

CONCENTRATION AND VELOCITY MEASUREMENT OF FLOWING OBJECTS
USING OPTICAL AND ULTRASONIC TOMOGRAPHY

MOHD SAZLI BIN SAAD

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering
(Electrical – Mechatronics and Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

APRIL 2007

Dengan nama Allah yang Maha Pemurah lagi Maha Pengasih.

*To my beloved and supportive wife Wan Sallha,
my sons Muhammad Danish Irfan and Muhammad Dini Irsyad*

ACKNOWLEDGEMENT

I wish to express sincere, heartfelt appreciation to those involved in the completion of this project.

First and foremost, I wish to express special thanks, appreciation and deep gratitude to my project supervisor, Dr. Sallehuddin Bin Ibrahim, who has been there to provide continuous guidance, advice, encouragement, support and generous amount of time in helping me to complete this project. His remarkable unique ways and professionalism of handling my weaknesses has turned my simplistic mind to see think in more rational and critical view. It has been a great pleasure and privilege to learn from someone who is professional like him.

Special thanks also to co-supervisor Mr Amri, lab technician Mr. Faiz and Mr. Helmi, for their kind assistance through the materials and technical supports.

Sincere appreciation of course goes to my friends who give me unselfish support and my family especially my wife Wan Sallha Bt. Yusoff for their support and encouragement throughout in the completion of this project. Without their endless sacrifices, constant love and steadfast support, I would never have reach this level. To my sons Muhammad Danish Irfan and Muhammad Dini Irsyad, it is to you I dedicate this effort.

Above all, I would like to offer my deepest appreciation and thanksgiving to Allah SWT. There is no way to measure what You've worth. You are The One who has made things possible. You deserve all glory and honor.

ABSTRACT

This thesis investigates a simple measurement of concentration and velocity of objects flowing in a pipe of 100mm diameter. The project aims to analyze the accuracy and repeatability of measurements by comparing the results from the concentration and velocity measurement of various objects between optical and ultrasonic sensors. Both sensors are based on process tomography technique. The optical and ultrasonic tomography measurements circuit consists of sensors, signal conditioning circuits and data acquisition system. Sensors fixture are designed based on fan beam projection technique. The signal is transmitted from the transmitter to the receiver. Interfacing card is used to interface the analog signals to the computer. The sensors detect the attenuation of light for optical system and acoustic energy for ultrasonic system. This provides information on the concentration of the flowing objects. To measure velocity, two arrays of sensors are placed upstream and downstream on the pipe. The output from both sensors is cross-correlated. The peak of the cross-correlation graph represented the time for the object to move from upstream to downstream. The velocity is obtained by dividing the time and the distance between upstream and downstream. The velocity is obtained by simply dividing the time and the distance between upstream and downstream. Prototype circuits have been implemented for optical and ultrasonic measurement system. Visual Basic 6.0 is used for software algorithms on concentration and velocity measurement. The data is collected using data acquisition system and it was an offline process. The comparison of concentration profiles has shown that optical tomography produced a better result compared to ultrasonic tomography. Whereas for velocity measurement, ultrasonic transducer produced better accuracy but lower repeatability compared to optical transducer.

ABSTRAK

Tesis ini mengkaji pengukuran mudah terhadap penumpuan dan halaju objek bergerak di dalam paip berdiameter 100mm. Matlamat project in adalah untuk menganalisa ketepatan dan keboleh-ulangan pengukuran melalui hasil perbandingan daripada pengukuran penumpuan dan halaju ke atas pelbagai objek di antara pengesan optikal dan ultrasonik. Kedua-dua pengesan adalah berasaskan kepada teknik proses tomografi. Litar pengukur bagi tomografi optikal dan ultrasonik terdiri daripada pengesan, litar kondisi isyarat dan system pemungutan data. Alat pemasangan pengesan direka berdasarkan kepada teknik 'fan-beam projection'. Isyarat dihantar dari pemancar ke penerima. Kad penyambungan digunakan untuk menyambung isyarat analog ke komputer. Alat pengesan optikal mengesan pengecilan cahaya dan alat pengesan ultrasonik mengesan pengecilan kuasa akuastik. Dengan ini, maklumat tentang penumpuan dapat diperolehi. Untuk mengukur halaju, dua susunan pengesan dipasang di sebelah atas dan bawah paip. Isyarat yang keluar daripada kedua-dua jenis pengesan akan disilang-kait. Puncak tertinggi bagi graf silang-kait menunjukkan masa untuk objek bergerak dari atas ke bawah paip. Halaju ditentukan melalui pembahagian jarak atas-bawah dengan masa. Litar prototaip telah dilaksanakan ke atas pengukuran sistem optikal dan ultrasonik. 'Visual Basic 6.0' telah digunakan dalam perlaksanaan algoritma perisian untuk pengukuran penumpuan dan halaju. Pemungutan data dilakukan secara 'offline'. Perbandingan di antara profil penumpuan ke atas kedua-dua teknik tomografi menunjukkan bahawa keputusan tomografi optikal adalah lebih baik berbanding tomografi ultrasonik. Sebaliknya bagi pengukuran halaju, transduser ultrasonik menghasikan keputusan yang lebih baik berbanding transduser optikal.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiv
	LIST OF ABBREVIATIONS	xv
	LIST OF APPENDICES	xvi
1	INTRODUCTION	1
	1.1 Overview of the Process Tomography	1
	1.2 Objectives of the Project	2
	1.3 Scope of the Project	3
	1.4 Project Planning	3
	1.5 Thesis Outline	3

2	LITERATURE REVIEW	5
2.1	Introduction	5
2.2	Tomography Technique	5
2.2.1	Optical Tomography System	6
2.2.2	Ultrasonic Tomography System	6
2.3	Optical Sensor Systems	7
2.4	Ultrasonic Sensor Systems	9
2.5	Arrangement of Transducers	12
2.5.1	Fan Beam Projection Technique	12
2.5.2	Parallel Beam Projection Technique	13
2.6	Summary of the Chapter	14
3	METHODOLOGY	16
3.1	Introduction	16
3.2	Optical Sensors	16
3.2.1	Sensor Selection	18
3.2.2	Sensor Fixture	19
3.2.3	Optical Transmitting Circuit	21
3.2.4	Optical Receiving Circuit	22
3.2.5	The Design of Optical Receiving Circuit	23
3.3	Ultrasonic Sensors	28
3.3.1	Sensor Fixtures and Arrangement	30
3.3.2	Ultrasonic Transmitting Circuit	32
3.3.3	Ultrasonic Receiving Circuit	32
3.3.4	The Design of Optical Receiving Circuit	33
3.3.5	Printed Circuit Board (PCB) Design	38
3.4	Velocity and Concentration Measurement	42
3.5.1	Velocity Measurement	42
3.5.2	Concentration Measurement	44
3.5.3	Linear Back Projection Technique	45
3.5	Software Development	45
3.6.1	Velocity Measurement Algorithms	46
3.6.2	Concentration Profiles Algorithms	48
3.7	The Data Acquisition System	50

3.8	Summary of the Chapter	51
4	RESULTS AND DISCUSSIONS	52
4.1	Introduction	52
4.2	Concentration Measurement	52
4.2.1	Experiment 1	53
4.2.2	Experiment 2	54
4.2.3	Experiment 3	55
4.2.4	Experiment 4	56
4.2.5	Discussions	57
4.3	Velocity Measurement	61
4.3.1	Experiment 1	62
4.3.2	Experiment 2	64
4.3.3	Discussions	66
4.3.4	Repeatability of Velocity Measurement	67
4.4	Summary of the Chapter	68
5	CONCLUSIONS AND SUGGESTIONS	69
5.1	Introduction	69
5.2	Conclusions	69
5.3	Suggestions for Future Work	71
	REFERENCES	72
	Appendices A - E	75-88

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Transmission speed of ultrasound in different media	12
3.1	Cross correlation algorithms	46
4.1	Comparison between calculated and experimental values in terms of percent error	66

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Reflection and transmission of ultrasonic wave	10
2.2	Fan-shaped arrangements to different array structure of the sensor. (a) 4 Light sources, 15 beams ; (b) 15 Light sources, 5 beams; (c) 15 Light sources, 15 beams	13
2.3	(a) Parallel beam projections, (b) Two orthogonal projections and (c) Two rectilinear projections	14
3.1	Optical system topology	18
3.2	Sensor fixture at upstream	20
3.3	Sensor fixture at downstream	21
3.4	Optical transmitting circuit	22
3.5	Optical receiving circuit	23
3.6	Differential input converter	24
3.7	Output after the differential converter	24
3.8	Inverting amplifier circuit	25
3.9	Output after amplifier and AC coupling	25
3.10	Lowpass filter circuit	26
3.11	Combination full wave rectifier and dc converter circuit	27
3.12	Output from the rectification circuit when there is no object	27
3.13	Output from the rectification circuit when an object dropped	27
3.14	Ultrasonic system topology	29
3.15	Sensor fixture at upstream	30

3.16	Sensor fixture at downstream	31
3.17	Ultrasonic transmitting circuit	32
3.18	Ultrasonic Receiving Circuit	33
3.19	Pre amplifier	34
3.20	Output of pre-amplifier	34
3.21	Amplifier	35
3.22	Signal output that was amplified	35
3.23	Bandpass filter circuit	37
3.24	Combination of full wave rectifier and dc converter circuit	37
3.25	Output of dc value	38
3.26	Optical transmitting circuit	39
3.27	Optical receiving circuit	39
3.28	Ultrasonic transmitting circuit	40
3.29	Ultrasonic receiving circuit	40
3.30	A combination of optical and ultrasonic receiving circuit (at downstream)	41
3.31	Complete hardware installation (side view)	41
3.32	Complete hardware installation (top view)	42
3.33	Basic concept of cross-correlation technique	44
3.34	Algorithm Of Cross Correlation	47
3.35	Sensitivity map for sensor 1 to sensor 8	49
3.36	Concentration measurement flow chart	50
4.1	Concentration measurement of no object flow by optical Tomography	53
4.2	Concentration measurement of no object by ultrasonic Tomography	53
4.3	Concentration measurement of object at 70mm diameter by optical tomography	54
4.4	Concentration measurement object at 70mm diameter by ultrasonic tomography	54
4.5	Concentration measurement of round object at 85mm diameter by optical tomography	55
4.6	Concentration measurement of round object at 85mm diameter	

	by ultrasonic tomography	55
4.7	Concentration measurement of round object at 40mm diameter by optical tomography	56
4.8	Concentration measurement of round object at 40mm diameter by ultrasonic tomography	56
4.9	Comparison between optical and ultrasonic concentration profiles in terms of pixel weighting value	58
4.10	Comparison between optical and ultrasonic concentration profiles in terms of pixel weighting value	59
4.11	Comparison between optical and ultrasonic concentration profiles in terms of pixel weighting value	60
4.12	Transducers arrangement for experiment 1	62
4.13	Velocity measurement at a distance of 220mm using ultrasonic transducers	63
4.14	Velocity measurement at a distance of 160mm using ultrasonic transducers	63
4.15	Transducers arrangement for experiment 2	64
4.16	Velocity measurement at a distance of 105mm using ultrasonic transducers	65
4.17	Velocity measurement at a distance of 45.8mm using optical transducers	65
4.18	Repeatability of velocity measurement for optical and ultrasonic sensors	67

LIST OF SYMBOLS

Z	-	Acoustic impedance
ρ	-	Density
c	-	Velocity of sound
μ	-	The linear attenuation coefficient
I_0	-	Original intensity of source
I	-	Measured intensity
s	-	Thickness of object
R	-	Characteristic impedances
L	-	Distance
$f(x, y)$	-	Attenuation function
I_T	-	Energy intensity of transmitter
I_R	-	Energy intensity of receiver
f_R	-	Resonance frequency
f_H	-	Upper cutoff frequency
f_L	-	Lower cutoff frequency
R_{xy}	-	Cross correlation function
T	-	Transit time
$V_{LBP(x, y)}$	-	Voltage distribution obtained using LBP algorithms
S_{R_x, T_x}	-	Signal loss amplitude of receiver Rx-th for projection Tx-th in unit of volt
$\overline{M}_{T_x, R_x}(x, y)$	-	The normalized sensitivity matrices for the view of Tx–Rx Linear Back Projection algorithms

LIST OF ABBREVIATIONS

ECT	-	Electrical capacitance tomography
EIT	-	Electrical impedance tomography
DAS	-	Data acquisition system
IR-LED	-	Infra-red Light Emitting Diode
d.c	-	Direct current
GUI	-	Graphical User Interface

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Project Planning Schedule	75
B	Visual Basic Programming Software	76
C	ExceLINX™ Configuration	83
D	Example of Data in Microsoft Excel format	84
E	List of Datasheets	88

CHAPTER 1

INTRODUCTION

1.1 Overview Of The Process Tomography

The imaging and measurement of flows provides an important inspection method in industrial processes (M.H. Fazalul Rahiman *et al.*, 2006). Various methods have been employed for measuring the volumetric concentration and the velocity of various objects through the pipeline. It has been of interest in many industrial applications to describe the characteristic of component flows using methods that are noninvasive, fast response, and suitable for optically opaque systems. Thus, ultrasonic technique holds good potential for matching these requirements (Ying Zheng *et al.*, 2004).

The ultrasonic sensor is sensitive to the density of sound changes and has the potential for imaging component flows such as oil, gas, and water mixtures. Ultrasonic tomography is one of the methods that enable the measurement of certain characteristics of objects that cannot be easily obtained by other methods. Ultrasounds can detect changes in acoustic impedance (Z) which is closely related to the density (ρ) of the media ($Z = \rho c$, where c is the velocity of sound) and thus complements other tomographic imaging technologies such as electrical capacitance tomography (ECT) and electrical impedance tomography (EIT) (M.H. Fazalul Rahiman *et al.*, 2006).

However, at present optical sensors techniques also plays an important role in measuring the volumetric concentration and the velocity of various objects. It will be

applied widely in the fields of biomedical imaging, material structure analyzing and blurry martial target distinguishing and etc (Shi Zhiwei *et al.*, 2004). Currently, optical tomography is an attractive method since it is conceptually straightforward, relatively inexpensive and has a better dynamic response than other radiation-based tomographic techniques such as x-ray and positron emission tomography (S Ibrahim *et al.*, 1999). Naturally, optic fiber sensor with high sensitivity, small volume, and finely insulating is paid much attention in the development of optical tomography technology (Shi Zhiwei *et al.*, 2004).

Since both techniques have a potential demand in current industries and the measurement in the volumetric concentration and the velocity of various objects becomes more important to obtain a good quality of product industries, further study on the issues of the accuracy and repeatability of the measurement should be analyzed. Thus this project aims to highlight the above issues.

1.2 Objectives of the Project

The aims of this project are to analyze the accuracy and repeatability of measurements by comparing the results from the concentration and velocity measurement of various objects between optical and ultrasonic sensors. Specifically the objectives of this project are:

1. To investigate simple measurement of concentration and velocity of flowing objects in a pipe using optical and ultrasonic sensors.
2. To design and develop the electronic measurement system which consist of sensors, signal conditioning circuits and output.
3. To compare the results from the concentration and velocity measurement of various objects between optical and ultrasonic sensors. Analysis will be made in terms of accuracy and repeatability of measurement.

1.3 Scope of the Project

This project is divided into two stages, which are:

Stage 1: Hardware Development

Firstly, literature study on the concept of flow measurement techniques using optical and ultrasonic sensors are revised. Second, the selection of sensors and design sensor's fixtures are made. Then, the signal conditioning circuit are designed and tested. Finally, the concentration and velocity of flowing object in a pipe line in terms of dc voltage are measured.

Stage 2: Software development and Interfacing to the data acquisition system (DAS)

At this stage, the designing of graphical user interface will be made by using Visual Basic 6. Then, the signal conditioning circuit is interface to the DAS card. Data is captured using Keithley ExceLINX software. The offline monitoring of velocity and concentration object flowing into the pipe are made. Then, the results are analyzed and finally completed the thesis writing.

1.4 Project Planning

This project is implemented base on the project planning schedule. The project started from July 2006 to April 2007. The project planning schedule is presented in Appendix A.

1.5 Thesis Outline

Chapter 1 presents an overview to process tomography, the objectives of the project, project schedule and thesis outline.

Chapter 2 covers the literature review on the tomography technique for optical and ultrasonic tomography, the principle of optical and ultrasonic sensor system and the arrangement of transducers.

Chapter 3 describes in details the optical and ultrasonic system methodology, the hardware and software development, and the techniques used to display the concentration profiles as well as velocity of flowing objects.

Chapter 4 presents the results of both experiments concentration and velocity measurement. All the results have been discussed in details.

Chapter 5 discusses the overall conclusions, limitations of the project and suggestions for future work.