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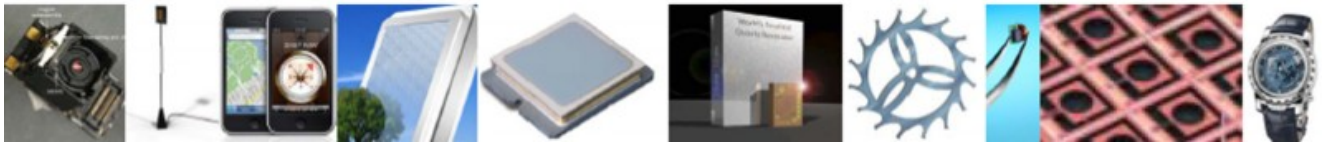

The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles

Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
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- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
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B. Computational systems
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Optical Tomography System: Charge-coupled Device Linear Image Sensors

[1]M. Idroas, [2]R. Abdul Rahim, [3]M. H. Fazalul Rahiman, [4]R. G. Green, [2]M. N. Ibrahim

[1]Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[2]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[3]School of Mechatronic Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

[4]School of Engineering, Sheffield Hallam University, Sheffield, United Kingdom

E-mail: mariani@fkkksa.utm.my

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Abstract: This paper discussed an optical tomography system based on charge-coupled device (CCD) linear image sensors. The developed system consists of a lighting system, a measurement section and a data acquisition system. Four CCD linear image sensors are configured around a flow pipe with an octagonal-shaped measurement section, for a four projections system. The four CCD linear image sensors consisting of 2048 pixels with a pixel size of 14 micron by 14 micron are used to produce a high-resolution system. A simple optical model is mapped into the system's sensitivity matrix to relate the optical attenuation due to variations of optical density within the measurement section. A reconstructed tomographic image is produced based on the model using MATLAB software. The designed instrumentation system is calibrated and tested through different particle size measurements from different projections. *Copyright © 2010 IFSA.*

Keywords: Bubbles velocity, Optical tomography, Inverse algorithm.

1. Introduction

Industrial processes are often controlled using process measurements at one or more points. The amount of information contained in such measurements is often minimal, and in some cases

(multiphase flow) there are no adequate sensors [1]. To understand better certain chemical processes, a more sophisticated approach is needed. Process tomography is a means of visualizing the internal behaviour of industrial processes, where tomographic images provide valuable information about the process for assessment of equipment designs and on-line monitoring [2].

Current activity in the development of new investigative techniques has focused on the use of tomography to provide cross-sectional and three-dimensional images of internal multi-phase flow behaviour in actual process flow [3]. The tomographic system usually consists of an array of sensors, a signal conditioning and data acquisition system, and a reconstruction and display system [4], where the collected data are processed using a reconstruction algorithm to provide an image [5].

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) [6]. Optical techniques are non-intrusive in nature and safe as the transducer does not require direct physical contact with the measurand. The technique has high efficiency [7] and could improve manufacturing in the chemical industries [8]. For processes handling transparent fluids and where optical access is possible, optical techniques can provide high-resolution images [9]. The optical tomography technique with its direct optical is capable of performing on-line measurements [10].

An optical tomography system based on optical fibres was developed by Horbury et al [11] aimed at providing information on particle size distribution, where three projections are used with each consisting of 16 or 32 pixels. Three ranges of bead size - 100 - 150 μm, 150 - 300 μm and 425 - 600 μm are used.

This paper presents a four projection, optical tomography system using charge coupled devices (CCD) as detectors. The CCD based optical tomography system has high definition sensors. Each of the four devices has 2048 sensors (or pixels), with sensor 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.

2. Design of the Optical Tomography System

The optical tomography system consists of four projections; each channel or projection has a lighting system, detection system, triggering system and data acquisition system. Fig. 1 shows the single projection set-up of the system.

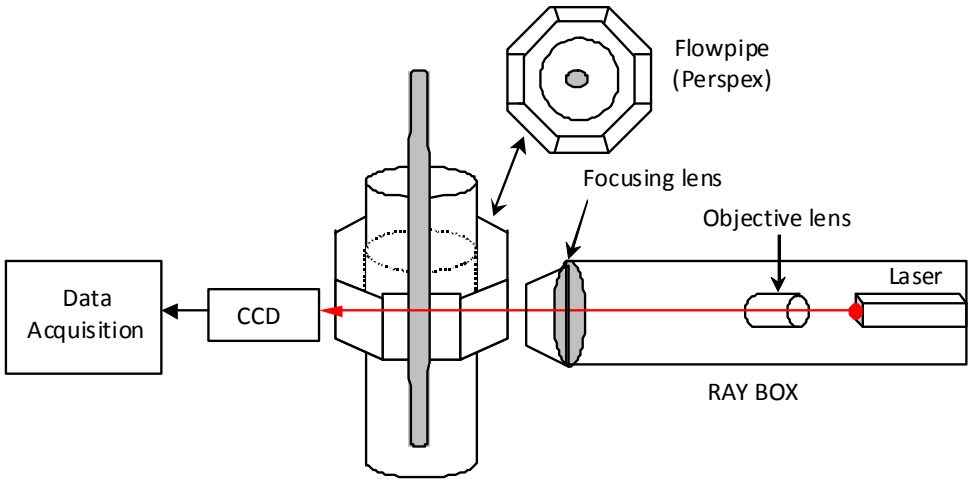

Fig. 1. The ultrasonic attenuation model [12].

2.1. The Lighting 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'.

The laser module used in the system produces 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 can be easily saturated if the light illuminating it is too bright. The other reason is due to safety as the laser module used is a Class II type.

The laser has a beam diameter of 1 mm. The minimum required output in order to illuminate the CCD linear image sensor is 28 mm. To provide reasonably uniform illumination the laser is to be expanded to 40 mm i.e. a beam expander of 40 times. The beam expander lens is used with a spherical lens as a telescope with a magnification of 40 times (Fig. 2).

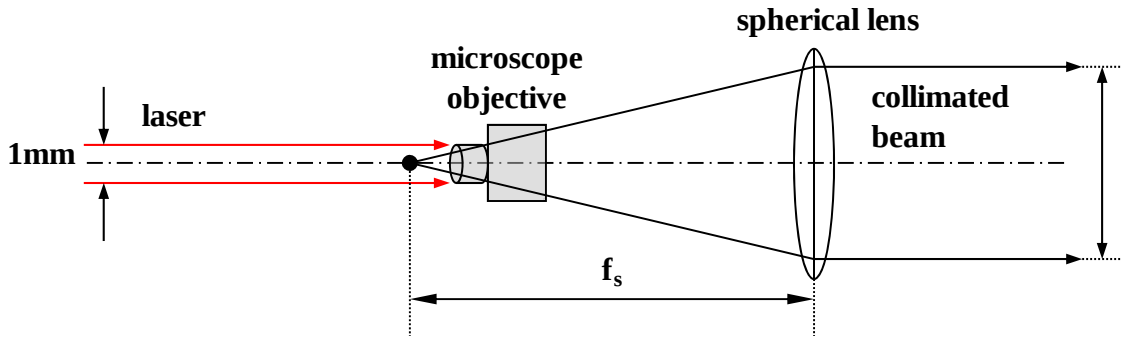

Fig. 2. Collimated beam produced by laser [12].

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.

2.2. The Detection System

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. The output of the CCD linear image sensor is then acquired by the data acquisition system. The linear image sensor is capable of scanning only a line of an object compared to an area image sensor, which can capture or scan a specific area depending on the size of the image sensor. However, the linear image sensor is relatively low cost and produces a high definition line scan which is readily transferred to a computer for further analysis.

The Sony ILX551A is a 22-pin DIP linear image sensor with a built-in timing generator and clock-drivers ensuring direct drive at 5 volts logic for easy use.

The four ray-boxes are arranged surrounding the hexagon part of the measurement section with the corresponding CCD linear image sensors on the opposite side (Fig. 3 and 4). Individual CCD drivers are connected to each of the CCD linear image sensors used.

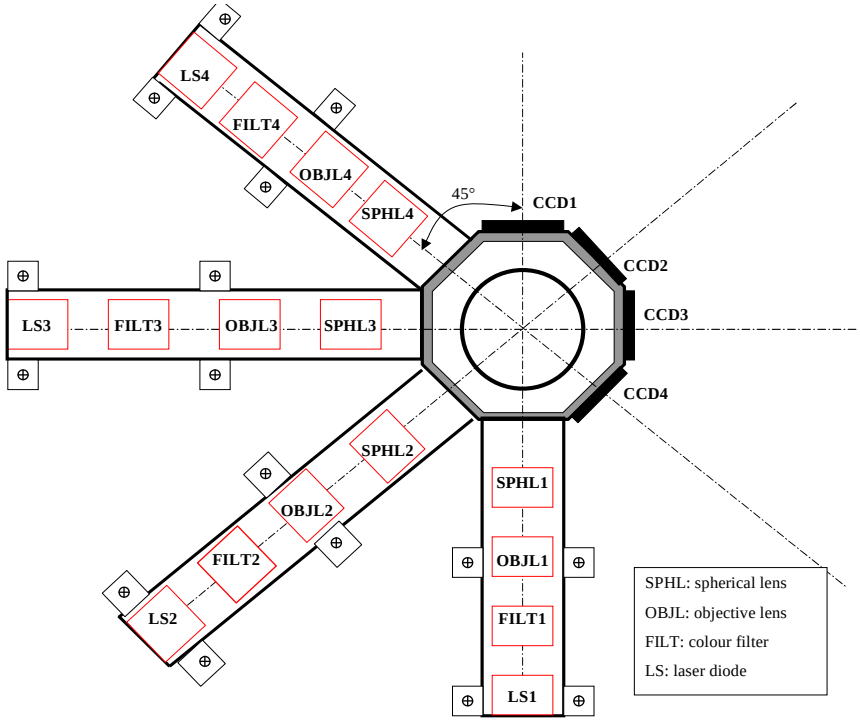

Fig. 3. The measurement section of the optical tomography system [13].

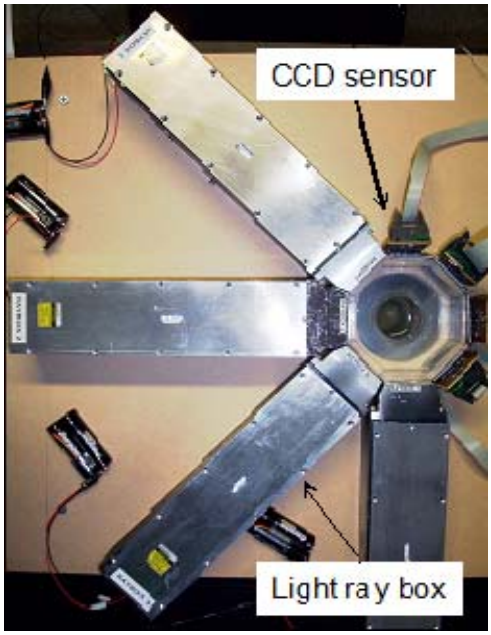

Fig. 4. A photograph of the CCD tomographic system [13].

2.3. Triggering and DAS System

A triggering system which is based on a PIC microcontroller, i.e. PIC16F84, is used to coordinate the timing and synchronization between the units in the system. The Keithley DAS was chosen as the data acquisition system, and it is capable of acquiring data at a maximum rate of 333 kHz. An external trigger and clocking input are connected to the data acquisition system for acquiring output voltage of every pixel on the CCD linear image sensor.

3. The Effect of Diffractions

An opaque body placed midway between a screen and a point source casts an intricate shadow made up of bright and dark regions due to bending of the light [14]. This phenomenon is called diffraction.

When the light source or the screen is close to the obstruction (Fig. 5), and the light comes from a point source, the diffraction effect is called Fresnel or Near-field diffraction. Whereas when the light source is extended and both it and the screen are far from the obstruction, this type of diffraction effect is called Fraunhofer or Far-field diffraction. It is assumed that the diffraction effect in the optical tomography system is mainly Fresnel diffraction, since the particle is close to the CCD linear sensor (the farthest distance between the particle and the sensor is 71 mm).

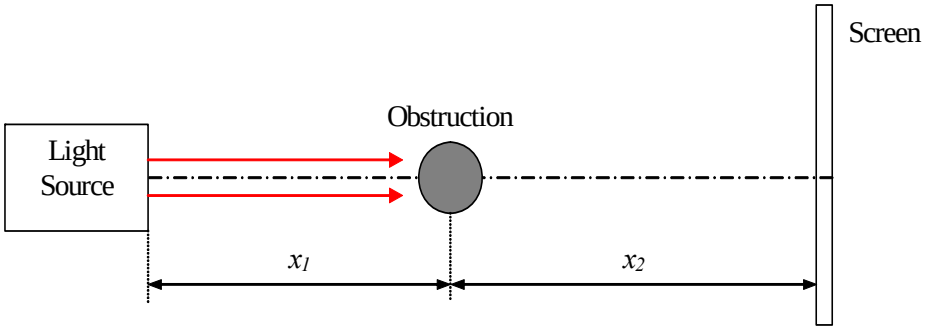

Fig. 5. A light strikes an obstruction [12].

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. 6 and Fig. 7 show the diffraction pattern for opaque screen and opaque sphere, respectively.

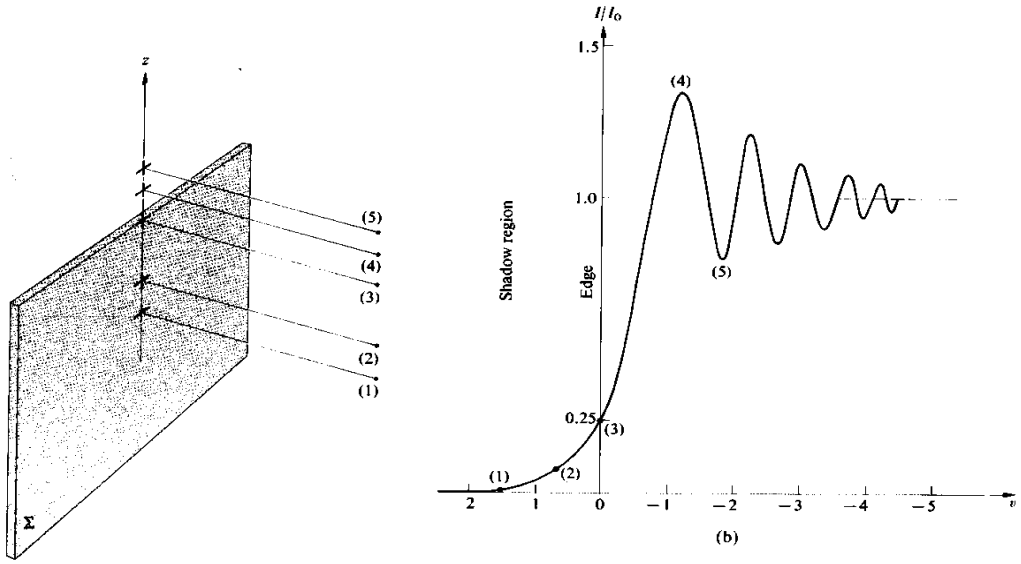

Fig. 6. The opaque screen and the intensity distribution [14].

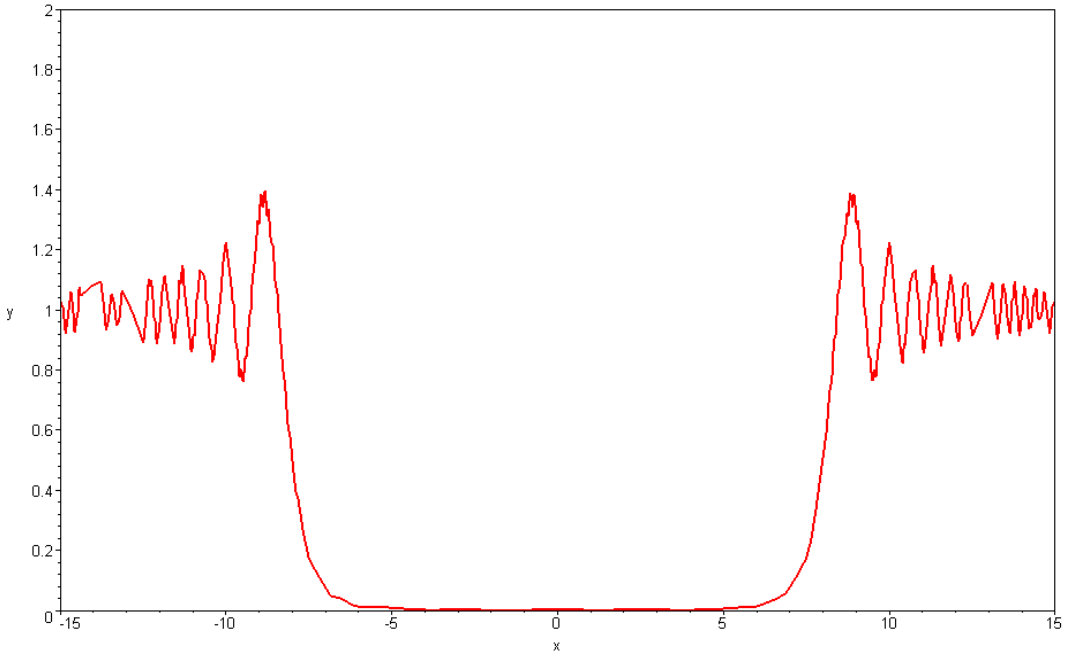

Fig. 7. Fresnel diffraction for spherical particle with a diameter of 2-mm.

4. Results and Discussions

Test pieces (spherical shaped beads) with known diameters (ranging from 200 micron to 2 mm) were used in the experiment. The test pieces (200 micron, 400 micron, 800 micron and 2 mm diameters) were positioned at the centre of the measurement section. Ten diameter measurements for each projection were taken and averaged for the final measured diameter of the particle. 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 measurements are obtained in the form of pixels which are in shadow. These measurements are converted to millimeters using one pixel as being equivalent to 0.014 mm. The measurements were repeated ten times for each of the four projections (projections 1, 2, 3 and 4) in order to obtain the mean and standard deviations of the measurement.

The tomographic reconstructed images of the measurements were performed using Matlab software on a computer. The images are reconstructed using the transpose and pseudo inverse sensitivity matrices. Fig. 8 shows the output voltage from the Keithley DAS for the test pieces and their corresponding simulation outputs. 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.

The tomographic image reconstruction of the test pieces was performed using the four projections measurements of each position of the particle. Fig. 9 shows an example of the particle's reconstructed image by means of transpose and pseudo inverse sensitivity matrices.

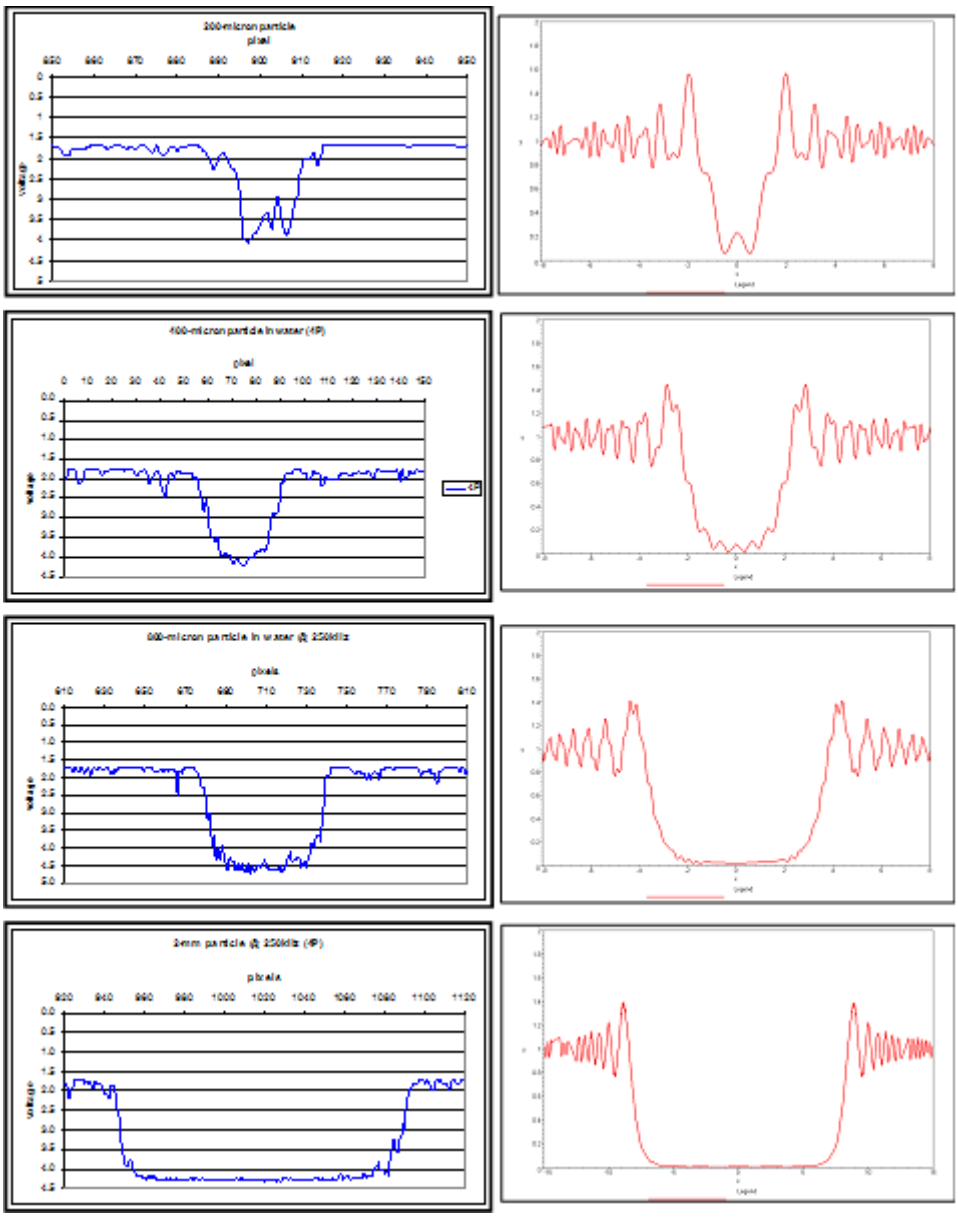

Fig. 8. Diffraction patterns for measured data (left) and model data (right) [12].

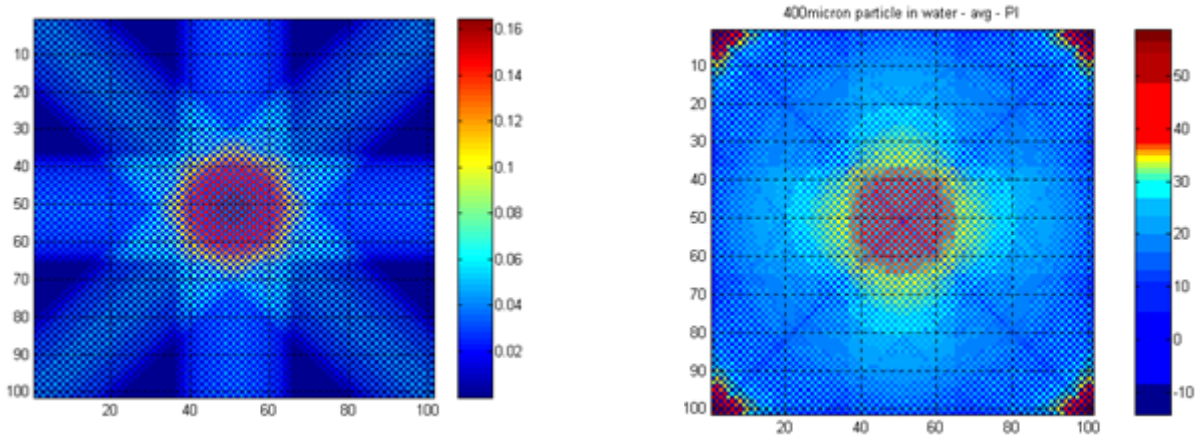

Fig. 9. Reconstructed tomographic images of a spherical particle using transpose (left) and pseudo inverse (right) matrices [13].

5. Conclusion

Particle size in many chemical processes is of great importance. Most of the techniques used in measuring particle size are based on sampling measurements, which may not represent the actual process flow. The optical tomographic instrumentation system based on the charge-coupled device linear image sensor is capable of performing particle size measurement over the full cross section of the pipe. Moreover, the processing and reconstructing the tomographic images based on transpose and pseudo inverse sensitivity matrices provide reasonable approximations to mathematical models of the inverse problem.

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- SAPSN: Software, applications and programming of sensor networks
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