

FLOW REGIME IDENTIFICATION OF PARTICLES CONVEYING IN
PNEUMATIC PIPELINE USING ELECTRIC CHARGE TOMOGRAPHY AND
NEURAL NETWORK TECHNIQUES

ALI MOHAMED AHMED ABUASSAL

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Mechatronics & Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JULY 2012

ACKNOWLEDGEMENT

In The Name Of Allah, Most Gracious, Most Merciful

First and foremost, I must be thankful to Allah SWT on His blessing for finishing the research.

I am deeply grateful for my beloved parents, brothers, sisters and other family members for all supports, kindnesses, and their love.

My sincerest appreciation goes to my supervisor, Prof. Dr. MohdFuaad bin Rahmat and co-supervisor Prof. Fabrice MERIAUDEAU for their ideas, guidance, encouragement, and thier precious advice which helped me to finish my work. I also very thankful to my friends and classmates in UTM and UB especially to Mutaz Alsawi.

I would also thanks to every person who has help and share a lot of material for this work. It is not possible to name everyone here; thanks go to all of them. Finally I would like to thank all my professors and lecturers in UTM and UB, for helping me all the way along my study.

ABSTRACT

A plastic beads (solid particles) flow in a pipeline is a common means of transportation in industries. Monitoring and controlling materials flow through the pipeline is essential to ensure plant efficiency and safety of the system. The pipeline transportation used in this project makes use of electrodynamic sensors which are charge to voltage converters. The process flow data is captured fitting an array of 16 sensors around the circumference of the pipe to capture the inherent charge on the flowing solid materials. A high speed data acquisition card DAS1800HC is used as the interface between the sensors and a personal computer which processes the data. A Radial Basis Function (RBF) neural network based flow regime identifier program is developed in Matlab environment. Baffles of different shapes are inserted to artificially create expected flow regimes and data captured in this way are used in training and evaluating the network's performance. The results of this work show significant improvements, the dataset which was check as the input gave good results, especially for full flow, three quarter flow and inverse quarter flow are 100%, and 95% has been succeed for each of quarter flow inverse three quarter flow and inverse half flow, and for the others flow regimes (center half and half flow) 90% succeed.

ABSTRAK

Aliran zarah pepejal menggunakan saluran paip merupakan salah satu medium pengangkutan biasa di dalam industri. Pemantauan aliran bahan-bahan yang melalui saluran paip adalah penting untuk memastikan kecekapan dan keselamatan sistem. Pengangkutan saluran paip yang digunakan di dalam kajian ini menggunakan pengesan elektronik yang menukar cas kapasitor kepada voltan elektrik. Data melibatkan aliran zarah pepejal direkodkan menggunakan 16 jenis pengesan elektronik (sensor) yang berbeza. Pengesan-pengesan elektronik ini disusun sekeliling paip. Kad perolehan data berkelajuan tinggi DAS1800HC digunakan sebagai kad antara muka di antara pengesan elektronik dan komputer peribadi yang memproses data tersebut menggunakan Algoritma unjuran linear kembali (Linear Back Projection Algorithm -LBPA) dan Algoritma unjuran belakang yang ditapis (Linear Back Projection Algorithm - FBPA). Program pengesan rejim aliran berasaskan Rangkaian Neural (Neural Network) berteraskan Fungsi Asas Radial (Radial Based Function - RBF) telah dibangunkan menggunakan Matlab. Sesekat tiruan dengan bentuk yang berbeza dimasukkan untuk mewujudkan rejim aliran yang dijangka dan data yang diperolehi dengan cara ini telah digunakan dalam melatih dan menilai Program pengesan rejim aliran. Hasil eksperimen berdasarkan dataset ini memberi keputusan yang baik, terutamanya bagi aliran penuh, aliran tiga suku dan aliran songsang adalah 100%. Keputusan 95% telah berjaya diperolehi untuk aliran tiga suku songsang dan aliran 1/2 songsang. Manakala bagi aliran rejim lain, keputusan diperolehi ialah 90%.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	ACKNOWLEDGEMENT	ii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENTS	vi
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF ABBREVIATIONS	xii
1	INTRODUCTION	
	1.1 An overview of process tomography	1
	1.2 Problem statement	3
	1.3 Objectives	4
	1.4 scope of work	4
2	LITERATURE REVIEW	
	2.1 Introduction	5
	2.2 Tomography sensors	5
	2.2.1 Electrical Capacitance Tomography (ECT)	6
	2.2.2 Optical tomography	8
	2.2.3 Ultrasonic tomography	9
	2.2.4 Electrodynamic Tomography	10
	2.3 The Data Acquisition System (DA)	13
	2.4 Image Reconstruction Algorithm	13

	2.4.1 The Inverse Problem	14
	2.4.2 Linear back projection algorithm (LBPA)	14
	2.4.3 Filtered back projection algorithm (FBPA)	14
	2.5 Flow Regimes Identification Using Neural Networks	15
	2.5.1 Types of Artificial Neural Networks	18
	2.5.1.1 Feed forward ANNs	18
	2.5.1.2 Feedback ANNs	19
3	METHODOLOGY	
	3.1 Introduction	21
	3.2 Baffles	21
	3.3 Collect the data	23
	3.4 Radial Basis Function ANNs	24
	3.4.1 Training of RBF ANN	27
	3.5 Image construction	28
	3.6 Classify the flow regimes	29
4	EXPERIMENTAL SETUP	
	4.1 Introduction	30
	4.2 Calibration of the Gravity Flow Regime	32
	4.3 Calibration of the sensors	33
	4.4 Collect the data	36
5	RESULTS AND DISCUSSION	
	5.1 Introduction	39
	5.2 Comparison between the Measured & desired Outputs	39
	5.2.1 Full flow	40
	5.2.2 Three quarter flow	41
	5.2.3 Half flow	42
	5.2.4 Quarter flow	43
	5.2.5 Center half flow	44
	5.2.6 Inverse three quarter flow	45
	5.2.7 Inverse half flow	46
	5.2.8 Inverse quarter flow	47
	5.3 Flow Regimes Identification of Measured Data	48
	5.3.1 Training Patterns	49
	5.3.2 Test Patterns	51

5.4 Concentration profile	52
6 CONCLUSION AND FUTURE WORK	
6.1 Conclusion	55
6.2 Future work	56
REFERENCES	57
BIBLIOGRAPHY	59

LIST OF TABLES

TABLE NO.	TITLE	PAGE
5.1	Training patterns samples	49
5.2	Target vectors of the flow regimes	50
5.3	Test pattern identification of flow regimes	51

LIST OF FIGURES

FIGURE No.	TITLE	PAGE
1.1	An overview of Process Tomography System	3
2.1	Sensor types, methods, and applications	6
2.2	Schematic diagram of ECT system	7
2.3	Faraday Cage and Electrodynamic Sensor	11
2.4	Basic artificial neuron components	16
2.5	Modeling of Artificial Neuron from Biological Neuron	17
2.7	Feed forward architecture	18
2.8	Feedback network architecture	19
3.1	Flowchart of the flow regime identification	22
3.2	The baffles	22
3.3	Electrodynamic sensor	23
3.4	Block diagram of Electrodynamic sensor	24
3.5	RBF neural network architecture	25
3.6	Basis function with different value of β	27
3.7	Flow chart for a RBF training process	29
4.1	Overview of the Experimental setup1	31
4.2	Overview of the Experimental setup2	31
4.3	Diagram of the gravity flow regime	32
4.4	Graph for mass flow rate versus flow indicator	33
4.5	Sensitivity output of the sensor 1 at no flow (0 g/s)	34
4.6	Sensitivity output of the sensor 2 at no flow (0 g/s)	34
4.7	Sensitivity output of the sensor 16 at no flow (0g/s)	34
4.8	The measured and desired outputs of the 16 sensors	35
4.9	Sensitivity output of the sensor 16 at low flow (21.4 g/s)	35

4.10	Sensitivity output of the sensor 1 at medium flow (621 g/s)	36
4.11	Sensitivity output of the sensor 1 at high flow (1241.5 g/s)	36
4.12	The relationship between the MATLAB and Keithley	38
5.1	Cross section of the pipe of full flow	40
5.2	The measured and desired output of the full flow	41
5.3	Cross section of the pipe in the three quarter flow case	41
5.4	The measured and desired output of the three quarter flow	42
5.5	Cross section of the pipe in the half flow case	42
5.6	The measured and desired output of the half flow	43
5.7	Cross section of the pipe in the quarter flow case	43
5.8	The measured and desired output of the quarter flow	44
5.9	Cross section of the pipe in the center half flow case	44
5.10	The measured and desired output of the center half flow	45
5.11	Cross section of the pipe in the inverse three quarter flow	45
5.12	The measured and desired output of inverse three quarter	46
5.13	Cross section of the pipe in the inverse half flow case	46
5.14	The measured and desired output of the inverse half flow	47
5.15	Cross section of the pipe in the inverse quarter flow case	47
5.16	The measured and desired output of inverse quarter flow	48
5.17	The RBF network	48
5.18	Training patterns samples of the flow regimes	50
5.19	The performance curve of training	50

LIST OF ABBREVIATIONS

RBF	- Radial Basis Function
IPT	- Industrial Process Tomography
PT	- Process Tomography
PC	- personal computer
ECT	- Electrical Capacitance Tomography
OT	- Optical tomography
OFPT	- Optical Fiber Process Tomography
GA	- Genetic Algorithm
ECHT	- Electrical Charge Tomography sensor
DAS	- The Data Acquisition System

- LBPA** - **Linear Back Projection Algorithm**
- FBPA** - **Filtered Back Projection Algorithm**
- ART** - **Algebraic Reconstruction Technique**
- ANN** - **Artificial Neural Network**
- RBF** - **radial basis function**

CHAPTER 1

INTRODUCTION

1.1 An overview of process tomography

The word tomography is derived from the Greek word tomos which means section, while the word graphy means image. According to the Oxford English Dictionary, the word tomography can be described as:

"Radiography in which an image of a predetermined plane in the body or other object is obtained by rotating the detector and the source of radiation in such a way that points outside the plane give a blurred image"(R A William et al, 1995)

This description is based on the new technique in diagnostic medicine during the early 1970s by utilizing X-rays to form images of tissues based on their X-rays attenuation coefficient. Over the last decade, the concept of tomography imaging was not restricted to medical field only; it has been successfully developed into a reliable tool for imaging numerous industrial applications. This field of application is commonly known as Industrial Process Tomography (IPT) or simply as Process Tomography (PT). However, techniques of tomography used in the industry and medical fields are different from each other due to the different aim of application. Normally medical tomography aims to measure the location of objects in space, while process tomography aims to measure the location concentration, phase proportions, and velocity of movement.

The use of process tomography is not limited to only obtaining cross-sectional image of processes. It can also be used to obtain mass-flows rate or volume flow rates and velocity profiles. Depending on the mechanism of the process tomography sensor can be used in processes involving solids, liquids, gases and any of their mixtures.

For process tomography, direct analysis and measurement of the internal characteristics of process plants in real time are carried out. A number of sensors are placed around the peripheral of a process vessel, pipeline, and multiplexed. By using a data acquisition system, the signal is converted to digital signal and fed into a computer in which a cross-section of the measured parameter will be reconstructed to produce images of concentration and movement of the components in the process vessel. Measurements are reconstructed to form two or three dimensional images, providing information to monitor processes and improving yields, quality, efficiency, and overall control. Process tomography can be applied to many types of processes and unit operations, including pipelines, stirred reactors, fluidized beds, mixers and separators.

Electrical tomography is one of the most investigated fields in process tomography. It is non-invasive, cost effective, safe and easy to implement technique. Electrical charge tomography is a system used in imaging particulate flow in pipelines using Electrodynamic sensors (charge-to-voltage transducer).It's a passive transducer where the field is generated by the flowing solid particles.

The motivation for using Electrodynamic sensors as the sensing device in tomography arises from the fact that many flowing materials pick up charge during transportation, primarily by virtue of friction of fine particles amongst themselves and abrasion on the walls of the conveyor.

Based on the above fact Electrodynamic sensors can be used to measure the charge on the flowing materials and convert it to voltage so that spatial information of the flowing material in the cross-section of the conveyor could be obtained.

In this project, 16 Electrodynamic sensors are fitted around the circumference of the conveying pipe to sense the inherent charge on the flowing particles. Each Electrodynamic sensor detects the charge on the flowing particles in its sensing zone and converts the detected charge into electrical signal (Small voltage) level. In the same manner all the 16 Electrodynamic sensors yield the level of sensed signal. The signals from the array of Electrodynamic sensors are filtered and amplified to a level suitable form for data acquisition system. The data acquisition system then converts the simultaneously captured data to a digital format. The data acquisition system is used as an interface between the sensors and the personal computer (PC) used in data storage and processing. These data are then manipulated using image reconstruction algorithms techniques to obtain tomography images in an offline method. The flow data are used in obtaining concentration. An overview of process tomography block diagram is shown in Figure 1.1.

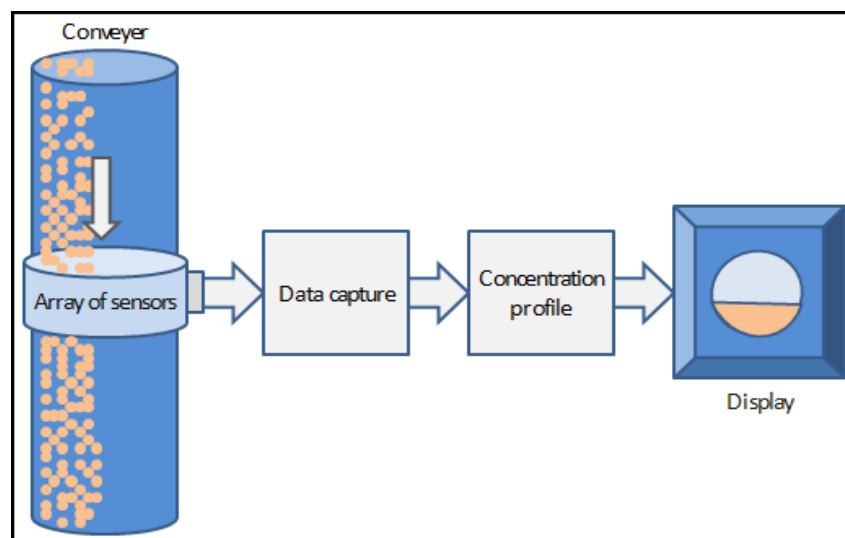


Figure 1.1:An overview of Process Tomography System

1.2 Problem statement

The Electrodynamic sensors are excellent in sensing flowing materials in close proximity to their location. However, when flowing material are far-off from the sensors location their accuracy diminishes. To improve this accuracy, there is the need to reconstruct the tomograms. This is done using the linear back projection image reconstruction algorithm. Another image reconstruction algorithm called

filtered back projection algorithm can also be used and both methods give good accuracy of the image of flowing material.

In this project 16 Electrodynamic sensors will be used to detect flowing material with a view to using the above mentioned algorithms to improve the accuracy of the tomograms.

1.3 Objectives

- 1) To measure voltage around the circumference of the pipeline using 16 Electrodynamic sensors and to capture the data.
- 2) To identify flow regimes in pneumatic pipeline using Electrodynamic sensors and neural network techniques.
- 3) To verify the flow regime using image reconstruction algorithms.

1.4 Scope of Work

The scopes of the project are:

- 1) To study the strategy of process tomography.
- 2) To reconstruct image of the flowing particles in the conveyer pipe.
- 3) Identify 8 different types of flowing particles.

REFERENCES

- D. S. Broomhead and David Lowe. (1988). "Multivariable Functional Interpolation and Adaptive Networks": Complex Systems Publications, Inc.
- Hakilo Ahmed Sabit. (2006). "Flow regime identification of particles conveying in pneumatic pipeline using electric charge tomography and neural network techniques ". UTM master thesis.
- Hoyle, B.S. and Xu, L.A. (1995). "Ultrasonic Sensors." In Williams, R.A. and Beck, M.S. (1995). "Process Tomography Principles, Techniques and applications." Jordan Hill: Butterworth-Heinemann Ltd. 119-149.
- H. Yan, Y H Liu and C T Liu. (2004) " Identification of flow regimes using back-propagation networks trained on simulated data based on a capacitance tomography sensor ": Institute Of Physics Publishing.
- Jing Chunguo, Bai Qiuguo. (2009) " Flow Regime Identification of Gas/Liquid Two-phase Flow in Vertical Pipe Using RBF Neural Networks": Chinese Control and Decision Conference.
- Machida, M. and Kaminoyama. (2008) "Sensor Design for Development of Tribo-Electric Tomography System with Increased Number of Sensors": Journal of Visualization.
- Masashi Machida and Brian Scarlett. (2005). " Process Tomography System by Electrostatic Charge Carried by Particles": IEEE Sensors Journal.
- Pang, J.F. (2004). "Real-time Velocity and Mass Flow Rate Measurement Using Optical Tomography." Universiti Teknologi Malaysia: M.Eng. Thesis.
- Rahmat, M.F. (1996). "Instrumentation of Particle Conveying Using Electrical Charge Tomography". Sheffield Hallam University: Ph.D Thesis.
- R. A. Williams and M S Beck. First edition (1995). Process tomography principles, techniques and applications.

- R. G. Green, M F Rahmat, K Evans, A Goude, M Henry and J A R Stone. (1997)
"Concentration profiles of dry powders in a gravity conveyor using an
electrodynamic tomography system" Meas. Sci. Technol.
- Ruzairi, A. R. (1996). "A Tomography Imaging System for Pneumatic Conveyor
Using Optical Fibers." Sheffield Hallam University: Ph.D. Thesis.
- Tomasz Dyakowski, Laurent F.C. JeanmeureandArtur J. Jaworski. (2000)
"Applications of electrical tomography for gas–solids and liquid–solids Flows"
review Powder Technology.
- Yan, Y. (1996). "Mass flow measurement of bulk solids in pneumatic pipelines".
Meas. Sci. Technol Journal. Vol.7.pp.1687-1706.
- Yaw Wee Lee M F Rahmat. (2007). "Real-time mass flow rate measurement for bulk
solid flow using electrodynamic tomography system":UTM master thesis.