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OPTICAL TOMOGRAPHY SYSTEM: APPLICATION OF CHARGE COUPLED DEVICE (CCD) FOR SOLID AND TRANSPARENT OBJECTS DETECTION

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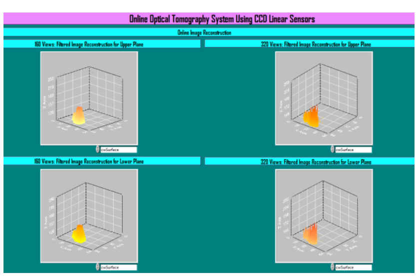
Graphical abstract



Abstract

This research presents an application of Charge Coupled Device (CCD) linear sensor and laser diode in an optical tomography system. These optoelectronic sensors are believed to detect solid objects rather than transparent objects. Based on the research results, the development of optical tomography system using Charge Coupled Device (CCD) and laser diode has helped to enhance the potential of these sensors in detecting high to low opacity objects. Experiments for detecting a solid rod, glass rod and transparent hollow straw in non-flowing crystal clear water were conducted in this study. Investigation on the effect of number of views also studied in this research. From the image reconstruction results, it clearly shows a cross-sectional image of a pipeline system with the existence of opaque and transparent objects in multiphase flows. For 320 views image reconstruction, it gives high resolution of image results compared to 160 views image reconstruction.

Keywords: Charge Coupled Device (CCD), lasers; optical tomography system, image reconstruction

1.0 INTRODUCTION

Charge Couple Device (CCD) sensor has high sensitivity and accuracy, high frame rates and low power consumption [1], [2]. The basic principle of CCD is to measure the level of light intensities received by its small sensors, which are made from semiconductor components [3]. As a result, CCD is believed to be able to detect opaque objects only. This is because opaque objects will reflect or absorb the light source that hits their surfaces [4]. The final amount of light intensities received by CCD will determine the existence and position of the object. This phenomena show that CCD has high sensitivity to detect dark spots only [5] [6]. CCD sensor has a problem in detecting low opacity object. For lower opacity objects, more light can penetrate through them. This may make it difficult for CCD to detect transparent objects because light intensities received by CCD may not differ significantly.

In view of this, a research has been conducted to solve the above problem by applying the optical tomography approach [7][19-21]. Firstly, this project has optimized the use of the above sensors in capturing and measuring a cross-section image of a non-invasive pipeline system by expanding the laser diode light source, with the assumption that the light expansion method will help these transceivers widen the coverage area [8].

Secondly, CCD linear sensors and laser diodes have been oriented in an octagon shape to enhance the image reconstruction of low opacity objects. Overlapping of the expansion light beam received by CCD sensors will help the detector determine the exact location and appearance of low opacity objects. Details on hardware construction are explained in the methodology section.

For image reconstruction, Linear Back Projection (LBP) algorithms have been used and enhanced by Hybrid [9] method for two phase flow. For clear image visualization of object being study, filtered algorithm is introduced. The LabVIEW software has been developed for image reconstruction and analysis.

2.0 METHODOLOGY

There are two types of CCD architecture: area array CCD and linear CCD. This project focuses on the line scan camera or linear CCD because it is small in size and consists of a single line photosensitive element [10]. As a result, linear CCD provides less time scan per frame compared to array CCD [10].

This research used CCD linear sensor Sony ILX551A [11]. Grey CCD (Sony ILX551A) has been chosen because its time scan rate ratio is 1:3 times lower than colour CCD [12]. Colour CCD consists of red, green and blue photosensitive elements and needs a large memory for saving output signals [13].

This type of CCD sensor can detect photons spectral range of 400 to 1100nm [14], [15]. For this flow measurement instrument, we chose low cost laser diode with a mixture of Helium and Neon gases in the ratio of 10:1. It is an atomic laser with low power device [16]. This type of laser diode emits photons with spectral range of 633 nm to 650 nm and is suitable for the Sony ILX551A CCD linear sensor. The sensitivity peaks that are detected by CCD sensors are normally in the range of 550 to 800 nm [14].

As mentioned before, the main purpose of this hardware development is to inspect the existence of different levels of opacities of objects in crystal clear water. Crystal clear water helps in absorbing heat that is produced by laser diode, thereby preventing overheating and causing damage to the CCD sensors. Besides that, high thickness of water level (refer to diameter of the pipeline system) can provide a long pathway that the lasers has to undergo, causing the heat affected zone (HAZ) of the laser diode to become less significant [17].

Eight numbers of CCD sensors and four numbers of laser diodes expansion systems were arranged in octagon orientation as shown in Figure 1. This arrangement of emitters and sensors helps to uniformly view the cross-sectional image of the flow system of upper and lower pipeline.

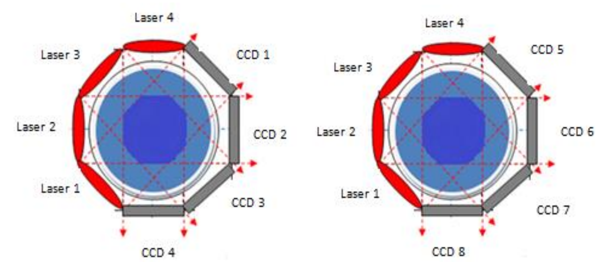


Figure 1 CCD and laser orientation for (a) upper plane and (b) lower plane

The diagram of the laser diode expansion system box is shown in Figure 2.

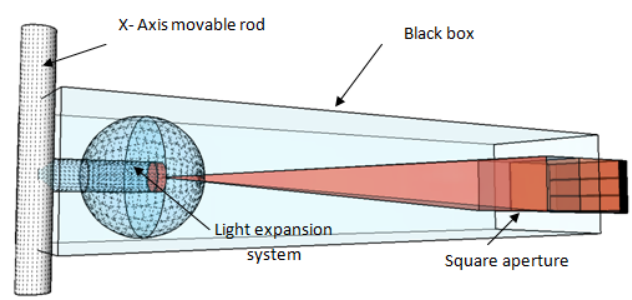


Figure 2 Laser diode expansion system box

The square aperture dimension of 40 mm x 40 mm were aligned parallel with upper and lower CCD sensors. A lens with a focal length of 0.5 was attached at the front of the laser diode source.

Laser with attached lens is covered using white table tennis ball. This white table tennis ball is used as a filter to reduce the laser diode light intensity from 0.7 to 0.5 Lux at air and 0.3 Lux after passing crystal clear water. The laser Lux values are measured using UNI-T UT381 Lux meter.

The laser diode light source expanded into a fan beam projection form. The expansion light source then passed through the square aperture. This square aperture was used to limit the area of the laser diode beam that can reached the CCD surface sensors. The final light source received by the CCD sensors is known as the square beam projection.
To obtain an accurate light source expansion, a laser diode was fixed to X-axis movable rod so the distance between the laser and CCD can be controlled manually. The CCD frame was used to fix the CCD sensors at a desirable level of the pipeline system. This frame provided six sockets for the CCD sensor to be attached at each column. However, this experiment used only two CCD socket in each column. The pipeline and sensors system were built in a closed black box to avoid the interruption of an external and visible light source. The hardware construction diagram can be seen in Figure 3. The lux received by each CCD sensor are measured as 0.3 lux value.

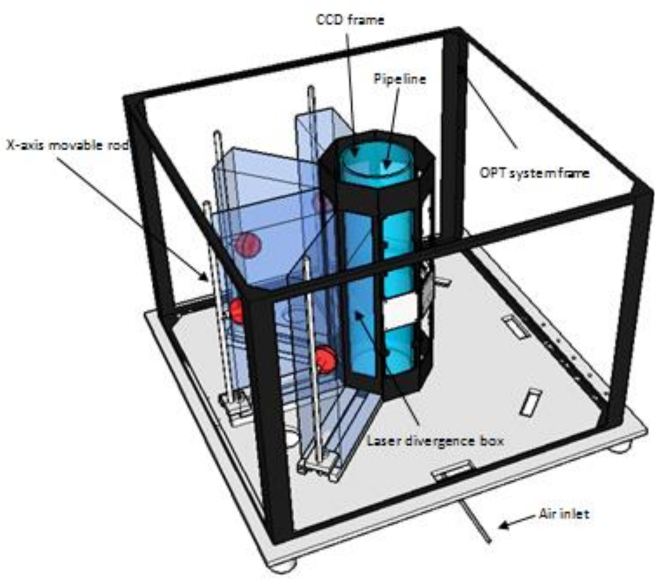


Figure 3 Hardware construction schematic diagram

Data acquisition NI USB6210 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.

Development of the LabVIEW programming for CCD image reconstruction was also involved in this study. The LabVIEW front panel for software program of this optical tomography system is shown in Figure 4.

Sensitivity maps for a 100 mm diameter acrylic pipeline with 160 and 320 views in 40 mm length of the sensor were developed using Visual Basic software. Each sensitivity map was multiplied by the normalized CCD voltage output for image reconstruction. Resulting images of the solid rod, glass rod, and air bubbles in static clear water were analysed to prove that CCD sensors are able to detect different opacities of objects using the optical tomography method. Next section will explain in detail about the performance of this optical tomography system hardware and software development in detecting and capturing image of multiphase flow.

3.0 RESULTS AND DISCUSSIONS ON IMAGE RECONSTRUCTION

Several experiments were carried out in detecting a solid rod as an opaque object, glass rod and transparent hollow straw as static transparent objects in non-flowing crystal clear water. All the experiments are conducted at room temperature between 25°C to 33°C and relative humidity is within 65% to 85%.

The main objectives of these experiments is to analyze the capability of online CCD OPT system in capturing static opaque and transparent objects image in static crystal clear water.

In the early stage of image reconstruction, Linear Back Projection (LBP) algorithm is used as a baseline. The basic LBP algorithm is shown in Equation 1 for 160 views and Equation 2 for 320 views [18].

$$V_{LBP(160\ views)}(x,y) = \sum_{tx=0}^{159} \sum_{rx=0}^{159} S_{tx,rx}\ x\ \bar{M}_{tx,rx} \quad (1)$$
$$V_{LBP(320\ views)}(x,y) = \sum_{tx=0}^{319} \sum_{rx=0}^{319} S_{tx,rx}\ x\ \bar{M}_{tx,rx} \quad (2)$$

V_{LBP} (x,y) refers to the voltage distribution of concentration profile; S is the sensor loss and $\bar{M}$ is the normalized sensitivity map. The concentration profile image is produced by multiplication of computed sensitivity map and sensor loss value obtained from each view.

However, LBP image reconstruction results will have smearing and ambiguous effect [9]. In this research study, hybrid approach was applied to eliminate the smearing and ambiguous effect [9] thus enhancing the image reconstruction quality.

To eliminate the smearing effect that still occurred to the combination of LBP and Hybrid image reconstruction, another steps of image reconstruction enhancement was applied. The filtered images are results of comparing the image under study with an initial image stage where no obstacles are present in the system. Equation (3) and (4) simplified the above statement in mathematical term.

$$V_{filtered\ (160\ views)}(x,y) = V_{LBP+Hybrid}(x,y) - V_i(x,y) \quad (3)$$
$$V_{filtered\ (320\ views)}(x,y) = V_{LBP+Hybrid}(x,y) - V_i(x,y) \quad (4)$$

Where, $V_{filtered}$ referred to the image reconstruction enhancement, $V_{LBP+Hybrid}$ referred to current image reconstruction using combination of LBP and Hybrid methods and V_i is the initial state of LBP and Hybrid image reconstruction without the existence of obstacle.

Table 1 shows the LBP and Hybrid image reconstruction results of static objects in two different opacity, solid and transparent objects. Meanwhile, Table 2 shows the image reconstruction of these static objects based on filtered algorithm. The image reconstructions are obtained from upper plane optical tomography system.

The LBP image results shown in Table 1 and Table 2 prove that CCD sensors can detect the existence of solid and transparent objects. It should be noted that images in both tables show the appearance and location of the static solid rod to be clearer than the static glass rod and transparent hollow straw because more light can penetrate through transparent objects compared to solid objects.

Table 3 and 4, shows the z-value analysis for the experiments of static objects. Z-value represents the z-axis of three dimensional image reconstructions. Its value refers to the pixel values based on the multiplication results of sensitivity map for 160 and 320 views with CCD normalized voltage values. Different level of opacity will give different z-value, where higher opacity level will produce a higher z-value. As a result, significant difference in z-value can be observed between solid and transparent objects.

For 160 views LBP and Hybrid image reconstruction for solid rod, z-value is between 1008 to 1072 pixel values. For glass rod and transparent hollow straw z-values are measured within 1008 to 1040 pixel values.

For 320 views image reconstruction for solid rod, z-value is between 1032 to 1144 pixel values. For glass rod and transparent hollow straw z-values are measured within 1032 to 1088 pixel values.

In 160 views filtered image reconstruction, solid rod will have the maximum z-value of 220 pixel values. For the transparent objects the maximum z-value are 167 pixel values.

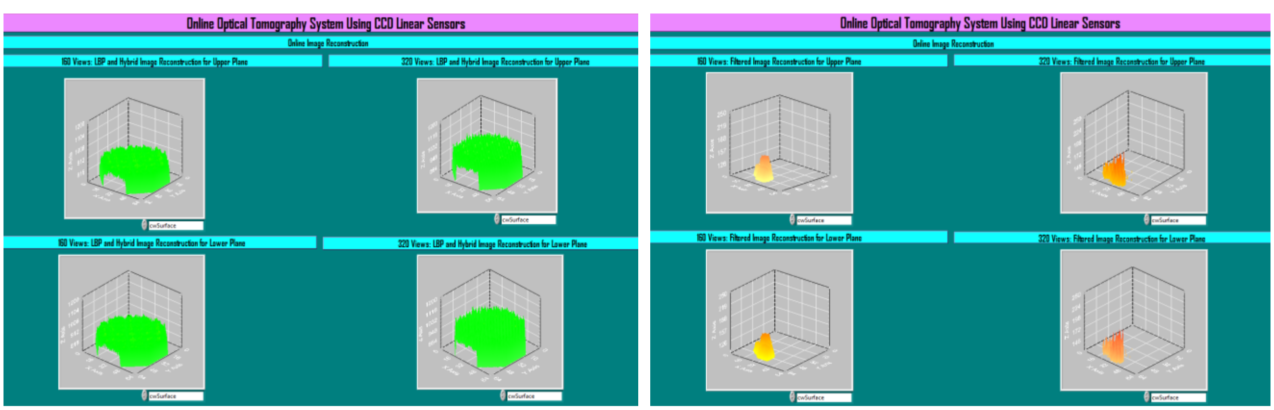
In 320 views filtered image reconstruction, solid rod will have the maximum z-value of 250 pixel values. For the transparent objects the maximum z-value are 198 pixel values.

With all above result statements and tables, there are two summaries can be concluded.

There are:

i) Z-value between solid and transparent objects will have a significant difference for both 160 and 320 views, where solid object will have a higher z-value.
ii) 320 views image reconstruction for the same object opacity will have a higher z-value compared to 160 views image reconstruction

For the images reconstructions of static objects in crystal clear water, it is proven that combination of LBP, Hybrid and Filtered algorithms are capable of reconstructing a cross-sectional image of multiphase pipeline system. Based on z-value the objects opacity level can be differentiate. Higher z-values are representing higher opacity level objects.



(a) (b)

Figure 4 Labview front panel for optical tomography system using CCD sensor with (a) LBP with Hybrid and (b) filtered algorithms

Table 1 LBP and Hybrid image reconstruction of static objects

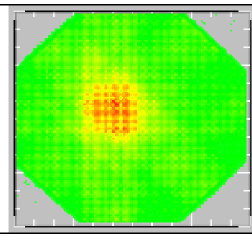
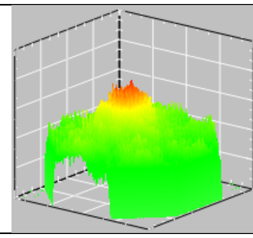
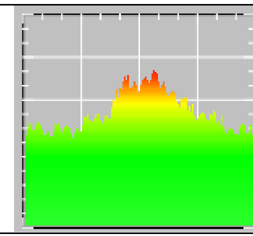
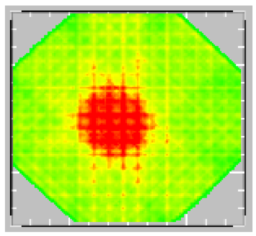
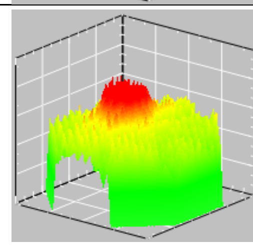
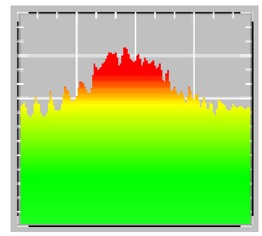
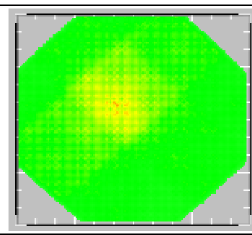
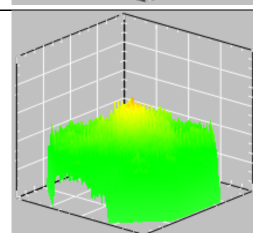
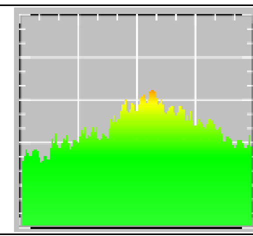
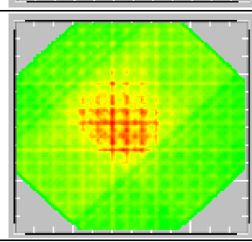
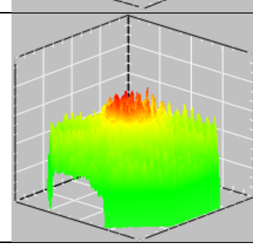
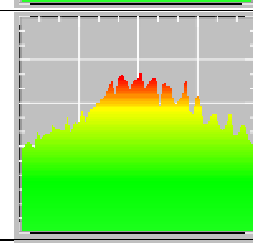
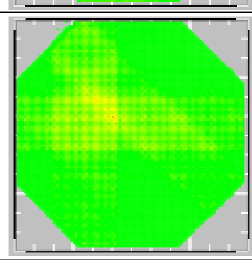
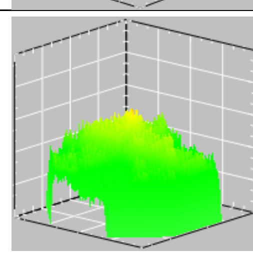
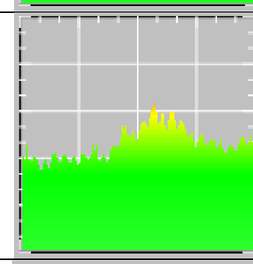
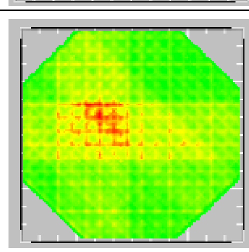
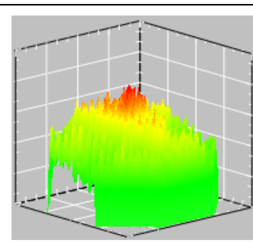
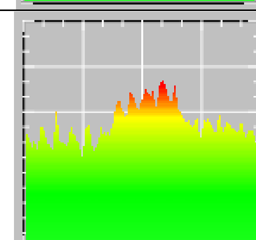
LBP and Hybrid Image Reconstruction				
Object	**Number of views**	**2D image**	**3D image**	**Side view**
Solid Rod	160			
	320			
Glass Rod	160			
	320			
Transparent Hollow Straw	160			
	320			

Table 2 Filtered image reconstruction of static objects

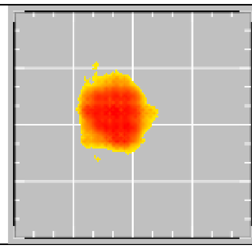
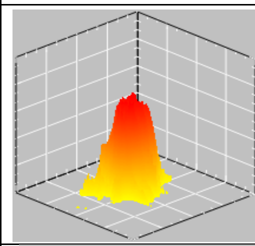
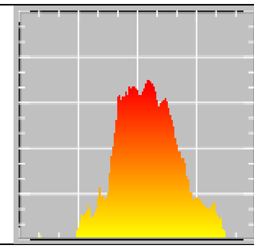
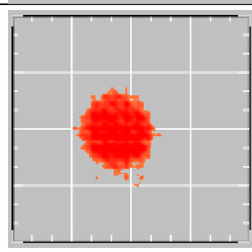
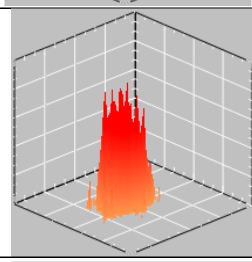
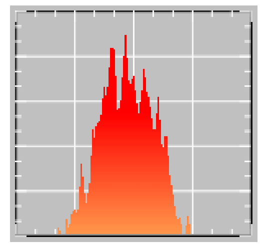
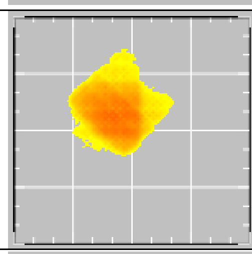
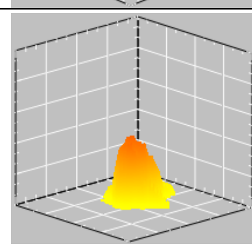
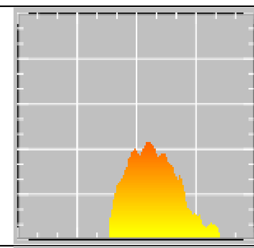
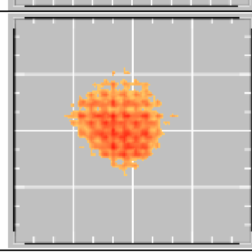
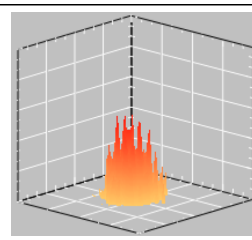
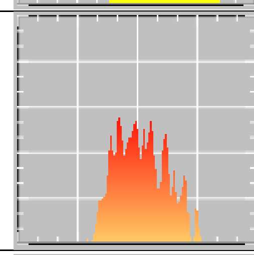
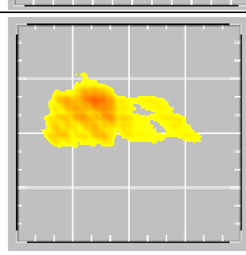
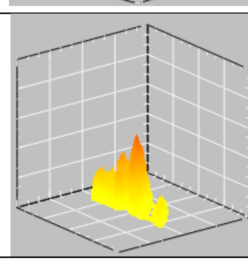
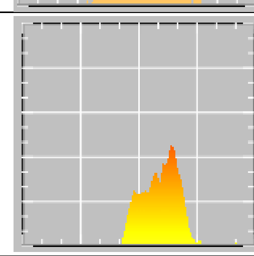
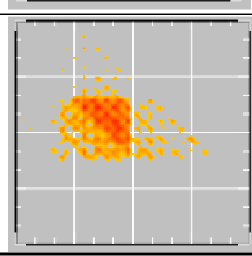
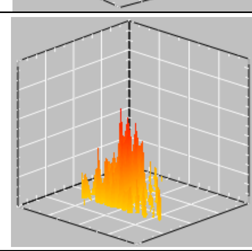
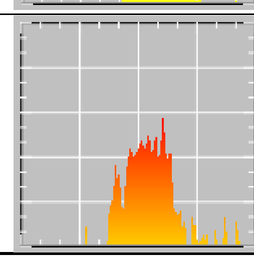
Filtered image reconstruction				
Object	**Number of views**	**2D image**	**3D image**	**Side view**
Solid Rod	160			
	320			
Glass Rod	160			
	320			
Transparent Hollow Straw	160			
	320			

Table 3 Z-value analysis for LBP and Hybrid image reconstruction

<table>
<tr><th colspan="6">LBP + Hybrid image reconstruction</th></tr>
<tr><th rowspan="2">Types of rod</th><th rowspan="2">Number of views</th><th rowspan="2">3D image</th><th rowspan="2">Side view image</th><th colspan="2">Z- value</th></tr>
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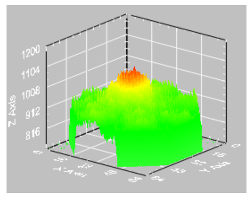
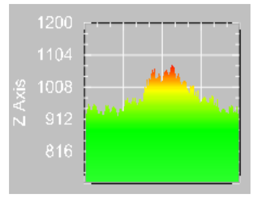
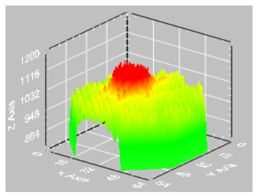
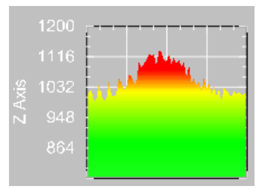
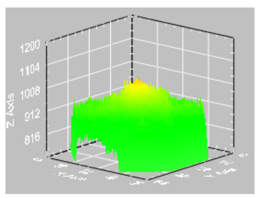
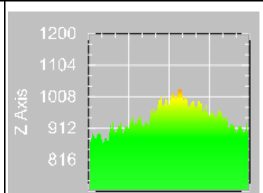
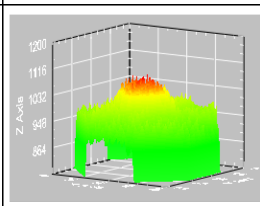
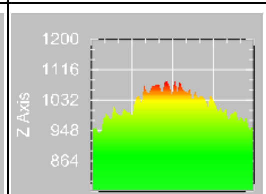
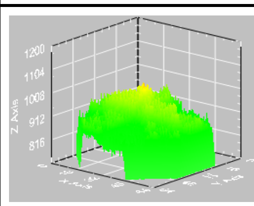
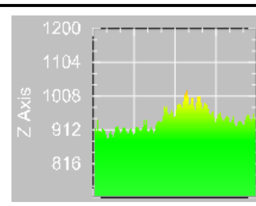
<tr><td rowspan="2">Solid rod</td><td>160</td><td>
</td><td>
</td><td>1008 < Z <1072</td><td></td></tr>
<tr><td>320</td><td>
</td><td>
</td><td></td><td>1032 <Z <1144</td></tr>
<tr><td rowspan="2">Glass rod</td><td>160</td><td>
</td><td>
</td><td>1008 < Z < 1040</td><td></td></tr>
<tr><td>320</td><td>
</td><td>
</td><td></td><td>1032 < Z < 1088</td></tr>
<tr><td rowspan="2">Transparent hollow straw</td><td>160</td><td>
</td><td>
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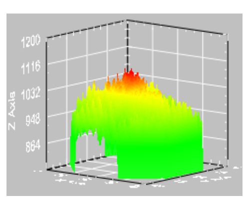
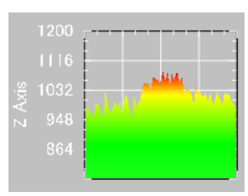
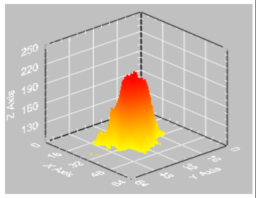
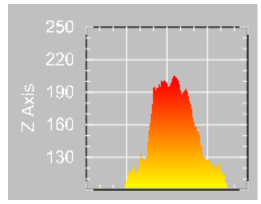
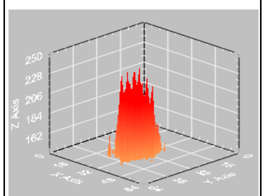
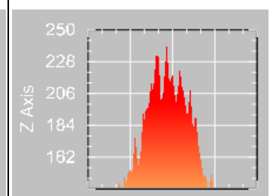
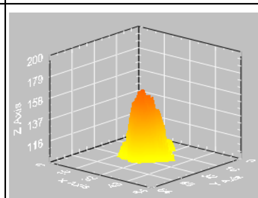
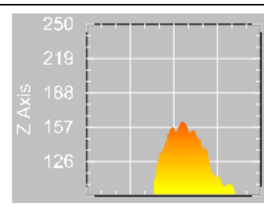
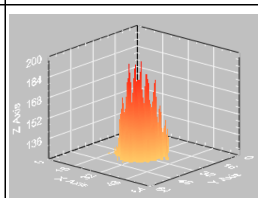
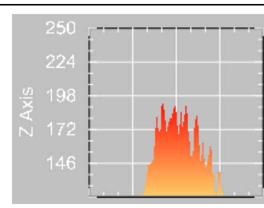
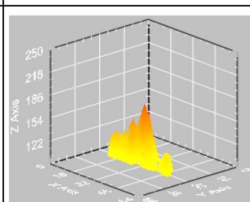
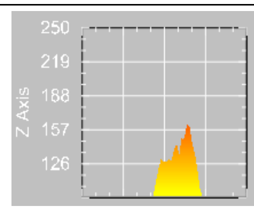
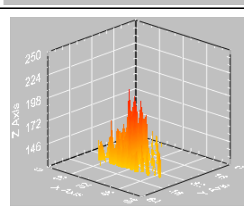
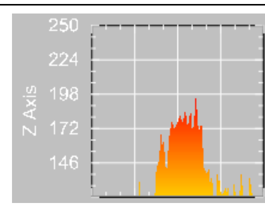
<tr><td>320</td><td>
</td><td>
</td><td></td><td>1032 < Z < 1088</td></tr>
</table>

Table 4 Z-value analysis for filtered image reconstruction

Filtered image reconstruction					
Types of rod	**Number of views**	**3D image**	**Side view image**	**Maximum peak of Z- value**	
				160 views	**320 views**
Solid rod	160			Z < 220	
	320				Z < 250
Glass rod	160			Z < 167	
	320				Z <198
Transparent hollow rod	160			Z < 167	
	320				Z <198

4.0 CONCLUSIONS

The application of CCD sensors and laser diode in an optical tomography may enhance the potential of these sensors in capturing a cross-sectional image from solid to transparent objects. This study also proves the ability of CCD sensors to measure the cross-sectional position of objects, in a multiphase pipeline system. Besides that, image reconstruction for 320 views gives a higher resolution of object distribution compared to 160 views. This non-invasive, non-intrusive and radiation free hardware has a bright future in the monitoring system of the multiphase flow industry.

Acknowledgement

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