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Octagon Modelling Using Parallel Projection of Optical Tomography

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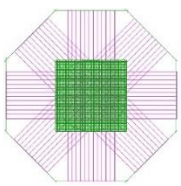

Abstract

This paper presents a hardware design, arrangement and measurement for optical tomography where optical tomography uses light sources as the transmitter and photodiodes as the receiver. By using parallel projection for 44 laser transmitters and photodiode receivers at the cross-sectional boundary, the existence of bubbles inside a vertical column pipeline is determined. Octagon modelling with an eight-sided jig is used for projection and the measurement method for this research is shown. An offline technique is used to collect readings from each signal and the image is reconstructed from the data received.

Keywords: Optical; projection; laser

■1.0 INTRODUCTION

In the medical field, process tomography has been widely used. The important factor featured in this process is the ability to unravel the complexities of a structure without invading the object. Furthermore, this method is able to explore the spatial distribution of the contents of a process vessel in an intrinsically safe manner and non-invasively [1]. Tomography literally means "writing a slice". It is a non-intrusive technique that can be used for the reconstruction of the cross-sectional distribution of the different phases in a multi-phase flow system such as fluidized beds. It relies on the measurement of a physical quantity that is different in the existing phases, gas and particles [2]. In this study we focus on how to arrange and measure a parallel projection in a two-phase flow bubble column. Multi-phase flow tomography systems exist widely in industry, as such 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, electromagnetic interference and moisture content have no effect on the system output and are safe. 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]. This research aims to detect bubbles by using parallel projection on the system and to optimize image construction around the covered pipe.

■2.0 OPTICAL TOMOGRAPHY

Optical tomography involves the use of non-invasive optical sensors to obtain vital information in order to produce images of the dynamic internal characteristics of the process system [7]. It has the advantages of being conceptually straightforward and relatively inexpensive. For parallel projection, the number of emitters and receivers is the same. In this research, we are using an octagon shape to cover all spaces. Each pair of trans-receivers is arranged in a straight line and the received signal only corresponds to its emitter source, whereas, for fan beam projection, the number of emitters and receivers can be unequal [8]. The optical tomography system uses a number of light emitter–receiver pairs and a wide variety of light sources, such as visible light, infrared or laser light. In this case, we are only using parallel projection. Figure 1 shows the sensor arrangements of parallel projection and fan beam projection.

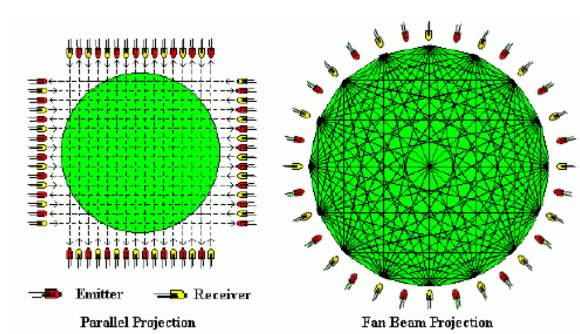

Figure 1 Parallel projection and fan beam projection in an optical tomography system

The optical tomography system was successfully developed by a previous researcher and used to undertake real-time image reconstruction using a solid form; a software program was implemented using Visual Basic. The main purpose of this tomography process is to visualize the internal flow or the process in a pipe or plant using an electronic measurement system to obtain the liquid/gas flow.

An array of 44 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 44 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]. First, the forward problem was modelled to determine the expected measurement values for known attenuation coefficients for water and air and known distributions of gas and liquid. Then the problem was solved to obtain the attenuation coefficient distribution from the measurement values [6]. The principle of this research is based on the light beams being emitted in a straight line towards the receivers. However, the size of the bubbles largely depends on the speed of the water flow, the speed of the air and the inner diameter of the hole/ needle. In this research we used lasers to make the light focus at one point. Based on the design, the light produced is limited with regard to the angle covered by the light and it can be adjusted using a variable resister design in the circuit. The light is fixed if the measurement is taken directly from the component [9].

Over the years, the way in which microbubbles have been created for use in experiments has changed along with the research that involves them. Since the 1970s, laser impulses have been used to form microbubbbles. Here, a strong pulse hits a liquid surface and creates a cavity which forms a microbubble filled with liquid vapour and dissolved gasses. Although this technique was invented many years ago, it is still used today [10]. However, since tomography provides light transmission information from many different projections, non-linear 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 non-linearity can be treated, to some extent, with dedicated reconstruction algorithms [11].

2.1 Projection Measurement

Forty-four pairs of transmitter and receiver sensors were used and this section evaluates a linear model of optical tomography. The line of the light source, 4.96 cm in diameter, travels from the transmitter before it is absorbed by the photodiode at the receiver side. The transmitter uses a laser sensor and the optical receiver uses a photodiode as it has a fast response compared to a phototransistor [12]. Figure 2 shows the maximum voltage, V_{max}, obtained when there is no obstacle between a transmitter and a receiver. V_{max} is supposed to be 5 V optimum.

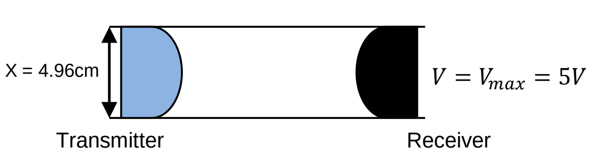

Figure 2 Maximum Voltage, $\boldsymbol{V_{max}}$, for the receiver

When there is an obstacle situated between the transmitter and the receiver, the voltage drop is defined as $\boldsymbol{V_{drop}}$ as shown in Figure 3.

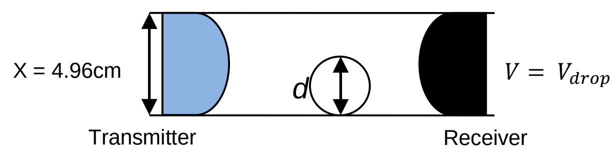

Figure 3 An object, diameter $'\boldsymbol{d}'$mm, situated between the transmitter and the receiver results in voltage drop, $\boldsymbol{V_{drop}}$

Therefore, the voltage drop at the receiver side can be obtained using the following formulas:

$$V_{drop} = V_{max} - V_{loss} \tag{2.1}$$

$$V_{loss} = {}^{d}/_{3} \times V_{max} \tag{2.2}$$

Therefore,

$$V_{drop} = V_{max} - \left({}^{d}/_{3} \times V_{max}\right) \tag{2.3}$$

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

To create a tomogram, the voltage loss, V_{loss}, will be selected rather than predicted, the voltage drop and the equation ares as shown below:

$$\boldsymbol{V_{loss} = V_{max} - V_{drop}} \tag{2.4}$$

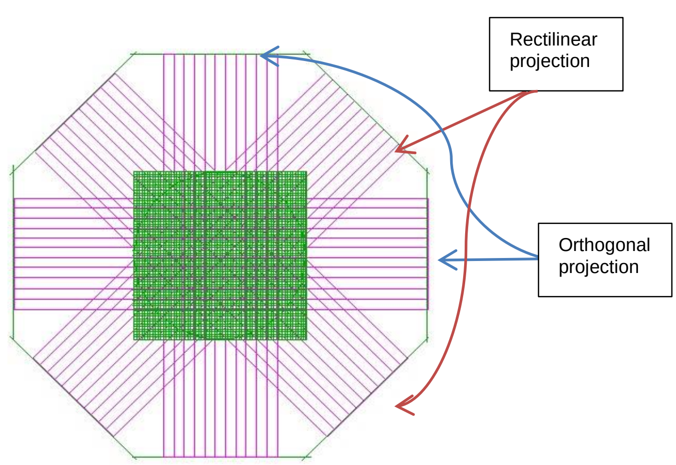

Figure 4 Projection of orthogonal and rectilinear projection

Figure 4 shows the arrangement of the actual hardware, where the first sensor is located at 20 mm from the edge of the pipe and there is a 7.5 mm gap between one sensor and another. To convert the measurement from millimetres to pixels, Equation (2.5) is used. This equation gives the measurement in millimetres for one pixel.

$$c = \frac{b \times d}{a} = \frac{125\ mm \times 1\ pixel}{512\ pixel} = 0.244\ mm \tag{2.5}$$

where,
c = measurement in mm
a = amount of pixels, 512
b = pipe diameter, 125 mm
d = measurement in pixels.

Based on Equation (2.5), the value of *b* represents the inner pipe diameter which is 125 mm and *a* is the maximum pixels to be used in this research being 512 pixels. As a result, 1 pixel is equal to 0.244 mm. Therefore, the conversion from millimetres to pixels can be expressed mathematically as below

$$d = \frac{c}{0.244} \tag{2.6}$$

where,
d = measurement in pixels
c = measurement in millimetres.

■3.0 ARRANGEMENT PROJECTION DESIGN

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 44 pairs 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 a length of 1.2 m, inner diameter of 125 mm and outer diameter of 130 mm was used as a pipeline. A red laser pointer was chosen as the transmitter (Tx), while a photodiode, Hamamatsu model S5972, with a wavelength of 800 nm was selected as the receiver (Rx). There were 44 transmitters and 44 receivers used to completely encircle the central section of the vertical column pipeline. A sensor jig was used to connect all the sensors. The receiving circuit from previous research was used [13].

The circuit was fabricated on one printed circuit board (PCB) that contained all 44 pairs of sensors. All the sensors were attached to the interface board. The voltage cannot go higher than 5 V, as this was the maximum voltage for the dsPIC microcontroller. A dsPIC30F6014A is used as the microcontroller due its many input/output pins. This quantity is enough for the system to convert the entire analogue data received from the receiver of the optical sensors. In this case, all the data can be directly connected to all the ports without the need to communicate with other microcontrollers to ensure an adequate port is obtained [14]. 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. Before the experiment was carried out, the transmitted light and received light were optimized to give an output of 5 V.

■4.0 SIMULATION RESULT

After some experiments, we have come up with an analysis. Using Visual Basic software and the linear back projection (LBP) algorithm, the tomogram will be visualized. When the water was at full flow, with 44 measurement sensor pairs we observed the image shown in Figure 5; the image is 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 based on Equation (2.1). Figure 6 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 is 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 44 pairs of sensors. The resolution is higher compared to 16 pairs of sensor in the previous research [15].

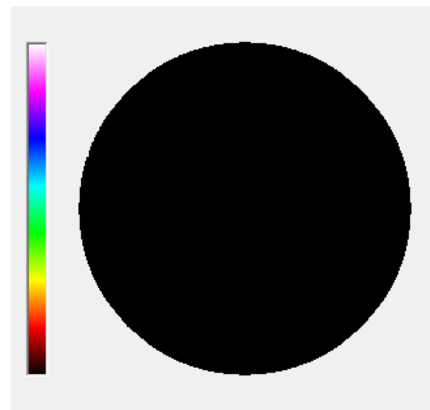

Figure 5 Full flow liquid phase

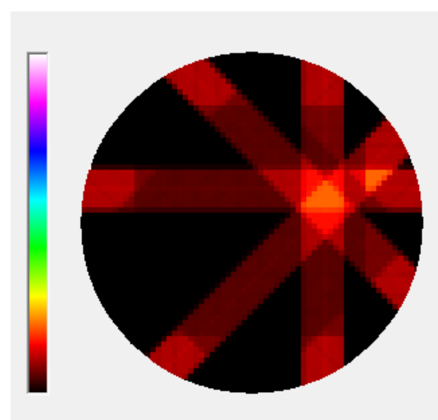

Figure 6 Air gap in the liquid phase

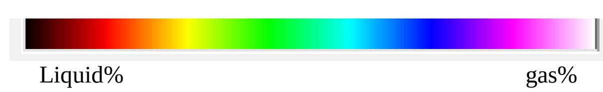

Figure 7 Colour indication

Figure 7 shows the colour indication for the tomogram. The liquid phase is on the left side where when the colour becomes black, it indicate that it is in liquid condition. Meanwhile, the gas phase is on the right side, where the white colour indicates there is a bubble within that region.

5.0 APPLICATION AREAS

Many researchers have been conducting experiments to develop the best way to detect bubbles and measure the volume of gas or the size of bubbles in a pipeline, since bubble detection is an important and emerging market in industry. In a bubble column, gas is spurge 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 [16, 17]. Optical sensors can be applied in many areas of industrial measurement and basic research where small gas bubbles occur due to local vaporization or gas production, such as chemical reactions under varying hydrodynamic pressures, electrolysis, fermentation processes, cavitation 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 [18]. However, the size of the bubbles largely depends on the speed of the water flow, the speed of the air and the inner diameter of hole/ needle.

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 the 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, operators can tell exactly when there is a gas bubble.

6.0 CONCLUSIONS

From the analysis, it is clearly observed that light can detect an object in a liquid phase. The number of the resolution increases where the number of projections along the pipe increases. The optical approach to process tomography is conceptually simple and inexpensive. Octagon modelling can give full coverage of the pipeline, hence giving a good image resolution. The image can be improved by using filters and additional algorithms to reduce the unwanted signal.

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