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Optical Tomography Sensor Configuration for Estimating the Turbidity Level of Water

Mohd Taufiq Mohd Khairi, Sallehuddin Ibrahim, Mohd Amri Md Yunus, Mohd Najmi Mohd Sulaiman, Mahdi Faramarzi
Control and Mechatronic Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia

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ABSTRACT

This paper presents an investigation on an optical sensor configuration to estimate the turbidity level in a sample of water based on tomography technique. The optical sensors consist of infrared light - emitting diodes (LED) as transmitters and photodiodes as the receivers where the projections of the sensors are designed in fan beam mode. The promising results obtained from the analysis of light path detection demonstrated the accuracy of the proposed technique in estimating the turbidity level of water. The approach has potential to contribute and utilize for monitoring the quality level of water in water treatment industries.

Corresponding Author:

Mohd Taufiq Mohd Khairi,
Control and Mechatronic Engineering Department,
Faculty of Electrical Engineering, Universiti Teknologi Malaysia,
81310, UTM Skudai, Johor Darul Takzim, Malaysia.
Email: taufiq_khairi@yahoo.com

1. INTRODUCTION

Turbidity is concerned with water quality or sometimes defined as haziness of water. Turbidity can be caused by the presence of suspended particles and organic matter such as algae, clay and silt [1]. Besides, the existence of chemical materials like oil and colour ingredients also can vary the turbidity level of water. The measurement of turbidity level of water is important to domestic water supply as it is related to public health and water treatment process. For instance, the quality of public health can be affected if untreated water is served for daily use. In water treatment industry, the quality level of water is vital has to be identified and monitored in order to avoid serious disaster to the community [2].

The sensor which is used to measure and estimate the turbidity level is called a turbidimeter. A turbidimeter investigates the optical characteristic of the light to be scattered and absorbed rather than transmitting in the straightway [1]. The presence of particles has caused the light to be scattered from the straight line and reduce the light intensity [3]. In addition, the existence of colour particle or contaminated water can absorb the light energy and this effect can be used for designing a precise turbidimeter. The main types of turbidimeters can be classified as two types; absorptiometers and nephelometers. Both types work in different optical properties. Absorptiometers are based on the attenuation of light after transmitting the water sample while nephelometers is based on the intensity of light scattering at 90° from the light path [4].

Process tomography is well-known in performing direct analysis and monitoring task in pneumatic conveyor and pipelines without invading the object [5]. It is vital to acquire information about the flow behaviour in order to optimise and minimise the cost of designing conveying equipment. The significant advantage of using the technique is that the operation can continue without disturbing the process flow since the sensors are located around and outside the pipelines [6]. Basically, the components of tomography method comprise sensors, a signal conditioning circuit, a data-acquisition system and a computer. The types of sensors that can be used in process tomography are electrical capacitance, electrical resistance, ultrasonic, electrical charge and optical. Previous researches utilized optical tomography for measuring the mass flow rate, concentration profile, particles sizing and velocity profile measurement [7].

Tomography has the potential to estimate the turbidity level of water using optical sensor based on Beer-Lambert's law. The turbidity sensor is usually designed in point sensor mode, which means the sensor has to collect or be placed in a water sample in order to measure the turbidity level. However, this sensor is not appropriate in industrial flow process since it cannot measure directly from the pipe and has disturbed the flow process. In this paper, the design of a tomography system using optical sensors is elaborated and preliminary result revealed that the design can estimated the turbidity level of water in the pipelines based on an optical attenuation model.

2. SENSOR MODELLING

The fan beam projection is applied with 18 x 18 pixels as each pixel represented the optical coefficient (α) as shown in Figure 1. The value of absorption coefficient is different based on the medium where the light is transmitted. If the medium is air, the value of α_a = 0.0142 mm^{-1} and for water, α_w = 0.0287 mm^{-1} [4]. Based on the Beer-Lambert's law, the model can be represented as:

$$A = \ln\left(\frac{V_m}{V_{in}}\right) = -\alpha\, l \qquad (1)$$

where A is the medium absorbance, V_m is the receiving sensor voltage, V_{in} is voltage of receiver when there is no beam attenuation (empty pipe), α is the absorption coefficient of liquid medium (mm^{-1}) and l is the path length of liquid medium (mm). Equation (1) can be expressed as:

$$V_m = V_{in}\exp(-\alpha\, l) \qquad (2)$$

When the transmitters are switched on, the receivers are expected to detect one or more light signal(s) from the transmitters, especially when light is transmitted through the water as the medium as shown in Figure 2, which is due to the reflection that occurs between light and water. From Equation (2), the value of voltage at a receiving sensor differs, which relies on the light intensity sensed by the receiver. Figure 2 shows the receiver 1 (RX1) is detecting light from all eighteen transmitters. The analysis of voltage and signal received by each receiver is explained in the experimental result part.

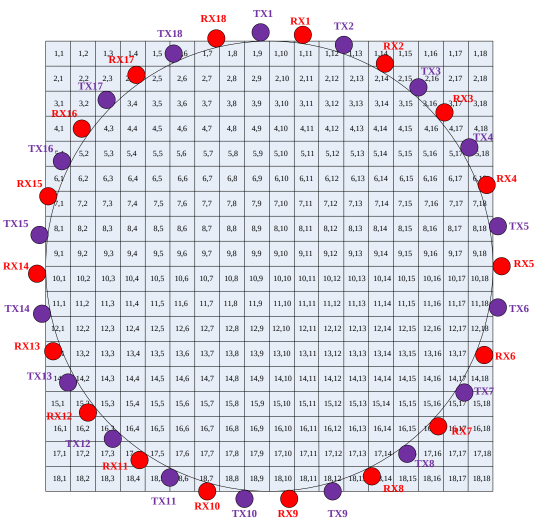

Figure 1. Sensors arrangement; TX (blue) is transmitter and RX (red) is receiver

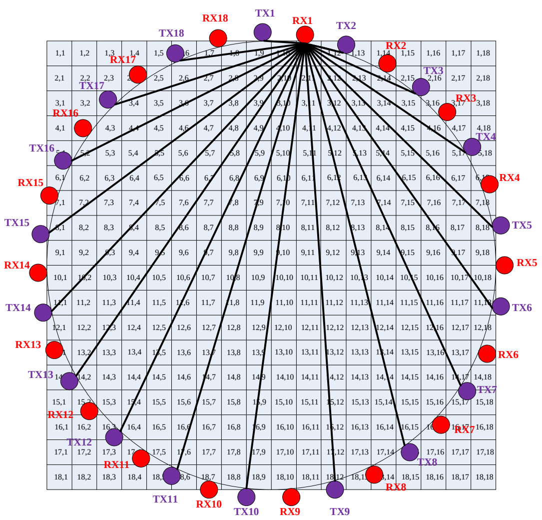

Figure 2. Light path detect by receiver 1 (RX1)

3. HARDWARE DESIGN

The optical sensors consist of eighteen transmitters using infrared light-emitting diodes (LED) model TSAL6200 and eighteen photo diodes model BPV10NF as the receiver. The sensors are mounted around the 100 millimetres (mm) diameter of acrylic pipe using a sensor jig which was specially constructed with accurate measurement. The sensor jig consists of 36 holes. Each hole has a diameter of 6 millimetres (mm) to allow fan beam mode of projection where the transmitters are placed next to receivers. The sensor jig is shown in Figure 3. The design of optical sensor is quite similar to the previous researches in the tomography's field for investigating the concentration profile [8], coal dust [9] and mass flow rate measurement [10]. The design contained several parts such as transmitter circuit, signal conditioning circuit and data-acquisition system (DAS). In the transmitter circuit as shown in Figure 4, the Peripheral Interface Controller (PIC) Microcontroller is used to supply the pulse signal (5V) to the 2N7000; a model of Metal Oxide Semiconductor Field Effect Transistor (MOSFET) for LED's switching purpose.

The PIC Microcontroller is specifically programmed in order to make sure that LED 1 to LED 18 is switched on in sequential mode from one millisecond (1 ms) until 18 milliseconds (18 ms). This means that each LED has their own pulse duration, e.g. LED 1 for one millisecond, LED 2 for two milliseconds, and followed by other LEDs respectively. By this method, it gives advantages when we want to recognize the LED being detected by the receiver which will be explained in the next part. For an optical sensor, there are many types of sources that can be used as the transmitter such as laser, halogen bulb, LED and Infrared LED. The TSAL6200 infrared LED with a peak wavelength 940 nanometer (nm) is selected for this project due to the peak wavelength is far away from the visible light's wavelength which is 380 nanometer (nm) until 750 nm [11]. This optical property is vital in getting accurate and reliable value for the measurement process where it helps to ensure the receivers detected light from LED only and not from surrounding light source, e.g. fluorescent light that has been used in the laboratory with the wavelength near 550 nm [12].

Figure 3. Sensor's fixture with 36 holes

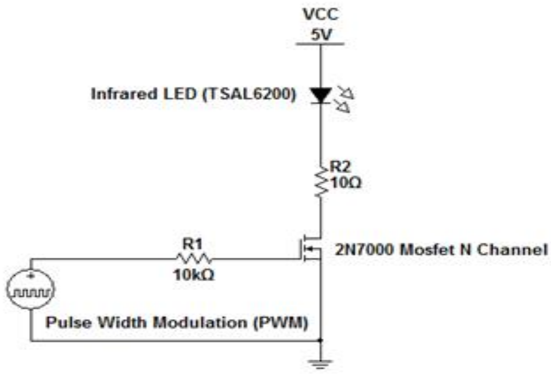

Figure 4. Transmitter circuit

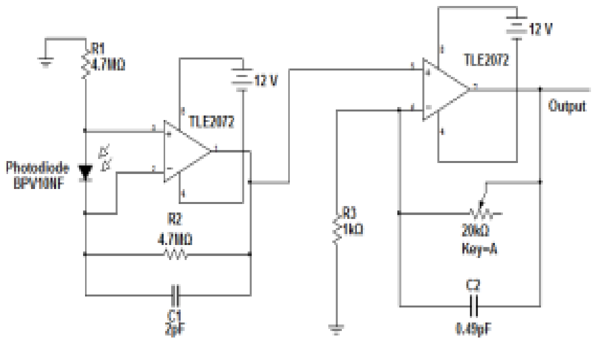

Figure 5. Signal conditioning circuit

The purpose of designing a signal conditioning circuit as shown in Figure 5 is to convert light into voltage. The circuit consists of two stages with the first-stage acting as light to voltage converter and the second stage amplifies the signal from the first stage. Eighteen TLE2072 operational amplifiers were used in this circuit. TLE2072 has high input impedance, three times slew rate which is 45 V/μs and low noise voltage compared to TL082 and TL072 [13]. The output of signal conditioning is in the analog form. Hence a data-acquisition system (DAQ) has to be used to convert the analog signal to digital form for further analysis. The DAQ manufactured by Agilent models U2331A with a sampling rate of 3 mega samples per second (MS/s) and has 64 channels is utilized for this project.

4. EXPERIMENTAL RESULT AND ANALYSIS

The purpose of the experiment is to investigate the optical path from each transmitter to the receivers. The experiment used an oscilloscope to check and measure the pulse duration of the signal. As mentioned in the previous part, the pulse duration for each transmitter is set in different values in order to facilitate the observation of the signals. The LabVIEW software is used to capture the waveform of each receiver. Figure 6 shows the signal amplitude versus time for receiver 1 (RX1). Figure 6 shows that the signals from all transmitters are detected by receiver RX1.

However, the significant signals with the highest amplitude of voltage (3.7 Volt) displayed on the graph are from transmitter 9 (TX9), transmitter 10 (TX10), transmitter 11 (TX11) and transmitter 12 (TX12). Each transmitter represents 9 ms, 10 ms, 11 ms, and 12 ms respectively. By referring to Figure 2, TX9, TX10, TX11 and TX12 are placed in front of the RX1. This reason gives the main influence to value of the voltage since the light paths from the four transmitters can directly be sensed by the RX1. Nevertheless, the other values of pulse duration discovered by the RX1 shows the light path from other transmitters also can be detected, but the voltage value is not very significant. Possibly, this was caused by the refraction of the light, which plays an important role to the light path, especially if the light is transmitted in a pure water medium. The experiments for other receivers are conducted which the result is compiled in the Table 1.

Table 1. Result of transmitters detect by receiver

Receiver	Transmitter (ms)
1	9, 10, 11, 12
2	10, 11, 12, 13
3	11, 12, 13, 14
4	12, 13, 14, 15
5	13, 14, 15, 16
6	14, 15, 16, 17
7	15, 16, 17, 18
8	16, 17, 18, 1
9	17, 18, 1, 2
10	18, 1, 2, 3
11	1, 2, 3, 4
12	2, 3, 4, 5
13	3, 4, 5, 6
14	4, 5, 6, 7
15	5, 6, 7, 8
16	6, 7, 8, 9
17	7, 8, 9, 10
18	8, 9, 10, 11

From Table 1, the result for the other receivers shows the same properties as the RX1. The light transmitted could be detected by a receiver which located in angle of 30° in front to the transmitter. The amplitude of voltage from the Figure 7 to Figure 23 also shows the value of each receiver is almost to be equal to 3.7 Volt. The actual voltage value that should be sense is 5 Volt, which is programmed by PIC Microcontroller. The voltage drop is happens due to the optical energy attenuates when the light passes to the water medium. It is expected that the light path will have more resistance when it passes through the contaminated water. Therefore, the voltage value at the receiver will be decreased. The contaminated water sample can be prepared by adding several volumes of colour flavour into the pure water.

The analysis for other receivers is continued to receiver 2 (RX2). From Figure 7, the pulse duration detected by RX2 is from TX10, TX11, TX12 and TX13 which located opposite directly to RX2. Similar to RX1, RX2 also can receive the light from other transmitters due to light refraction and scattering but the level of light intensity is not high due to the transmitters are located in indirect place to transmit the lights to RX2. In Figure 6 to Figure 23, the level of light intensity is expressed in amplitude of voltage. The high value of voltage displayed by the pulse signal means the receiver has received a high level of light intensity. In addition, from Figure 6 to Figure 23, it can be proved that each receiver is capable to detect four significant signals which are in the pulse signal form. The four important signals are concentrated for analysis purpose in estimating the turbidity level of water. The analysis of optical path for the others receivers like RX3, RX4, RX5 until RX18 are consider similar to RX1 and RX2 since its show the same properties as in the waveform graphs.

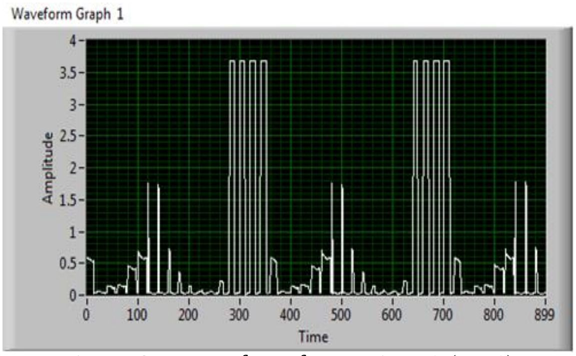

Figure 6. Waveform for receiver 1 (RX1)

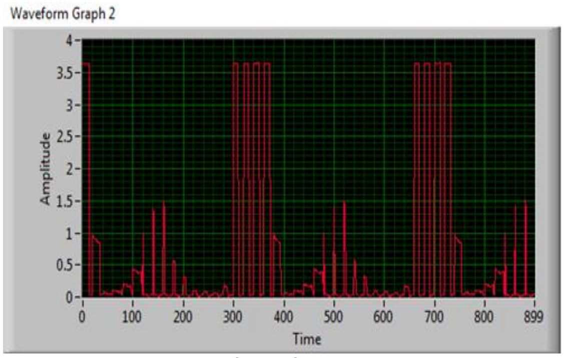

Figure 7. Waveform for receiver 2 (RX2)

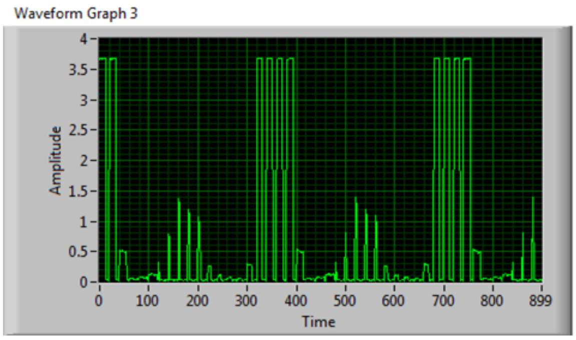

Figure 8. Waveform for receiver 3 (RX3)

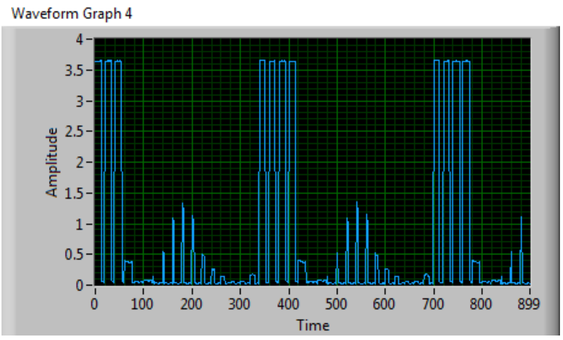

Figure 9. Waveform for receiver 4 (RX4)

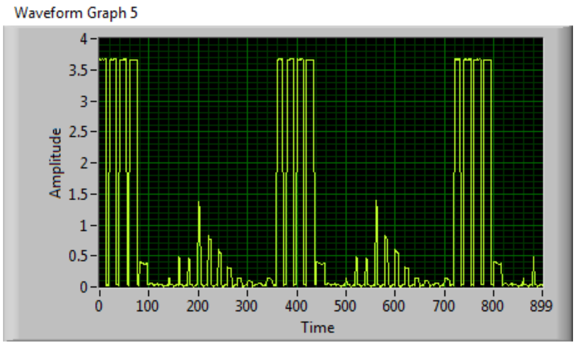

Figure 10. Waveform for receiver 5 (RX5)

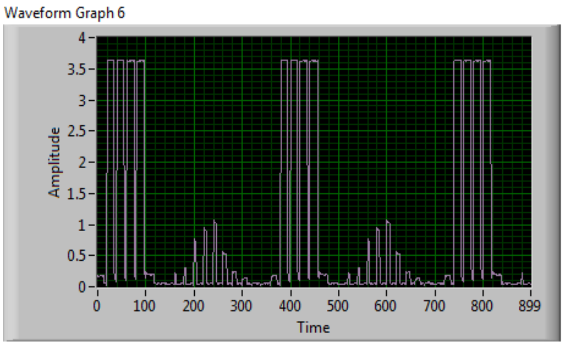

Figure 11. Waveform for receiver 6 (RX6)

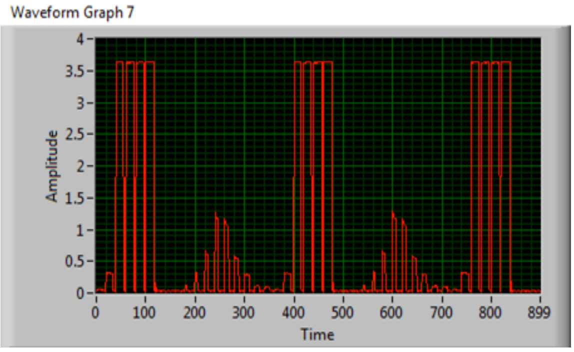

Figure 12. Waveform for receiver 7 (RX7)

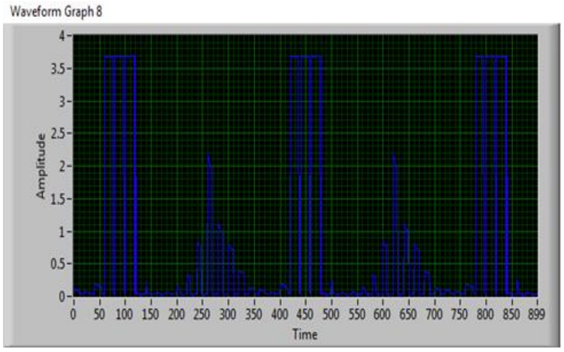

Figure 13. Waveform for receiver 8 (RX8)

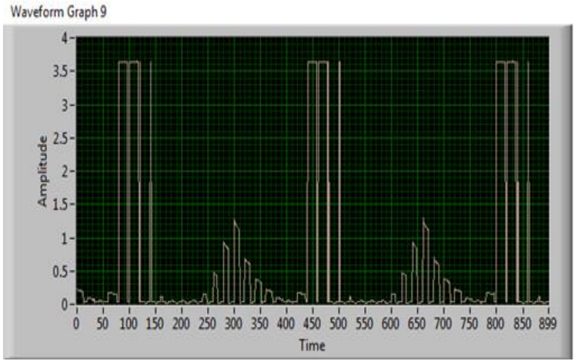

Figure 14. Waveform for receiver 9 (RX9)

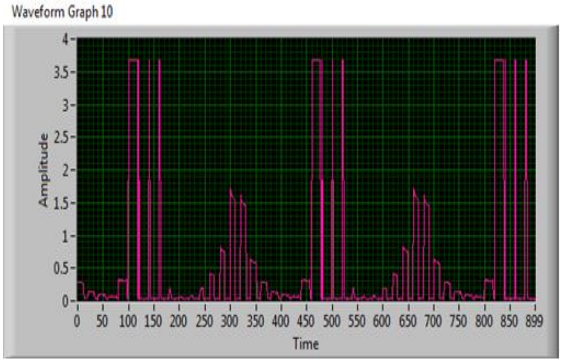

Figure 15. Waveform for receiver 10 (RX10)

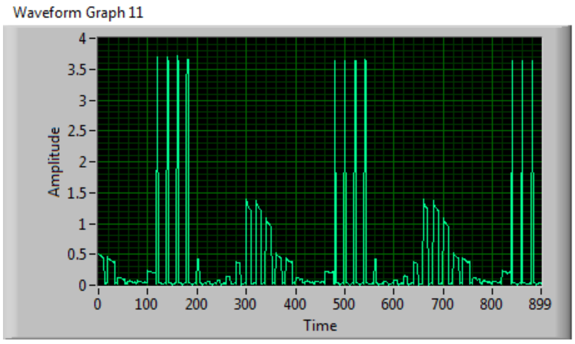

Figure 16. Waveform for receiver 11 (RX11)

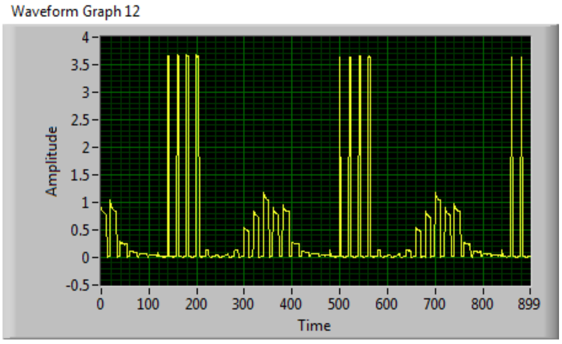

Figure 17. Waveform for receiver 12 (RX12)

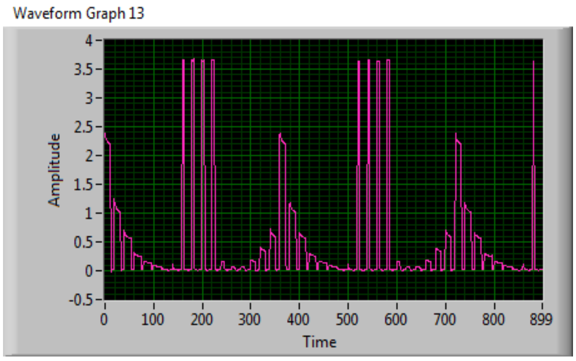

Figure 18. Waveform for receiver 13 (RX13)

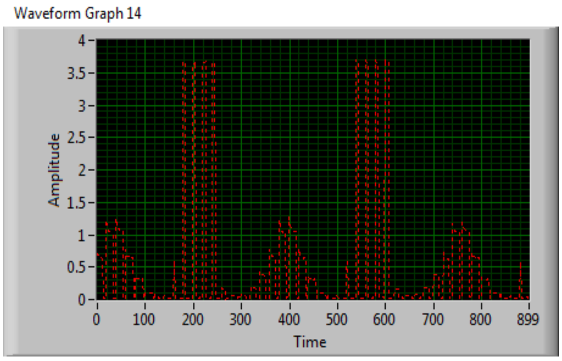

Figure 19. Waveform for receiver 14 (RX14)

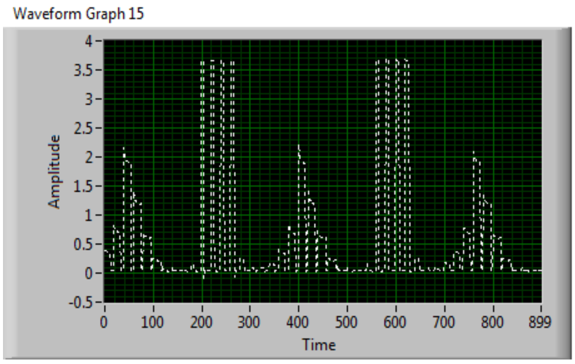

Figure 20. Waveform for receiver 15 (RX15)

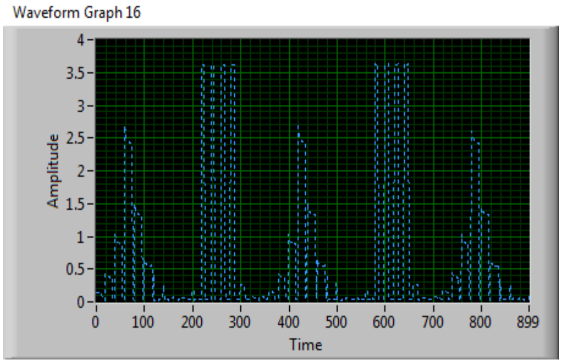

Figure 21. Waveform for receiver 16 (RX16)

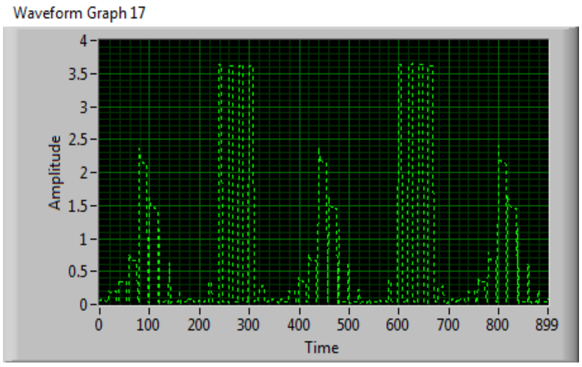

Figure 22. Waveform for receiver 17 (RX17)

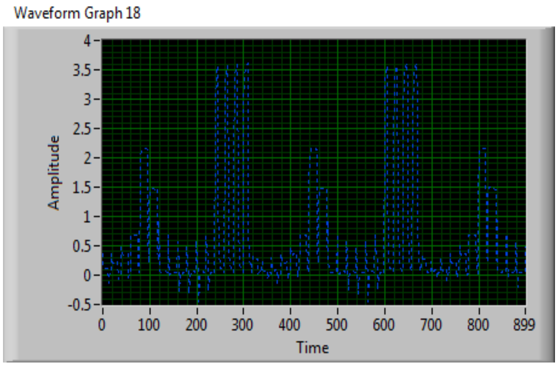

Figure 23. Waveform for receiver 18 (RX18)

5. CONCLUSION

In this paper, an optical tomography sensor configuration for estimating the turbidity level of water has been presented. The results obtained proved that the proposed method is efficient and accurate in estimating the turbidity level of water. Another significant feature of the proposed approach is the ease of design for turbidity measurement for pure water, which is based on optical tomography. Further study and continuation of the software-development aspect for turbidity measurement based on the optical attenuation concept is in progress.

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BIOGRAPHIES OF AUTHORS

Mohd Taufiq Mohd Khairi was born on 8th of September 1988. He received the B.Eng. degree in Engineering (Electrical) from Universiti Teknologi Malaysia in 2011. He is currently further his study in Masters degree in the same institution under Control and Mechatronic Engineering Department, Faculty of Electrical Engineering. His current research interest includes process tomography and sensing technology.

Sallehuddin Ibrahim received the Ph.D. degree in process tomography from Sheffield Hallam University, Sheffield, U.K., in 2001. He is currently an Associate Professor with the Control and Mechatronic Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, Malaysia. He has published several papers in journals. He has presented papers in various conferences. His current research interests include instrumentation, sensors, and tomography.

Mohd Amri Md Yunus received the B.Eng. degree (honors) in electrical control and instrumentation and the M.Eng. degree in electrical engineering from Universiti Teknologi Malaysia, Skudai, Malaysia, in 2002 and 2005, respectively, and the Ph.D. degree in electrical engineering from the School of Engineering and Advanced Technology, Massey University, Palmerston North, New Zealand, in 2011. His dissertation is titled “Planar electromagnetic sensors for environmental monitoring.” He joined the Control and Mechatronic Engineering Department, Universiti Teknologi Malaysia, as a Lecturer in 2006. His current research interests include process tomography, planar electromagnetic sensors, and sensing technology.

Mohd Najmi Mohd Sulaiman received the B.Eng. degree in Engineering (Electrical) from Universiti Teknologi Malaysia in 2011. His current research interests include electrical charge tomography, instrumentation and sensor.

Mahdi Faramarzi received his B.Eng degree in communication system (2004) and M.Sc in control engineering (2010) from Shahid Bahonar University, Iran and Gonabad Azad University, Iran, respectively. He is currently pursuing his Ph.D's degree in Electrical Engineering with the department of Control and Mechatronic Engineering Department at the Universiti Teknologi Malaysia. His current research areas of interest are application of artificial neural network and fuzzy system application in ultrasonic process tomography.