FLOW VISUALISATION FOR GAS SOLID MEASUREMENT USING OPTICAL TOMOGRAPHY FAN BEAM PROJECTION

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In the name of Allah, Most Gracious, Most Merciful

To my beloved and supportive parent, brothers and sisters

To my beloved wife & children

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ABSTRACT

In granules manufacturing industry, a real time monitoring is vital to observe the distribution of solid and gas mixture in pipelines. For solid and gas mixture such as pharmaceutical and grain production, the tiny pills and grains are poured through industrial chutes and silos in mass quantities. Nevertheless, the uncontrolled large scale flow can cause blockage in the pipeline and consequently can cause severe limited production efficiency. To determine the blockage area as well as its size, various flow meters are available in the market. However, most of the flow meters are intrusive and invasive; therefore can disrupt material flow. The optical tomography system technique is one of the methods to be adopted because of the ability of the system to observe material flow non-intrusively, hence determine the affected blockage area. In this research, alternate arrangements of 16 pairs of optical sensors which consist of transmitters and receivers have been mounted on a 10cm acrylic pipeline. Since the fan beam projection technique has been used, infrared Light Emitting Diode (LED) and photodiode with greater angle of projection and response were chosen. A specially designed jig has been developed for sensor positioning to ensure they are exactly on the periphery of the pipeline. Most previous researchers utilised digital timing and Data Acquisition System (DAS) units to control the projection and receiving unit of the optical tomography system. In this research, a circuit integrated with a dsPIC30F6014A microcontroller has been designed for controlling the projection of light by transmitters and the receiving signal of receivers. To operate the dsPIC30F6014A microcontroller together with the designed circuit, C programming language via MicroC compiler is applied. For image reconstruction, Linear Back Projection (LBP) has been applied via Visual Basic 6. Different flow regimes have been tested and analysed thoroughly to observe the overall performance of the system. The results obtained show that the optical tomography system developed is capable of observing multiple flows with different flow regimes; hence successfully determine blockage area of the solid gas flow. Apparently, the proposed single dsPIC30F6014A microcontroller usage indicates its ability to control acquisition process effectively with 480 μs sampling time rate.

ABSTRAK

Dalam industri pembuatan bijirin, pemantauan masa nyata adalah penting bagi memerhatikan proses percampuran pepejal dan gas dalam paip. Untuk campuran pepejal dan gas seperti farmaseutikal dan pengeluaran bijirin, pil-pil yang kecil dan bijirin di tuangkan melalui pelongsor industri dan silo dalam kuantiti yang banyak. Walau bagaimanapun, aliran dalam skala besar tidak terkawal boleh menyebabkan saluran paip tersumbat dan seterusnya menghadkan pengeluaran bahan efisien. Bagi mengenalpasti kawasan tersumbat dan saiz, pelbagai meter aliran boleh didapati dalam pasaran. Walau bagaimanapun, kebanyakan meter aliran mengganggu pengaliran dan bersifat invasif; boleh mengganggu pengaliran bahan. Teknik sistem tomografi optik adalah salah satu kaedah yang boleh digunapakai kerana keupayaan sistem untuk melihat aliran bahan tanpa mengganggu pengaliran, dengan itu dapat mengenalpasti kawasan tersumbat terlibat. Dalam kajian ini, 16 pasang sensor optik terdiri daripada pemancar dan penerima telah dipasang pada paip akrilik diameter 10 cm. Memandangkan teknik unjuran berbentuk kipas digunakan, Diod Pemancar Cahaya (LED) radiasi infra merah dan fotodiod dengan sudut lebih besar telah dipilih. Jig direka khas telah dibangunkan bagi memastikan kedudukan sensor berada disekeliling paip. Kebanyakan penyelidik sebelum ini menggunakan litar masa digital dan Sistem Pemerolehan Data (DAS) untuk mengawal unit unjuran dan penerimaan sistem tomografi optik. Dalam kajian ini, penggabungan litar bersama dsPIC30F6014A mikropengawal telah direka untuk mengawal unjuran cahaya untuk pemancar dan penerimaan isyarat untuk penerima. Bagi pengoperasian dsPIC30F6014A mikropengawal dan litar yang direka, bahasa pengaturcaraan C melalui pengkompil MicroC digunakan. Untuk pembinaan semula imej, Unjuran Kembali Linear (LBP) telah digunakan menggunakan Visual Basic 6. Pelbagai model aliran telah diuji dan dianalisis dengan teliti untuk melihat prestasi keseluruhan sistem. Dari keputusan yang diperolehi, sistem tomografi optik mampu digunakan untuk melihat pelbagai aliran di kawasan berbeza, seterusnya dapat menentukan kawasan yang tersumbat. Secara jelasnya, penggunaan mikropengawal dsPIC30F6014A tunggal menunjukkan keupayaan bagi pengambilan data dengan kadar masa 480 µs bagi persampelan data.

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LIST OF SYMBOLS

V	-	Voltage
Ω	-	Ohm
3D	-	Three Dimension
dB	-	Decibel
s	-	Second
k	-	Kilo
M	-	Mega
mm	-	Milimeter
nm	-	Nano Meter
A_v	-	Gain
V+	-	Non-inverting Input
V-	-	Inverting Input
V_{in}	-	Input voltage at the receiver

LIST OF ABBREVIATIONS

ADC	-	Analogue to Digital Conversion
AGC	-	Averaging Group Colour
CT	-	Computed Tomography
DAQ	-	Data Acquisition
DAS	-	Data Acquisition System
ECT	-	Electrical Capacitance Tomography
EIT	-	Electrical Impedance Tomography
FBP	-	Filtered Back Projection
GND	-	Ground
GUI	-	Graphical User Interfaces
Hz	-	Hertz
I2C	-	Inter-Integrated Circuit
IC	-	Integrated Circuit
IR	-	Infrared Light Emitting Diode
kHz	-	Kilo Hertz
LBP	-	Linear Back Projection
LBPA	-	Linear Back Projection Algorithm
LED	-	Light Emitting Diode
MHz	-	Mega Hertz

MIT	-	Magnetic Induction Tomography
MSE	-	Mean Square Error
OP-AMP	-	Operational Amplifier
PC	-	Personal Computer
PCB	-	Printed Circuit Board
PCI	-	Peripheral Component Interconnect
PIC	-	Peripheral Interface Controller
PSNR	-	Peak Signal To Noise Ratio
PVC	-	Poly(vinyl chloride)
Rx	-	Receiver
SIE	-	Space Image Evaluating
Tx	-	Transmitter
UART	-	Universal Asynchronous Receiver/Transmitter
USB	-	Universal Serial Bus
VB	-	Visual Basic

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CHAPTER 1

INTRODUCTION

The word tomography derives from the Greek and means a cut picture or image. From an engineering perspective, tomography is about obtaining information or data on the internal structure of an object without the need to invade or disrupt material flow.

Even though the tomography field is considered as mature technology and offers only low-resolution imaging, it remains popular thanks to its ability to penetrate the internal structure of the object without the need to slice the object. Tomography was first used for medical examination purposes, and gradually its industrial application occurred where online monitoring is concerned (Dyakowski *et al*, 2000).

Several tomography sensors exist and they are divided into “hard field” and “soft field” sensors. Hard field sensors are equally sensitive to parameters measured in all positions throughout the measurement volume and its sensitivity is independent of the distribution inside and outside the measurement region whereas with soft field sensors the sensitivity of the measured parameter depends on position in the measurement volume as well as on the distribution of parameters inside and outside this region (Johansen *et al*, 1996). An example of a hard field sensor is the X-ray (earliest technique) and an electrical capacitance tomography sensor (ECT) is an example of soft field sensors.

1.1 Background Problem

Process tomography has begun to spread extensively in industrial field research which uses different tomography techniques for monitoring flows of various types of component mixture inside pipelines. Indeed, study of the flow of solid and gas mixtures is vital and the tomography technique can improve the overall performance of the industrial process. The important feature of process tomography is its capability in terms of providing information for multiphase flow rates and material distribution or concentration profile inside pipelines in real time.

An industrial tomography system must have significant characteristics such as high speed of data acquisition, good responses (capable of online monitoring) and low cost compared with the current flow meter industry. This is vital since most of the material flow inside a pipeline moves at very high speed and requires very good responses, especially particle flow in the food and chemical industries.

The right data acquisition system, besides very high speed, must also have sufficient analogue input and digital output and be able to be integrated with tomography sensors and computers. Most previous research has utilised a combination of the PIC microcontroller or designed circuit and the data acquisition system (DAQ) in developing a tomography system (Abdul Rahim, 2005; Zheng *et al*, 2008). DAQ cards have been used for interfacing the sensor device in computers for better image reconstruction. Even though the DAQ card has often been selected by researchers, it is not a good choice in terms of the cost-effectiveness of the whole system. The price of DAQ cards ranges from RM 6 k to RM 20 k per unit (retail value from official website National Instrument http://www.ni.com/data-acquisition/), which is exorbitant. This is at odds with the original aim of producing a sensor device using low-cost apparatus (Minagawa *et al*, 2012). Alternative methods of data conversion should be considered. Muji (2012) used a different combination of a peripheral interface controller **(**PIC) and I2C protocol to develop an optical tomography system. This method is much better than the DAQ system in terms of cost-effectiveness. The I2C protocol is needed for combination of several PICs. This combination is required since a single PIC is unable to provide enough analogue input and digital output for most tomography systems. Using the I2C protocol could be intricate and complicated, however. Hence, an alternative microcontroller should be chosen to fulfil the above-mentioned needs. In 2001, Microchip released a dsPIC series of chips with a 16-bit microcontroller instead of an 8-bit for normal PIC. This dsPIC can cater for large numbers of analogue and digital input/output ports, thus eliminating the need for an I2C protocol.

1.2 Problem Statement

The production, processing and transport of particulate or granular materials such as minerals, powders or cereals, is of immense industrial importance. A pneumatic conveying system is a common process to transfer this bulk material through an enclosed pipeline. However, in pneumatic conveying system often could cause blockage due to uncontrolled large scale and condense flow of the material inside the pipeline; hence could adversely affect the whole productivity. There are several current flow meters available to detect material flow and identifying blockage area inside the pipeline. However, most of this equipment is intrusive with exorbitant price. The developed optical tomography is the cost effective option to observe and identifying the blockage area without need to invade the material flow.

In gravitational driven flow of granular material, the pipeline used has its minimum size of diameter so that conveying of the bulk material could flow easily. In the same way, the developed optical tomography fixture should be the same size with the diameter of the pipeline to capture the data without disrupts the material flow. However, most of the develop optical tomography by previous researcher do not meet the minimum size of the pipe line. Instead, the designed fixture is lower size in diameter compared with the diameter of the pipeline used in industry. This will limit the capability of the sensor observing the flow with larger size of the pipeline.

For construction of optical tomography system, most of previous researcher utilizing the usage of DAQ card along with projection circuit for transmitting and receiving signals. Besides, the combination of several microcontrollers is one of the options for researchers in this area to manage the system with higher number of input and output. However, both of this approach may not fulfill the main aims which are to produce low cost and uncomplicated flow meter towards industrial needs.

Over the past several years, observing black material flows is always an option for many of the researcher. However, the capability of this system to monitor only one type of color range could restrain its application towards certain industries only.

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1.3 Importance of Study

In the chemical and food industries, several types of material or foods need to be processed or produced in liquid solid form such as particles and granules. In terms of solid forms, the material might be presented as raw material or final products. Identifying the internal characteristics of solid flows along the conveying system is essential for observation of the overall performance of the process flow. This can be done by obtaining the concentration profile or distribution of particles inside the pipeline. Most of the pipeline or conveying system of solid flow is opaque, and the flow pattern cannot be observed with the naked eye. Hence, non-intrusive monitoring flow is needed to observe solid flow in gas medium. This is important to avoid flow disruption or collision between the material and the monitoring device.

Tomography is the most effective technology for observing the internal characteristics of solid flow without interrupting the internal process flow. There are several tomography sensing approaches but to date there is no specific online monitoring system for monitoring solids in a pneumatic conveying pipeline (Zheng *et al*, 2010).

The optical tomography system is one of the most popular techniques for observing the solid flow inside the pipeline. Most research utilises a pipeline which has a small diameter of 60mm as medium of solid and gas flow (Chan, 2002; Leong *et al*, 2005). A personal visit to a rice manufacturing industry in Malaysia (Appendix A) revealed, however, that the minimum diameter of the pipeline applied in this kind of industry is actually 100mm. This suggests that the ability of optical sensors to observe material flow should be examined in the case of pipelines with a bigger diameter. The complexity of the overall circuit will also be simplified by the usage of a dsPIC30F6014A microcontroller. Most of the manufacturing industries handle material which is generally dark or bright in colour. The performance of the sensors on different colours is thoroughly examined here to observe the compatibility of the system. It is hoped that the result will help other researchers to contribute to the development and application of optical tomography in real industry.

1.4 Research Objectives

The aim of this research is to develop an optical tomography system using fan beam projection configuration and an online monitoring system for solid-flow visualisation.

1.4.1 Specific Objectives

This researched aimed to meet the following objectives:

i. Design optical tomography measurement hardware
ii. Develop tomography software display
iii. Integrate the software and hardware for verification purposes
iv. Test and verify the ability of the system to observe different flow models with black and white colours.

1.5 Research Scope

(i) Design of a Sensor Fixture

The important things when deciding on a sensor fixture are the sensors' physical parameters, light projection angle, type of material suitable for constructing a fixture that suits the desired system and integration of the fixture with the designed circuit.

(ii) Sensor Selection

The type of sensors for transmitters and receivers needs to be decided. In this optical tomography system, infrared (IR) LED is selected for the transmitters and a photo-detector LED for the receivers.

(iii) Circuit design

Current for transmitter, amplifier circuit for receivers and microcontroller unit for digital timing are required, plus data conversion from analogue to digital form.

(iv) Software design for real-time image reconstruction

The software needed has two parts. The first part involves programming with a MicroC compiler to give instructions to the microcontroller for activation or deactivation of transmitters and data conversion at the receiver side. The second part involves developing an algorithm for image reconstruction using Visual Basic 6.

1.6 Organisation of Thesis

Chapter 1 presents an introduction to process tomography, the research's background problem, the problem statement, the importance of the study, the research objectives and the scope of the study.

Chapter 2 lists several common types of tomographic techniques and the general principles of optical tomography.

Chapter 3 explains optical tomography modelling and hardware design. This includes optical sensor arrangement, mounting techniques, signal conditioning circuits and data acquisition systems.

Chapter 4 details the software development for generating a pulse for activation and deactivation of the transmitter, timing sequence, data acquisition and image reconstruction.

Chapter 5 describes the image obtained from different types of flow models. Comparisons of the concentration value of the different models are presented.

Chapter 6 concludes, mention state research contribution and suggests further work to improve on the present study.

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