FOUR-PROJECTION OPTICAL TOMOGRAPHY BASED ON CCD LINEAR IMAGE SENSOR

[1]MARIANI IDROAS, [2]M.NASIR IBRAHIM, [3]M.A.HAMZAH AB GHANI, [4]SUHAILA M.NAJIB

[1]Faculty of Petroleum and Renewable Energy Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia
[2,3,4]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
E-mail: mariani@petroleum.utm.my, mnasir@fke.utm.my, amirjah86@yahoo.com, suhailamohdnajib@yahoo.com

Abstract- This paper presents the use of charge coupled device (abbreviated as CCD) linear image sensors in an optical tomographic instrumentation system used for sizing particles. Four CCD linear image sensors are configured around an octagonal shaped measurement section for a four projections system. The system consists of lighting system, data acquisition system and image reconstruction system. The measurement system is explained and uses four CCD linear image sensors consisting of 2048 pixels with a size of 14 micron by 14 micron. Hence, a high-resolution system is produced. Image reconstruction for the four-projection optical tomography system is generated using Matlab software.

Keywords- CCD, Image, Optical, Tomography.

I. INTRODUCTION

Process tomography is a means of visualising the internal behaviour of industrial processes, where tomographic images provide valuable information about the process for assessment of equipment designs and on-line monitoring [1]. Tomography provides cross-sectional and three dimensional images of internal multi-phase flow behaviour in actual process flow [2]. A typical tomographic system consists of an array of sensors, a signal conditioning and data acquisition system, and a reconstruction and display system [3], where the collected data are processed using a reconstruction algorithm to generate a tomographic image [4]. There are several modalities used in process tomography such as electrical (impedance, capacitance, inductance), radiation (optical, x-ray, positron electromagnetic (PET), magnetic resonance) and acoustic (ultrasonic) [5].

Optical techniques are desirable because of their inherent safety where the transducer does not require direct physical contact with the measurand, high efficiency [6] and could improve manufacturing in the chemical industries [7]. For processes handling transparent fluids and where optical access is possible, optical techniques can provide high-resolution images [8-11] i.e. 1% spatial resolution [12]. The system of optical tomographic instrumentation based on the charge-coupled device (CCD) linear image sensor has the ability to fully measure the cross section of the pipe. In addition, the optical tomographic system is known as safe and non-intrusive [13].

The optical tomography is also useful for investigating and monitoring flow of solid or gas [14]. Direct contact of the transducer and the measurand are not necessary. The efficiency of the technique is high and has the possibility to improve manufacturing sector especially in the chemical industries. The technique is also able to provide on-line and real time measurements.

This paper presents a four projection, optical tomography system with charge coupled devices (CCD) linear image sensors as detectors. The CCD based optical tomography system has high definition sensors, with 2048 pixels. Each pixel has a size of 0.014 mm by 0.014 mm. Moreover, the system is capable of sizing the whole volume of process flow and the technique is non-intrusive.

II. DESIGN OF OPTICAL TOMOGRAPHY

The developed optical tomography system (Fig. 1) consists of four projections (Fig. 2); with each channel or projection has a lighting system, a detection system, a triggering system and data acquisition system.

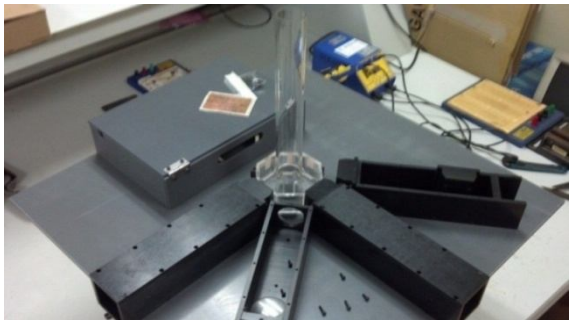

Fig. 1. Photograph of a complete optical tomography system with four projections.

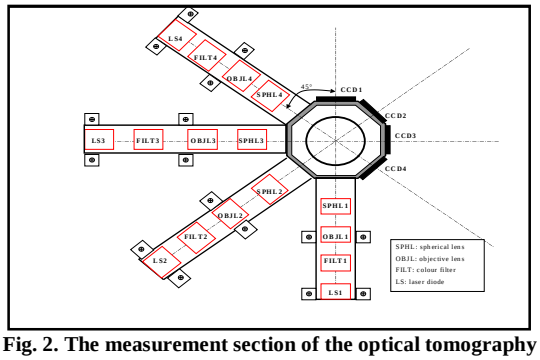

Fig. 2. The measurement section of the optical tomography system.

The lighting system consists of a laser diode, an objective lens and a spherical lens. All of these components are assembled in a metal-box termed the 'ray-box'. Fig. 3 shows the ray-box used in the optical tomography system.

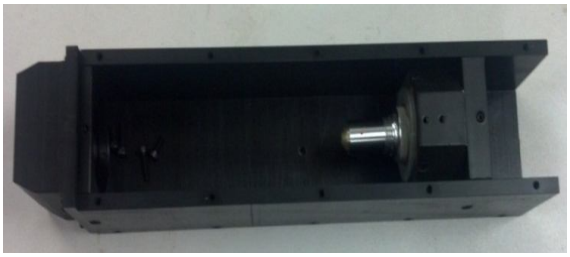

Fig.4. Light ray-box.

The laser diode used in the system produced red light at a wavelength of 680 nanometer. The laser module operates at low power since the CCD linear image sensor (ILX551A) is very sensitive to light. The CCD linear image sensor can be easily saturated if the light illuminating on it is too bright. The other reason is due to safety as the laser module used is a Class II type.
The diameter of the spherical lens is 50 mm to ensure the magnified beam is transmitted out properly onto the CCD linear image sensor. The output light from the ray-box is collimated and monochromatic, and is passed through a 1 mm width slit at the 'nose' of the ray-box.

The detection system is the sensing components in the optical tomography system where objects in the test cell are sensed using a charge coupled device (CCD) linear image sensor. The linear image sensor used is the Sony ILX551A with 2048 pixels where each pixel size is 14-micron by 14-micron. Fig. 5 shows the CCD linear image sensor used in the system. The output of the CCD linear image sensor is then acquired by the data acquisition system.



Fig. 5. CCD linear image sensor.

III. EXPERIMENTAL SET-UP

Fig. 6 shows the experimental set-up used to measure the size of the test samples in a single projection. The octagonal part of the flow pipe enables four projections of the tomographic system to be assembled around the pipe, with four pairs of the illumination-detection system arranged opposite to each other.

The four-projection tomographic system is mounted on a platform to ensure that the system is stable. The whole rig is elevated to allow liquid used in the pipe to be collected from the bottom.

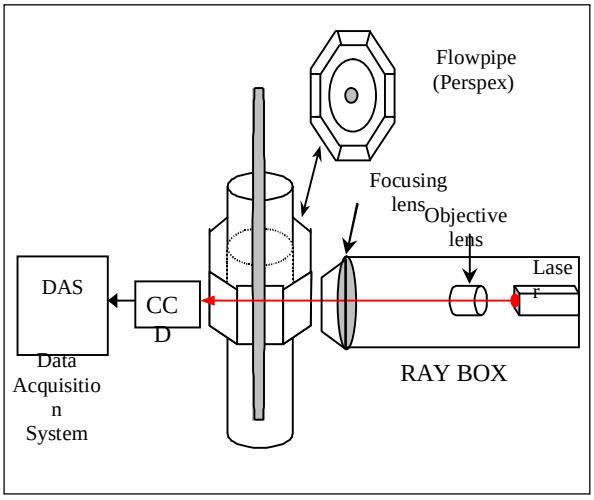

Fig. 6. The experimental set-up (single projection).

The four ray-boxes are arranged surrounding the hexagon part of the pipe with the corresponding CCD linear image sensors on the opposite side. Individual CCD drivers are connected to each of the CCD linear image sensors used.

The projections were identified in the following notations – Projection 1 as P1, Projection 2 as P2, Projection 3 as P3 and Projection 4 as P4. The measurements are obtained in the form of pixels, which are in shadow. These measurements are converted to millimetres using one pixel as being equivalent to 0.014 mm. The measurements were repeated ten times for each of the four projections (P1, P2, P3 and P4) in order to obtain the mean and standard deviations of the measurement.

The experiments were performed in a dark room to avoid any light from the surroundings interfering with the system. The tomographic reconstructed images of the measurements were processed using Matlab version 6.1. The images are reconstructed using pseudo inverse sensitivity matrix.

IV. EXPERIMENTAL RESULTS

The tomographic instrumentation system was used to measure a test piece with known diameter (3 mm) i.e. a sphere plastic bead. A micrometer system was designed to measure different positions of the bead as it was lowered down into the measurement cross-section. The bead was lowered in steps of approximately 0.2 mm through the measurement section and the outputs from the four projections were monitored (Fig. 7). Hence all four projections view the same diameter due to the symmetry of the sphere. Therefore, the average diameters of all four projections are used in the diameter distribution.

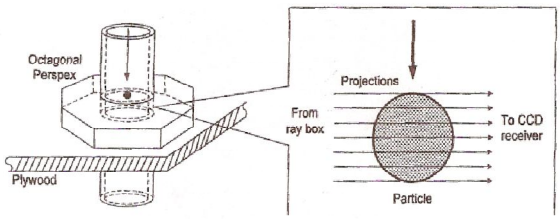

Fig. 7. Different positions of bead.

The diameter measurement is based on the diffraction theory, where the measured value was taken at a threshold level of 25% of the signal's amplitude. The diffraction patterns of the measured particles were compared with the calculated Fresnel diffraction patterns. The effect of diffraction is closely related to the size of the obstruction. If the size of the particle or the obstruction is very large compared to the wavelength of the light source, the diffraction effects will be small. Diffraction effects become more pronounced, as the size of the obstruction becomes smaller. The diffraction patterns of the measured particles were compared with the calculated Fresnel diffraction patterns. Fig. 8 and Fig. 9 show the diffraction pattern for opaque screen and opaque sphere, respectively.

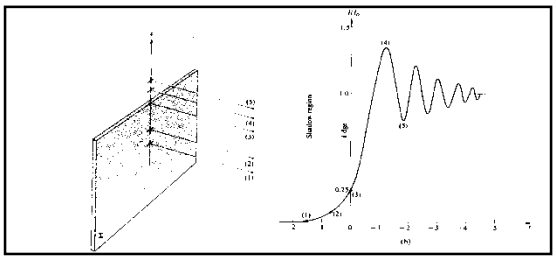

Fig. 8 The opaque screen and the intensity distribution [15].

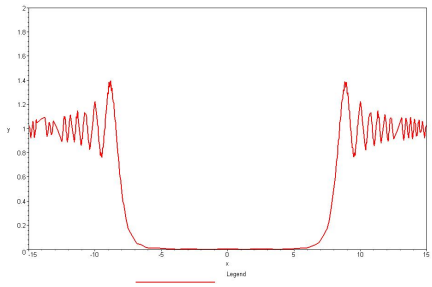

Fig. 9. Fresnel diffraction for spherical particle with a diameter of 2-mm.

The tomographic image reconstruction of the bead was performed using the four projections measurements of each position of the bead. Fig. 10 shows the reconstructed images of the bead by means of pseudo inverse sensitivity matrix at different positions.

The reconstructed images of the bead showed that the diameter of the bead keep increasing as the bead was lowered down until it reached the maximum diameter. Then the diameter was decreased until the last position which showed the image of air only.

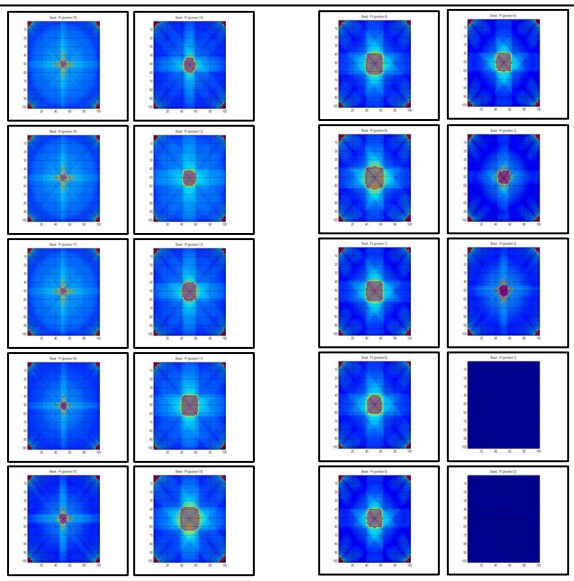

Fig. 10. Reconstructed images of the bead (pseudo inverse) at different positions.

The designed system has accuracy better than 0.0085 mm (0.6 pixel), with the percentage error better than 1.456%. The accuracy is acceptable because the error is less than 1 pixel i.e. 0.014 mm.

CONCLUSION

The developed optical tomography system based on CCD linear image sensor is capable of imaging full cross section of the 30 mm diameter pipe, in a non-intrusive way. Image reconstruction of the measured particle is based on solving the inverse problem using the pseudo inverse matrix. The novel arrangement of the pixels, provides a useful matrix for the image reconstruction process.

ACKNOWLEDGEMENT

The authors would like to acknowledge Ministry of Education (Malaysia) and Universiti Teknologi Malaysia for the support and a research grant under Vot 4F502

REFERENCES

[1] A.J Peyton, Z.Z Yu, S. Al-Zeibak. "An overview of electromagnetic inductance tomography: description of three different systems". Meas. Sci. Technol., vol 7, pp. , 1996.

[2] S.J.R. Simon,. "Imaging techniques for fluidised bed systems: a review," In M.S. Beck (editor), Process tomography: A strategy for industrial exploitation, 1994.

[3] R.G. Green, R. Thorn, "Sensor system for lightly loaded pneumatic conveyor," Powder Technology, Vol. 95, pp 79-92, 1998.

[4] C.G. Xie, "Review of image reconstruction methods for process tomography," In M.S. Beck (editor) A strategy for industrial exploitation, 1993.

[5] M.S. Beck and R.A. Williams, "Process Tomography: a European innovation and its applications," Meas. Sci. Technol., Vol. 7, pp 215-224, 1996.

[6] Y. Kostov and G. Rao, "Low-cost optical instrumentation for biomedical measurements," Review of Sci. Instruments. vol. 71, pp4361-4371, 2000.

[7] K. Leutwyler, "Optical Tomography," Scientific American, pp 147-149, 1994.

[8] M.S Beck and R.A Williams, "Sensor design and selection," In D.M. Scott and R.A Williams (editors), Frontiers in Industrial Process Tomography, 1995.

[9] M. Idroas, R. A.Rahim, M.H.F. Rahiman, M.N. Ibrahim, "Optical tomography system based on charge-coupled device linear image sensors: Particle size measurement," Journal Sensor and Actuators: B (Chemical), vol. 156, Issue 2, pp 572-577, 2011.

[10] M. Idroas, S. M.Najib, M.N. Ibrahim, R. A.Rahim, M.S.B. Mansor, "Initial study on optical tomographic instrumentation system based on CMOS area image sensor," Journal Sensors and Transducers, vol. 139 No 4, pp 133-140, 2012.

[11] N. Ramli, M. Idroas, M.N. Ibrahim, N.H. Shafie, "Design of the optical tomography system for four projections CMOS linear image sensor," Jurnal Teknologi Special Edition, vol. 61 No 2, pp 79-85, 2013.

[12] R. A.Rahim, K.S. Chan, J.F. Pang, L.C. Leong, "A Hardware Development for Optical Tomography System Using Switch Mode Fan Beam Projection," Sensors and Actuators A, vol. 120, pp 277-290, 2005.

[13] H. Zhang, Z. Xu, S. Zhang, "Research Of Optical Coherence Tomography Microscope Based On CCD Detector," Proceeding. of SPIE, 2008.

[14] R. MohdZain, R. A.Rahim, M.H.F Rahiman, J. Abdullah, "Simulation of Image Fusion of Dual Modality (Electrical Capacitance and Optical Tomography) in Solid/Gas Flow," Sensing and Imaging, vol. 11(2), pp 33–50, 2010.

[15] E. Hecht, "Optics", 2nd Edition, Addison-Wesley, 1987.

★★★