OPTICAL TOMOGRAPHY SYSTEM USING CHARGE-COUPLED DEVICE

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Specially dedicated to my husband, *Jemmy*, for his helps, supports and encouragement during the challenges of graduate study and life. This work also dedicated to my mother, parents in law and in memory of my late father, *Jamaludin.*

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ABSTRACT

This research presents an application of Charge-Coupled Device (CCD) linear sensor and laser diode in an optical tomography system. Optical tomography is a non-invasive and non-intrusive method of capturing a cross-sectional image of multiphase flow. The measurements are based on the final light intensity received by the sensor and this approach is limited to detecting solid objects only. The aim of this research was to analyse and demonstrate the capability of laser with a CCD in an optical tomography system for detecting different types of opaque objects in crystal clear water. The image reconstruction algorithms used in this research were filtered images of Linear Back Projection algorithms. These algorithms were programmed using LabVIEW programming software. Experiments in detecting solid and transparent objects were conducted, including experiments of rising air bubbles analysis. Based on the results, statistical analysis was performed to verify that the captured data were valid compared to the actual object data. The diameter and image of static solid and transparent objects were captured by this system, with 320 image views giving less area error than 160-views. This suggests that high image view resulted in high resolution image reconstruction. A moving object's characteristics such as diameter, path and velocity can also be observed. The accuracy of this system in detecting object acceleration was 82%, while the average velocity of rising air bubbles captured was 0.2328 m/s. In conclusion, this research has successfully developed a non-intrusive and non-invasive optical tomography system that can detect static and moving objects in crystal clear water.

ABSTRAK

Kajian ini membentangkan penggunaan Peranti Terganding Cas (CCD) dan laser di dalam sistem tomografi optik. Tomografi optik adalah satu kaedah tomografi yang tanpa rejah dan tidak invasif dalam merakam imej keratan rentas pelbagai aliran fasa bendalir. Kaedah pengukuran ini adalah berdasarkan kepada keamatan cahaya akhir yang diterima oleh peranti pengesan dan pendekatan ini adalah terhad untuk mengesan objek padu sahaja. Tujuan kajian ini dijalankan untuk menganalisis dan demonstrasi terhadap keupayaan laser dengan CCD dalam sistem tomografi optik untuk mengesan perbezaan objek mengikut kelegapan yang wujud di dalam air jernih. Algoritma pembinaan semula imej yang digunakan dalam kajian ini adalah daripada imej Pancaran Kembali Linear yang ditapis. Algoritma ini diprogramkan menggunakan perisian pengaturcaraan LabVIEW. Ujikaji dalam mengesan objek padu dan telus termasuk ujikaji kenaikan buih udara dijalankan dan dianalisis. Berdasarkan hasil ujikaji, analisis statistik dilakukan untuk mengesahkan data yang dirakam adalah sama dengan data objek yang diketahui. Diameter serta imej objek padu dan telus yang berkedudukan statik yang dirakam oleh sistem ini menunjukkan bahawa 320 paparan imej memberi ralat kawasan yang kurang berbanding 160 paparan imej. Ini menyatakan bahawa bilangan paparan imej yang tinggi menghasilkan imej yang beresolusi tinggi. Ciri-ciri objek yang bergerak seperti diameter, cara laluan dan halaju boleh diketahui. Ketepatan sistem ini dalam mengesan pecutan objek adalah 82%, sementara itu, halaju purata kenaikan gelembung udara yang berjaya dirakam adalah 0.2328 ms^{-1}. Kesimpulannya, kajian ini telah berjaya membangunkan sistem tomografi optik yang tanpa rejah dan tidak invasif dalam mengesan objek statik dan bergerak di dalam air yang jernih.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
CCD	-	Charge Coupled Device
CT	-	Computed Tomography
HAZ	-	Heat Affected Zone
HOV	-	Homogeneity of Variance Test
LBP	-	Linear Back Projection
LED	-	Light Emitting Diode
OPT	-	Optical Tomography System
ROG	-	Read Out Gate
SPECT	-	Single Photon Emission Computed Tomography

LIST OF SYMBOLS

A	-	Area
B	-	Magnetic field
D, d	-	Diameter
E	-	Tangential electric field
h	-	Height
l	-	Length
M	-	Sensitivity map
N	-	Refraction index
N	-	Total number of pixels
Q	-	Flow rate
r	-	Radius
rx	-	Receiver
S	-	Sensor loss
T	-	Time
tx	-	Transmitter
V	-	Voltage
w	-	Width
θ	-	Angle
α	-	Absorption coefficient
Ø	-	Diameter

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The tomography method has been used since 1950 in medical fields and spread into industry by 1990 [1]. The tomography system is suitable to apply for non-invasive and non-intrusive monitoring, especially in industries that deal with multiphase flow. Figure 1.1 shows the basic block diagram for a tomography system.

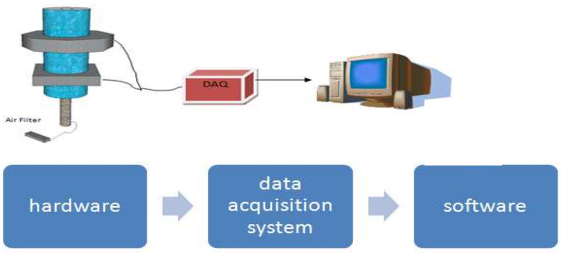

Figure 1.1: Basic block diagram for tomography system

Petroleum refining systems, textile and fabric industries, oil and gas pipeline systems, geothermal wells, steam generation in boilers and burners, and steam condensation all deal with two-phase flow which is in the form of gas bubbles and liquid [2]. Engineers need to monitor the condensation process or the distribution of steam bubbling to avoid any damage occurring in the high cost and high maintenance of their system. The existence of miniature gas bubbles of hydrocarbons, for example, will affect the temperature and viscosity of the flowing mixture. The increasing number of smaller bubbles will form an elongated Taylor bubble. As a result, the surrounding liquid will be pushed by the gases to the sides of the pipe wells and damage the system [2]. In geothermal well processing systems, increase of the water temperature will cause an increase in the number of air bubbles. Unfortunately, this will affect the fluid pressure. Therefore, continuous monitoring by engineers is very important [2]. The gas percentage in the liquid medium, gas flow rate, appearance and disappearance of gases, shape of gases, and their diameters are imperative information for monitoring and process control. The available gas detectors use intrusive and invasive techniques such as impedance probes, optical fibre probes, ultrasound Doppler and isokinetic probes. For non-intrusive and non-invasive techniques, examples of gas bubble detectors are pressure transducers, the gamma ray density gauge technique, laser technique and tomography technique. Optical tomography (OPT) is the best approach because this method consists of hard field sensors [3] where the sensor does not depend on the changes of conductivity or permittivity of the subjects that are being analysed. The OPT system provides a good spatial resolution, where it can capture a very detailed image without making the pixels visible. OPT also provides a high-speed data capture system and it is suitable for online monitoring system applications.

The aim of this research project is to build an OPT system using the combination of a Charge-Coupled Device (CCD) linear sensor and laser diodes with LabVIEW software to detect multiphase flow. The basic principle of the OPT system with CCD is similar to the Single Photon Emission Computed Tomography (SPECT) concept, where source photons of SPECT gamma are converted into visible light. Then, this visible light will be converted into electrical signals by a photomultiplier [4]. The difference between these two systems is their application and the type of sensors used. SPECT is mostly used for medical purposes and requires a contrast agent [4]. SPECT uses a gamma ray as the transmitter and it exposes the patient to radiation. However, the suggested OPT system promises a non-intrusive, non-invasive and non-hazardous radiation system for online industrial inspection of multiphase flow measurement. This hardware development is capable of detecting opaque and transparent objects without the help of a contrast agent, which can disturb the stability of multiphase flow. Qualitative and quantitative analyses were done using LabVIEW and Minitab software. Minitab software is used for statistical analysis, while LabVIEW programming has been developed to measure the object diameter and velocity for offline data, and to produce a cross-sectional pipeline image for real-time data. Linear Back Projection (LBP) and filtered image algorithms were introduced and applied on 160 and 320 image views reconstruction analysis. The image captured is displayed in 64 x 64 image resolution but in different numbers of views. A view is a term for the single combination of emitter and detector which are aligned in a parallel array known as projection [5]. The main reason for selecting 160 views and 320 views to study is to verify the statement that a higher number of sensors will generate a better quality image reconstruction [6].

1.2 Problem Statement

Optical tomography systems are widely applied in detecting solid objects compared to transparent objects. Research that uses chromatic light, such as a Light Emitting Diode (LED), has difficulty in detecting transparent objects. A transparent object will act as a prism that can diffract white light into its basic light spectra. This will result in inaccurate data being obtained. A laser diode is the best transmitter because it is a monochromatic light source.

Research was conducted using a laser diode with a Charge-Coupled Device (CCD) linear sensor in the tomography field to detect solid objects. The system is capable of measuring the solid object's diameter and velocity. Problems that occurred in this research are that the low data sampling (250 kHz sample per second for the whole system) will cause data losses. This will give inaccurate data measurement because the diameter values are based on the total effective number of CCD pixels. A correction factor should be applied to compensate the inaccurate data measurement. The previous research also claimed that a single plane of the CCD OPT system was able to capture the object's velocity based on the length of the CCD pixel. Unfortunately, this technique gives inaccurate results, where different object sizes will have different time intervals and distances.

Previous OPT system researchers are keen to use a fast operational speed monochromatic transmitter such as a laser diode that will apply a switching mode technique. This method captures a single fraction of a view in a measurement frame. Delay in alternation from one projection to the next projection will increase the time per scan for a full measurement frame. The probability of data losses, especially in moving object research, is very high. Simultaneous projection is proposed to overcome the mentioned problems.

1.3 Research Objectives

This research project consists of three main objectives, as listed below:

i. To investigate and analyse the appropriate OPT system modelling, with a correction factor to overcome data loss, and image reconstruction algorithms that will match with the CCD linear sensors and laser diodes in producing high quality image reconstruction.
ii. To design and develop a dual-plane OPT system to enable more solid research for object velocity data. LabVIEW programming for real-time image reconstruction of a cross-sectional pipeline system and offline measurement are developed.
iii. To conduct a number of experiments with static objects (solid, glass rod and transparent hollow straw) and moving objects (air bubbles) to prove the ability of the OPT with CCD sensors system to capture and analyse the data of objects in transparent liquid.

1.4 Research Scopes and Limitations

The scope of this research project can be divided into four main parts. The first is to analyse and develop the optical system and image tomography modelling that is appropriate for the CCD linear sensors and their light sources.

Then, hardware and software developments based on the above modelling are involved. Early stage experiments concerned with analysing the suitability of LEDs and laser diodes with CCD linear sensors were conducted. After selection of a laser as the most suitable sensor for the CCD, prototypes of the OPT system were developed as a guideline for a fixed hardware fabrication. During this stage, basic LabVIEW programming was developed for offline and online measurement based on improved previous research on mathematical modelling.

Once the fixed hardware and advanced LabVIEW programming were developed, a series of experiments were conducted to evaluate the capability of this system in capturing and measuring objects with various levels of opacity. These experiments consist of two important stages, namely the detection of single static objects with three different opacity levels and the detection of two static objects with different opacity levels. The first stage is to confirm the system's ability to capture and analyse these objects. The second stage is to prove that multiple objects can be captured and processed in the same pipeline system.

In the final stage of evaluations, the detection of rising air bubbles that were generated by a syringe and by an air pump was carried out. The purpose of these experiments is to prove that moving air bubbles can be detected by this system. Part of the evaluation is to analyse the air bubble's diameter and velocity with two-plane sensor alignments. With this technique, the air bubble shape and path can be evaluated.

A few research limitations and assumptions should be mentioned here. In this research, light absorption, reflection and reflectance are included in the theoretical calculation, while light's other characteristics are assumed to be negligible. For the data acquisition system (DAQ), NI USB 6210 is capable of capturing 31k samples per second for each port. There is 40 us of data lost because of this DAQ limitation. So it is assumed that 5 continuous pixels will have the same voltage values as the first pixels sampled. For the experiment involving crystal clear water, the pressure level is assumed at atmospheric pressure level, 101.3 kPa.

1.5 Research Methodology in Brief

This research constructs an OPT system using a Sony ILX551A CCD and laser diodes class IIIA oriented in an octagonal shape to give a wide coverage area of an acrylic pipeline system. There are two software programs involved in this research: real-time image reconstruction and offline data measurement. Both softwares are developed in LabVIEW. For real-time image reconstruction, Linear Back Projection and filtered algorithms are applied. For offline programming, data on the object diameter and velocity are collected for evaluation. Several experiments are conducted to investigate the capability of this OPT system in detecting and capturing images of static or moving solid and transparent objects. The data collected shall be analysed and evaluated using a statistical engineering analysis technique with the help of Minitab software.

1.6 Structure of Thesis

This thesis consists of six chapters as described below.

i. Chapter 1 briefly describes the research background, problems statements, objectives, scopes, and its contributions.

ii. Chapter 2 consists of a literature review on tomography systems, light characteristics, OPT image reconstruction, CCD sensors, multiphase flow criteria, bubble characteristics and detectors.

iii. Chapter 3 discusses the optical system modelling and image reconstruction modelling.

iv. Chapter 4 presents the research methodology for the OPT hardware development and LabVIEW programming.

v. Chapter 5 presents the experiments and results for static objects and moving air bubbles. Detailed analysis and discussion on diameter measurement, object velocity and image reconstruction are examined here.

vi. Chapter 6 is the final chapter with the research conclusions and recommendations for future work.

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