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IMAGING OF SOLID FLOW IN AIR USING DUAL MODALITY TOMOGRAPHY

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Abstract. The overall aim of this project is to investigate the benefits of dual modality (optical and electrodynamics) tomography system for the measurement of tomographic images of solids flow. This research will investigate the distribution of conveying plastic beads in a conveying pipe by placing optical and electrodynamics sensors around the pipe without interrupting the flow inside the pipe. The dual modality tomography system is divided into two main parts, which are the development of hardware and software. Optical hardware is designed using 32 BPX65 photodiode sensors acting as receivers and two halogen bulbs acting as light transmitters. The sensors are arranged as two parallel projections. The electrodynamics sensors are designed using 16 electrodes positioned equidistantly around the periphery of the pipe wall. The tomography system is able to display the concentration profile of the objects inside the pipe.

Keywords: Concentration profiles; two phase flow; optical tomography; infra-red; solid flow

Abstrak. Matlamat keseluruhan projek ini ialah untuk menyelidiki manfaat yang boleh diperoleh daripada sistem tomografi dwi ragam (optik dan elektrodinamik) untuk mengukur imej tomografi terhadap aliran pepejal. Penyelidikan ini melibatkan kajian ke atas pengagihan manik-manik plastik yang dialirkan dalam sebuah paip dengan memasang penderia-penderia optik dan elektrodinamik di sekeliling paip tanpa mengganggu aliran di dalam paip. Sistem tomografi dwi raga mini dibahagikan kepada dua bahagian, yang terdiri dari perkakasan dan perisian. Perkakasan optik direka bentuk menggunakan 32 BPX65 penderia foto diod yang bertindak sebagai penerima dan dua lampu halogen yang bertindak sebagai pemancar cahaya. Penderia-penderia ini diatur sebagai dua projeksi selari. Penderia-penderia elektrodinamik direka bentuk menggunakan 16 elektrod yang dipasang pada jarak yang sama di sekeliling dinding paip. Sistem tomografi ini mampu memaparkan agihan kepekatan objek di dalam paip.

Kata kunci: Profil kepekatan; aliran dwi fasa; tomografi optic; infra-merah; aliran pepejal

1.0 INTRODUCTION

Tomographic system can be used to discover the complexities of structure without

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invading the object [1]. The various research on tomography is an expansion from the early research involving x-ray tomography, which focused on how to obtain 2-D cross-section images of animals, human, and non-living things [2].

There have been various investigations in the field of two component flows including Dugdale *et al.* [3], who applied optical methods on the problem of liquid/air interactions and has attempted to identify the types of flow that occur. The concept of combining both sensing mechanisms provides the opportunity to obtain and compare the results from more than one sensing mechanism to improve the accuracy of concentration profiles. The combination of two sensing mechanisms around objects of interest to unravel the distribution profiles is called dual modality tomography.

In medical industry, dual modality imaging is emerging as a method of improving the visual quality and quantitative accuracy of radionuclide imaging for diagnosis of patients with cancer and heart disease [4]. There is no single sensing method that is capable of detecting all suspended solids flow. Therefore, it is beneficial to combine the technologies of optical sensors and electrodynamics sensors to produce a single measurement system. Both sensors were positioned around the periphery of static, circular phantom to allow comparisons between dual and single modalities.

In tomography, a variety of sensing methods can be used based on very often contradictory factors. While most devices employ a single type of sensor, there are a number of opportunities for multi mode systems using two or more different principles. Dual modality tomography is a technique that uses two modalities to produce two separate tomographic images of the same interrogated area or object. Since, in principle, each modality produces a mapping or image of the distribution of separate or different object properties, dual modality tomography produces two (complimentary) images of an object which show the distribution of two separate object properties [5].

Multimodality tomographic systems are systems in which two or more different sensing modalities are used to locate or measure different constituents in the object space. The multimodality tomography platform was originated and developed as part of the Technology Foresight Challenge (TFC) research project, which began in UK in 1996. This was a collaborative project between the Universities of Manchester (former UMIST) and Leeds, together with a number of companies from both the process and instrument sectors [6].

In the medical field, Hasegawa *et al.* [7] investigated the implementation and application of dual modality imaging in medical diagnosis that combine X-ray and radionuclide imaging in one device. It allowed the X-ray and radionuclide images to be acquired in a single procedure without having the patient leave the system. They developed the M3000 instrument which is the only commercial tomography system that provides dual capacitance and resistance modality to visualize multi-component systems such as air/ oil/water in real time in industrial tomography system. The most significant problem in such multimodality imaging systems is that of image registration because the field equip potential map can be influenced by the distribution of material in the object space. This project investigates the benefits of dual modality (optical and electrodynamics) tomography system for the measurement of plastic beads (solids) flow.

2.0 SYSTEM CONFIGURATION

The objective of a particular measurement is to exploit the differences in the characteristics of the process being investigated. An outline of the dual modality measurement in tomography system is shown in Figure 1. It illustrates sensors for both optical and electrodynamics tomography mounted on a section of a pipe.

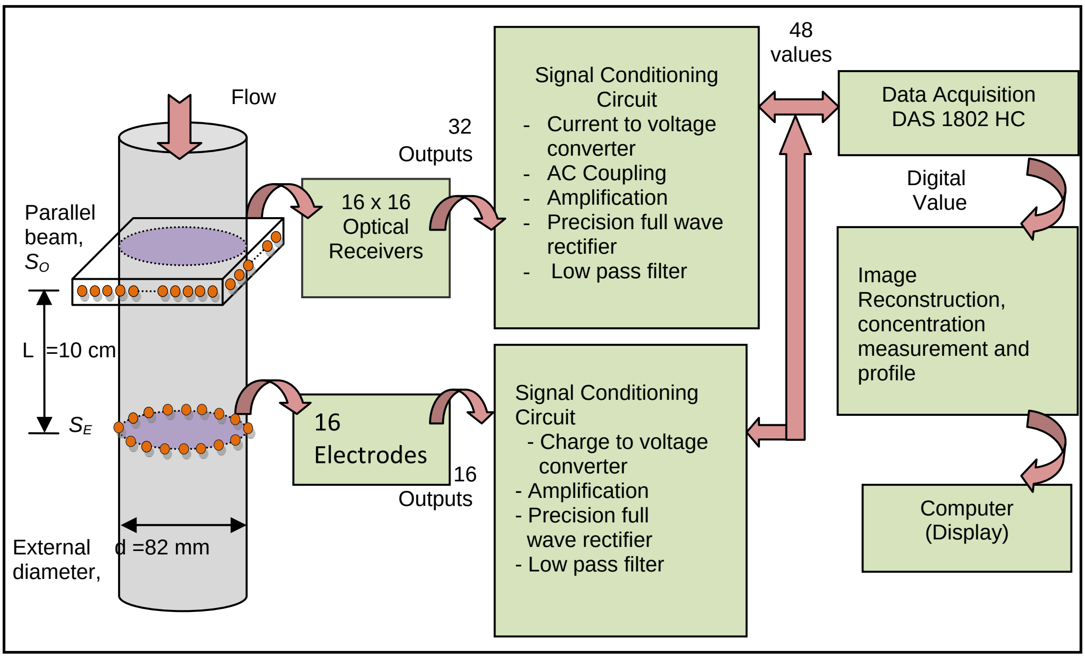

Figure 1 A block diagram of the dual modality tomography system

The optical hardware is designed using two projections where each projection consists of 16 pair of transducers allowing image reconstruction to be applied to the acquired data. The arrangement of holes on a PVC plate for optical sensors is shown in Figure 2 (a). It has a pair of 16 holes for the transmitting and receiving system. The sensing configuration of all optical sensors are arranged in orthogonal parallel position. The electrodynamics holes are shown in the Figure 2 (b). The electrodynamics hardware designed using 16 electrodes are placed around the circumference of the pipe wall.

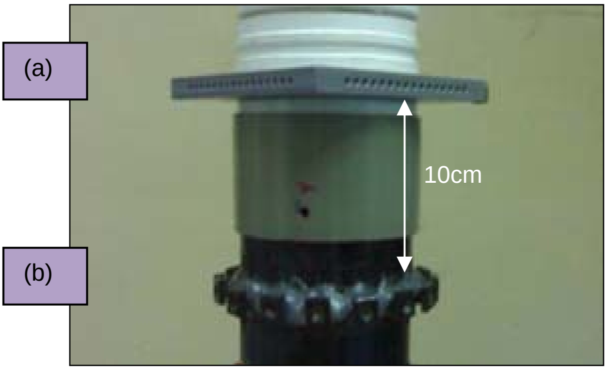

Figure 2 The arrangement of the holes around the pipe (a) Optical (b) Electrodynamic

3.0 MATHEMATICAL MODELING

The projection employs dual modality sensors consisting of optical and electrodynamics position, equally placed outside a pipe with 82 mm outer diameter and 80 mm inner diameter. The optical sensor has 32 sensors arranged in orthogonal projection and the electrodynamics system has 16 electrodes. Hence, for the dual modality, the total number of sensors used is 48.

In optical tomography, the cross section of an object scanned by a parallel projection. When light passed through the object along the straight line AB in the sensing zone from the light source to the photodiode, light is attenuated as shown in Equation 1.

$$I = I_o exp(-\mu d) \quad [1]$$

Where:

I_o = original intensity of the light source
I = measured intensity
μ = linear attenuation coefficient
d = thickness of object

The coordinate systems illustrated in Figure 3 are used to describe line integrals and projections. The object is represented by a two-dimensional function *f(x, y)* and each line integral is represented by the projection angle ϕ and a detector position *x'* parameters [10]. The Equation of AB in Figure 3 is shown in Equation 2.

$$x cos\emptyset + y sin\emptyset = x' \qquad [2]$$

where:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} cos\emptyset & sin\emptyset \\ -sin\emptyset & cos\emptyset \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad [3]$$

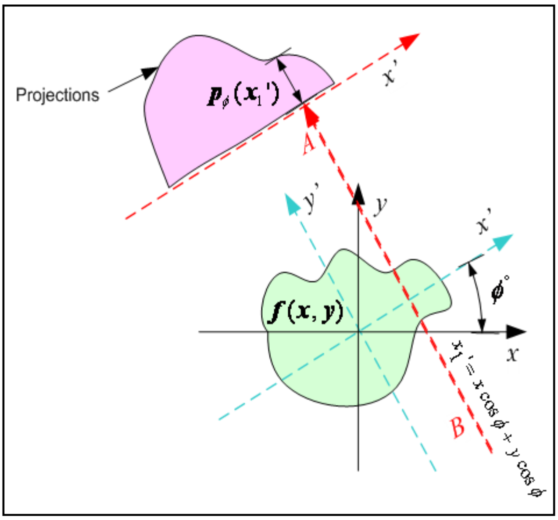

Figure 3 An object $f(x, y)$, and its projection $p_\emptyset(x_1')$, shown for angle $\emptyset^\circ$

In addition, this resulted in the line integral $p_\emptyset(x')$

$$p_\emptyset(x') = \int_{(\emptyset,x)line} f(x,y)ds \qquad (4)$$

By using delta function, this can be rewritten as:

$$p_\emptyset(x') = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\partial(x\cos\emptyset + y\sin\emptyset - x')dxdy \qquad (5)$$

For the discrete implementation, Equation 4 can be rewritten as:

$$p_{\emptyset}(x') = \sum_{M_i=0}^{M_i-1}\left[\sum_{N_i=0}^{N_i-1} f(x,y)\partial(x cos\emptyset + y \sin \emptyset)\Delta x\right]\Delta y \qquad (6)$$

where:

N_i = total number of horizontal cell/pixel.
M_i = total number of vertical cell/pixel.

The pipe cross section for electrodynamics system is mapped onto (16 x 16) rectangular arrays of 256 pixels as shown in Figure 4. This is similar to the pixels used for optical sensors. The numbers of pixels used by researchers before are 9 x 9 (81 pixels) by Mohd Fua'ad [11] and 11 × 11 (121 pixels) by Hakilo [12].

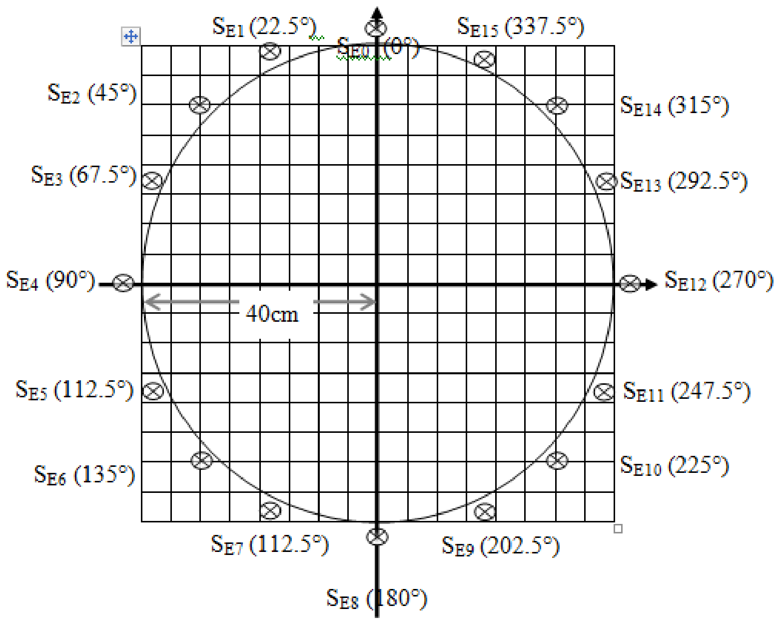

Figure 4 A 16 × 16 rectangular array of 256 pixels withelectrodynamics sensors position

4.0 EXPERIMENTS AND RESULTS

The concentration profiles of optical sensors in two-Dimension (2D) and three-Dimension (3D) are illustrated in Figures 5 (a) and (b). The optical sensors measured are the voltage measured experimentally when the plastic beads flow in the pipeline without a baffle. Visual inspection of the conveyor shows that the plastic beads are relatively uniformly distributed over the measurement cross-section. The result in Figures 5 (a) and (b) show that the concentration is not uniform. This might be due to the limitation of the linear back projection algorithm or due to the non-uniform distribution of the beads in the pipe.

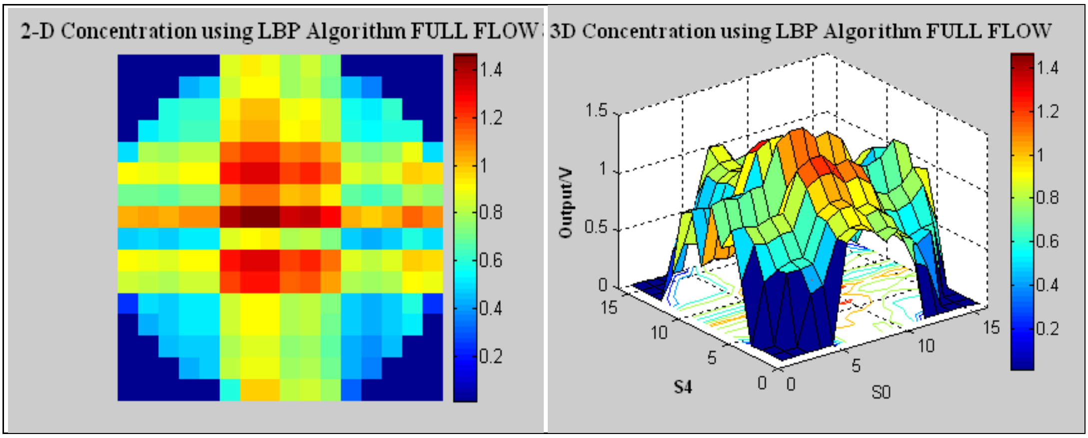

Figure 5 Concentration profile of measured voltage for optical sensor for full flow condition (a) 2D (b) 3D

Figure 6 clearly shows that the peripheral pixels near the electrodynamic sensors have bigger concentration values compared to the centre pixels. This is probably due to the weaknesses of the LBPA algorithm and the limitation of the electrodynamics sensors.

In the case of full flow, the optical tomography system gave a better result as in Figure 6 compared to the electrodynamics system because the concentration profile for the optical tomography system is more uniform compared to the electrodynamics tomography system. This is due to the non-linear sensing of the electrodynamics sensor [11].

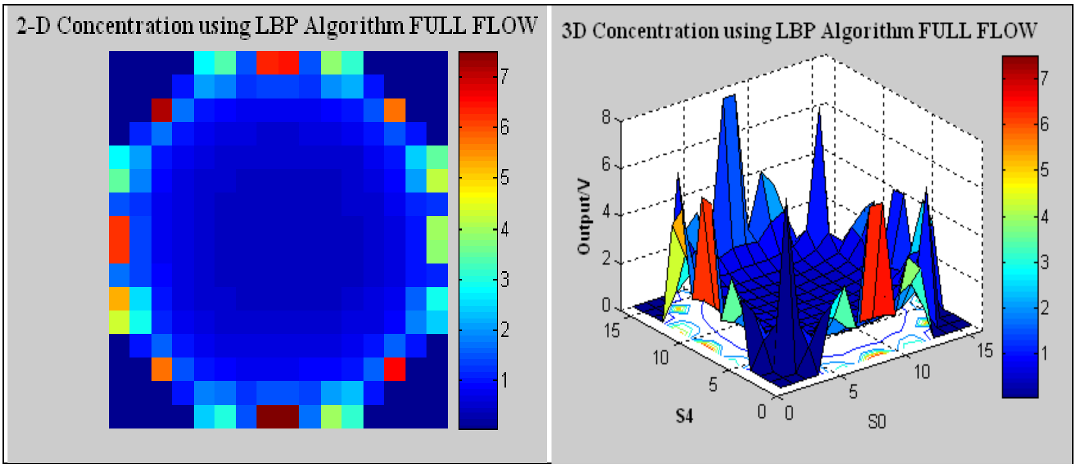

Figure 6 Concentration profile of measured voltage for electrodynamics sensor for full flow condition (a) 2D (b) 3D

It shows that the area near the electrodynamics sensors (electrodes) has a bigger value compared to the middle of the pipe. A dual modality tomographic system is described for the concentration profile of the plastic beads for optical and electrodynamics tomographic images with the same pattern flow using the same material in each experiment. So, it shows two different sensing entities to measure different constituents in the pipeline. It compares both tomographic modalities, which are electrodynamics and optics to image the interrogated area. These results show that combination of the tomographic modalities, electrical current and light is complementary to produce the best mapping of the distribution beads in the different flow regimes.

The concentration profile for electrodynamics shows that the response of the material flowing near the pipe wall is better compared to the middle of the pipe. In other words, the detection of the material near the sensing zone is higher compared to the area far away to sensors. The electrodynamics is insensitive to permittivity changes at the center of the sensor which is located far from the electrodes.

On the other hand, the images produced by the optical measurement system are shown to be uniform when detecting the materials flow in the pipeline. It is most sensitive at the center of the pipe. Therefore, in many cases, the application of only one tomographic modality is not sufficient to explore all important flow characteristics.

5.0 CONCLUSION

A dual modality tomography system has been successfully constructed. The dual modality reconstruction algorithm based on processing the data collected from electodynamic and optical tomography systems for imaging plastic beads distribution was presented individually. Plastic beads were dropped and various images involving a single pixel, half flow and full flow were obtained. The results show that a tomography system combining electrodynamics and optical sensors provide beneficial information which is worthy for further investigation. Further investigations can be performed on the fusion of the measurements obtained from optical and electrodynamics sensors to produce improved tomographic images.

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