# AN INFRARED OPTICAL TOMOGRAPHY BASED ON INDEPENDENT COMPONENT ANALYSIS FOR MEASUREMENT IN TURBID LIQUID

MOHD TAUFIQ BIN MOHD KHAIRI

UNIVERSITI TEKNOLOGI MALAYSIA

# AN INFRARED OPTICAL TOMOGRAPHY BASED ON INDEPENDENT COMPONENT ANALYSIS FOR MEASUREMENT IN TURBID LIQUID

MOHD TAUFIQ BIN MOHD KHAIRI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

AUGUST 2014

The thesis is dedicated
to my parents Mohd Khairi Jusoh and Rohani Jaafar
who made enormous sacrifice in order to educate and guide me,
to my siblings Nur Aina, Harithan, Abdul Hannan and Laila Fajriyah
who provide a lot of motivation to me,
to my nephew Amirul Amsyar
who cheered me a lot and
to all my friends
who always support me.

**ACKNOWLEDGEMENTS**

I would like to express my deepest gratitude to my supervisor Associate Professor Dr. Sallehuddin Ibrahim for his invaluable guidance, excellent supervision and become my inspirer to finish the study. Special thanks to my co-supervisor Dr. Mohd Amri Md Yunus who provide me a lot of ideas and continuous support.

I am particularly grateful to my parents, Rohani Jaafar and Mohd Khairi Jusoh for their advice, inspiration and support, which led me to finish my master's research work. Special thanks to my brothers and sisters for giving me a lot of motivation to complete this stage of study.

I would also like to thank Mr Anuar who assisted me to construct the printed circuit board. My gratitude to Muhammad Sani Gaya who kindly checked my thesis. Special thanks to all P10 Process Control Laboratory members, especially the lab technician, Mr Hazrul Azhar who ensures the lab facilities were in good condition to use, and other researchers for their assistance to my research.

Finally, my special appreciation to Universiti Teknologi Malaysia and the Ministry of Higher Education for providing me the financial assistance to further my study and without it this research could not have been carried out.

# ABSTRACT

Process tomography is a tool that provides an unperturbed way to examine and investigate the internal behaviour of flow process. The tool has successfully made a beneficial contribution in measuring parameters such as mass flow rate, concentration profile and particle sizing. Among the parameters that can be inspected using tomography technique is the turbidity level of water. Most of the turbidimeters in the market are in the form of point sensor, which means the meter needs to be put on the water sample. This kind of measurement is unsuitable for industrial flow since it disturbs the flow. The investigation in distinguishing the spatial distribution in two-phase flow attracts a major interest in industry. In beverage industry, the existing of gas bubble in opaque liquid such as milk has degraded the quality of product. This thesis presents an investigation into the application of optical tomography through the use of Independent Component Analysis (ICA) method to estimate turbidity level of water and explore the presence of gas bubble in contaminated water. The system consists of eighteen infrared transmitters and eighteen receivers in which the light projection is designed in fan beam mode. An ICA algorithm has been implemented to analyse the data and the LabVIEW software was used to construct 18 x 18 pixels of concentration profile. In water turbidity experiment, several volumes of green colour ingredients were mixed together with pure water for varying the turbidity level of the water. For gas bubble's investigation, three types of flow conditions were studied: low bubble flow, medium bubble flow and high bubble flow. The behaviour of gas bubbles was investigated in contaminated water in which the water sample was prepared by adding 25 ml of colour ingredients into 3 liters of pure water. The result shows that the application of ICA has enabled the system to estimate the turbidity level and detect the presence of gas bubbles in contaminated water. This information is expected to provide vital information on the flow inside the pipe and hence, could be very significant in increasing the accuracy of the process industries.

# ABSTRAK

Proses tomografi ialah satu kaedah yang membolehkan pemeriksaan dan penyiasatan dijalankan terhadap keadaan dalaman proses pengaliran melalui teknik tanpa gangguan. Alat ini telah berjaya dimanfaatkan dalam mengukur parameter seperti kadar aliran jisim, profil taburan dan saiz zarah. Di antara parameter yang boleh diukur melalui proses tomografi adalah kadar kekeruhan air. Kebanyakan alat pengukur kadar kekeruhan air di pasaran adalah dalam bentuk penderia sesentuh di mana penderia itu perlu diletakkan di dalam air. Cara ini tidak sesuai dalam bidang industri pengaliran kerana ia mengganggu pengaliran. Penyiasatan tentang pengasingan dua fasa yang mengalir mendapat perhatian yang tinggi dalam industri. Dalam industri minuman, kehadiran buih gas dalam cecair legap seperti susu telah menurunkan kualiti produk. Tesis ini mengemukakan satu penyiasatan tentang aplikasi tomografi cahaya melalui kaedah Analisis Komponen Bersendiri (ICA) untuk menjangka tahap kekeruhan air dan kehadiran buih gas dalam air yang telah dicemari. Sistem ini mempunyai lapan belas pemancar infrared and lapan belas penerima di mana unjuran cahaya direka dalam bentuk kipas. Algoritma ICA telah digunakan untuk menganalisis data dan perisian LabVIEW digunakan untuk membina profil taburan berpixel 18 x 18. Dalam eksperimen kekeruhan air, beberapa isipadu pewarna makanan berwarna hijau telah dicampurkan ke dalam air bersih untuk mengubah tahap kekeruhan air itu. Dalam penyiasatan buih gas, sebanyak tiga jenis pengaliran telah dikaji: pengaliran buih rendah, sederhana dan tinggi. Penyiasatan gas buih dilakukan dalam air yang telah tercemar di mana air itu disediakan melalui campuran 25 ml isipadu bahan pewarna ke dalam 3 liter air bersih. Keputusan menunjukkan bahawa penggunaan ICA membolehkan sistem menjangka tahap kekeruhan air dan mengesan buih gas di dalam air yang telah dicemari. Informasi ini dijangka dapat memberi maklumat penting tentang keadaan pengaliran dalam paip dan seterusnya memberi manfaat dalam meningkatkan ketepatan dalam industri proses.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | - | Alternating Current |
| ADCP | - | Acoustic Doppler Current Profiler |
| ANN | - | Artificial Neural Network |
| BSS | - | Blind Source Separation |
| CCD | - | Charge-Couple Device |
| CT | - | Computrised Tomography |
| DAS | - | Data-Acquisition System |
| DI | - | Digital Input |
| DO | - | Digital Output |
| ECT | - | Electrical Capacitance Tomography |
| EIT | - | Electrical Impedance Tomography |
| EPA | - | Environment Protection Agency |
| ERT | - | Electrical Resistance Tomography |
| GUI | - | Graphical User Interface |
| ICA | - | Independent Component Analysis |
| INWQS | - | Interim National Water Quality Standards |
| L | - | Length |
| LED | - | Light Emitting Diode |
| MIT | - | Mutual Inductance Tomography |
| MOSFET | - | Metal Oxide Semiconductor Field Effect Transistor |
| NI | - | National Instrument |
| NMRT | - | Nuclear Magnetic Resonance Tomography |
| NTU | - | Nephelometric Turbidity Unit |
| PCA | - | Principal Component Analysis |
| PCB | - | Printed Board Circuit |
| PIC | - | Peripheral Interface Controller |
| PT | - | Process Tomography |

| | | |
|---|---|---|
| PVC | - | Premature Ventricular Contraction |
| RX | - | Receiver |
| RX1 | - | Receiver 1 |
| RX2 | - | Receiver 2 |
| RX3 | - | Receiver 3 |
| RX4 | - | Receiver 4 |
| RX5 | - | Receiver 5 |
| RX6 | - | Receiver 6 |
| RX7 | - | Receiver 7 |
| RX8 | - | Receiver 8 |
| RX9 | - | Receiver 9 |
| RX10 | - | Receiver 10 |
| RX11 | - | Receiver 11 |
| RX12 | - | Receiver 12 |
| RX13 | - | Receiver 13 |
| RX14 | - | Receiver 14 |
| RX15 | - | Receiver 15 |
| RX16 | - | Receiver 16 |
| RX17 | - | Receiver 17 |
| RX18 | - | Receiver 18 |
| SNR | - | Signal Noise Ratio |
| TI | - | Texas Instrument |
| TSS | - | Total Suspended Solids |
| TX | - | Transmitter |
| TX1 | - | Transmitter 1 |
| TX2 | - | Transmitter 2 |
| TX3 | - | Transmitter 3 |
| TX4 | - | Transmitter 4 |
| TX5 | - | Transmitter 5 |
| TX6 | - | Transmitter 6 |
| TX7 | - | Transmitter 7 |
| TX8 | - | Transmitter 8 |
| TX9 | - | Transmitter 9 |

| | | |
|---|---|---|
| TX10 | - | Transmitter 10 |
| TX11 | - | Transmitter 11 |
| TX12 | - | Transmitter 12 |
| TX13 | - | Transmitter 13 |
| TX14 | - | Transmitter 14 |
| TX15 | - | Transmitter 15 |
| TX16 | - | Transmitter 16 |
| TX17 | - | Transmitter 17 |
| TX18 | - | Transmitter 18 |
| USB | - | Universal Serial Bus |
| VAC | - | Volts Alternating Current |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| ms | - | Millisecond |
| ns | - | Nanosecond |
| ml | - | Milliliter |
| ° | - | Degree |
| $X$ | - | Matrix of mixture of source signal |
| $A$ | - | Mixing matrix |
| $S$ | - | Matrix denoting a source signal |
| $W$ | - | Un-mixing matrix |
| $\hat{S}$ | - | Estimation of source signal |
| $S(t)$ | - | Original Signal |
| $w^+$ | - | Temporary variable used to calculate weight vector |
| $w^T$ | - | Transpose of weight vector |
| $x$ | - | Input data |
| $E\{\ldots\}$ | - | Averaging over all column-vectors of matrix $x$ |
| $g$ | - | Derivative of non-quadratic used in the contrast function f or solving ICA problem |
| $H(s_1,s_2)$ | - | conditional entropy where the entropy of $s_1$ conditional on $s_2$ |
| $H(s_1)$, $H(s_2)$ | - | Entropy of $s$ |
| $I(s_1,s_2)$ | - | Mutual information |
| $R_N$ | - | Total number of linearly independent voltage |
| $n$ | - | Total electrode |
| V | - | Volt |
| $I$ | - | Output of light's intensity |
| $Io$ | - | Input of light's intensity |
| $l_1$ | - | Path length of light travel through the material 1 (mm) |
| $l_2$ | - | Path length of light travel through the material 2 (mm) |

| | | |
|---|---|---|
| $l_3$ | - | Path length of light travel through the material 3 (mm) |
| $l_4$ | - | Path length of light travel through the material 4 (mm) |
| $a$ | - | Regression-estimated coefficients |
| $b$ | - | Approximately equal to value of 1 |
| l | - | Liter |
| $\alpha_1$ | - | Attenuation coefficient for material 1 ($mm^{-1}$) |
| $\alpha_2$ | - | Attenuation coefficient for material 2 ($mm^{-1}$) |
| $\alpha_3$ | - | Attenuation coefficient for material 3 ($mm^{-1}$) |
| $\alpha_4$ | - | Attenuation coefficient for material 4 ($mm^{-1}$) |
| $\alpha_w$ | - | Attenuation coefficient for water ($mm^{-1}$) |
| $\alpha_a$ | - | Attenuation coefficient for air ($mm^{-1}$) |
| $l_w$ | - | Pipe diameter (mm) |
| $l_a$ | - | Length of small bubble (mm) |
| $V_R$ | - | The receiving sensor voltage (V) |
| $V_T$ | - | The voltage of receiver when there is no beam attenuation (V) |
| $exp(-\alpha l)$ | - | Exponential value |
| $V_{R1}$ | - | Receiver RX1 voltage (V) |
| $V_{R2}$ | - | Receiver RX2 voltage (V) |
| $V_{R3}$ | - | Receiver RX3 voltage (V) |
| $V_{R4}$ | - | Receiver RX4 voltage (V) |
| cm | - | Centimetre |
| mm | - | Millimetre |
| nm | - | Nanometre |
| Ω | - | Ohm |
| kΩ | - | Kilo ohm |
| $\lambda_p$ | - | Peak wavelength (nm) |
| V/µs | - | Volt per microsecond |
| MS/s | - | Mega samples per second |
| Xt | - | Signals from receivers |
| $K$ | - | Average value |
| $M$ | - | Turbidity factor |
| $M_{e,f}$ | - | Turbidity factor for transmitter *e* and receiver *f* |

| | | |
|---|---|---|
| $P$ | - | Pixel |
| $P_{r,c}$ | - | Pixel at row (*r*) and column (*c*) |
| $u$ | - | Path length of light that has crossed the pixel (cm) |
| $t$ | - | Total length from transmitter to receiver (cm) |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction to process tomography

The word 'tomography' is the combination of Greek words in which 'tomos' means slice and 'graph' means image (Williams and Beck, 1995). In other words, tomography can be defined as a process of getting a slice of a picture. The expansion of tomography comes from the idea where the x-ray technology is utilized in order to scan and obtain the internal body image without cutting the subject. The tomography technique has been extensively used in the medical field since 1970s where it started by getting the image of tissue based on the x-ray attenuation coefficient (Dyakowski *et al.*, 2000).

After being successfully used in the medical field, the technique looks like to have a great potential to expand in the other field since it promises an unperturbed way to examine some substances. Hence, tomography has been introduced to the industrial field and successfully provided huge contributions in imagining and identification of the various flow patterns and boundaries. A tomography system consists of several sensors which are located externally around the pipeline or process vessel to unravel the inside condition without disturbing the process flow (Ibrahim, 2000). It offers an ability to get a real-time cross-sectional image and obtain analytical information about internal behaviour of the process (Bennett *et al.*, 2002). The technique also has an ability to assist in optimising the process design by identifying the material distribution and movement in the process vessels or pipelines (Abdul Rahim, 1996).

The concept of tomography can be implemented by installing several sensors around the pipe. Then, the output signals from the sensors will be taken to create the reconstructed image on a computer by using suitable algorithm (Rahmat, 1996). The location of sensors either outside or fixed to the inner pipe wall depends on the type of sensor and the parameter that has to be collected for further analysis. Ultrasonic and optical sensors, for example can be positioned outside the pipe as shown in Figure 1.1 since the signal from the sensor can penetrate the pipe wall. However, certain type of sensor such as electrode and capacitance sensors has to be fitted to the inner pipe wall in order to detect the condition of electrical charge between the moving particles as shown in Figure 1.2.

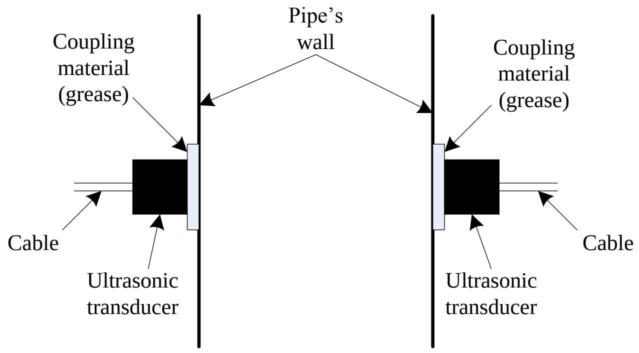


**Figure 1.1:** The configuration of an ultrasonic sensor when it is mounted to the pipe (Nor Ayob *et al.*, 2010)

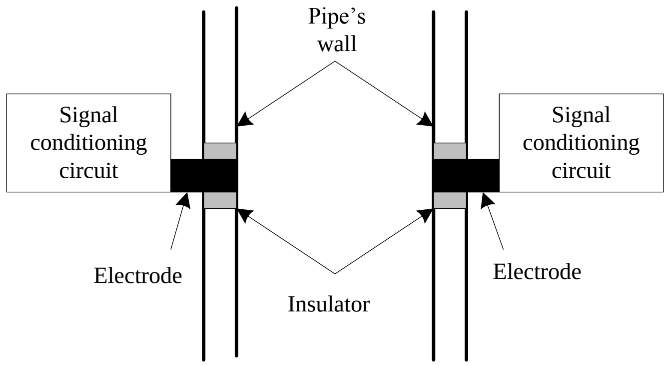


**Figure 1.2:** The electrode sensor installed to the pipe wall (Rahmat *et al.*, 2010)

Initially, researchers in tomography focused only on a single modality which made use of a single type of sensor, although innovation and development within this area have grown rapidly with promising prospect. In reality, the system is not bounded and limited to a single modality only. It has made great progress with the introduction of a new method called 'dual modality' system in the year 1996 for improving the observation process (Qiu *et al.*, 2007). Dual modality means two types of sensor has been installed and worked separately in the same pipe cross-section (Johansen *et al*., 1996). With this development, image reconstruction between the two different types of sensors can be compared where sensors can be compared to observe which sensor shows better outcome. Dual modality technique also has designed to solve some problems occurring in the single modality system where it sometimes gives unsatisfactory result and lacked vital information regarding the image quality (Hasegawa *et al*., 2001).

## 1.2 Problem Statement

Investigation regarding single-phase flow using tomography method has been conducted for various applications such as milk processing industry and environment field. A research carried out by Sharifi and Young (2013) have applied electrical resistance tomography (ERT) system for measuring the flow and velocity profile information of a single flow in a horizontal pipe. The research used saline and milk solution as single phase solution where the change of flow conductivity is investigated. ERT also has been chosen by Nijland *et al*. (2010) where they successfully measured the soil moisture and plant water use based on the spatial patterns data. The system has the capability of making the measurement in shallow and rocky condition. Other than that, the system also can be used to investigate the vegetation subtracts water from a depths down to 6 m and below.

Tomography method has the potential to estimate the turbidity level of water using optical sensor based on Beer-Lambert's law. In sale marketing area, the turbidity sensor is usually designed in point sensor mode, which means the sensor has to collect or be placed in a water sample in order to measure the turbidity level. However, this sensor is not appropriate in flow industrial process since it cannot measure directly from the pipe and has disturbed the flow process. Hence, a new design for predicting the turbidity water level is proposed using a non-invasive technique based on the use of independent component analysis (ICA) method.

The distinguishing of spatial distribution of two-phase flow is widely used in large-scale application such as oil and nuclear industry to provide better understanding of the flow process (Johansen *et al*., 1996; Schleicher *et al*., 2008). Two-phase flow can be liquid-gas, gas-solid and solid-liquid. Investigation on gas bubble behaviour in industry such as food and pharmaceutical are essential, since the existence of unwanted bubbles can reduce the quality of product (Detsch and Sharma, 2000; Pilon *et al*., 2004). Previous research on bubble measurement in the tomography field was conducted by Rzasa (2009), Fazalul Rahiman (2012) and Jin *et al*. (2013) using pure water as a liquid. Generally, in the chemical sector, the unwanted gas bubbles were in the form of opaque liquid such as oil and paint.

Therefore, this thesis focuses on two-phase flow by exploring the gas bubbles behaviour in contaminated water.

## 1.3 Research Objectives

Aim

The aim of this research is to utilise the offline optical tomography system for estimating the turbidity level of water and bubble detection in the contaminated water based on the Independent Component Analysis (ICA) method.

Specific Objectives:

(i) To develop an optical tomography system, synchronise hardware as well as software and to utilize the LabVIEW software for data analysis.
(ii) To investigate the application of the fan beam projection and optical attenuation model in the system.
(iii) To investigate the performance of the ICA method in estimating the turbidity level of water and detecting the gas bubbles in contaminated water.

## 1.4 Research Methodology

The optical tomography system consists of eighteens transmitters and eighteen receivers for estimating the water turbidity level and gas bubble detection in contaminated water. The sensors are mounted around a 100 millimeter (mm) of acrylic pipe and fan beam projection is utilized. The transmitters are operated in sequence timing mode where each transmitter has its own pulse duration. Mathematical modelling for both experiments has been made. For water turbidity level, two models are introduced; pure water and contaminated water. In gas bubble investigation, three types of modelling are investigated; no bubble, a single bubble and double bubbles.

This research has implemented an Independent Component Analysis (ICA) algorithm for separating the transmitter's signal from the receivers. ICA has formed the matrix containing the exponential value where the value can be used for analysing the turbidity level and gas bubble, but the matrix is formed in an arbitrary row. Hence, the matrix row has to be rearranged based on the transmitter sequence before calculating the *K* value. Several volumes from 5 millimeter (ml) to 35 ml are added to 3 liter of pure water and the *K* value is calculated for analysis. For gas bubble investigation, five types of air opening flow condition are selected which are a single bubble, double bubble, 25% of air opening, 50% of air opening and 100% of air opening. The bubble flow is conducted in 25 ml of contaminated water. The investigation is also performed in pure water for bench-marking purpose.

## 1.5 Research Scope and Limitation

Several scopes of the work are:

(i) Eighteen infrared transmitters and eighteen receivers have been applied in this research.

(ii) Fan beam projection is utilized as light projection mode.

(iii) Each transmitter has its own pulse duration ranging from one millisecond (1 ms) to eighteen millisecond (18 ms).

(iv) The energy of light is assumed to attenuate when it travels in a water medium. The scattering and refraction effect are considered negligible in this research.

(v) The volume of green food colouring is from five millilitres (5ml), 15 ml, 25 ml and 35 ml. The volume is added to three litres of pure water in order to pollute the water.

(vi) Five types of flow have been used to investigate the behaviour of bubbles flow; a single bubble, double bubble, 25% of air opening, 50% of air opening and 100% of air opening.

In this research, the experiment for estimating the water turbidity level is done by polluting 3 liters (l) of pure water with several volumes of green food colouring. The selected volume of food colouring is from 5 ml until 35 ml. For gas bubble experiment, the research is done by investigating the presence of gas bubble in 25 ml of green contaminated water. The limitation of this research is the experiment cannot be performed in 35 ml of green contaminated water. This is due to the fact that the ICA cannot separate the source signals properly since the water sample is too dark.

## 1.6 Significant Findings

The main significant finding of this research is the application of the Independent Component Analysis (ICA) method in the optical tomography system for estimating the level of water turbidity and detecting the gas bubble in contaminated water. This research utilizes eighteens infrared Light-Emitting Diode (LED) for transmitting the light and eighteen receivers for detecting the light. The LabVIEW software is used to analyse the data and create the concentration profile for the turbidity level and gas bubble. The result shows that the ICA method has an ability to estimate the water turbidity level and detect the gas bubble in contaminated water by analysing the $K$ value. The $K$ value increased when the level of turbidity water increased. The analysis for gas bubble experiment also has been made where the bubble location can be estimated based on the highest $K$ value of the pixels in the cross section of the pipe.

## 1.7 Organization of the Thesis

Chapter 1 discusses about the overall project which consists of an overview about process tomography, problem statement, aim and objectives and finally, the scopes of the study.

Chapter 2 presents the literature review on process tomography, turbidity measurement, and the concept of ICA. Several types of sensor and projection modes are also discussed in this chapter.

Chapter 3 elaborates the mathematical modelling of optical tomography system. This chapter discusses the fan beam projection, optical attenuation model for the light and also explained the implementation of the ICA process.

Chapter 4 describes the hardware and software development. The hardware development includes the transmitter and receiver circuit, sensor jig and pipe. The data-acquisition system (DAS) and the LabVIEW software are discussed as the software component.

Chapter 5 presents the results and analysis of varying the colour of the water and bubbles flow.

Chapter 6 provides the conclusion, suggestion and recommendation for future works.

**REFERENCES**


Abdul Rahim, R. (1996). *A Tomography Imaging System for Pneumatic Conveyors using Optical Fibers*. PhD Thesis, Sheffield Hallam University.

Abdul Rahim, R., Pang, J. F., and Chan, K. S. (2005a). Optical Tomography Sensor Configuration using Two Orthogonal and Two Rectilinear Projection Arrays. *Flow Measurement and Instrumentation*, *16*(5), 327–340.

Abdul Rahim, R., Chiam, K. T., Pusppanathan, M. J., Susiapan, and Shaan-Li, Y. (2009). Embedded System Based Optical Tomography: The Concentration Profile. *Sensor Review*, 29(1), 54–62.

Abdul Rahim, R., Md. Yunos, Y., Fazalul Rahiman, M. H., and Abdul Rahim, H. (2010). Mathematical Modelling of Gas Bubbles and Oil Droplets in Liquid Media using Optical Linear Path Projection. *Flow Measurement and Instrumentation*, *21*(3), 388–393.

Abdul Rahim, R., Mohd Yunos, Y., Fazalul Rahiman, M. H., Mohd Muji, S. Z., Kok Thiam, C., and Abdul Rahim, H. (2012). Optical Tomography: Velocity Profile Measurement using Orthogonal and Rectilinear Arrangements. *Flow Measurement and Instrumentation*, *23*(1), 49–55.

Abdul Rahim, R., Chan, K. S., Pang, J. F., and Leong, L. C. (2005b). A Hardware Development for Optical Tomography System using Switch Mode Fan Beam Projection. *Sensors and Actuators A: Physical*, *120*(1), 277–290.

Abdul Rahim, R., Thiam, C. K., Hafiz, M., and Rahiman, F. (2008). An Optical Tomography System Using a Digital Signal Processor. *Sensors*, *8*, 2082–2103.

Aiestaran, P., Arrue, J., and Zubia, J. (2009). Design of a Sensor Based on Plastic Optical Fibre (POF) to Measure Fluid Flow and Turbidity. *Sensors*, *9*, 3790–3800.

Arai, R., Nakatani, N., and Okunol, T. (2008). Measurement Method of Turbidity Depth Profiles using ADCP for Monitoring of Coastal Sea Area. P*roceedings of the IEEE Oceans 2008*. 8-11 April. Kobe, Japan, 1–6.

Baker, E. T., Tennant, D. A., Feely, R. A., Lebon, G. T., and Walker, S. L. (2001). Field and Laboratory Studies on the Effect of Particle Size and Composition on Optical Backscattering Measurements in Hydrothermal Plumes. *Deep-Sea Research Part I*, *48*, 593–604.

Beck, M. S., and Williams, R. A. (1996). Process Tomography: A European Innovation and its Applications. *Measurement Science and Technology*, *7*, 215–224.

Bell, A. J., and Sejnowski, T. J. (1995). An Information-Maximization Approach to Blind Separation and Blind Deconvolution. *Neural Computation*, *7*(6), 1129–1159.

Bennett, M. A., West, R. M., Luke, S. P., and Williams, R. A. (2002). The Investigation of Bubble Column and Foam Processes using Electrical Capacitance Tomography. *Minerals Engineering*, *15*, 225–234.

Bilro, L., Prats, S. A., Pinto, J. L., Keizer, J. J., and Nogueira, R. N. (2010). Design and Performance Assessment of a Plastic Optical Fibre-Based Sensor for Measuring Water Turbidity. *Measurement Science and Technology*, *21*(10), 1–4.

Bogue, R. (2011). Robots for Monitoring the Environment. *Industrial Robot: An International Journal*, *38*(6), 560–566.

Brown, G. J., Reilly, D., and Mills, D. (1995). Ultrasonic Transmission-Mode Tomography Applied to Gas/solids Flow. *Proceedings of the Process Tomography '95: Implementation for Industrial Processes*. Bergen, Norway, 176–186.

Campos, I., Alcañiz, M., Aguado, D., Barat, R., Ferrer, J., Gil, L., and Vivancos, J.-L. (2012). A Voltammetric Electronic Tongue as Tool for Water Quality Monitoring in Wastewater Treatment Plants. *Water Research*, *46*, 2605–2614.

Cesare, G. De, and Schleiss, A. (1999). Turbidity Current Monitoring in a Physical Model Flume using Ultrasonic Doppler Method. *Proceedings of the 2nd International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engmeering*. 20-22 September. Switzerland, 61–64.

Chen, J., and Wang, X. Z. (2001). A New Approach to Near-Infrared Spectral Data Analysis using Independent Component Analysis. *Journal of Chemical Information and Computer Sciences*, *41*, 992–1001.

Chen, L. L. (2005). *Implementation of Multiple Fan Beam Projection Technique in Optical Fibre Process Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Daniels, A. R. (1996). *Dual Modality Tomography for the Monitoring of Constituent Volumes in Multi-Component Flows*. PhD Thesis, Sheffield Hallam University.

Deisingh, A. K., Stone, D. C., and Thompson, M. (2004). Applications of Electronic Noses and Tongues in Food Analysis. *International Journal of Food Science and Technology*, *39*, 587–604.

Del Valle, M. (2012). Sensor Arrays and Electronic Tongue Systems. *International Journal of Electrochemistry*, *2012*, 1–11.

Detsch, R. M., and Sharma, R. N. (2000). The Critical Angle for Gas Bubble Entrainment by Plunging Liquid Jets. *The Chemical Engineering Journal*, *44*(1990), 157–166.

Dickin, F. J., and Wang, M. (1995). Impedence Sensors-Conducting System. In Williams, R.A and Beck, M.S (Eds). In *Process Tomography: Principles, Techniques and Applications* (pp. 63–84). Oxford: Butterworth-Heinemann Ltd.

Dyakowski, T. (1996). Process Tomography Applied to Multi-Phase Flow Measurement. *Measurement Science and Technology*, *7*, 343–353.

Dyakowski, T., Jeanmeure, L. F. C., and Jaworski, A. J. (2000). Applications of Electrical Tomography for Gas – Solids and Liquid – Solids Flows — A Review. *Powder Technology*, *112*, 174–192.

Elmajri, M. M. (2008). *A Tomography Imaging System using Two Types of Sensor*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Epa. (1999). *Basic Turbiditimeter Design And Concept*. Retreived on November 15, 2013, from www.epa.gov/ogwdw/mdbp/pdf/turbidity/chap_11.pdf.

Fazalul Rahiman, M. H. (2002). *Real Time Velocity Profile Generation of Powder Conveying using Electrical Charge Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Fazalul Rahiman, M. H. (2012). *Ultrasonic Tomography System for Liquid/Gas Bubble Column*. PhD Thesis, Universiti Teknologi Malaysia, Skudai.

Fazalul Rahiman, M. H., Abdul Rahim, R., and Nor Ayob, N. M. (2010). The Front-End Hardware Design Issue in Ultrasonic Tomography. *IEEE Sensors Journal*, *10*(7), 1276–1281.

Fernandez, M. C., Sanjosea, M. L. G., and Navarro, R. P. (2000). Evaluation of Turbidity : Correlation between Kerstez Turbidimeter and Nephelometric Turbidimeter. *Food Chemistry*, *71*(4), 563–566.

Fischer, S. (2012). Evaluation of a High Resolution Acoustic Profiler for Hydraulic Erosion Studies Key words. *Proceedings of the International Conferences on Scour and Erosion (ICSE)*. 27-31 August. Paris, France, 973-980.

Fleet, C. F., and Siebert, K. J. (2005). Effect of Illumination Intensity on Visual Perception of Turbidity. *Food Quality and Preference*, *16*, 536–544.

Garcia, A., Perez, M. A., Ortega, G. J. G. O., and Dizy, J. T. (2007). A New Design of Low-Cost Four- Beam Turbidimeter by using Optical Fibers. *IEEE Transcations of Instrumentation and Measurement*, *56*(3), 907–912.

Garvey, J. H. (2007). *Independent Component Analysis by Entropy Maximization (Infomax)*. Master Thesis, Naval Postgraduate School, Monterey, California.

Gasim, M. B., Toriman, M. E., Rahim, S. A., and Islam, M. S. (2006). Hydrology and Water Quality and Land-Use Assessment of Tasik Chini ' s Feeder Rivers , Pahang , Malaysia. *Geografia: Malaysian Journal of Society and Space*, *2*(1), 72–86.

George, D. L., Torczynski, J. R., Shollenberger, K. A., and Hern, T. J. O. (2000). Validation of Electrical-Impedance Tomography for Measurements of Material Distribution in Two-Phase Flows. *International Journal of Multiphase Flow*, *26*, 549–581.

Green, R. G., Abdul Rahim, R., Evans, K., Dickin, F. J., Naylor, B. D., and Pridmore, T. P. (1998). Concentration Profiles in a Gravity Chute Conveyor by Optical Tomography Measurement. *Powder Technology*, *95*(1), 49–54.

Guangzhu, C., Yi, Q., and Feng, L. (2012). Prediction of Groundwater Quality in Pu'er Emergency Water Source by Numerical Simulation. *Proceedings of the World Automation Congress (WAC).* 24-28 June. Puerto Vallarta, Mexico, 1–4.

Hasegawa, B., Tang, H. R., Da Silva, A. J., Wong, K. H., Iwata, K., and Wu, M. C. (2001). Dual-Modality Imaging. *Nuclear Instruments & Methods in Physics Research A*, *471*, 140–144.

Hofmann, F. (2000). Drawbacks and Limitations of the Ultrasonic Doppler Flowmeter. In *Fundamentals of Ultrasonic-Flow Measurement for Industrial Applications* (p. 6). KG Duisburg: Krohne Messtechnik GmbH & Co.

Holliday, C. P., Rasmussen, T. C., and Miller, W. P. (2003). Establishing the Relationship Between Turbidity and Total Suspended Sediment Concentration. *Proceedings of the 2003 Georgia Water Resources Conference*. 23–24 April. Athens, Georgia, 1-3.

Hossain, M., Lu, G., Member, S., and Yan, Y. (2012). Optical Fiber Imaging Based Tomographic Reconstruction of Burner Flames. *IEEE Transactions on Instrumentation And Measurement*, *61*(5), 1417–1425.

Hoyle, B. S. (1996). Process Tomography using Ultrasonic Sensors. *Measurement Science and Technology*, *7*, 272–280.

Huang, J. P., and Mar, J. (2004). Combined Ica and Fca Schemes for Hierarchical Network. *Wireless Personal Communications*, *28*(1), 35–58.

Hyvärinen, A. (1999). Fast and Robust Fixed-Point Algorithms for Independent Component Analysis. *IEEE Transactions on Neural Networks*, *10*(3), 626–634.

Hyvärinen, A., and Oja, E. (2000). Independent Component Analysis : Algorithms and Applications. *Neural Networks*, *13*(4-5), 411–430.

Ibrahim, S. (2000). *Measurement of Gas Bubbles in a Vertical Water Column using Optical Tomography.* PhD Thesis, Sheffield Hallam University.

Ibrahim, S., Green, R. G., Dutton, K., and Abdul Rahim, R. (2002). Lensed Optical Fiber Sensors for On-Line Measurement of Flow. *ISA Transactions*, *41*(1), 13–8.

Ibrahim, S., Green, R. G., Dutton, K., Evans, K., Rahim, R. A., and Goude, A. (1999). Optical Sensor Configurations for Process Tomography. *Measurement Science and Technology, 10*, 1079–1086.

Ibrahim, S., Yunus, M. A. M., Green, R. G., and Dutton, K. (2012). Concentration Measurements of Bubbles in a Water Column using an Optical Tomography System. *ISA Transactions*, *51*(6), 821–826.

Idroas, M., Abdul Rahim, R., Fazalul Rahiman, M. H., Ibrahim, M. N., and Green, R. G. (2011). Design and Development of a CCD Based Optical Tomography Measuring System for Particle Sizing Identification. *Measurement*, *44*(6), 1096–1107.

Ivarsson, P., Krantz-Rülcker, C., Winquist, F., and Lundström, I. (2005). A Voltammetric Electronic Tongue. *Chemical Senses*, *30*(1), 258–259.

James, C. J., and Hesse, C. W. (2005). Independent Component Analysis for Biomedical Signals (Topical Review). *Pysiological Measurement*, *26*(1), 15–39.

Jin, H., Lian, Y., Yang, S., He, G., and Guo, Z. (2013). The Parameters Measurement of Air–Water Two Phase Flow using the Electrical Resistance Tomography (ERT) Technique in a Bubble Column. *Flow Measurement and Instrumentation*, *31*, 55–60.

Johansen, G. A., Froystein, T., Hjertaker, B. T., and Olsen, O. (1996). A Dual Sensor Flow Imaging Tomographic System. *Measurement Science and Technology*, *7*, 297–307.

Jon Fea, P. (2004). *Real-Time Velocity and Mass Flow Rate Measurement using Optical Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Jutten, C., and Herault, J. (1991). Blind Separation of Sources, Part 1: An Adaptive Algorithm Based on Neuromimetic Architecture. *Signal Processing*, *24*, 1–10.

Kelly, E. G., and Spottiswood, D. J. (1989). The Theory of Electrostatic Separations: A Review. *Minerals Engineering*, *2*(2), 193–205.

Kourunen, J., Käyhkö, R., Matula, J., Käyhkö, J., Vauhkonen, M., and Heikkinen, L. M. (2008). Imaging of Mixing of Two Miscible Liquids using Electrical Impedance Tomography and Linear Impedance Sensor. *Flow Measurement and Instrumentation*, *19*(6), 391–396.

Krantz-Rülcker, C., Stenberg, M., Winquist, F., and Lundström, I. (2001). Electronic Tongues for Environmental Monitoring Based on Sensor Arrays and Pattern Recognition: A Review. *Analytica Chimica Acta*, *426*, 217–226.

Kuklina, I., Kouba, A., and Kozák, P. (2013). Real-time Monitoring of Water Quality using Fish and Crayfish as Bio-indicators: A Review. *Environmental Monitoring and Assessment*, *185*(6), 5043–5053.

Liu, S., Chen, Q., Wang, H. ., Jiang, F., Ismail, I., and Yang, W. . (2005). Electrical Capacitance Tomography for Gas–Solids Flow Measurement for Circulating Fluidized Beds. *Flow Measurement and Instrumentation*, *16*, 135–144.

Liu, Y., Chen, W., and Liu, J. (2008). Research on the Swing of the Body of Two-Joint Robot Fish. *Journal of Bionic Engineering*, *5*, 159–165.

Liu, Z., He, M., and Xiong, H. (2005). Simulation Study of the Sensing Field in Electromagnetic Tomography for Two-Phase Flow Measurement. *Flow Measurement and Instrumentation*, *16*, 199–204.

Ma, H., Tsai, T.-F., and Liu, C.-C. (2010). Real-time Monitoring of Water Quality using Temporal Trajectory of Live Fish. *Expert Systems with Applications*, *37*(7), 5158–5171.

Machida, M., and Scarlett, B. (2005). Process Tomography System by Electrostatic Charge Carried by Particles. *IEEE Sensors Journal*, *5*(2), 251–259.

McKee, S. (1995). Applications of Nuclear Magnetic Resonance Tomography. *In Williams R.A and Beck M.S. (ed), Process Tomography-Principles, Techniques and Applications* (pp. 539–548). Oxford: Butterworth-Heinemann, Ltd.

Md Yunus, M. A. (2005). *Imaging of Solid Flow in a Gravity Flow Rig using Infra-Red Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Md Yunus, M. A. (2011). *Planar Electromagnetic Sensors for Environmental Monitoring*. PhD Thesis, Massey Univesity, Palmerston North, New Zealand.

Mimendia, A., Gutiérrez, J. M., Leija, L., Hernández, P. R., Favari, L., Muñoz, R., and del Valle, M. (2010). A Review of the Use of the Potentiometric Electronic Tongue in the Monitoring of Environmental Systems. *Environmental Modelling & Software*, *25*, 1023–1030.

Mingsheng, W., Minming, T., Jifei, H., Li, C., and Jie, X. (2012). Detection of Coal Dust in a Mine using Optical Tomography. *International Journal of Mining Science and Technology*, *22*, 523–527.

Mohamad, E. J. (2005). *Flame Imaging using Laser Based Transmission Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Mohamad, E. J., Rahim, R. A., Ling, L. P., Rahiman, M. H. F., Marwah, O. M. F., and Ayob, N. M. N. (2013). Visualization of Recovered Palm Oil using Portable ECT Imager in Extraction Palm Oil Process. *Flow Measurement and Instrumentation*, *31*, 61–68.

Mohd Muji, S. Z. (2012). *Optical Tomography for Solid Gas Measurement using Mixed Projection*. PhD Thesis, Universiti Teknologi Malaysia, Skudai.

Naik, G. R., and Kumar, D. K. (2011). An Overview of Independent Component Analysis and Its Applications. *Informatica*, *35*, 63–81.

Neri, J., Paniz, G., Flores, É. M. M., Dressler, V. L., and Martins, A. F. (2001). Flow Injection Turbidimetric Determination of Total Organic Carbon with a Gas – Liquid Transfer Microreactor. *Analytica Chimica Acta*, *445*, 139–144.

Nijland, W., van der Meijde, M., Addink, E. a., and de Jong, S. M. (2010). Detection of Soil Moisture and Vegetation Water Abstraction in a Mediterranean Natural Area using Electrical Resistivity Tomography. *Catena*, *81*(3), 209–216.

Niskanen, I., Räty, J., and Peiponen, K.-E. (2006). A multifunction Spectrophotometer for Measurement of Optical Properties of Transparent and Turbid Liquids. *Measurement Science and Technology*, *17*(12), 87–91.

Nor Ayob, N. M., Rahiman, M. H. F., Zakaria, Z., Yaacob, S., and Rahim, R. A. (2010). Detection of Small Gas Bubble using Ultrasonic Transmission-Mode Tomography System. *Proceedings of the 2010 IEEE Symposium on Industrial Electronics and Applications (ISIEA)*. 3-5 October. Penang, 165–170.

Nuñez, L., Cetó, X., Pividori, M. I., Zanoni, M. V. B., and del Valle, M. (2013). Development and Application of an Electronic Tongue for Detection and Monitoring of Nitrate, Nitrite and Ammonium Levels in Waters. *Microchemical Journal*, *110*, 273–279.

Omar, A. F. B., and Matjafri, M. Z. B. (2009). Turbidimeter Design and Analysis: A Review on Optical Fiber Sensors for the Measurement of Water Turbidity. *Sensors*, *9*(10), 8311–8335.

Peyton, A. J., Yu, Z. Z., Al-Zeibak, S., Saunders, N. H., and Borges, A. R. (1995). Electromagnetic Imaging using Mutual Inductance Tomography: Potential for Process Applications Particle & Particle Systems Characterization. *Particle & Particle Systems Characterization*, *12*(2), 68–74.

Pilon, L., Fedorov, A. G., Ramkrishna, D., and Viskanta, R. (2004). Bubble Transport in Three-Dimensional Laminar Gravity-Driven Flow – Mathematical Formulation. *Journal of Non-Crystalline Solids*, *336*(2), 71–83.

Polder, G., Heijden, G. W. A. M. Van Der, and Young, I. T. (2003). Tomato Sorting using Independent Component Analysis on Spectral Images. *Real-Time Imaging 9*, *9*, 253–259.

Prerana, Shenoy, M. R., Pal, B. P., and Gupta, B. D. (2012). Design , Analysis, and Realization of a Turbidity Sensor Based on Collection of Scattered Light by a Fiber-Optic Probe. *IEEE Sensors Journal*, *12*(1), 44–50.

Pu, Q., and Yang, G. (2006). Short-Text Classification based on ICA and LSA. *Advance in Neural Network - ISNN 2006*, *3972*, 265–270.

Qiu, C., Hoyle, B. S., and Podd, F. J. W. (2007). Engineering and Application of a Dual-Modality Process Tomography System. *Flow Measurement and Instrumentation*, *18*, 247–254.

Rahmat, M. F. (1996). *Instrumentation of Particle Conveying using Electrical Charge Tomography*. PhD Thesis, Sheffield Hallam University.

Rahmat, M. F., Isa, M. D., and Hussin, T. A. B. S. R. (2012). A New Image Reconstruction Method for Electrical Charge Tomography System. *Arabian Journal for Science and Engineering*, *37*, 1625–1643.

Rahmat, M. F., Isa, M. D., Jusoff, K., Hussin, T. A., and Rozali, S. (2010). Image Reconstruction Algorithm for Electrical Charge Tomography System. *American Journal of Applied Science*, *7*(9), 1254–1263.

Rivière, P. J. La, and Meng, L. (2009). The Price of Tomography : SNR Comparisons of Acquisition Strategies for X-ray Fluorescence Imaging. *Proceedings of the 2009 IEEE Nuclear Science Symposium Conference Record.* 24 October - 1 November. Orlando, Florida, 3026–3028.

Ródenas-Torralba, E., Morales-Rubio, A., Lavorante, A. F., Dos Reis, B. F., and de la Guardia, M. (2007). Micropumping Multicommutation Turbidimetric Analysis of Waters. *Talanta*, *73*, 742–747.

Rzasa, M. R. (2009). The Measuring Method for Tests of Horizontal Two-Phase Gas–Liquid Flows, using Optical and Capacitance Tomography. *Nuclear Engineering and Design,*, *239*(4), 699–707.

Rzasa, M. R., and Plaskowski, A. (2003). Application of Optical Tomography for Measurements of Aeration Parameters in Large Water Tanks. *Measurement Science and Technology*, (14), 199–204.

Saad, M. S. (2007). *Concentration and Velocity Measurement of Flowing Objects Using Optical and Ultrasonic Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

San, C. K. (2002). *Real Time Image Reconstruction for Fan Beam Optical Tomography System.* Master Thesis, Universiti Teknologi Malaysia, Skudai.

Schleicher, E., Silva, M. J., Thiele, S., Li, A., Wollrab, E., and Hampel, U. (2008). Design of an Optical Tomograph for the Investigation of Single- and Two-Phase Pipe. *Measurement Science and Technology*, *19*, 1–14.

Serra-Toro, C., Montoliu, R., Traver, V. J., Hurtado-Melgar, I. M., Nunez-Redo, M., and Cascales, P. (2010). Assessing Water Quality by Video Monitoring Fish Swimming Behavior. *Proceedings of the 2010 20th International Conference on Pattern Recognition.* 23-26 August. Istanbul, Turkey, 428–431.

Sharifi, M., and Young, B. (2013). Electrical Resistance Tomography ( ERT ) for Flow and Velocity Profile Measurement of a Single Phase Liquid in a Horizontal Pipe. *Chemical Engineering Research and Design*, *91*(7), 1235–1244.

Shin, D., Na, S. Y., Kim, J. Y., and Baek, S.J. (2007). Fish Robots for Water Pollution Monitoring Using Ubiquitous Sensor Networks with Sonar Localization. *Proceedings of the 2007 International Conference on Convergence Information Technology (ICCIT 2007)*. 21-23 November. Gyeongju, South Korea, 1298–1303.

Steig, T. W., and Johnston, S. V. (1996). Monitoring Fish Movement Patterns in a Reservoir using Horizontally Scanning Split-Beam Techniques. *ICES Journal of Marine Science*, *53*, 435–441.

Tai, H., Li, D., Wang, C., Ding, Q., Wang, C., and Liu, S. (2012). Design and Characterization of a Smart Turbidity Transducer for Distributed Measurement System. *Sensors and Actuators A: Physical*, *175*, 1–8.

Tajjudin, M. (2005). *Fan Beam Optical Tomography*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Tan, C., and Dong, F. (2010). Cross Correlation Velocity of Oil-water Two-Phase Flow by a Dual-Plane Electrical Resistance Tomography System. *Proceedings of the Instrumentation and Measurement Technology Conference (I2MTC).* 3-6 May. Austin, 766 – 770.

Tapp, H. S., Peyton, A. J., Kemsley, E. K., and Wilson, R. H. (2003). Chemical Engineering Applications of Electrical Process Tomography. *Sensors And Actuators B*, *92*, 17–24.

Terzija, N., Yin, W., Gerbeth, G., Stefani, F., Timmel, K., and Wondrak, T. (2011). Use of Electromagnetic Induction Tomography for Monitoring Liquid Metal/Gas Flow Regimes on a Model of an Industrial Steel Caster. *Measurement Science and Technology*, *22*(1).

Vedam, S. S., Keall, P. J., Kini, V. R., Mostafavi, H., Shukla, H. P., and Mohan, R. (2003). Acquiring a Four-Dimensional Computed Tomography Dataset Using an External Respiratory Signal. *Physics Medicine and Biology*, *48*, 45–62.

Verma, S., and Prachi. (2012). Wireless Sensor Network Application for Water Quality Monitoring in India. *Proceedings of the National Conference on Computing and Communication System (NCCCS)*. 21-22 November. Durgapur, India, 1–5.

Wang, G., Ding, Q., and Hou, Z. (2008). Independent Component Analysis and its Applications in Signal Processing for Analytical Chemistry. *Trends in Analytical Chemistry*, *27*(4), 368–376.

Williams, R. A., and Beck, M. S. (1995). *Process Tomography: Principles, Techniques, and Applications*. Oxford: Butterworth-Heinemann Ltd.

Wood, J. D., and Boye, D. (2007). Suspended Sediment Plumes Using an Acoustic Doppler Current Profiler Monitoring. *Proceedings of the IEEE Oceans 2007*. 29 September - 4 October. Vancouver, Canada, 1–7.

Wright, P., Ozanyan, K. B., Member, S., Carey, S. J., and Mccann, H. (2005). Design of High-Performance Photodiode Receivers for Optical Tomography. *IEEE Sensors Journal*, *5*(2), 281–288.

Xu, Y., Wang, H., Cui, Z., Dong, F., and Yan, Y. (2010). Separation of Gas-Liquid Two-Phase Flow Through Independent Component Analysis. *IEEE Instrumentation And Measurement*, *59*(5), 1294–1302.

Yan, C., Zhong, J., Liao, Y., Lai, S., Zhang, M., and Gao, D. (2005). Design of An Applied Optical Fiber Process Tomography System. *Sensors And Actuators B*, *104*, 324–331.

Yang, G.-H., and Ryuh, Y. (2013). Design of High Speed Fish-like Robot "Ichthus V5.7." *Proceedings of the 2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*. 31 October -2 November. Jeju, South Korea, 451–453.

Yaw, W. L. (2007). *Real-Time Mass Flow Rate Measurement for Bulk Solid Flow using Electrodynamic Tomography System*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Yu, C., and Deyun, C. (2009). Two-phase Flow Parameters Measurement and Gauss-Newton Image Reconstruction Algorithm for Electrical Capacitance Tomography. *Proceedings of the 2009 International Conference on Industrial Mechatronics and Automation (ICIMA)*. 15-16 May. Chengdu, China, 192–195.

Zain, R. M. (2009). *The Development of a Dual Modality Tomography (DMT) System using Optical and Capacitance Sensors for Solid/Gas Flow Measurement*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Zakaria, Z., Abdul Rahim, R., Mansor, M. S. B., Yaacob, S., Ayub, N. M. N., Muji, S. Z. M., and Syed Aman, S. M. K. (2012). Advancements in Transmitters and Sensors for Biological Tissue Imaging in Magnetic Induction Tomography. *Sensors*, *12*, 7126–7156.

Zhang, Q., and Jiang, H. (2005). Three-Dimensional Diffuse Optical Tomography of Simulated Hand Joints with a 64 × 64-Channel Photodiodes-Based Optical System. *Journal of Optics A: Pure and Applied Optics*, *7*(5), 224–231.

Zheng, Y., and Liu, Q. (2006). Investigation on Concentration Distribution and Mass Flow Rate Measurement for Gravity Chute Conveyor by Optical Tomography System. *Measurement*, *39*, 643–654.