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Optical Tomography System Using Charge-Coupled Device for Transparent Object Detection

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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 detect solid objects only. The aim of this research is to analyse and demonstrate the capability of laser with a CCD in an optical tomography system for detecting objects with different clarity in crystal clear water. Experiments for detecting transparent objects were conducted. The object's diameter and image reconstruction can also be observed. As a conclusion, this research has successfully developed a non-intrusive and non-invasive optical tomography system that can detect objects in crystal clear water.

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

1. Introduction

The optical tomography system (OPT) is one of the famous tomography methods that have been used in the medical and process industries. The OPT system is considered as a hard-field sensor because the sensing field is based on the measurement of the attenuation or absorption of radiation [1,5]. Generally, the main concept of OPT is to analyse the structure and composition of objects by examining the waves or radiation intensity after crossing the measured object [2,7].

The concept of the optical tomography system is based on the interaction of light and particles and this interaction will give the reading of an object's composition and structure. Information on how light is being absorbed or being emitted by the material is important to analyse, because this is the type of data that researchers have to observe to measure the composition or molecular structure of solids, liquids, and gases. Usually, an object such as a solid material has a high optical absorption, while an object that allows light to penetrate partially is known as a translucent object, such as a frosted window. Objects that allow almost 100% light penetration are known as transparent objects, such as a glass window [2,6].

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 to detect transparent object. 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 transparent objects without the help of a contrast agent, which can disturb the stability of multiphase flow.

2. Hardware Construction

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.

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This research applies parallel and fan beam projection methods in modifying its laser light beam. The combination of the fan beam and parallel projections will pass through the square opening and will produce a square beam projection. This square beam projection is able to cover multiple CCD sensors that are aligned in a parallel arrangement. Fig. 1 shows the light transmitting process from the laser to the CCD sensors in detail [3].

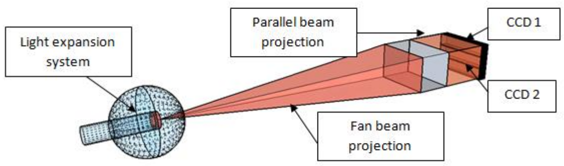


Fig. 1: Light transmitting process

The combination of rectilinear and orthogonal projection in the same plane produces an octagonal shape for sensor orientation. A high number of projections can reduce the smearing effect in the image reconstruction [4]. The Sony ILX551A has 2048 pixels with a size of 14 µm x 14 µm. Its sensitive pixels total length is equal to 28.6720 mm. In this research, a pipeline with a diameter of 100 mm was used. Fig. 2 illustrates the OPT system and its dimensions.

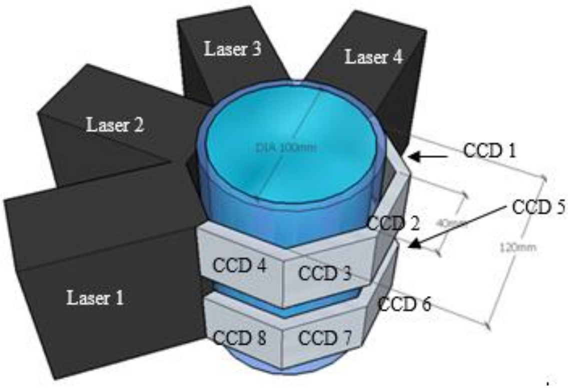


Fig. 2: The position of sensors and dimensions of pipeline and OPT system

3. Experimental Setup

All the experiments are conducted at room temperature between 25oC and 33oC and the relative humidity is within 65% to 85%, according to a KT-903 humidity device. Light scattering and diffraction effects are minimal and are ignored in the calculations. The luminosity for lasers is maintained at 0.3 Lux for the full non-flowing crystal clear water experiments. For the early stage experiments to compare and analyse the LED and laser performance, values of 0.5 Lux for the laser and 1.4 Lux for the LED are maintained [3].

These experiments were conducted not only for evaluating the OPT system's capability in capturing images of transparent objects in crystal clear water; we also analysed the diameter of these objects. In order to have a targeted diameter value, the objects must first be measured by a Vernier caliper. The accuracy of the Vernier caliper is known to be ±0.01 mm, while the OPT system accuracy is ±0.0001 mm

In this straight forward experiment, the transparent rod 6.51 mm based on the Venier Caliper reading shown in Fig. 3. A total of 50 data were observed using the OPT system. The data were obtained by repeating measuring the same rod for 50 readings. The LabVIEW programming for diameter measurement is developed to automatically calculate the average diameter of objects captured.

Fig. 3. Diameter values for transparent rod using Vernier caliper

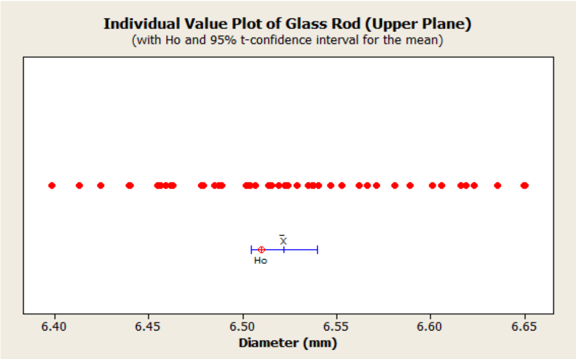
4. Results and Discussions

The t-test was used to validate the ability of the OPT system to measure the diameter of transparent objects. The main objective of this analysis is to compare the measured diameter captured by the OPT system with the actual diameter value measured by a Vernier caliper. The two hypotheses involved in this analysis are:

H0: Mean of experiment object diameter data = Caliper measured object diameter data

H1: Mean of experiment object diameter data $\neq$ Caliper measured diameter data

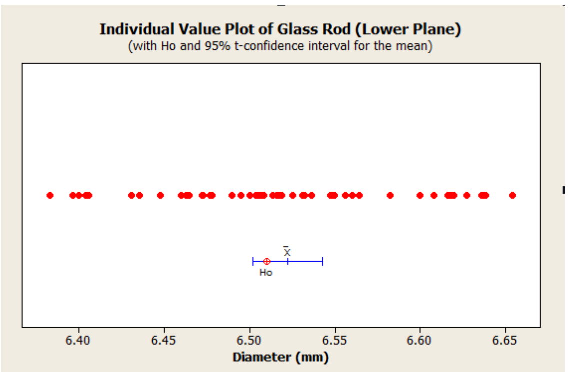
In Fig. 4, the P-value for the OPT system upper plane data of the glass rod is more than 0.05, thus we fail to reject the null hypothesis. This shows that, based on the one-sample t-test, the mean value of the upper plane OPT system glass rod diameter measurements is statistically the same as the glass rod diameter value measured by the Vernier caliper.



One-Sample T: Glass Rod: Upper Plane
Test of mu = 6.51 vs not = 6.51
Variable N Mean StDev SE Mean 95% CI T P
Upper Plane 50 6.52211 0.06180 0.00874 (6.50455, 6.53968) 1.39 0.172

Fig. 4: T-test graph result for glass rod diameter measurement using upper plane OPT system

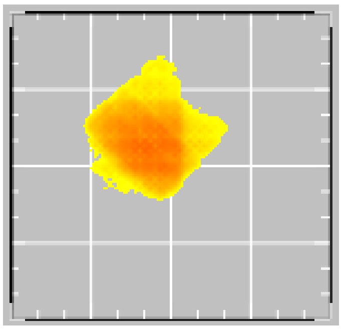
In Fig. 5, the P-value for the OPT system lower plane data of the glass rod is more than 0.05, thus we fail to reject the null hypothesis. This shows that, based on the one-sample t-test, the mean value of the lower plane OPT system glass rod diameter measurements is statistically the same as the glass rod diameter value measured by the Vernier caliper.



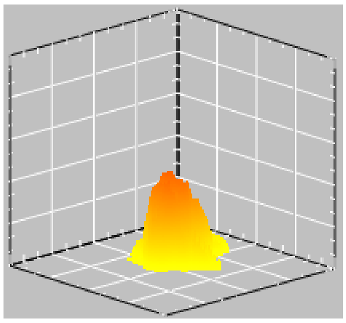
One-Sample T: Glass Rod: Lower Plane
Test of mu = 6.51 vs not = 6.51
Variable N Mean StDev SE Mean 95% CI T P
Lower Plane 50 6.5224 0.0717 0.0101 (6.5020, 6.5428) 1.22 0.229

Figure 5: T-test graph result for glass rod diameter measurement using lower plane OPT system

Fig. 6 shows two-dimensional and three-dimensional image reconstruction of glass rod based on the Linear Back Projection (LBP) method. The appearances of objects are highlighted with a higher contrast colour which in this table is dark orange.



(a)



(b)

Fig. 6: Glass rod image at (a) two-dimensional and (b) three-dimensional view

5. Conclusions

In short, the experiments indicate that the OPT system able to measure the diameter and capture the image of transparent object. It is concluded that the OPT system consisting of laser and CCD as it transmitter and receiver are proven to have the capabilities in measuring transparent objects characteristics and its cross sectional images reconstruction in the pipeline system. Based on the T-test results, it is proved that CCD linear sensor OPT system are reliable system in measuring transparent objects diameter. This non-invasive, non-intrusive and radiation free hardware has a bright future in the monitoring system of the multiphase flow industry

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