DUAL MODALITY TOMOGRAPHY : Principles, Techniques & Applications

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Abstract: There is a widespread need for the direct analysis of the internal process plants in order to improve design and operation of equipment. Process tomography involves using tomographic imaging methods to manipulate data from remote sensors in order to obtain precise quantitative information from inaccessible locations. This book discusses on Dual Modality Tomography - Principles, Techniques & Application. It’s very useful to the process engineer and researcher in this area.

Keywords: Sustainable, tomography, operation, advanced

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Preface

There is a widespread need for the direct analysis of the internal process plants in order to improve design and operation of equipment. Process tomography involves using tomographic imaging methods to manipulate data from remote sensors in order to obtain precise quantitative information from inaccessible locations.

This book discusses on Dual Modality Tomography - Principles, Techniques & Application. It's very useful to the process engineer and researcher in this area.

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CHAPTER 1
Introduction

1.1 Background of Process Tomography

Process tomography is a process employed to construct and visualize a cross sectional image from a set of data obtained by tomography sensors (F. J. Dickin et al., 1992). This technique is excellent in visualizing the internal characteristics and behavior of a subject inside a particular region of interest. It has been widely used for medical purposes since the early 1970s.

In recent years, industrial tomography has been extensively studied for applications such as multiphase flow measurement, flow monitoring, and pipe conveyor in various field. Basically, process tomography is divided into the soft-field type and hard-field type. Electrical tomography techniques such as electrical capacitance tomography (ECT), electrical resistance tomography (ERT), and electrical impedance tomography (EIT) are soft-field related (T. Dyakowski, 1996; H. H. Ji, Zhiyao et al., 2003; M. Soleimani et al., 2013). Meanwhile, techniques such as ultrasonic tomography (UT), x-ray tomography, positron emission tomography (PET), microwave tomography (MT), optical tomography (OT) and others are hard-field related (T. Dyakowski, 1996; K. B. Ozanyan et al., 2011).

Most of these tomography systems employ a single measurement technique which often drawdown the system to measure two-phase flow such as liquid-gas phase, liquid-liquid phase, liquid-solid phase and solid-gas phase. Depending on the application, a relevant and appropriate tomography technique is applied. Each of these technique has its own advantages and limitations whereby combining two or more tomographic techniques has been recognized as an important imaging method to maximize measurement data (G. Steiner, 2006).

Multimodality tomography greatly extended the range of possible applications when two or more modalities are integrated and incorporated with each other. These integrated techniques provide complementary

CHAPTER 2

Process Tomography Imaging

2.1 An Overview of Process Tomography

Process tomography is a technique used to investigate the internal activity of a cross-sectional plane of a pipeline vessel. This technique is widely used especially in the medical field such as X-ray system, magnetic resonance imaging (MRI) scan and others. These single-modality techniques are very useful for two phase flow measurement and widely applied in the field of chemical engineering, palm oil industry, food processing and many more (C. G. Xie et al., 1995). The basic tomography system can be subdivided into three basic blocks; the sensor, the sensor electronics and the image reconstruction, interpretation and display is illustrated in below Figure 2.1 (F. J. Dickin et al., 1992).

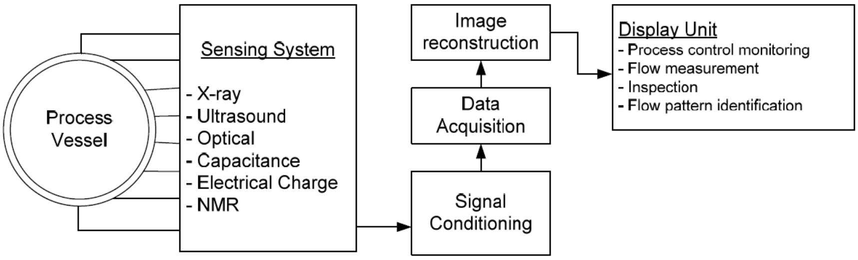

Figure 2.1: Tomography system block diagram

The aim of this technique is to view the flow concentration of the flowing material in a pipeline conveyor (D. G. Hayes et al., 1995; P. J. F. Ruzairi Abdul Rahim & Chan Kok San, 2006). This can be done by installing an array of sensors at the pipe circumference to interact with the interest subject inside the process vessel. The acquired signals will then be interpreted via customized software to reconstruct images and finally visualize it on a display unit for flow measurement, monitoring purpose and others.

CHAPTER 3

Modelling and Analysis of Dual Modality Tomography

3.1 Introduction

Since ECT system estimates the cross-sectional distribution of an object by performing boundary measurements while UT relies upon detectable interactions between mediums, numerical technique will be involved which demands complex mathematical model of the sensor system. It is often difficult to solve the geometry model and the boundary conditions of such system. Therefore, forward modelling using finite element method (FEM) is necessary to simulate the measurement conditions thus solve the forward model as to acquire an algorithm for quantifying the image reconstruction (W. Yang, 2006; W. Yang, 2006).

COMSOL Multiphysics has the capability to establish such analysis and simulation by using the Electrostatic Module (EM) for capacitance sensor and Pressure Acoustics Module (PA) for ultrasonic sensor simultaneously.

3.2 Modelling of dual modality tomography

To model the dual modality tomography system (DMT), the finite element method (FEM) is used to solve the complex physics of this system. The model is constructed according to the following modelling workflow (M. A. Zimam, 2011).

i) Selecting the physics module for ECT and UT
ii) Constructing the geometry of the model by using the built-in computer-aided design (CAD) tools.
iii) Domain property settings of each physics interfaces including assigning material properties to the model.
iv) Discretize the whole model by using meshing tool.
v) Compute and solve the modelled conditions.
vi) Post-processing and result analysis.

CHAPTER 4

The Tomogram Reconstruction

4.1 Introduction

Image reconstruction is a mathematical process that reconstructs images from a set of projection data acquired at different angles around the pipe peripheral (M. Ai, 1996). It was initiated for X-ray tomography (M. H. F. Rahiman et al., 2006) due to its advantages of low computation cost and high computation speed. In this research, the data acquired from DMT system needs to be interpreted in a visual form namely a tomographic image. The common challenge in performing image reconstruction is to solve the inverse and forward problems.

4.2 The forward Problem

The forward problem is addressed to determine the theoretical sensor data by discretizing an image plane into a grid of 128 x 128 pixels for each sensor projections (M. H. F. Rahiman et al., 2007).

DMT system uses an acrylic pipe with an inner diameter of 100 mm which is the region of interest (ROI) for measuring multiphase flow. The ROI area needs to be convert into smaller elements called pixel according to equation (4.1):

$$P_x = \frac{d}{N} = \frac{100\boldsymbol{m}}{128\,pixel} = 0.7813\ \boldsymbol{m} \qquad (4.1)$$

where, P_x is the pixel size, d is the pipe inner diameter and N is the number of pixels in the ROI.

Therefore, the 100 mm diameter pipe is discretized into an image plane which consist of 16384 element array of which 13076 effective pixels within the boundary circle or within the ROI while 3308 pixels are ineffective as in Figure 4.1.

CHAPTER 5

Design of an Single-Plane Dual Modality Tomography (DMT) System

5.1 Single-plane DMT System

A single-plane DMT system is developed in this research by emerging ultrasonic and electrical capacitance sensors to measure multiphase phase flow components of water, oil and gas. The implementation of DMT could permit the integration of both UT and ECT system data via a customized sensory configuration. The basic block diagram of the DMT system is illustrated in Figure 5.1.

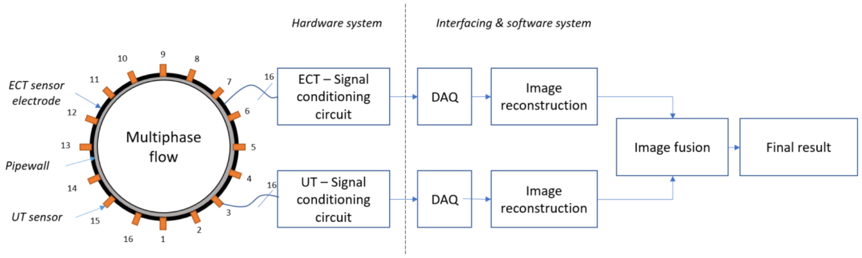

Figure 5.1: Basic block diagram of a dual modality tomography setup

This single-plane DMT composite emerged as a set of electrical capacitance measurement electrodes and ultrasonic transceivers mounted symmetrically inside, or more typically, outside an insulated pipe. All sensors are designed to be non-invasive and non-intrusive which are more preferable considering no internal interference will occur with the measurement subject (W. Yang, 2006). Figure 5.2 shows the actual hardware system of DMT.

CHAPTER 6

The Experimental Design

6.1 Introduction

This chapter presents the experimental results obtained from the dual modality tomography system (DMT) for two-phase and three phase compositions both in vertical column and horizontal setup.

6.2 Experiment Procedure and Setup

To test the DMT system, five test profiles were configured to carry out this experiment. These test profiles are similar to the ones used in previous section 4 with a set of pre-defined liquid-gas composition for horizontal setup and pre-defined position for gas bubbles in vertical column setup. The reconstructed cross-sectional image results are divided into two sections; two-phase flow and three phase flow in both horizontal and vertical column setup. Each of the setup utilizes its respective colormap as in figure 6.1.

6.2.1 Two Phase Flow Experimental Result

Figure 6.1 (a) and (b) shows the reconstructed test profile using linear back projection (LBP) and convolution back projection filter (CBPF) respectively in horizontal flow condition.

CHAPTER 7

Practical Design Experiment and Apllication of dual Modality Tomography

This section provides an overview of the potential application for the dual modality tomography (DMT). Examples of practical applications in brief for the DMT range is as follows:

a) Multiphase hydrocarbon flow application

A dual modality tomography (DMT) which include capacitance and gamma-ray sensors showed feasibility in relation to the hydrocarbon flow application and has been developed in (F. J. Dickin et al., 1992).

b) Multiphase flow monitoring process application

The design of composite dual modality tomography can be implemented as an information provider to perform multiphase flow measurement and monitoring process application (T. Dyakowski, 1996). This application involved of multi-modality system emergence of ultrasonic transceivers and electrical capacitance sensor studies.

c) Multiphase flow imaging application

A single plane DMT can be applied into the multiphase flow imaging application by working on integrating electrical capacitance and ultrasonic sensors. Work by (H. H. Ji, Zhiyao et al., 2003) developed an experimental study for this research work for water-oil-gas three phase flow imaging.

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