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Charge-Coupled Device Based on Optical Tomography System for monitoring multiphase flow

Juliza Jamaludin[1], Ruzairi Abdul Rahim[2], Mohd Hafiz Fazalul Rahiman[3], Siti Zarina Mohd Muji[2], Jemmy Mohd Rohani[4], Yasmin Abdul Wahab[5]

[1]Electronic Engineering Department, Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, 71800 Bandar Baru Nilai, Negeri Sembilan, Malaysia.
[2]Faculty of Electrical and Electronic Engineering, Universiti Tuen Hussien Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.
[3]Tomography Imaging Research Group, School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia.
[4]Jemmy Mohd Rohani Enterprise, No. 43, Jalan Merak 1/2, Bandar Putra, Kulai, Johor, Malaysia.
[5]Instrumentation and Control Engineering Department, Faculty of Electrical and Electronic Engineering, Universiti Malaysia Pahang, 26000 Pekan, Pahang, Malaysia.

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Abstract: Tomography is a method to capture a cross-sectional image based on the data obtained by sensors, distributed around the periphery of the analyzed system. Optical tomography is one of the tomography methods which are non-invasive and non-intrusive system, consisting of emitter with detectors. Combinations of Charge-Coupled Device and low intensity laser diode are used in this research. Experiments on air bubbles detecting in non-flowing crystal clear water are conducted. Cross-sectional image of two phase flow; air and liquid are captured using this optical hardware construction and the information on air diameter, shape and path are observed using LabVIEW programming.

Keywords: Optical tomography, Charge-Coupled Device, laser diode, image reconstruction

1. Introduction

Tomography method has been used since 1950 in medical fields and being spread into industry by 1990 [1]. Tomography system is suitable to apply for non-invasive and non-intrusive monitoring system, especially for the industries that deal with the multiphase flow.

Gas percentage in liquid medium, gas flow rate, appearance and disappearance of gasses, shape of gasses, and their diameters are imperative information for monitoring and process control. Available gas detectors are intrusive and invasive technique such as impedance probe, optical fiber probe, ultrasound Doppler and isoknetic probe. They need regular maintenance to avoid inaccurate data acquired [2]. For non-intrusive and non-invasive techniques, the examples of gas bubbles detector are, pressure transducer, gamma ray density gauge technique and laser technique. Some of these techniques involved contrast agent and emitted hazardous radiation [2] [3].

Optical tomography is the best approach because this method consists of hard field sensors [4] where the sensor does not depend on the changes of conductivity or permittivity of subjects that are being analyzed. Optical tomography system (OTS) provides a good spatial resolution where it can capture a very detailed image without making the pixels visible. Optical tomography also provides a high-speed data capturing system and it is suitable for online monitoring system applications [5].

The aim of this research project is to build an OTS using the combination of Charge-Coupled Device (CCD) and laser diode with LabVIEW software to detect multiphase flow. The focus here is to detect low opacity object in static crystal clear water.

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2. Research Methodology

OTS consists of two main parts; hardware and software developments. CCD linear sensor Sony ILX551A was used as a receiver and low cost laser diode (Class IIIA) with a mixture of Helium and Neon gases in the ratio of 10:1 was used as a transmitter. LabVIEW software was applied for image reconstruction.

2.1 Hardware Construction

Fig. 1 shows the illustration arrangement of optic components involved for laser light source expansion system.

Flexible rod was used to control the light distance manually. Light expansion system consists of laser diode with attached lens and covered by a thin frosted plastic (table tennis ball). Laser fan beam projection will pass through the square aperture and this square laser light

*Corresponding author: juliza@usim.edu.my

beam will have reached the CCD sensor. This laser expansion system was built in black box which acts as light absorber by absorbing the unnecessary external or internal light reflections [6][7].

Sony ILX551A CCD linear sensor has 40 mm length. It has 2048 number of pixels with size 14 µm x14 µm each [8]. The total length for this CCD sensitive pixel is 28.6720mm [8]. Eight numbers of CCD linear sensors and four numbers of laser diodes are arranged in octagon shape. Fig. 2 shows the orientation of these optoelectronic components around the pipeline system.

The acrylic pipeline and optical tomography system were built in a closed black box to avoid the interruption of an external and visible light source and its schematic diagram shown in Fig. 3(a) and real-time hardware shown in Fig.3(b).

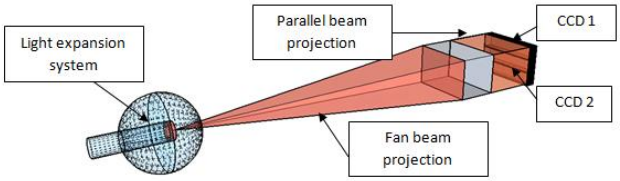


Fig. 1 Laser diode light expansion system

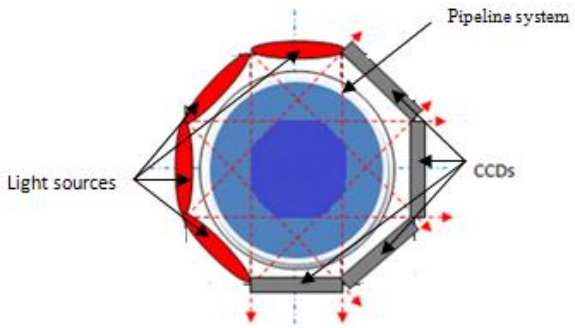
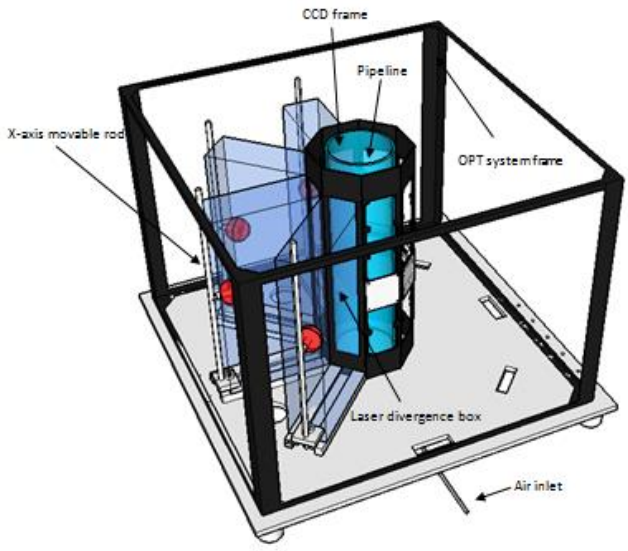
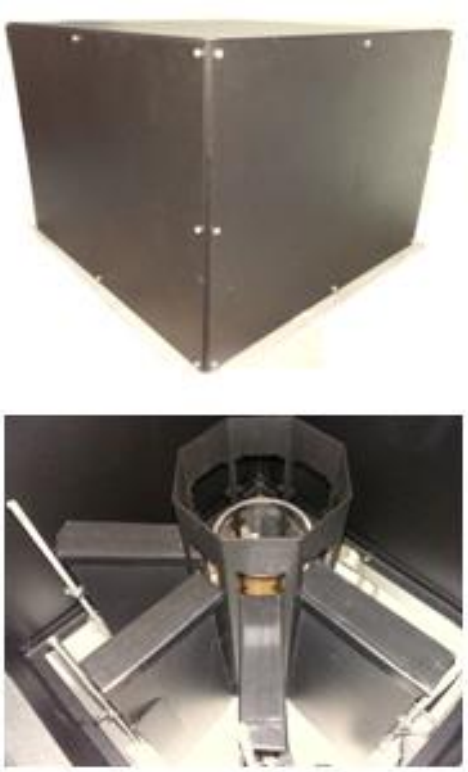


Fig. 2 CCD and laser diode sensors orientation from the top view



(a)



(b)

Fig. 3 (a) Schematic diagram and (b) hardware construction

2.2 Software Development

Data acquisition NI 6210 was used for the interfacing process between the hardware and software construction. The CCD linear sensor Sony ILX551A requires two signals: Read Out Gate (ROG) and a clock pulse generator to function, with both signals programmed using C language in PIC16F877A. For the clock pulse, the time per cycle was 8.80 µs. Total time per scan for this optical tomography system was 18.4 ms.

Linear Back Projection (LBP) algorithms are used for image reconstruction using LabVIEW software development. Fig. 4 shows the flow chart for image processing. There are two number of views that being investigate, 160-view and 320-views.

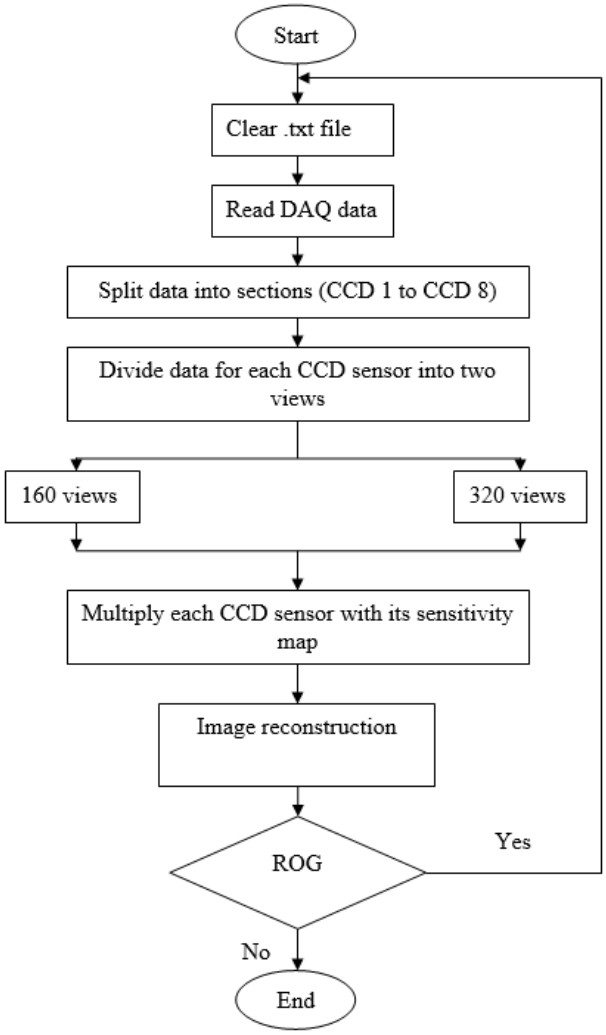


Fig. 4. Flow chart for reading real-time data for image reconstruction

3. Results and Discussion

This hardware and software developments are testing for its performance by detecting low opacity object in crystal clear water. The experiments that involved are to capture the image of rising air bubbles in non-flowing crystal clear water. 20 ml volume of air is generated by syringe. Bubble that moved from the lower to upper plane of OTS is considered as free rising bubbles.

3.1 Air Bubbles Characteristics and Image Reconstruction

This 20-ml air is manually pumped into the pipeline system to generate the air bubble by using syringe. Thirty experiments data are collected for statistical analyses and images reconstruction. The crystal-clear water is assumed at atmospheric pressure level. Statistical analyses are done to analyze the diameter of air bubbles captured by this OTS. The data evaluations are based on the P-value. P-value is known as attained significant level where P-value that less than 0.05 will consider the data obtained are not normally distributed. More experiments need to be conduct [9].

There are 30 numbers of experiments were done to validate the capability of this OTS in capturing air bubble. The summarization of statistical analysis result in Fig. 5 shows the P-value of air bubbles data using syringe was equal to 0.055 and the data are considered as normally distributed. According to the statistical summary, the bubbles diameter ranges are between 9.433 mm to 14.507 mm with the mean value of 12.407 mm. Based on the previous research, the bubbles shape are considered as spherical cap with spiral or helical path [10].

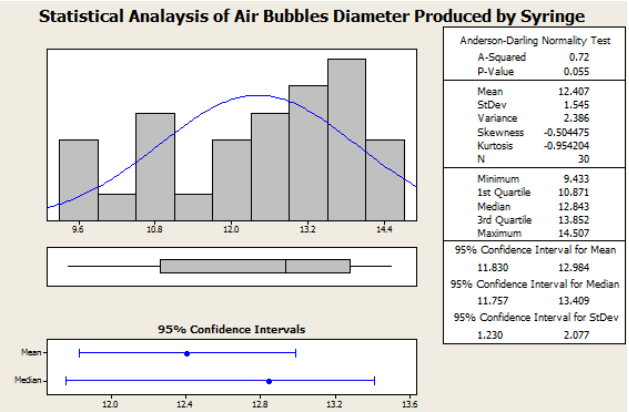


Fig. 5 Statistical analysis for diameter of air bubble produced by syringe at 20 ml volume[7]

Table 1 and 2 are showing three-dimensional image reconstructions of air bubble generated. LBP method are used for Table 1 and the filtered image shown in Table 2.

The rising bubble movement can be separated into three stages, initial detections, full detections and final detections time frame. Initial detection is at time frame one and two representing time zero until time 0.0368 second. Here the early appearance of bubbles can be observed. Second detection are at time frame three until time frame five representing time 0.0369 second till time 0.0920 second. This time is known as full detection stage where the full object diameter can be observed. Final detection stage is from time frame six and seven representing time 0.0921 till time 0.1288. This is where the disappearance of bubble can be observed.

As shown in the Table 2, the air bubble moving from right side of the pipeline system at lower plane of OTS and move to the left side of the pipeline system at upper plane of optical tomography system. This observation strengthens the theories of bubbles are moving in helical path. According to Luo et. al [8] the crystals clear water or fluid at atmospheric pressure will let the rising air bubble diameter become larger and let it moving in spiral or helical path.

4. Summary

From above experiments, it is concluded that this OTS is able to detect moving air bubbles in crystal clear water. These detections data can be translated into object diameter during the full detection time scan. Based on the diameter data, the shapes and paths of the bubbles can be estimated. The development of CCD sensor based on OTS offering a non-intrusive, non-invasive, no additional of contrast agent and environmentally friendly optical detector for low opacity object measurement. This OTS and LabVIEW programming is suggested to apply in multiphase flow industries for monitoring and inspecting purpose. It is because, this optical detector can provide essential information of low opacity object in multiphase flow such as the image concentration, diameter of object captured, object shape and path.

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Table 1 Three-dimensional image reconstructions of air bubbles produced by syringe in LBP and Hybrid method

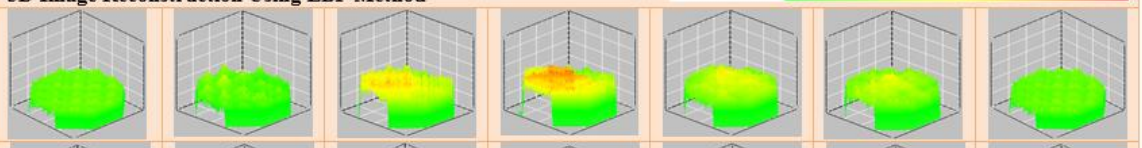
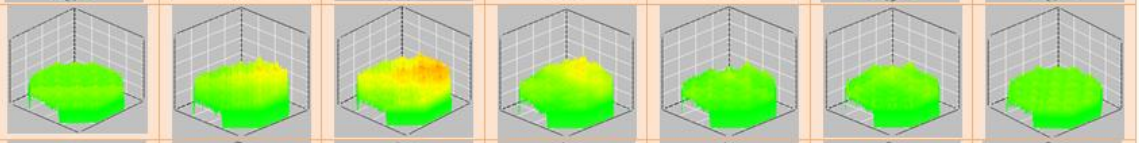
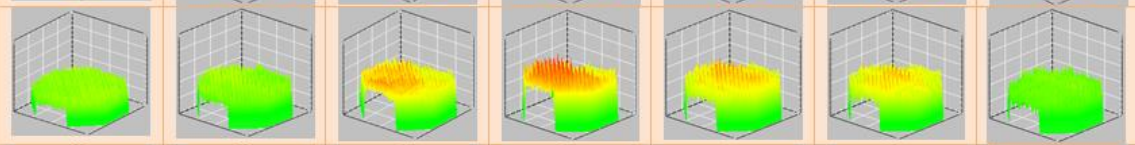
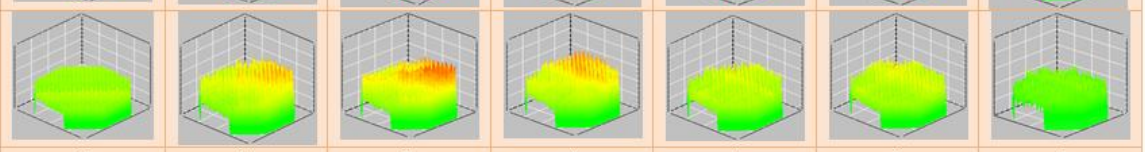
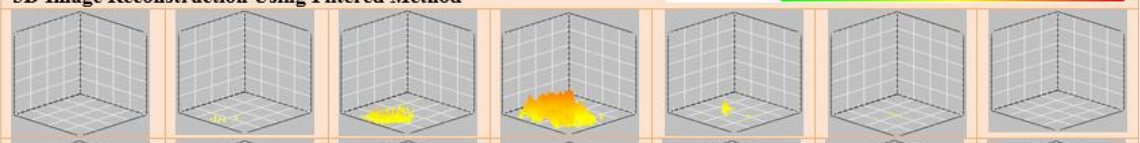
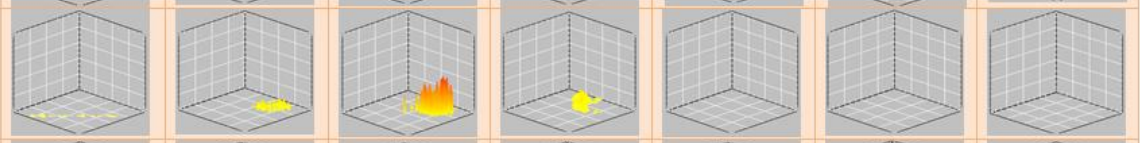
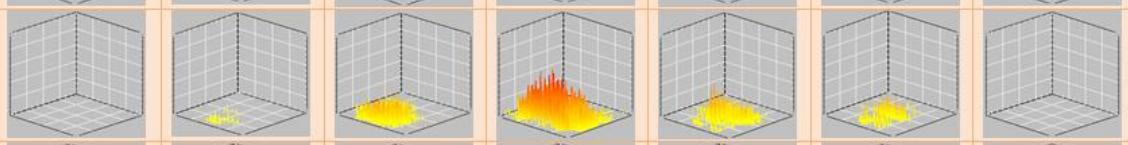
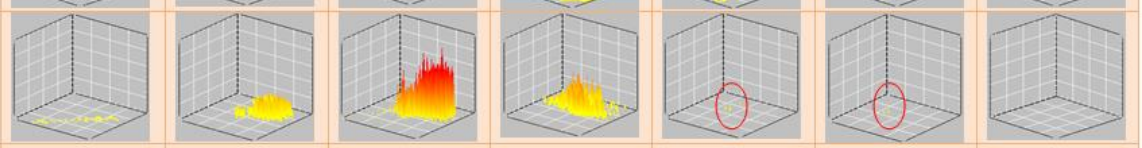
Criteria	3D Image Reconstruction Using LBP Method (Colour Legend: Low — Opacity object — High)						
Upper Plane (160 views)							
Lower Plane (160 views)							
Upper Plane (320 views)							
Lower Plane (320 views)							
Time Scan	1	2	3	4	5	6	7

Table 2 Three-dimensional image reconstructions of air bubbles produced by syringe in filtered method

Criteria	3D Image Reconstruction Using Filtered Method						
	Colour Legend: Low — Opacity object — High						
Upper Plane (160 views)							
Lower Plane (160 views)							
Upper Plane (320 views)							
Lower Plane (320 views)							
Time Scan	1	2	3	4	5	6	7