Jurnal Teknologi

Full paper

Hardware Design of Laser Optical Tomography System for Detection of Bubbles Column

Naizatul Shima Mohd Fadzil[a], Ruzairi Abdul Rahim[a*], Mohd Safirin Karis[c], Siti Zarina Mohd Muji[c], Mohd Fadzli Abdul Sahib[c], Mohd Saiful Badri Mansor[a], Nor Muzakkir Nor Ayob[a], Mohd Fahajumi Jumaah[a], Mohd Zikrillah Zawahir[a]

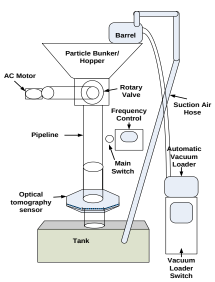
[a]*Process Tomography and Instrumentation Engineering Research Group (PROTOM-i), Infocomm Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor Malaysia*
[b]*Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Hang Tuah Jaya Melaka, Malaysia*
[c]*Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*

*Corresponding author: ruzairi@fke.utm.my

Article history

Received :1 April 2013
Received in revised form :
23 May 2013
Accepted :5 June 2013

Graphical abstract



Abstract

This paper presents a hardware design and optical tomography application for fast cross sectional detection of single or two phase flows in pipes or bubble columns. Sixteen laser pointer transmitters and photodiode receivers are arranged at the object cross sectional boundary to detect the existence of bubbles inside a vertical column pipeline. A valve is installed at the bottom of the pipe to produce the source of bubbles. Due to the simple operation, good heat transfer and mass transfer of bubble columns, they can be applied in a wide range of applications in the chemical process industry. The size of the bubbles produced was estimated to be between 5 mm and 20 mm in diameter. The voltage drop at the sensor directly shows the existence of bubbles between the transmitter and receiver.

Keywords: Optical; gas bubbles; laser pointer

■1.0 INTRODUCTION

Tomography is an interdisciplinary field that is concerned with obtaining cross sectional images of an object. The word "*tomography*" is derived from the Greek language; *tomo*, which means cutting section, and *graph*, which means picture. Therefore, the tomography process can be defined as the process of obtaining plane section images of an object [1]. This study focuses on detection of a two phase flow in pipe or bubble columns. Multi-phase flow tomography systems exist widely in industry, as systems are used in the monitoring and control process to enhance product quality, reduce product cost and ensure product safety. The goal of the tomographic measurement is therefore to generate a two-dimensional image of the cross section of the measurement object [1, 2]. In recent years, optical tomography has become a viable imaging modality. One of the major advantages of optical sensors is that variations in chemical composition and moisture content have virtually no effect on the system output. The advantages of optical sensors include fast response, high performance and simple construction [3-5]. Optical tomography involves projecting a beam of radiation through a medium from one boundary point and detecting the level of radiation received at another boundary point [6, 7]. It also exists in the form of computed tomography, which creates a digital volumetric model of an object by reconstructing images made from radiation transmitted and scattered through an object [8]. Our research aims to use a simpler and less expensive measurement approach based on optical sensing and image processing methodologies. This method gives the highest measurement accuracy, even for larger gas fractions or more complex particle shapes.

■2.0 EXPERIMENTAL SET-UP

The optical tomography system was successfully developed by a previous researcher, and used for performing real time image reconstruction using a solid form; a software program was implemented using Visual Basic. The average bubble diameter is one of the most important hydrodynamic parameters, and yields information about the gas-liquid interfacial area as well as about the liquid mixing in the column. However, until now it has not been possible to accurately predict the bubble size [9]. The main purpose of this tomography process is to visualise the internal flow or the process in a pipe or plant using an electronic measurement system to obtain the liquid/gas flow. In this case, a pipe was used as a prototype. The pipe was placed vertically, and liquid flowed inside it.

An array of 16 pairs of optical sensors was mounted in an octagon-shaped jig around the circumference of the vertical flow pipe. Half of the optical sensors were transmitters and the other 16 sensors acted as receivers. These sensors generated an electric signal representing the flow inside the pipe. The signals were then fed to the data acquisition system (DAS) and then to the computer to reconstruct the image of the internal flow inside the pipe [1]. There are three popular forward models used to determine the sensor output modelling in the optical tomography system; optical path length model, optical attenuation model and optical width path model. The optical width path model was applied in this research following the reasoning of Chan [4], where the signal conditioning system that employs the light intensity measurement is not suitable for the optical path length model, while the high absorption characteristics of solid materials used as detected particles inside the pipeline leads to unsuitable implementation of the optical attenuation model. The principle of this research is based on the light beams being emitting in a straight line towards the receivers. The sensor output, which is a voltage, is dependent on the blockage effect that occurs when solid particles intercept the light beam [4, 16].

Today, particle and gas bubble detection and measurement are typical applications of numerous optical sensors based on light scattering. Measuring the liquid's profile is necessary to determine whether the equipment and vessels used can withstand the liquid's pressure and velocity. Bubbles occur when conveying liquids in a pipeline or a conveyor. Bubbles in a liquid flowing in a pipe may affect the efficiency of the liquid transmission. Although this situation is unavoidable, a measurement of the amount of bubbles is essential to determine the level of efficiency of the transmission process [2]. However, since tomography provides light transmission information from many different projections, nonlinear effects are to some extent reduced, and optical tomography images still provide a considerable amount of qualitative information about the flow structure. Furthermore, it is assumed that nonlinearity can be treated, to some extent, with dedicated reconstruction algorithms [10].

2.1 Sensor Selection

Transmitter selection was carried out using different laser sources. The selection process was carried out using three types of laser: OPV 302; a 650 nm laser pointer and OPV 380 (see Table 1). The laser pointer was chosen because it transmits the best signal to the receiver. A laser pointer emits a very narrow, coherent, low-powered beam of visible light, which illuminates the receiver with a small bright spot of radiation [11].

Table 1 Selection of transmitter

Type	Manufacture	Wavelength (Nm)	Remarks
OPV 302	OPTEK, invisible	860	Too much noise. Needs to be carried out in a closed space.
Laser Pointer	CHINA, visible red	650	Smooth and good signal.
OPV 380	OPTEK, invisible	850	Too much noise. No signal received.

The selection of the receiver was made considering 11 different photodiodes. The experiment was carried out with 25 μs time division, and compared the received signal strength from the red laser pointer for the different photodiodes, as shown in Table 2.

Table 2 Selection of receiver

No	Type	Model	Wavelength (nm)	Voltage Transmitter Vtx	Voltage Receiver Vrx	Remark
1	BP104	VISHAY	950	4.08	2.64	The signal is not static.
2	BP104FS-Z	OSRAM	950	4.08	2.24	The signal is good but not static.
3	BPV10NF	VISHAY	940	4.32	1.12	The output voltage is very low.
4	SLD-70 C2A	SILONEX	930	4.08	0.420, 0.440	Output voltage has opposite sign and a signal is hard to achieve.
5	OP906 Plastic T-1	OPTEK	935	4.08	3.44, 2.99	If the light is too bright, no signal is achieved.
6	BPX65	CENTRONIC	900	4.08	3.04	Good output signal.
7	AEPX65	CENTRONIC	900	4.08	2.40	The light must be exactly aligned on the receiver and the wave is opposite.
8	BPW34S	OSRAM	880	4.08	3.04	The light must not directly hit the receiver, or else it will only be a straight line.
9	S5972	HAMAMATSU	800	4.08	3.52, 3.2	Good wave signal if the light hits the centre of the receiver.
10.	S597	HAMAMATSU	760	4.08	3.36,2.80	Good wave signal if the light hits the centre of the receiver.
11	EPD-660-5	EPIGAP	660	4.08	3.92, 3.12	The wave signal is good and has a high output voltage.

There are four types of photodiode giving a good signal: the Hamamatsu S597; Hamamatsu S5972; Centronic BPX65 and Epigap EPD-660-5. Of these four photodiodes, EPD-660-5 gives the most static result and highest output voltage. Hence, it is selected as the receiver in this experiment.

2.2 Circuit Design

The circuit design can be divided into three parts: the light projection unit, the received signal conditioning unit and the digital timing and control unit [12]. The light projection unit contains the laser projection source, which gives a high and precise dynamic current to each laser. In the signal conditioning unit, the received light intensity is measured and calibrated. The signal is then converted to a proportional voltage. This is achieved using a parallel processing technique employing 16 sets of circuits. In the digital timing and control unit, a master clock is used to control the sequence of light projection with DAS while capturing the output voltage.

A vertical column with length of 1.2 m, inner diameter of 125 mm and outer diameter of 130 mm was used as a pipeline. The red laser pointer was chosen as the transmitter (Tx), while photodiode model EPD-660-5 was selected as the receiver (Rx). There were 16 transmitters and 16 receivers used to completely circle the central section of the vertical column pipeline. A sensor jig was used to connect all the sensors. The receiving circuit from previous research [13] (Figure 1) was used to give the optimum signal at a particular voltage. Meanwhile, Figure 2 shows the transmitter circuit using the red laser pointer.

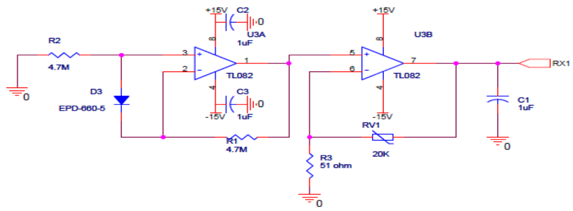


Figure 1 Receiver circuit

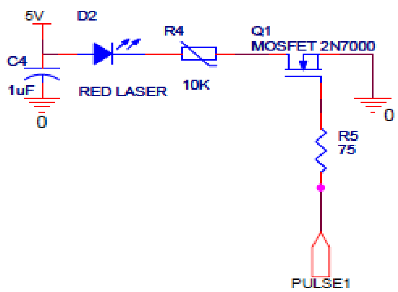


Figure 2 Transmitter circuit

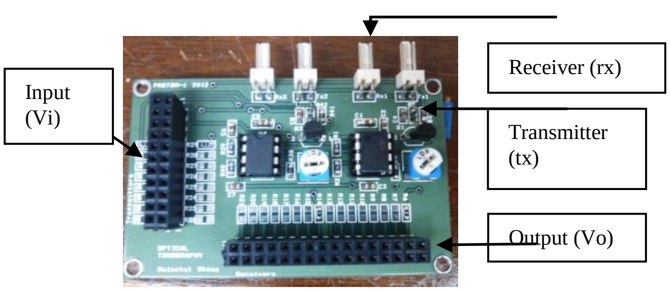


Figure 3 Circuit controlling two transmitters and two receivers on one PCB

Figure 4 16 pairs of sensors top view)

Figure 5 16 pairs of sensors (side view)

The circuit was fabricated on one printed circuit board (PCB) that contained all 16 pairs of sensors. The voltage cannot go higher than 5V, as this was the maximum voltage for the dsPIC microcontroller. The vertical column pipe length was fixed at 1.2 m. In the vertical column, there was a hole for the bubble column and a valve for water disposal. Figure 3 shows two pairs of sensors on one PCB. Figure 4 is a complete set of PCBs viewed from the top and Figure 5 is the side view of the same system. Before the experiment was carried out, the transmitted light and received light were optimised to give an output of 5V.

2.3 Sensor Jig Design

To place the sensor in a fixed position, a sensor jig was designed and fabricated by Istone Manufacturing Company. An octagon shape was designed for this project to enable more light to be projected into the column and to give a high resolution. There were 44 pairs of holes in the jig, which the diameter of each laser port was 5.99 mm and each photodiode port was 4.96 mm. However, only 16 pairs of sensors were designed to capture the centre image. Images of the jig are shown in Figure 6 and Figure 7.

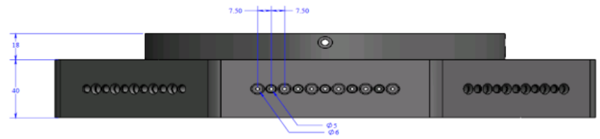


Figure 6 Side view of the jig

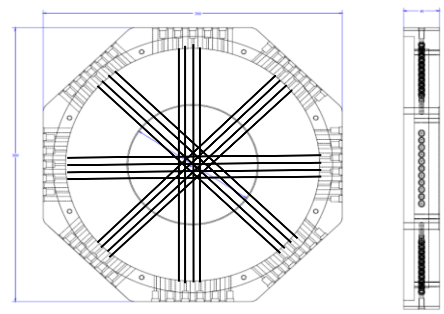


Figure 7 Top view of the jig with sensors

3.0 SIMULATION RESULT

When the water was at full flow, with 16 measurement sensor pairs, we observed the image shown in Figure 7; the image was black around the pipe. When there was no object medium in the liquid phase, the full transmitted laser signal was received; the voltage drop was zero. The voltage loss formula, Equation 1, defines the predicted voltage drop:

$$V_{loss} = V_{max} - V_{drop} \tag{1}$$

where, V_{drop} is the predicted voltage drop when there is an obstacle, V_{max} is the maximum voltage when there is no object, V_{loss} is the voltage loss and d is the particle size in mm.

Figure 8 shows the plot obtained when there was a medium inside the liquid phase. We observe from the tomogram that the middle intercept is where the medium was positioned. The colours indicate a clear image of the object inside the pipe. When there were bubbles inside the pipe, the colour would be near white, because there was no flow inside the object. This pipe covers a small range because there were only 16 pairs of sensors.

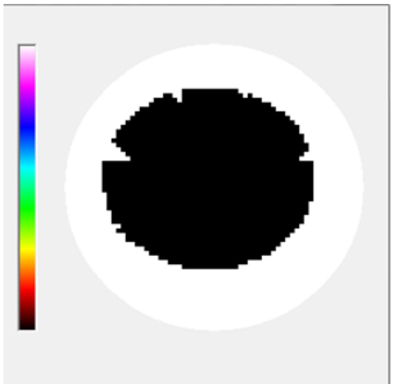


Figure 7 Full flow liquid phase

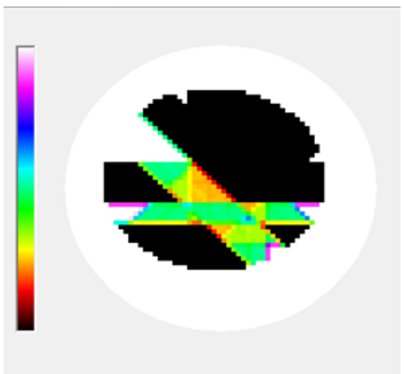


Figure 8 Air gap in the liquid phase

■4.0 APPLICATION AREAS

Since bubble detection is an important and emerging market in industry, many researchers have been conducting experiments to develop the best way to detect bubbles and measure the volume of gas or size of bubbles in a pipeline. In a bubble column, gas is spurged by a distributor into a liquid or a solid-liquid suspension. The simple construction of bubble columns, with no mechanically moving parts and good heat and mass transfer, ensure they are widely popular in gas-liquid and gas-liquid-solid reactions [9, 14]. The optical sensor can be applied in many areas of industrial measurement and basic research where small gas bubbles occur due to local vaporisation or gas production, such as chemical reactions under varying hydrodynamic pressures, electrolysis, fermentation processes, cavitations and boiling, as well as gas dissolution and dispersion in fluids. The sensor specifically measures flow concentration, flow velocity and mass flow rate determination. Variations in particle density and size distribution should potentially be able to be obtained by manipulating the control scheme [15].

In the oil industry, this method is used to detect and quantify the presence of gas bubbles in the drilling slurry during drilling operations. Detection of the bubbles gives the operator important information, allowing the pressure of the slurry to be increased to push against an imminent increase in pressure from the gas pockets, potentially preventing a dangerous explosion. This method gives oil companies another potential benefit, where the observation of refractive index allows operators to distinguish between actual gas bubbles and other debris floating in the drilling slurry. Through prior knowledge of the refractive index of the gas, you can tell exactly when you have a gas bubble [15].

In the main frame, the application program functions were arranged into a number of subroutines, as shown in Figure 9 [1]. The tasks for each subroutine are as follows.

(i) DAS acquisition: Basic application program commands for real time monitoring. The initialisation button is to initialise the software and hardware before data is acquired and manipulated by the software. The start/stop button is used to instruct the application program to start or stop collecting data, and also to reconstruct the image. The stop button is also used to hold the image currently being displayed on the tomogram.
(ii) Off-line reconstruction: Commands for the off-line reconstruction algorithm.
(iii) Colour scheme: Colour index selection for the tomogram visualisation.
(iv) Tomography form: The tomogram visualisation.
(v) Frame rate: The image processing speed for the current tomogram is displayed (frames/second).
(vi) Gas and liquid percentages: Percentage of gas and liquid distributed in the visualised tomogram.
(vii) Exit button: Enables the user to simply quit the application program.

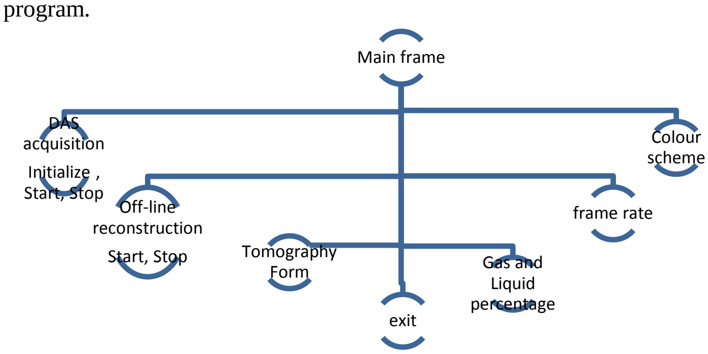


Figure 9 Main frame

■5.0 CONCLUSIONS AND OUTLOOK

From the analysis, it is clearly observed that light can detect an object in a liquid phase. To increase the resolution, the number of sensors should be increased. The optical beams travel in straight lines which simplifies the tomographic reconstruction. The optical approach to process tomography is conceptually simple and inexpensive. Good spatial resolution of as low as 1 mm is possible, which is an order of magnitude improvement on methods that employ electric fields. Parallel projection using lasers can also overcome the diffraction effect, and at the same time give good image resolution.

Acknowledgement

The author would like to thank Universiti Teknologi Malaysia for supporting the research study and also this appreciation goes to the other members in PROTOM groups for their cooperation.

References

[1] Abdul Rahim, R.a.M.N., Norkharziana and Fazalul Rahiman, Mohd. Hafiz. 2006. *Ultrasonic Tomography System For Liquid/Gas Flow: Frame Rate Comparison Between Visual Basic And Visual C++ Programming.* Jurnal Teknologi. 131–150.

[2] Hashim, M. A. B. 2011 .*Optical Process Tomography for Measurement of Bubbles*. UTM.

[3] Kazantsev, D. and V. Pickalov. 2008. *Fan-beam Tomography Iterative Algorithm Based on Fourier Transform*. In *Nuclear Science Symposium Conference Record, 2008. NSS '08. IEEE*.

[4] Rahim, R. A., *et al*. 2010. Modeling Orthogonal and Rectilinear Mixed-Modality Projection of *Optical Tomography for Solid-particles Concentration Measurement*. *Sensors and Actuators A: Physical*. 161(1–2): 53–61.

[5] Ruzairi Abdul Rahim, G.C.L., Mohd. Hafiz Fazalul Rahiman, Chan Kok San, Pang Jon Fea, Leong Lai Chan. 2010. Optical Tomography System Using Microprocessor and Ethernet Controller-based Data Acquisition System. Emerald Research, 2010. *Sensor Review*. 30/2 (2010). 124–129

[6] Md. Yunos, Y. a. A. R., Ruzairi and Green, R. G. and Fazalul Rahiman, Mohd. Hafiz. 2007. *Image Reconstruction Using Iterative Transpose Algorithm for Optical Tomography*. Jurnal Teknologi. 47: 91–102.

[7] Rahim, R. A., J. F. Pang, and K. S. Chan. 2005f. Optical Tomography Sensor Configuration Using Two Orthogonal and Two Rectilinear Projection Arrays. *Flow Measurement and Instrumentation*. 16(5): 327–340.

[8] Wikipedia, *Tomography*. wikipedia. http://en.wikipedia.org/wiki/Tomography

[9] V. P. Chilekar, M. J. F. W., J. van der Schaaf, B. F. M. Kuster, and J. C. Schouten. 2005. *Bubble Size Estimation in Slurry Bubble Columns From Pressure Fluctuations.* Wiley InterScience.

[10] E Schleicher, M. J. d. S., S. Thiele, A. Li, E. Wollrab and U. Hampel. 2008. Design of an Optical Tomograph for the Investigation of Single-and Two-Phase Pipe flows. *Meas. Sci. Technol.* 19(9): 094006.

[11] Wikipedia. *Laser*. http://en.wikipedia.org/wiki/Laser.

[12] R. Abdul Rahim, K. C. *Optical Tomography System for Process Measurement Using Led as a Light Source*. Spie.

[13] Muji, S. Z. M., M. Morsin, and R. A. Rahim. 2009. *Criteria for sensor selection in optical tomography*. in *Industrial Electronics & Applications, 2009. ISIEA 2009. IEEE Symposium on*.

[14] Dominique Toye, E. F., Daniel Simon, Michel Crine, Guy L'Homme, Pierre Marchot. 2008. Possibilities and Limits of Application of Electrical Resistance Tomography in Hydrodynamics of Bubble Columns. *The Canadian Journal*. May Wiley Online.

[15] Shirley, K. 2010. *Can Lasers Help Stop Blowouts*. http://www.aapg.org/explorer/2001/04apr/lasers.cfm.

[16] R. Abdul Rahim. S.Z Mohd. Muji. January 2013. Optical Tomography : Image Improvement using Mix Projection of Parallel and Fan Beam Mode. *Measurement Journal (ISSN: 0263-2241) Elsevier Science*. 46: 1970–1978.