

**DEVELOPMENT OF ULTRASONIC  
TOMOGRAPHY SYSTEM FOR LIQUID/GAS  
FLOW MEASUREMENT IN A VERTICAL  
COLUMN**

NOR MUZAKKIR BIN NOR AYOB

**UNIVERSITI MALAYSIA PERLIS  
2011**

© This item is protected by original copyright



**Development of Ultrasonic Tomography  
System for Liquid/Gas Flow Measurement  
in a Vertical Column**

by

**Nor Muzakkir Bin Nor Ayob  
(0830610258)**

A thesis submitted  
In fulfilment of the requirements for the degree of  
Master of Science (Mechatronic Engineering)

**School of Mechatronic Engineering  
UNIVERSITI MALAYSIA PERLIS**

2011

# UNIVERSITI MALAYSIA PERLIS

## DECLARATION OF THESIS

Author's full name : Nor Muzakkir Bin Nor Ayob  
Date of birth : 21 November 1985  
Title : Development of Ultrasonic Tomography System for Liquid/Gas  
Flow Measurement in a Vertical Column  
Academic Session : 2010 / 2011

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of \_\_\_\_\_ years, if so requested above).

  
\_\_\_\_\_  
**SIGNATURE**

851121-14-6037  
\_\_\_\_\_  
**(NEW IC NO. / PASSPORT NO.)**

Date : 18/4/2011

Certified by:

  
\_\_\_\_\_  
**SIGNATURE OF SUPERVISOR**

Prof. Dr. Sazali Bin Yaacob  
\_\_\_\_\_  
**NAME OF SUPERVISOR**

Date : 18/4/2011

**NOTES :** \* If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

*Dengan nama Allah yang Maha Pemurah lagi Maha Penyayang.*

*To my beloved and supportive parents,*

*my brothers and sister,*

*and Intan Maisarah Bt. Abdul Rahim.*

© This item is protected by original copyright

## ACKNOWLEDGEMENT

Praise to Allah, the Cherisher and Sustainer of the worlds. With His blessings I have completed this thesis.

My deep appreciation and gratitude goes to my supervisor Prof. Dr. Sazali Yaacob for his kindness, constant endeavour, guidance and the numerous moments of attention he devoted through out this work.

My heartfelt gratitude goes to Mr. Mohd Hafiz Fazalul Rahiman and Mr. Zulkarnay Zakaria for the helpful suggestions, endless supports and encouragement that have greatly helped me in finishing this research. I extend my gratitude to Mr. Ammar Zakaria, Muhammad Naufal Mansor, Lim Sin Chee and Mohd Rizal Manan who have spent a lot of their precious time to guide, advice and support me. Special thanks go to Intan Maisarah Abdul Rahim for being there by my side and always lend a hand during the experiments and data collections. Not to forget all my friends and colleagues especially the Intelligent Signal Processing Research Cluster members for all the experience and joyful moments that we have shared together and for all the help, support, interest and valuable hints.

I would like to express my deepest gratitude to my dearest family especially both to my understanding and beloved parents for their love and their endless support in any possible way. This research would have never reached to this point if not because of their support and patience on their son. My success will always be their success too.

Last but not least, thanks to those who have helped me in one way or another throughout the whole duration of my research development. For other researchers or students who wish to contact me, please do so via my email, [normuzakkir@mail.com](mailto:normuzakkir@mail.com).

## TABLE OF CONTENTS

<b>TOPICS</b>	<b>PAGE</b>
TITLE	i
DECLARATION OF THESIS	ii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xvi
ABSTRAK	xix
ABSTRACT	xx
<b>CHAPTER 1</b>	
<b>INTRODUCTION</b>	
1.1 Background Problems	3
1.2 Problem Statements	4
1.3 Importance of Study	5
1.4 Aims and Objective of the Research	7
1.5 Dissertation Structures	8

## CHAPTER 2 LITERATURE REVIEW

2.1 Introduction	10
2.2 Flow Measurement	10
2.3 Importance of Two-Phase Flowmeters	11
2.4 An Introduction to Process Tomography	13
2.5 Types of Tomography Sensors	14
2.5.1 Electrical Capacitance Tomography (ECT)	16
2.5.2 Electrical Resistance Tomography (ERT)	17
2.5.3 Electrical Impedance Tomography (EIT)	17
2.5.4 Electromagnetic Tomography (EMT)	18
2.5.5 Positron Emission Tomography (PET)	19
2.5.6 Optical Tomography	19
2.5.7 Ultrasonic Tomography	20
2.6 Process Tomography using Ultrasonic Sensor	21
2.6.1 Ultrasonic Tomography Sensing Modes	21
2.6.2 Ultrasonic Frequency and Wavelength	22
2.6.3 Acoustic Impedance	23
2.6.4 Ultrasonic Attenuation	25
2.6.5 Ultrasonic Propagation	26
2.7 The Non-Invasive Measurement	27
2.8 Type of Projections	29
2.9 Summary	30

## **CHAPTER 3      **HARDWARE DEVELOPMENT OF THE ULTRASONIC TOMOGRAPHY****

3.1 Introduction	33
3.2 Vertical Column	33
3.3 Sensors Fixture Design	35
3.4 The Non-invasive Fabrication Technique	37
3.5 Ultrasonic Sensors	39
3.5.1 Sensor Selection	40
3.5.2 Sensor Arrangement	43
3.6 Electronics Circuitry and Embedded System	44
3.6.1 Pulse Generator Circuit	46
3.6.2 Signal Amplifier Circuit	48
3.6.3 Sample and Hold Circuit	50
3.6.4 Digital Controller Unit using dsPIC30F6014A	52
3.7 System Programming Structures	53
3.7.1 Transmitting Ultrasound Signals	54
3.7.2 Receiving Ultrasound Signals	55
3.8 Printed Circuit Board (PCB) Design	57
3.9 The Data Acquisition System using NI USB-6218	58
3.10 Summary	59



<b>CHAPTER 4</b>	<b>SOFTWARE DEVELOPMENT FOR TOMOGRAPHIC IMAGING</b>	
4.1	Introduction	61
4.2	Projection Geometry	62
4.3	Sensitivity Maps	64
4.4	Tomographic Image Reconstruction	66
4.4.1	Linear Back Projection Algorithm	67
4.4.2	Eminent Pixel Reconstruction Algorithm	68
4.4.3	Eminent Pixel Reconstruction Algorithm with Median Filtering	69
4.5	Ultrasonic Tomography System Calibration	70
4.6	Measurement Process	71
4.7	Composition Determination from Concentration Profile	77
4.8	Image Reconstruction Error Measurement	79
4.9	Simulative Study on Flow Measurement	80
4.10	Summary	81
<b>CHAPTER 5</b>	<b>SIMULATIVE VELOCITY MEASUREMENT FOR ULTRASONIC TOMOGRAPHY: A CASE STUDY</b>	
5.1	Introduction	82
5.2	Cross-correlation Principle	82
5.3	Simulation Model	85
5.4	Velocity Measurement using Cross Correlation Technique	88
5.4.1	Mean Correlation	88
5.4.2	2-D Correlation Coefficient	90
5.5	Summary	91

<b>CHAPTER 6</b>	<b>IMAGING EXPERIMENTS, RESULTS AND ANALYSIS</b>	
6.1	Introduction	92
6.2	Forward Model Simulation Results	92
6.3	The Experimental Design	96
6.3.1	Single Gas Bubble Measurement	97
6.3.2	Dual Gas Bubbles Measurement	98
6.3.3	Multiple Gas Bubbles Measurement	99
6.3.4	Measurement Error Analysis	100
6.4	Reconstruction Algorithm Repeatability	106
6.5	Simulative Velocity Measurement Analysis	108
6.6	Summary	111
<b>CHAPTER 7</b>	<b>CONCLUSION AND SUGGESTIONS FOR FUTURE WORK</b>	
7.1	Conclusion	113
7.2	Contributions towards Process Tomography	114
7.3	Recommendation for Future Works	115
<b>REFERENCES</b>		117
<b>APPENDICES</b>		
	Appendix A (The Acoustic Impedances)	122
	Appendix B (Ultrasonic Transducer's Datasheet)	123
	Appendix C (The Sensor Values)	126
	Appendix D (Sensitivity Matrix Projections)	127
	Appendix E (Application Software)	141
	Appendix F (List of Publications)	147
	Appendix G (Research Awards and Expositions)	148

## LIST OF TABLES

Table		Page
2.1	Different modes of sound wave propagations .....	27
3.1	Ultrasonic sensor specifications .....	41
3.2	Voltage readings during reception angle observation (NL - No Linearity) .....	42
3.3	Observation timings ( $\mu$ s) logged for all scanning geometries .....	56
3.4	Developed PCBs and their functions .....	58
4.1	GUI-generated callbacks for software operations .....	73
6.1	Smallest deviation of measured gas area versus estimated value using EPR .....	103
6.2	Smallest deviation of measured gas area versus estimated value using EPR with Median Filter technique .....	103
6.3	Maximum Concentration, $C_{max}$ values .....	105
6.4	Spatial analysis using the linear functions .....	106
6.5	10 sets of on-line data used for testing the system's repeatability performance .....	107

## LIST OF FIGURES

Figure		Page
2.1	Illustration of process tomography, with the most common measurement techniques and its applications .....	15
2.2	The ultrasonic attenuation model .....	25
2.3	The attenuation model for ultrasonic transmitter .....	26
2.4	Invasiveness and intrusiveness of different sensor configurations .....	28
2.5	Various type of projections through a cross-section object .....	29
3.1	Prototype vertical column design (Dimension in mm) .....	34
3.2	Base holder design .....	35
3.3	Sensor fixture design .....	36
3.4	Sensor arrangement .....	43
3.5	3D printed sensors fixture .....	44
3.6	Ultrasonic tomography system - Block diagram .....	44
3.7	Schematic for pulse generator circuit .....	47
3.8	Schematic for signal amplifier circuit .....	49
3.9	Typical sample and hold circuit .....	50
3.10	Sample and hold circuit and signal response .....	51
3.11	Schematic for digital controller unit .....	53
3.12	Transmitting structure .....	54
3.13	Determining the peak amplitude and its observation time information ..	55
3.14	Illustration of sample and hold process .....	57
3.15	Developed PCBs in the hardware system .....	58
3.16	The data acquisition system (NI USB-6218) .....	59
4.1	The measurement section configuration .....	62

4.2	Ultrasonic fan-beam projection .....	63
4.3	Sensing area scanning geometry .....	63
4.4	Matrix containing virtual projection path for Transmitter 1 to Receiver 12 .....	64
4.5	Sensitivity map for Transmitter 1 to Receiver 12 .....	65
4.6	Normalized sensitivity maps .....	65
4.7	Back projecting an image .....	66
4.8	Median filter in reducing the amount of intensity variation pixels .....	69
4.9	Tomographic images before and after Median filtering .....	70
4.10	Graphical user interface for measurement process .....	72
4.11	Operation structure for the application software .....	74
4.12	Data acquisition flow .....	75
4.13	<i>Draw_Tomogram</i> image reconstruction structure .....	76
4.14	Programming structure for <i>Display_Tomogram</i> callback .....	76
4.15	Forward model for annular flow .....	80
5.1	The dual-plane UTT transducers array .....	83
5.2	The principle of velocity measurement using cross correlation technique .....	83
5.3	Simulation model for a single gas bubble hold-up movement.....	86
5.4	Simulation model for the single gas bubble .....	87
5.5	Reconstructed tomogram images of flow imaging recorded at Upstream and Downstream sensing area .....	87
5.6	Mean values for reconstructed flow images between Frame 10 to Frame 32 at the Downstream sensing area .....	89
5.7	Mean values plotted for each frame recorded at Upstream sensing area	90
5.8	Mean values plotted for each frame recorded at Downstream sensing area .....	90

5.9	Cross-correlation signal between Upstream and Downstream .....	90
5.10	Signal cross-correlation between upstream and downstream using 2-D Correlation Coefficient .....	91
6.1	Forward model simulation for single gas bubble .....	93
6.2	Forward model simulation for dual gas bubble .....	94
6.3	Forward model simulation for multiple gas bubbles .....	95
6.4	The experimental setup .....	96
6.5	On-line measurement - Single gas bubble ( $d_1 = 8$ mm) .....	97
6.6	On-line measurement - Dual gas bubbles ( $d_1 = 15.8$ mm, $d_2 = 8$ mm) .....	98
6.7	On-line measurement - Multiple gas bubbles ( $d_1 = 15.8$ mm, $d_2 = 8$ mm, $d_3 = 9.2$ mm) .....	99
6.8	Sensitivity test for discrete gas bubble ( $d = 3.45$ mm) .....	101
6.9	Accuracy test for small gas bubble ( $d = 8$ mm) .....	101
6.10	Accuracy test for large gas bubble ( $d = 18.8$ mm) .....	102
6.11	Gas distribution deviation analysis using EPR algorithm .....	103
6.12	Gas distribution deviation analysis using EPR with Median Filter .....	104
6.13	Linear regression between $C_{max}$ and $C_{Th}$ (EPR Algorithm) .....	105
6.14	Linear regression between $C_{max}$ and $C_{Th}$ (EPR with Median Filter) .....	105
6.15	Gas distribution deviation analysis based on linear regression method ..	106
6.16	Repeatability performance using LBP algorithm .....	107
6.17	Repeatability performance using EPR algorithm and EPR with Median filtering technique .....	108
6.18	Mean Correlation results for $Gas\_Up_{xy}(15,15)$ and $Gas\_Down_{xy}(15,15)$	109
6.19	2-D Correlation Coefficient results for $Gas\_Up_{xy}(15,15)$ and $Gas\_Down_{xy}(15,15)$ .....	109
6.20	Mean Correlation results for $Gas\_Up_{xy}(45,45)$ and $Gas\_Down_{xy}(15,15)$	110
6.21	2-D Correlation Coefficient results for $Gas\_Up_{xy}(45,45)$ and $Gas\_Down_{xy}(15,15)$ .....	110

## LIST OF ABBREVIATIONS

<b>Abbreviation</b>	<b>Definition</b>
AC	- Alternating Current
ADC	- Analogue-to-Digital Converter
CAT	- Computerised Axial Tomography
CPU	- Central Processing Unit
CS	- Control Signal
CT	- Computerised Tomography
DA	- Dielectric Absorption
DAQ	- Data Acquisition System
DC	- Direct Current
DCU	- Digital Controller Unit
ECT	- Electrical Capacitance Tomography
EIT	- Electrical Impedance Tomography
EMT	- Electromagnetic Tomography
EPR	- Eminent Pixel Reconstruction
ERT	- Electrical Resistance Tomography
GUI	- Graphical User Interface
IC	- Integrated Circuit
ICSP™	- In-Circuit Serial Programming™
IPT	- Industrial Process Tomography
LBP	- Linear Back Projection
MATLAB	- Matrix Laboratory
MCU	- Microcontroller Unit
MIPS	- Million Instruction Per Second

MRI	-	Magnetic Resonance Imaging
NMR	-	Nuclear Magnetic Resonance
Op-Amp	-	Operational Amplifier
PC	-	Personal Computer
PCB	-	Printed Circuit Board
PCI	-	Peripheral Component Interconnect
PET	-	Positron Emission Tomography
PT	-	Process Tomography
RISC	-	Reduced Instruction Set Computer
RS232	-	Recommended Standard 232
SHA	-	Sample and Hold Amplifier
SnH	-	Sample-and-Hold
TI	-	Texas Instruments
USB	-	Universal Serial Bus
UT	-	Ultrasonic Tomography
UTT	-	Ultrasonic Transmission Tomography



## LIST OF SYMBOLS

<b>Symbol</b>	<b>Definition</b>
$\bar{A}$	- Average Mean of Matrix A
$\bar{B}$	- Average Mean of Matrix B
$A_G$	- Percentage of Gas Area
$Agas$	- Measured Gas Area
$A_L$	- Percentage of Liquid Area
$Aliquid$	- Measured Liquid Area
$B(x,y)$	- EPR Marking Matrix
$c$	- Velocity of Sound
$C$	- Capacitor
$C_{max}$	- Maximum Concentration
$C_{Th}$	- Concentration Threshold
$d$	- Diameter
dB	- Decibel
$E_a$	- Estimated Gas Area
$F_c$	- Center Frequency
fps	- Frames per second
$Gas\_Down_{xy}$	- Simulated Gas Bubble (Downstream)
$Gas\_Up_{xy}$	- Simulated Gas Bubble (Upstream)
$Gas_{xy}$	- Simulated Gas Bubble
kHz	- Kilohertz
$L$	- Distance
$M_a$	- Measured Gas Area
$ME$	- Measurement Error

MHz	-	Megahertz
$M_P$	-	Maximum Total Pixels
$M_{Tx,Rx}(x,y)$	-	Normalized Sensitivity Matrices
$N_{delay}$	-	Number of Delayed Frames
nF	-	Nanofarad
$P_{gas}$	-	Gas Component Percentage
$P_{liquid}$	-	Liquid Component Percentage
$P_r$	-	Reflection Coefficient
$P_t$	-	Transmissions Coefficient
R	-	Resistor
Rx	-	Receiver
SimMap	-	Simulated Phantom Matrix
$Sim_x$	-	Simulation Profile
SnH	-	Sample-and-Hold
$S_{TxRx}$	-	Sensor Loss Voltage
$t_s$	-	Observation Time
Tx	-	Transmitter
$V$	-	Flow Velocity
V-	-	Inverting Input
$V(x,y)$	-	Concentration Profile
V+	-	Non-inverting Input
$V_{EPR}(x,y)$	-	Concentration Profile using LBP
$V_{LBP}(x,y)$	-	Concentration Profile using LBP
$V_{p-p}$	-	Voltage Peak-to-Peak
$V_{ref}$	-	Voltage Reference
$V_{ref\ TxRx}$	-	Reference Sensor Voltage
$V_{Supply}$	-	Voltage Supply

$V_{TxRx}$	- Measured Sensor Voltage
$Z$	- Acoustic Impedance
$\rho$	- Density
$\tau$	- Transit Time
$f$	- Frequency
$\alpha$	- Attenuation Coefficient
$\lambda$	- Ultrasound Wavelength
$^{\circ}$	- Degree
$\mu\text{F}$	- Microfarad
2D	- Two Dimensional
3D	- Three Dimensional

© This item is protected by original copyright

# PEMBANGUNAN SISTEM ULTRASONIK TOMOGRAFI UNTUK PENGUKURAN ALIRAN CECAIR/GAS DALAM SALURAN MENEGAK

## ABSTRAK

Aliran cecair/gas dua-fasa boleh didapati secara meluas dalam pelbagai aplikasi termasuk industri kimia dan petroleum. Pengukuran aliran dua-fasa adalah parameter yang penting untuk aplikasi yang memerlukan ketepatan pengukuran aliran. Aliran dua-fasa adalah fenomena yang sangat penting untuk sektor petroleum dan gas. Jika dibandingkan dengan aliran satu-fasa, ciri-ciri aliran dua-fasa adalah jauh lebih kompleks. Oleh kerana itu, peningkatan teknologi instrumentasi dan pengukuran aliran dua-fasa seperti penciptaan meter dua-fasa akan mempunyai peningkatan permintaan kerana akan memberi manfaat yang signifikan kepada banyak industri. Berdasarkan pada kelebihan teknik pengimejan tomografi, teknik pengesanan ultrasonik yang tidak mengganggu proses aliran dapat direalisasikan. Litar elektronik digunakan untuk proses penghantaran dan penerimaan isyarat analog, serta sistem perolehan data untuk pemindahan data kepada computer. Algoritma rekonstruksi imej yang sesuai juga penting untuk menyediakan akses visual kepada aliran cecair/gas dua-fasa sambil memberikan maklumat anggaran distribusi komponen untuk proses pemerhatian masa nyata. Ciri-ciri penting bagi pemilihan sensor telah diambil perhatian dan diseimbangkan antara frekuensi operasi yang tinggi untuk kepekaan yang lebih baik dan keluasan saluran menegak untuk mengelakkan isyarat pengukuran tidak dapat dikesan akibat redaman lengkap. Kualiti pengimejan pergerakan komponen cecair dan gas telah berjaya ditingkatkan melalui penggunaan algoritma baru Rekonstruksi Pikel Penting (RPP) jika dibandingkan dengan algoritma Unjuran Kembali Linear (UKL) yang umum. Kajian simulatif terhadap pengukuran halaju aliran dua-fasa cecair/gas untuk sistem ultrasonik tomografi satah berganda telah dijalankan. Dua cara berbeza berdasarkan penggunaan teknik korelasi-silang telah menunjukkan kesesuaian teknik tersebut untuk menganggarkan kelajuan aliran. Kualiti rekonstruksi imej terhadap aliran dua-fasa dilihat mempunyai kesan yang signifikan dengan menggabungkan algoritma RPP dengan teknik Penapisan Median yang mengabaikan bacaan piksel yang tidak serasi dengan keadaan sekitar. Gabungan algoritma RPP dengan teknik Penapisan Median dilihat memberi kesan yang signifikan dalam meningkatkan kualiti rekonstruksi imej dengan mengabaikan bacaan piksel yang tidak serasi dengan keadaan sekitar. Kelebihan lain akibat dari kombinasi tersebut adalah kesan yang halus terhadap rekonstruksi imej sambil memberikan gambaran komponen cecair dan gas dua-fasa yang lebih baik, malah hasilnya juga mempunyai bentuk dan saiz yang menghampiri keadaan sebenar aliran. Kaedah statistik linear juga diperkenalkan untuk menganggarkan nilai ambang-atas yang sesuai untuk pengimejan saiz komponen gas yang berbeza dalam saluran yang ingin dipantau terutama dalam kejayaan mengesan gelembung gas yang kecil. Keputusan yang diperolehi mungkin berguna bagi pemantauan aliran cecair/gas dalam pelbagai industri seperti proses campuran kimia, penghantaran bahan kimia atau pemantauan proses.

# DEVELOPMENT OF ULTRASONIC TOMOGRAPHY SYSTEM FOR LIQUID/GAS FLOW MEASUREMENT IN A VERTICAL COLUMN

## ABSTRACT

*Liquid/gas two-phase flow widely exists in many applications including chemical and petroleum industries. Measurement of this two-phase flow is an essential parameter for these applications where accurate flow measurement is required. Two-phase flow, a phenomenon of critical importance to oil and gas sector where compared with single-phase flow, its flow characteristic is much more complex. Thus, the improvement of the instrumentation and measurement technology for the two-phase flow such as the development of two-phase flowmeters will have a growing demand since it will bring significant benefits to many industries. Based on the advantage of tomographic imaging technique, non-invasive ultrasonic sensing technique is realized by using electronic measurement circuits for transmitting and receiving the analog signals, data acquisition system for transferring the data to the PC and most importantly the suitable image reconstruction algorithm for providing visual access to the two-phase liquid/gas flow and estimating the component distribution for real-time measurement. The important characteristic for sensor selection is noted and balanced between high operating frequency for increased spatial sensitivity and the cross-sectional area of the vertical column to avoid undetected measurement signal caused by complete attenuation. The enhancement of liquid and gas component distribution imaging over the common Linear Back Projection (LBP) algorithm has been successful by implementing the new Eminent Pixel Reconstruction (EPR) algorithm. Simulative study on liquid/gas two-phase velocity measurement for dual-plane ultrasonic tomography system also has been made. Two different methods based on the use of cross-correlation technique have shown the usability of the technique for estimating the flow velocity. The image reconstructions quality of the two-phase flow is seen to have a significant increase by combining the EPR algorithm with Median Filtering technique that eliminated pixel values which are unrepresentative of their surroundings. Another advantage of such combination is the smoothen effect on the reconstructed images, resulting in better visualization of the two-phase liquid and components because the outcome have approximating shape and size if compared with the actual flow condition. Linear regression method are also introduced for configuring the appropriate threshold values for imaging different size of gas component inside the investigated column especially on the successful detection of small gas bubbles. The results obtained can be useful for the online monitoring of liquid/gas flow in many industrial processes such as chemical mixing process, fluid transportation or process monitoring.*

## CHAPTER 1

### INTRODUCTION

The word 'tomography' which according to the Oxford English Dictionary means a technique for displaying a cross section through a human body or other solid objects using X-rays or ultrasound. The origin of the word 'tomography' is the combination of the word *tomos* which originates from Greek and the word *graphy*. *Tomos* means "a section" or "a cutting" while *graphy* is a technique of producing images. The Encyclopaedia Britannica describes tomography in a more application-orientated manner:

A still more complex technique variously called computerised tomography (CT), or computerised axial tomography (CAT), was developed by Godfrey Hounsfield of Great Britain and Allan Cormack of the United States during the 1970s. Since then it has become a widely used diagnostic approach. In this procedure, a narrow beam of X-rays sweeps across an area of the body and is recorded not on film but with a radiation detector as a pattern of electrical impulses. Data from many sweeps are integrated by a computer, which uses the radiation absorption figures to assess the density of tissues at thousands of points. The density values appear on a television-like screen as points of varying brightness to produce a detailed cross-sectional image of the internal structure under scrutiny (Vol. 11, p. 837)

As it can be concluded from this description, tomography is often commonly perceived as an imaging tool for medical examination purposes. It has to be emphasized, however, that the concept of tomography and its non-invasive way of imaging are not restricted to the medical field. Over the last decade, tomography has been developed, into a reliable instrumentation tool for imaging numerous industrial applications. This field of application is commonly known as Industrial Process Tomography (IPT) or simply Process Tomography (PT). Process tomography consists

of tomographic imaging of systems, such as process pipes in industry. In tomography the two-dimensional (2D) and even three-dimension (3D) distribution of some physical quantity in the object is determined. There is a widespread need to get tomographic information about process. This information can be used, for example, in the design and control of processes. Tomography involves taking measurements around the periphery of an object (e.g. process vessel or patient) to determine what is going on inside. The best known technique is CAT scanning in medicine, however process tomography instrumentation needs to be cheaper, faster and more robust (York, 2001).

External non-invasive sensors are used to detect signals from the investigated process, and the three dimensional material distribution or the velocity field is computed using the measured data. Process tomography is an area of rapid growth both in terms of research and applications. There are number of challenges remaining in this area including data processing for image reconstruction (Soleimani, 2008), and application of imaging modalities in a real applications. Process Tomography is undoubtedly providing new ways to look inside industrial processes, where in industry, seeing is believing. Process Tomography also becomes even more appealing since non-intrusive sensors are used to obtain the cross-sectional images.

Generally a tomography system can be built by mounting a number of sensors around the circumference of a vertical or horizontal pipe. The output signal from the sensors can be processed through a signal conditioning circuit and will be sent to the Personal Computer (PC) by means of any Analogue-to-Digital Converter (ADC). Data processing will be performed on the digitized signal from respective sensors that has been received by the PC. Finally the processed data will be used to reconstruct the cross-section flow image in the pipe. Information obtained from tomography systems will enable concentration, velocity and flow-rate to be determined over a wide range of

flow regimes by providing better averaging in time and space through multi-projections of the same observation. Improvement of the quantity and quality of information is also expected in any applications in using tomography systems.

### **1.1 Background Problems**

Previous research in adopting ultrasonic sensors in process tomography was introduced by Gai et al. (1989) when they documented their research on the non-invasive ultrasonic tomography fabrication technique. The history of ultrasonic tomography continues with the development that was focused to liquid/gas flow measurement (Xu et al., 1993; Xu & Xu, 1998; Xu et al., 1997). The latter system however implements invasive technique which is mostly not favoured by the industries. Additionally, the proposed technique by Xu et al. (1997) utilized high excitation voltage (around 200V) for the transmitter. This is however troublesome and the electrocution danger or technical breakdown would be dangerous if any fault accidentally appeared to be in the system. Nevertheless, the high excitation voltage has put a restriction on the system and also the application (Fazalul Rahiman, 2005).

©The latest development on ultrasonic tomography by Fazalul Rahiman (2005) however have solved the earlier problems described. The implemented system have successfully developed an ultrasonic tomography system using low operating voltage transducers (20V) which has been proved to be sufficient for liquid/gas flow imaging as long as the acoustic energy could pass through the process vessel (Fazalul Rahiman, 2005). More importantly, the developed system has successfully implement 16-pairs of ultrasonic transducers for non-invasive ultrasonic measurement system. The non-invasive transducer fabrication techniques were realised by using silicon grease as the