through the water sample. Furthermore, it has been one of the conventional standard liquids used in the early invention of turbidity measurement instruments. Finally, the *Vout* values from these experiments were collected and the turbidity values were measured using the HACH Turbidimeter. Data collected were then compared to the previous standard reference data to observe the performance of the receiver circuit in measuring the turbidity of different samples.

RESULTS AND DISCUSSION

The result from the first step of this study is shown in Figure 2 where, *Vout* with *Vi* set to 2.0V and 4.17V are represented by *Vout1* and *Vout2* respectively.

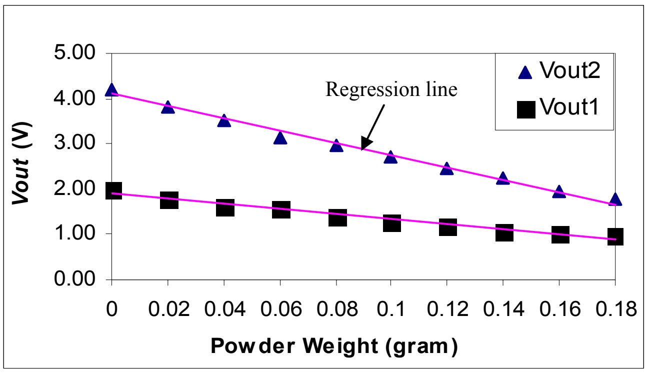


Figure 2: Relationship between Vout and Powder Weight

Figure 2 shows that both *Vout*s are inversely proportional to coffee powder weight. Moreover, the slope of regression line for *Vout2* is found to be greater than *Vout1* implying that there will be a greater voltage drop measured if *Vi* is set to a higher voltage. It was well observed that during the study, *Vout1* could give more stable and consistent output compared to *Vout2* when measurement was taken repeatedly. Thus, the linear relationship between *Vout1* and coffee powder weight would be used as standard reference data for the data analysis of random water samples in the following steps in the study. The mathematical equation that could be derived for the relationship between *Vout1*(y) and powder weight(x) is shown in equation (1.1).

$$y = -5.79x + 1.9166 \tag{1.1}$$

Consequently, the relationship between turbidity (NTU) measurement and the coffee powder weight can be shown in Figure 3.

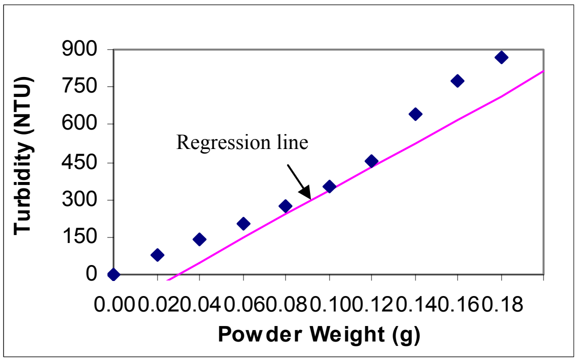


Figure 3: Relationship between Turbidity and Powder Weight

It can be observed that the turbidity is proportionally related to coffee powder weight where the increase of coffee powder weight increases the turbidity of samples been studied. The mathematical equation that could be derived for the relationship between turbidity(y) and powder weight(x) is shown in the following equation (1.2).

$$y = 4745.4x - 139.03 \tag{1.2}$$

The combination result of both results in Figure 2 and Figure 3 gives the relationship between *Vout1* and turbidity as shown in the Figure 4. It can be observed that *Vout1* is inversely proportional to the turbidity where the increase of turbidity would cause the *Vout1* to decrease.

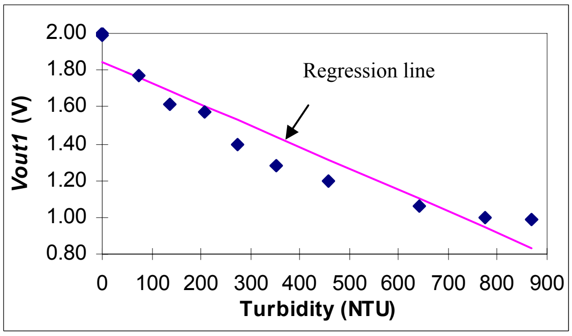
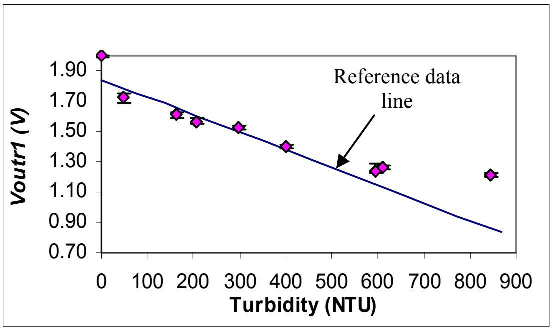


Figure 4: Relationship between Vout1 and Turbidity

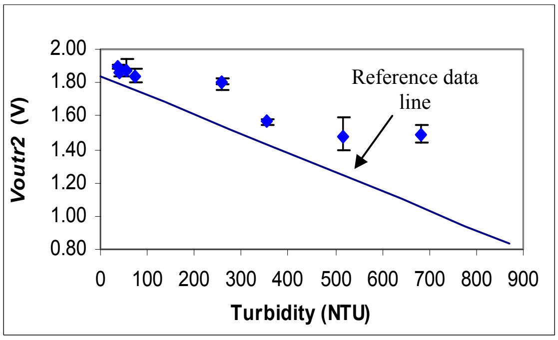
The mathematical equation that could be derived for the relationship between *Vout1*(y) and turbidity(x) can be shown in the following equation (1.3).

$$y = -1.606 \times 10^{-3} x + 1.8419 \tag{1.3}$$

In the following steps of the study, the measured output voltage on two sets of coffee and ordinary soil random samples, *Voutr1* and *Voutr2* respectively, versus turbidity are shown in Figure 5.



(a)



(b)

Figure 5: Comparison between Turbidity versus Vout1 (a) and Vout2 (b)

Voutr1 and Voutr2 can be observed to relate inversely proportional to the turbidity value but the error increases with the increase of turbidity. Figure 5(a) shows that 78% of random data have less than 10% of error while the maximum error of 40% is calculated at the *Voutr1* measured from the sample with the highest turbidity value of 845 NTU. Figure 5(b) shows that 56% of random data have less than 10% of error while the maximum error of 41% is calculated at the *Voutr2* measured from the sample with the highest turbidity value of 681 NTU.

The final step using a set of kaolin clay samples is presented in Figure 6. It can also be shown that *Voutr3* is inversely proportional to the turbidity value but the errors are smaller compared to the errors produced by the previous set of samples using coffee powder and garden soil. The result from this experiment showed a much improved *Vout* measurements compared to the previous two experiments. The highest error is found occurred at the highest turbidity of sample with an agreeable low percentage error of 18% at 790 NTU which shows that the correlation as compared with the turbidimeter is better.

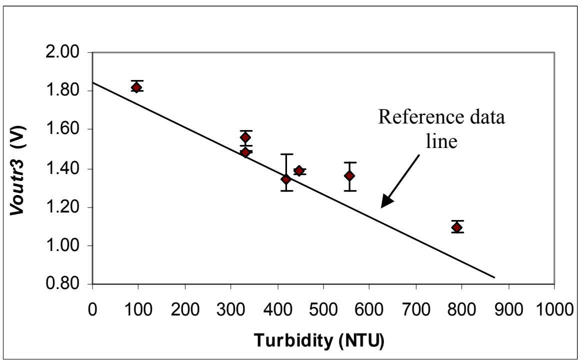


Figure 6: Comparison between Voutr3 versus Turbidity

CONCLUSION

In this study, experiments have been implemented to understand the behaviour and performance of the proposed measurement system. This includes the measurement tests on random water samples consisting coffee powder, ordinary soil and kaolin soil where the output result were compared to a standard turbidity meter to analyse the performance of the system on different type of grain or source of turbidity.

Results obtained in this study shows that the proposed optical transmission-based turbidity measurement system could give a linear relationship between the input and the output of the system. The input can be referred to as the water samples and the output is the output voltage, *Vout* from the receiver circuit. Output voltage was measured for a set of controlled samples based on two parameters that are the coffee powder weight and turbidity. The results were then used to produce the standard reference data for *Vout* against turbidity before being utilized for the calibration of the system.

Furthermore, it can be concluded that the measurement results for two set of random samples using coffee powder and garden soil, show a significant outcomes. In both cases, highest error occurred when output voltage was measured at the highest turbidity value. Besides, the value of error when measuring turbidity of garden soil sample was found greater than that of the coffee powder sample which prospected to the existence of foreign materials which impede the penetration of light through the water sample and consequently affect the measurement of *Vout*. This shortfall was solved by applying kaolin clay in water samples due to its ability to provide better distribution of particles in water. As a result, the performance of the proposed measurement system showed better measurement of turbidity and comparable to the existing turbidimeter. Furthermore, the ability to handle many samples and the implementation of on-line monitoring could be realized using the proposed system.

For future work, the standard reference data will be used to program a PIC microcontroller to display the equivalent turbidity value (NTU) on LCD. Experiments need to be implemented to observe the capability of PIC to show output on LCD, thus to produce a real time optical transmission-based turbidity measurement system.

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