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DESIGN OF AN INFRARED TOMOGRAPHY SYSTEM FOR DETECTION OF BUBBLES

MOHAMAD AIZAT HASHIM[1], YUSRI YUNOS[2], RUZAIRI ABDUL RAHIM[3*], HERLINA ABDUL RAHIM[4], SAIFUL BADRI MANSOR[5] & NOR MUZAKKIR NOR AYOB[6]

Abstract In this study, an optical process tomography with 2 orthogonal projections is being designed to be implemented at a vertical column modelled. The tomography system will be designed from the development of transducer pairs to the data acquisition system implemented. Infrared emitters are being considered as a light source due to the difference of its wavelength with the wavelength of visible light. Photodiodes are being characterized and compared for maximizing its performance when integrated with the system. Microcontrollers are functioned to perform analogue-to-digital conversion. Experiments are being conducted to investigate whether the system is able to detect gas bubbles in the vertical column. The results from the studies will be compared with theoretical hypotheses of light absorption and light attenuation.

Keywords: Optical tomography; mass flow rate; process tomography

Abstrak Dalam kajian ini, sebuah sistem tomografi menggunakan penderia direka untuk digunakan untuk model paip menegak. Sistem tomografi ini akan digunakan untuk mengira jumlah buih sambil mengukur saiz buih yang terkandung dalam model paip yang diisi dengan air. Sistem ini akan direka bermula dari pemilihan jenis penderia optik sehinggalah ke teknik pemprosesan data. Penderia cahaya infra merah digunakan sebagai sumber cahaya untuk sistem ini. Sifat-sifat beberapa diod foto dikaji dan dibandingkan bagi memilih model yang sesuai untuk sistem ini. Mikro pengawal berfungsi untuk melakukan kerja penukaran isyarat analog ke digital. Beberapa eksperimen telah dijalankan bagi mengenal pasti prestasi sistem penderia tersebut. Hukum Lambert-Beer menyatakan bahawa atenuasi dan penyerapan cahaya berlaku apabila cahaya melintasi bahan yang berlainan. Beberapa eksperimen dijalankan bagi mengetahui sama

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[1-4] Process Tomography Research Group (PROTOM), Control and Instrumentation Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Darul Ta'azim

[5&6] Biomedical Electronic Engineering, School of Mechatronic Engineering, University Malaysia Perlis, 02600 Jejawi, Arau, Perlis, Malaysia

* Corresponding author: ruzairi@fke.utm.my

ada sistem ini mampu mengesan buih dalam paip yang mengandungi air. Data yang diperoleh akan dibandingkan dengan hipotesis yang dibuat mengenai atenuasi dan penyerapan cahaya.

Kata kunci Tomografi optik; kadar halaju zarah; proses tomografi.

1.0 INTRODUCTION

Optical process tomography is a method for obtaining profiles and characteristics of materials in a conveyor. The principle used in optical tomography involves projecting a beam of light through a medium from one boundary point and detecting the level of light received at another boundary point [1]. Optical tomography is a much better method compared to other radiation based tomography such as gamma ray and positron emission.

Bubbles occur when conveying liquids in a pipeline or a conveyor. Bubbles in a liquid flowing pipe may affect the efficiency of a liquid transmission. Although this situation is unavoidable, a measurement of the amount of bubbles will be essential in determining the level of efficiency of the transmission process.

In process industries, multi-phase flows in conveyors and columns are investigated to determine the efficiency and the flow transmission process. By studying liquid profiles, the durability of the equipment in process system can be improved.

This paper presents the design process of an optical tomography system used for detecting bubbles in a conveyor. There are a few important parameters and properties in measuring gas bubbles. Firstly, gas bubbles may be produced in different sizes. Therefore, the bigger the size of the bubbles, the slower it will travel through the liquid flow in the conveyor. Secondly, the velocity of the bubbles varies in different sections of the conveyor. Lastly, the position of the bubbles at a specified cross section of the conveyor is important to produce the tomographic image of the conveyor's cross section.

1.1 Lambert Beer Law of Light Attenuation and Light Absorption

Three methods have been identified in detecting particles inside a process vessel: light attenuation, light absorption and light scattering. Scattering of light is complex to describe mathematically due to the random positioning of the particles responsible, but absorption and attenuation may be quantified by relatively simple mathematical models. Absorption occurs when incident light energy passes through a medium and is converted to heat causing attenuation; some materials exhibit selective absorption to specific frequencies of light. Attenuation arises because of opaque material interrupting the beam. Different materials cause varying levels of attenuation and scattering and it is this fact that forms the basis of optical tomography [2].

According to Beer-Lambert Law, the properties of the material in which the light travels through influences the amount of light absorption. The law states that there is a logarithmic dependence between the transmission of light through a substance, the product of the absorption coefficient of the substance and the distance the light travels through the material [3].

2.0 METHODOLOGY

2.1 Optical Tomography System Design

In optical process tomography, sensors are an important part of the system. The measurement system will be based on the modelled vertical column. A Poly (Methyl) Methacrylate (PMMA) pipe with an outer diameter of 130 mm and an inner diameter of 124.4 mm will be used as a vertical column.

2.1.1 Light Projection

A parallel beam projection is the simplest type of projection for optical process tomography. Basically, one set of parallel projection cannot pinpoint the exact position of the flowing particles but this can be solved by using placement of another set of projection in different axes. In parallel beam projection technique, the projection measurements can be grouped in sets of parallel rays whereby all measurements in a single view are along parallel paths and the image reconstruction algorithm is relatively simple to implement.

The system design in this project uses 2 parallel projections as Figure 1, 26 transducer pairs are implemented in this system.

2.1.2 Optical Sensors

The design of an optical tomography system starts with the selection of a proper light emitter based on several characteristics of the emitter. The wavelength, radiant intensity, and the angle of half intensity influence the performance and the sensitivity of the measurement system (Zarina, 2009).

Beam collimators are required for the emitters to reduce light scattering and light refraction. When light passes through the acrylic pipe, some of the light will be refracted causing the light beam to widen.

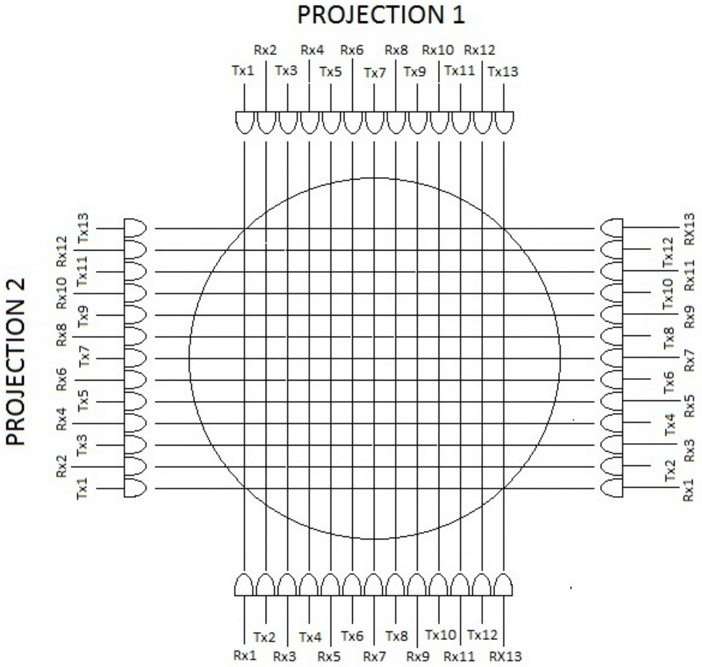

Figure 1 Sensor arrangement for 2 parallel projections

The selection of the receiver is the most essential part of the sensor system. The wavelength, speed of response, noise limit and the sensitivity determines the performance of the light detectors. Semiconductor detectors have higher response time and smaller leakage current [5]. Photodiodes and phototransistors are 2 alternatives to be made as receivers. Since phototransistors have poor linearity and sensitive to temperature [5], photodiodes will be used for this design.

Infrared emitters are implemented in the system. The wavelength selected is 940 nm and the radiant intensity of the light is 60 mW/sr. The angle of half intensity is 17° because in parallel projection, the light beam desired needs to be as narrow as possible.

The photodiode peak sensitivity wavelength for this tomography system matches the wavelength of the infrared light beam. However, the angle of half sensitivity is 20° because the photodiode needs to receive light from the widest angle possible.

2.1.3 Emitter Circuit

An emitter circuit is designed according to the allowable specification of the emitter itself. In designing a simple emitter circuit, shown in Figure 1, the resistance value, *R* must be determined using the following equation:

$$R = \frac{V_{cc} - V_F}{I_F} \tag{1}$$

Where V_{cc} is the supplied voltage while V_F and I_F are the forward voltage and forward current, respectively.

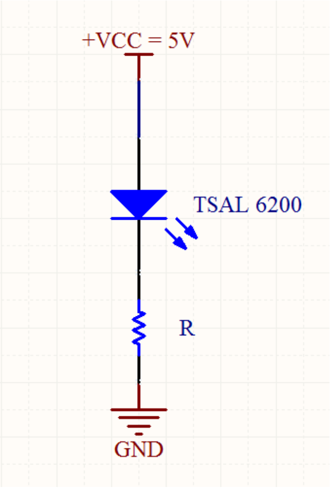

Figure 2 Simple emitter circuit

However, to allow switching for every emitter circuit, a switching device needs to be introduced. An enhancement type Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is used as the switching device to allow current to flow in the emitter. A modified circuit is shown as in Figure 3.

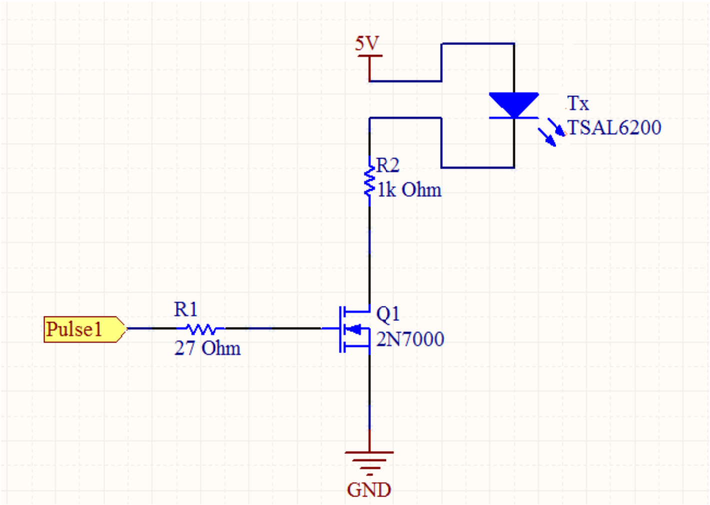

Figure 3 Final emitter circuit

2.1.4 *Receiver Circuit*

The parallel signal processing has been utilized in this system. This technique assigns each photodiode with a set of optical transducer individually.

There are 2 stages of signal conditioning designed for this receiver circuit. It is divided in such way for ease of analysis to simplify the analysis later. The first stage of the receiver is a light-to-voltage conversion. When the photodiode converts the light received into measureable current. Then, the current is fed to an amplifier. The amplifier then amplifies the voltage signal to a significant measureable value. The amplification ratio is based on the following equation:

$$V_o = \qquad \frac{\quad}{\quad} \quad V_I \tag{2}$$

Where V_o is the output voltage and V_I is the input voltage. The gain depends on the value of the feedback resistor, R_F and the input resistor, $R1$. The final emitter circuit is shown as in Figure 4.

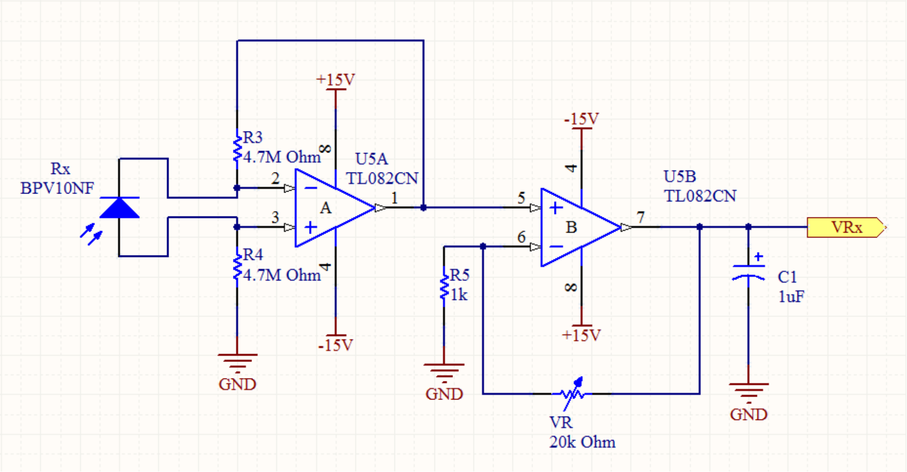

Figure 4 Final receiver circuit

2.1.5 Analog to Digital Conversion and Data Transfer Using Microcontrollers

Digitizing analogue signals is necessary for most systems nowadays. The signal received from the receiver sensors are in analogue form. Hence, A/D conversion must be executed before sending the data to the main computer. A PIC18F4550 microcontroller is able to complete the required tasks. It is a 40-pin microcontroller where 13 pins are reserved for analogue inputs. Since there 26 analogue signals from the receivers to be converted, 2 identical microcontrollers is used, 1 for each light path projection. Besides digitizing analogue signals, the microcontroller also provides pulse signals for the emitters to use for switching purposes. The digital data can be transferred to the main computer using Serial Communication Interface (SCI). The data will be sent through 2 USB ports, 1 for each microcontroller. Figure 5 shows the relationship of each device in the tomography system.

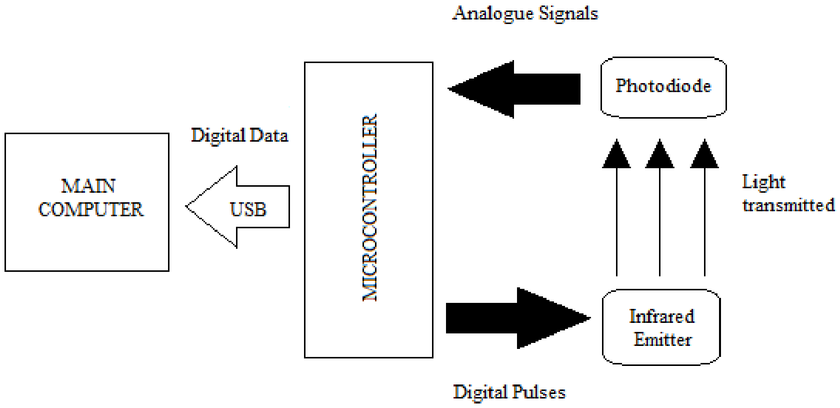

Figure 5 Block diagram of the system

Phantoms are used to test the results of the reconstruction images based on the use of the sensitivity maps in solving the forward problem. The image on the left of Figure 3.1 to Figure 3.5 shows the phantom distribution while the image on right of these figures shows the reconstructed images.

3.0 RESULTS AND DISCUSSIONS

3.1 Detection Of Bubbles

The analogue signals were analysed through an oscilloscope. When gas bubbles were generated in the vertical column, the output signal from the receiver is observed. When 5 Volts is supplied at the gate pin of the MOSFET, the gain at the receiver is adjusted so that the output would produce a 4.1 Volts signal. At a timescale of 500 ms/division, the output obtained are as in Figure 6, 7, 8 and 9 respectively.

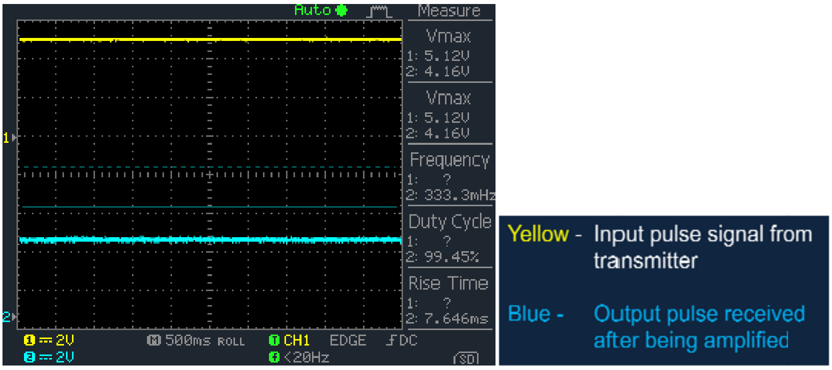

Figure 6 No bubbles detected

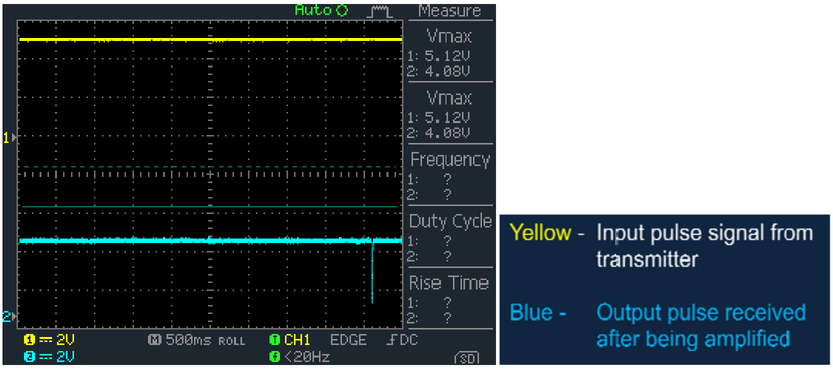

Figure 7 1 bubble detected

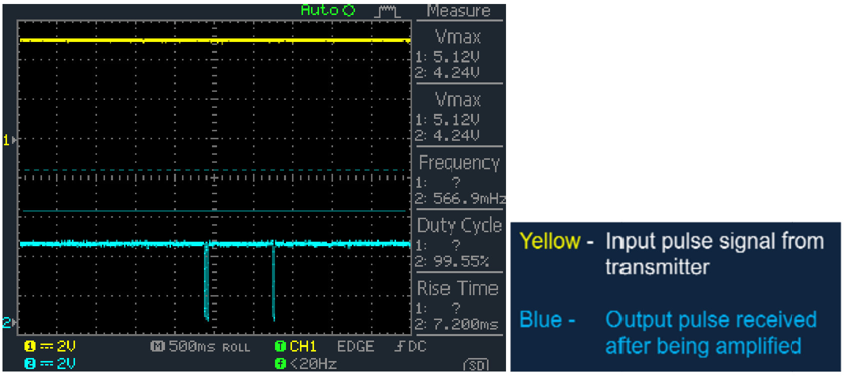

Figure 8 2 bubble detected

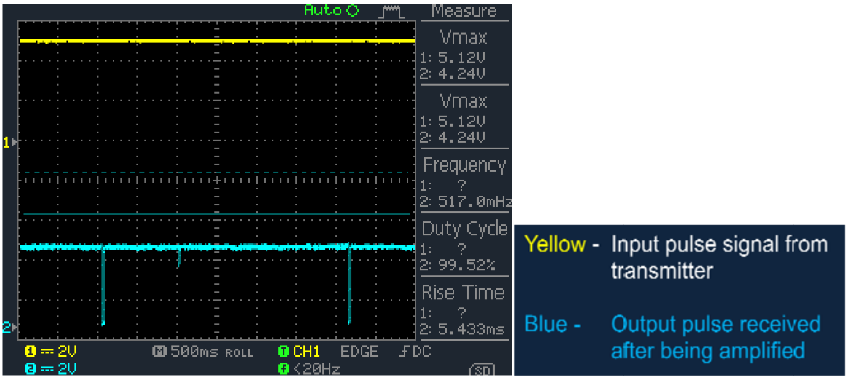

Figure 9 3 bubble detected (1 small)

By changing the timescale of 50 ms/division, the following output result is obtained as in Figures 10, 11 and 12 respectively.

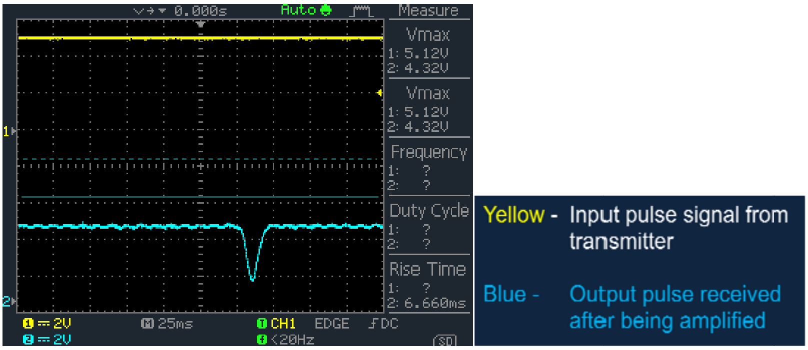

Figure 10 1 small bubble

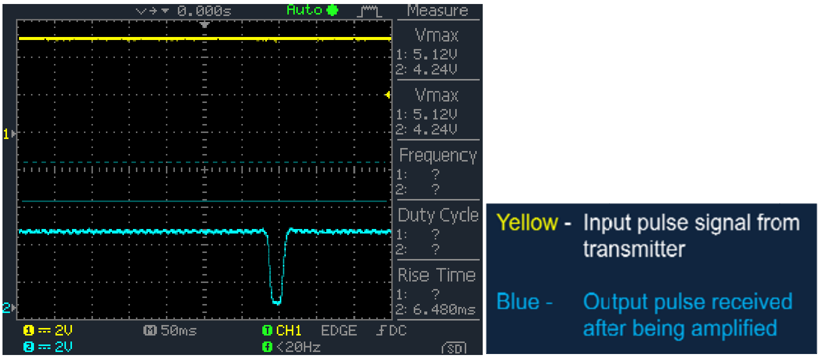

Figure 11 1 medium bubble detected

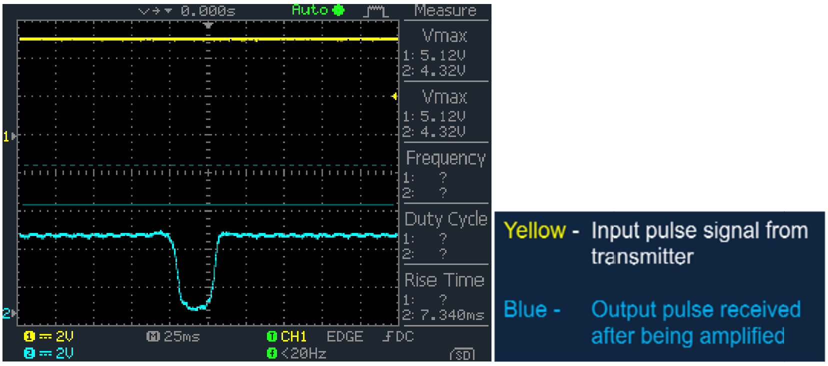

Figure 10 1 large bubble detected

4.0 CONCLUSION

The infrared tomography designed is able to detect the presence of gas bubbles in a vertical column. If the bubbles block the light path between the emitter and the receiver, a voltage drop occurs. The size of each bubble can be determined by observing at how many photodiode receivers produces voltage drop. The distance between 2 bubbles can also be determined. However, this can only be determined when the velocity of the gas bubbles is calculated.

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