

## CHAPTER 1

### INTRODUCTION

Wilhelm Roentgen discovered x-rays in the year 1895, his discoveries contributed to the most important diagnostic methods in modern medicine. Since then, it is possible to look through into both non-living and living things without cutting the certain area of the subject by taking X-ray radiography (Ellenberger *et al.*, 1993). This method of projection is far from being a perfect image of the real subject since the images were a superposition of all planes normal to the direction of X-ray propagation. In the 30's conventional tomography was the tomographic method using the X-ray radiation and gave possibility to restore information of 2D and 3D images (William and Beck, 1995).

The word 'tomography' is derived from the Greek words, where 'tomo' meaning 'to slice'/'section' and the word 'graphy' means image. In the year 1970 all the possibilities in the 30's became true when this technique utilized the x-rays to form images of tissues based on their x-ray attenuation coefficients. However, this technique does not stop at the medical studies area and it was successfully developed into the industrial field and commonly known as the Industrial Process Tomography (IPT). This technique aims to measure the location concentration, phase proportions, and velocity measurement (Chan, 2003) retrieved from the quantitative interpretation of an image or, more likely, many hundreds of images corresponding to different spatial and temporal conditions using direct measurement/real time due to the dynamic changes of internal characteristic.

There are many parameters such as 2D and 3D images, velocity, and Mass Flow Rates (MFR) which can be retrieved from the tomography visualizing techniques within the processor or unit operation. Hence, the latter parameters give the information of the distributions of material in a pipeline. Therefore, from the knowledge of material distribution and material movement, a mathematical model can be derived and it can be used to optimize the design of the process (Tapp *et.al*, 2003).

## 1.1 Background of Problems

Process Tomography has become one of the vast growing technologies nowadays. The tomographic imaging of objects offers a unique opportunity to unravel the complexities of structure without the need to invade the object (Beck and Williams, 1996). It is a diversification from the original research on x-ray tomography, which focused on how to obtain 2-D cross-section images of animals, human, and non-living things (Syed Salim, 2003). Process Tomography can be applied to many types of processes and unit operation, including pipelines (Neuffer *et al.*, 1999), stirred reactors (Wang *et.al*, 1999), fluidized bed (Hallow and Nicoletti, 1992), mixers, and separator (Alias, 2002). Process tomography is an essential area of research involving flow imaging (image reconstruction) and velocity measurement. For example in the research that was carried out by Ibrahim (2000), the Linear Back projection (*LBP*) algorithm which was originally designed for x-ray tomography was used to obtain the concentration profiles of bubbles in liquid contained in a vertical flow rig. This project investigated the two-phase flow (solid particle and air) using a vertical pneumatic conveyor flow rig.

Flow imaging usually involved obtaining images of particles and gas bubble (Yang and Liu, 2000) and the measurements can be either done using on-line (real time) or off-line. For on-line measurement, there are many performance aspects that must be considered such as hardware performance, data acquisition (signal interfacing), and algorithm performance. Limited numbers of measurement affect the

quality of images obtained. The input channel of the data acquisition system has to be increased with the increase in the number of sensors used.

*LBP* algorithm is the most popular technique that was originally applied in medical tomography. Research conducted by Chan (2003) improved flow imaging using 16 alternating fan-beam projections with an image reconstruction rate of 20 fps, but this image reconstruction rate not is sufficient to achieve an accurate measurement of velocity. Generally, this project performed an investigation on how to improve the sensing method developed by Abdul Rahim (1996) which used fiber optics in flow visualization. Instead of using one light source, this project focused on using individual light source meaning one infra-red LED emitter for one photodiode. This method was then combined with an infra-red tomography system which consist of a hardware fixture, a signal conditioning system, and a data acquisition system by synchronizing the whole process operation.

Furthermore, image reconstruction in the spatial domain and frequency domain were investigated for this project. Generally, the information retrieved from the measurement system can be used to determine both the instantaneous volumetric and velocity of solids over the pipe cross section.

## **1.2 Problem Statement**

The process tomography system requires the knowledge of various discipline such as instrumentation, process, and optics to assist in the design and development of the system. Generally, the solutions to the problems that were carried out in this project are:

- Development of a suitable sensor configuration for the selected infra-red emitter and receiver. Design of the fixture must be able to avoid the infra-red sensor from being exposed to any kind of ambient light (day light, lamp etc) and placed around the boundary of the pipe so that light emitted from the

emitter will be the only one that is in contact with the solid particle in the pipeline.

- Determine the best infra-red emitter and receiver based on the physical nature of the design of material that is involved in the transmission of the infra-red light, light emission, spectral characteristic, sensor radiation characteristic, receiver respond, optical power, and availability from suppliers.
- Selecting suitable signal conditioning and electronic controller. The characteristic of the component used will determine the whole measurement result, such as power consumption, offset current, input impedance, slew rate, and common mode input voltage range (Tan, 2002).
- Increasing the number of sensor measurement (128 pairs of infra-red transmitter and receiver for upstream and downstream planes). The number of measurement and projection angle subsequently affect the quality of the image reconstructed (Ibrahim, 2000).
- Synchronization of the data acquisition with the circuitry operation. A digital controller with sufficient of memory, easy programming language, programmable, stable, and has a high operation speed.
- The programming language that drive and control the interface between the hardware developed must be compatible with the application programming language in Windows environment.
- Implementation of the image reconstruction algorithm and velocity measurement. The image reconstruction estimated the distribution of material within the pipe which would provide the measured sensor output and the velocity measurement provide the solid particles velocities values.

The idea based on Hartley *et al.* (1995) and Chan (2003) where the method of research covers:

- Two orthogonal parallel projections those are perpendicular to each other.
- The design of the system started with the aim of flow imaging.
- The output of several sensors for each projection are multiplexed, in order to minimize the system complexity and cost.
- Hartley's system (Hartley *et al.*, 1995) made use of  $8 \times 8$  sensors, in which each projection has 8 views for image reconstruction, but when larger number of views are needed it has to be determined off-line since the transputer being used was slow.

In conjunction with the previous research, the solutions required are listed as follow:

- The SFH485P infra-red LED transmitter and the SFH203P photodiode receiver selected have a matching wavelength at 990nm, a flat top surface for full light collimation before it is distributed using fiber optics, fast switching characteristic, and low optical power.
- The appropriate technique of constructing the signal conditioning circuit where it is very important to convert the amount of incident infra-red light using the photodiode to a suitable voltage level. Then a sample and hold circuit will be used to hold the measured signal.
- Increase the numbers of view/measurement by optimizing the time required to capture 128 sensor channels, using a data acquisition system with 64 analog input channels.
- Synchronization between signal conditioning and data acquisition, using a PIC controller where the operation between the data acquisition system and circuitry operation that involved settling time for hold and sample must be configured to make sure data obtained from upstream and downstream sensors can be differentiate.

- The Microsoft Visual C++ 6.0 was selected because the C language has the advantages of being small size, fast, support modular programming, and memory efficient (Bronson, 1999). Microsoft Visual C++ 6.0 is a powerful language with a standard user interface and enables device independent program.
- A software driver for real-time data acquisition in the Microsoft Window environment called DriverLINX provided by Keithley customized to support the data acquisition system interface system between the software and hardware developed.
- Solving the forward and reverse problem based on the projection theorem. The forward problem provides the theoretical output of each sensor under no-flow and flow conditions when the sensing area is considered to be two-dimensional and the inverse problem estimates the distribution of material within the pipe which would provide the measured sensor outputs (Ibrahim *et al.*, 1999).
- Numerous image reconstruction technique adapted in the tomography, such as Linear Back projection and Fourier reconstruction. In this study the reconstruction, covered image reconstruction in the spatial domain, frequency domain, and the hybrid approach (Ibrahim, 2000).
- The application of cross correlation technique for velocity measurement.

### **1.3 Significance and Objective of the Study**

Uchiyama *et al.* (1985) pointed out that the use of thermography is an inappropriate technique for measuring the temperature distribution in flames, as the infra-red radiation received by the sensor is the line integral of the emitted radiation along the optical path. Infra-red radiation, having wavelengths which are much

longer than visible light, can pass through dusty regions of space without being scattered. This means that we can study objects hidden by gas and dust in the infra-red, which we cannot see in visible light (Mass, 1972). These are the advantages using infra-red light where the dust or gas that is produced or fetched by the conveyed particles does not affect the measuring systems.

Studies have shown that both contrast and spatial resolution of optical images are affected by the optical properties of the background medium, and high absorption and scattering are generally beneficial. Based on these observations, wavelengths shorter could be profitable for optical measuring systems (Taroni *et al.*, 2004). X-rays, gamma-rays, and ultraviolet-light have a shorter wavelength but the problems arise on how to handle properly this kind of material because it's dangerous to living things.

Research by Ibrahim *et al.* (1999) has proved that the use of fiber optic can enhance the image resolution with the purpose of measuring the concentration and velocity of gas bubbles in a vertical water column. Chan (2003) utilized the concept of fan beam switching mode to increase the total projections, image resolution and the total number of measurements to analyze images of solid particle flow. Pang (2004) developed an optical tomography system to perform real-time mass flow rate by using two local networked PC and five programs. Based on those researches, the tomography system in this project can enhance the image resolution, increase the total number of measurements in order to image the flow of solid particles and perform velocity measurement based on the use of fiber optic and parallel beam switching mode between the measurement planes using one PC and one programs (upstream and downstream planes).

The objectives of this investigation are:

- 1) To become familiar with the concept of process tomography, and associated sensors.
- 2) To understand the application of data acquisition system and tomographic imaging reconstruction.

- 3) To study the interaction between the collimated infra-red light and the targeted object (which is dropped into the flow pipe).
- 4) To solve the forward and reverse problems (Ibrahim, 2000).
- 5) To calculate the velocity of dropping particle using results from the cross correlation method (Plaskowski *et al.*, 1997) and free fall motion.
- 6) To design a hardware system for the infra-red tomography system.
- 7) To incorporate the signal conditioning (circuitry operation) with the data acquisition system by synchronizing the signal conditioning with the data sampling processes.
- 8) To determine the better reconstruction algorithm for flow imaging between spatial domain, frequency domain, and hybrid image reconstruction.
- 9) To implement a measurement system that will obtain data from the infra-red sensors for concentration and velocity measurements for various flow rates.
- 10) To test this system on a pneumatic flow conveyor by distributing solid particles into a vertical pipe and to investigate the concentration and velocity profiles using the experimental data that have been obtained for various flow rates.



## **1.4 Scope of Study**

The aim of the study is to investigate the flow regimes (image reconstruction) and flow velocity in pipe due to dropping particles and velocity measurement (Kaplan, 1993) using a conveyor flow rig. The scope of study includes:

- 1) Absorption by the emission of infra-red light.
- 2) Flow rates, concentration profiles, and velocity of dropping particles.
- 3) Signal conditioning and data acquisition system.
- 4) Process modeling: includes sensors fixture, flow rig model, signal conditioning circuit's design and software development.
- 5) Image reconstruction algorithm and cross-correlation method.
- 6) Thesis writing.

## **1.5 Organization of the Thesis**

Chapter 1 presents an introduction on process tomography research's background problem, problem statement, significance and objective and scope of study.

Chapter 2 presents a brief review of process tomography, types of process tomography such as electrical capacitance, electrical impedance, ultrasonic, x-ray, nuclear resonance magnetic, positron emission, mutual inductance, microwave, and optical tomography.

Chapter 3 presents a discussion on the relationship between projection and object functions, modeling of the infra-red optical system sensor, software signal

conditioning, image reconstruction algorithm, reconstructed image error measurement, and velocity of flow.

Chapter 4 discusses a presentation on the development of infra-red tomography measuring system.

Chapter 5 presents a discussion on the single pixel flow, multiple pixels, half, and full flow modeling, image reconstruction algorithm for flow models, results of reconstructed model images, comparison of algorithms performance, and conclusion from the results.

Chapter 6 presents a discussion on the concentration measurement and the concentration profiles.

Chapter 7 presents a discussion on the introduction of free fall and air resistance theory, velocity measurement, and velocity measurement.

Chapter 8 presents the conclusion and the recommendations for future work.