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A Dual Modality Reconstruction Algorithm for Optical and Electrical Capacitance Tomography

1. Introduction

In recent years, numerous types of tomography sensor have been designed for monitoring and investigation in solid/gas flow. However, the research has been done for many years in an imaging of gas/solid flow but it still remains a notorious task [1, 3].

Several sensing principles of tomography were approach to produce images on solid/gas flow, such as electrical capacitance, gamma, and optical tomography. Therefore, in previous researches, the utilization of only one tomography modality is not capable to gain a high-resolution image in full range distribution, and not sufficient to explore all important flow characteristics [3]. Currently, a new trend in sensor development in solid/gas flow is applying dual or triple mode of tomography in one sensor plane, such as the research groups from University of Manchester (United Kingdom) and University of Bergen (Norway) produced Dual Mode Tomography (DMT) for electrical capacitance and gamma ray and also derived a new algorithm for DMT to realize a good quality image [3]. The advantages and limitations of sensing modalities are shown in Table 1.

In order to consider all the advantages and limitations of sensing principle, the new idea comes up with combination advantages mode tomography as electrical capacitance and optical sensor in one sensor plane. The main purpose of this project is to obtain a high resolution image fusion in full range distribution generated from a new image reconstruction algorithm.

The paper presents the novel idea to produce image fusion of dual mode tomography by using a new image reconstruction algorithm in solid/gas flow.

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Table 1
The advantages and limitation of tomography modalities in solid/gas flow measurement

Sensing Principle	Advantages	Limitations
Electrical Capacitance	Low cost, no radiation, rapid response and robustness [1, 3, 6], full concentration distribution [2], temporal resolution [3]	Blurred image in low concentration distribution below <30% [2, 5], low image resolution: 0,2% for a single object near the wall of the pipe; 2% at the centre of the pipe [2], image reconstruction complicated [1]
Optical	Spatial resolution 2% [2, 5], good measurement at medium distribution and content in whole investigated cross section simultaneously [7], safe and free of electromagnetic interference [7], low cost	Limited measurement in high distribution flow above 35% [2]
Gamma ray	Spatial resolution 1% [3, 4]	Require relatively long time for energy integration, mechanical movement to scan the whole region [7, 4], radiation dose to the surrounding [3, 4], heavy shielding [4]
Dual Mode; (electrical capacitance & gamma)	High spatial & temporal resolution image [3, 4].	Radiation dose to the surrounding [3, 4], heavy shielding [4], high cost.

2. Theoretical consideration

2.1. Overview of system design

In this paper the sensor is based on hard-field and soft-field techniques. A hard-field system like optical tomograph is equally sensitive to the parameter it measures in all positions throughout measure volume [4]. Meanwhile soft-field sensors, like capacitance tomograph, the sensitivity to the measured parameter depend on the position in the measurement volume. In a dual mode system, however, the different sensors often provide some complementary process information [4].

To evaluate the setup, the optical and capacitance sensors were approximately close each to another due to the assumption of flow regime behaviour was the same in cross-section of each sensor. The set of electrodes of capacitance sensor consists of eight electrodes. They were designed by using finite element method (FEM) [3]. The material of electrode is copper plate, due to high conductive material. Meanwhile the optical sensor consists of 16 transmitter and receiver pairs. The fan beam projection was selected, an equivalent rotating source in the fourth generation medical X-ray imaging system. The system design and configuration of DMT is shown in Figure 1.

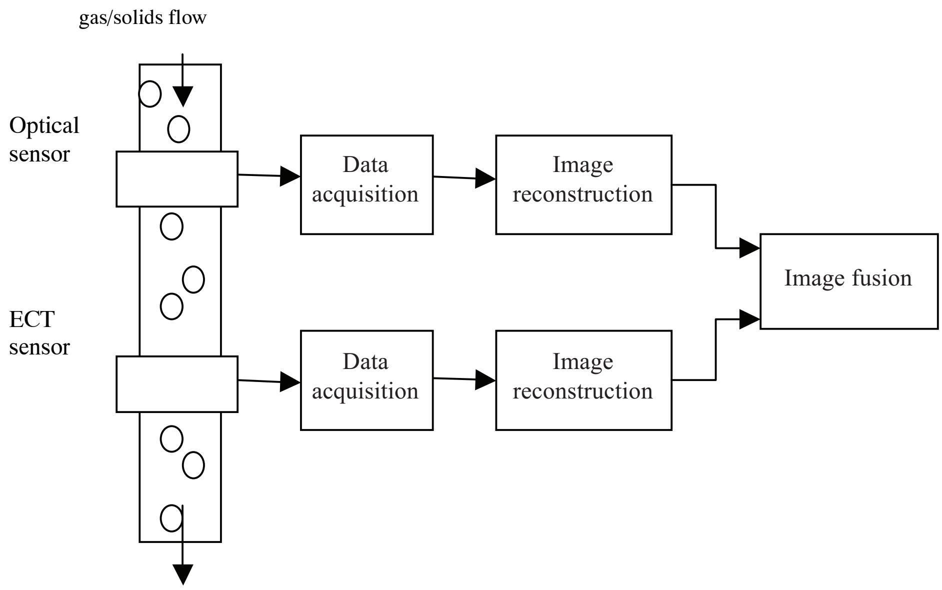


Fig. 1. Dual Mode Tomography system configuration

2.2. Image reconstruction for optical tomography

The sensor output for optical sensor was based on the model of light beams that travel in straight line towards the receivers. The sensor output is dependant on the blockage effect where solid particles intercept of the light beam.

This approach uses the following five assumptions:

1) Solids concentration distribution in range from 0% to 35% [2, 5, 7].
2) The relationship between the number of solids particle passing through a beam and the corresponding sensor output voltage is linear [2, 5].
3) The emission light's intensity from each LED is uniform along all covered directions. In a single projection, it is assumed that each photodiode has been exposed to a beam from emitter. i.e. a single projection resulted in 16 light beams from the emitter towards the photodiodes. Each light beam possesses a different width, depending on the sensor geometry and projection angle.
4) The attenuation factor for gas is assumed to be zero while the attenuation factor for solid particle is assumed to be one. All incident lights on the surface of solid particle are fully absorbed by the solid particle.
5) Light scattering and beam divergence effect are neglected [2, 5, 7].

To generate the sensitivity matrices for image resolution 32×32 square pixels, a custom-created software using Visual C++ is used. The dimensions of each element in sensitivity map for optical output are present by value '1' if light passes while 0 if no light passes through.

In this sensor, the linear back projection (LBP) algorithm has been used to perform the image reconstruction [5]. Combining the projection data from each sensor with its computed sensitivity maps generates the concentration profile. To reconstruct the image, each sensitivity matrix is multiplied by its corresponding sensor reading. The process can be expressed mathematically as below [5]

$$V_{LBP}(x,y) = \sum_{T_x=0}^{15} \sum_{R_x=0}^{15} S_{R_x T_x} \overline{M}_{T_x,R_x(x,y)} \tag{1}$$

where:

$V_{LBP}(x,y)$ – voltage distribution obtained using LBP algorithm;
S_{RxTx}, – signal loss amplitude of receiver R_x-th for projection T_x-th in unit volt;
$\overline{M}_{T_x,R_x(x,y)}$ – normalized sensitivity matrices for the view of T_x-th.

Due the blurred and not accuracy image produced by LBP algorithm the Hybrid Back Projection (HBP) algorithm is applied to produce cross-section image in this project. This algorithm determines the condition of projection data and improves the reconstruction by marking the empty area during reconstruction [4]. The algorithm assumes binary values from the sensors, either zero for no material or one for the presence of material. If the sensor reading equals to zero, then any pixels traversed by that sensor's beam are set to zero and omitted from further calculations.

2.3. Image reconstruction for electrical capacitance tomography

Electrical capacitance sensor is based on measuring change in capacitance to reconstruct the cross-sectional distribution of permittivity inside the pipe [1, 3, 4, 6]. The sensor output from electrical capacitance sensor was linear to the distribution of solid particles inside the cross-section of pipe. This sensor was utilized for full range distribution, 0 up to 100%.

The most popular image reconstruction applied for electrical capacitance sensor is the linear back projection (LBP). In this method an image is obtained by superimposing a set of predetermined sensitivity maps, using the measured data as weighting factors. Due to the inherent non-linear nature of electric field, the LBP algorithm produces low quality images [1]. In order to obtain the quality image in this project the iterative image reconstruction algorithm has to be used. This method was used to correct the sets of capacitance and pixel values in turn and hence produce a more accurate image from capacitance measurement.

2.4. Image reconstruction for Dual Mode Tomography

For produce the image fusion from the raw data of both sensors, a procedure is needed.

The procedure approach follows this assumption:

– The sensitivity maps of both sensors have the same resolution 32×32.

– $C_i(\Delta T)$ defines the temporal material concentration for the i-th pixel of a pipe cross section on a time interval ΔT. Let $p_i^O(\Delta t)$ defines corresponding pixel value into reconstructed image from data capture by optical sensor and $p_i^C(\Delta t)$ defines data capture by electrical capacitance sensor. Due both of this sensor are good in temporal resolution, $C_i(\Delta T) = p_i^O(\Delta t) = p_i^C(\Delta t)$.
– Image fusion obtains full range distribution as shown in Figure 2. For distribution below 35% the p_i^O was used meanwhile for 35% and above distribution the p_i^C was applied, where p_i^O corresponding pixel value from optical sensor and p_i^C corresponding pixel value from electrical capacitance sensor.

The reconstructed image from the electrical capacitance sensor represents capacitance distribution in a pipe cross-section and normalized concentration distribution $\boldsymbol{c}$, $0 \leq \boldsymbol{c} \leq 1$ in full range distribution. Meanwhile the reconstructed image from the optical sensor represents a normalized intensity distribution $\boldsymbol{O}$, respectively, $0 \leq \boldsymbol{O} \leq 1$ below 35% distribution.

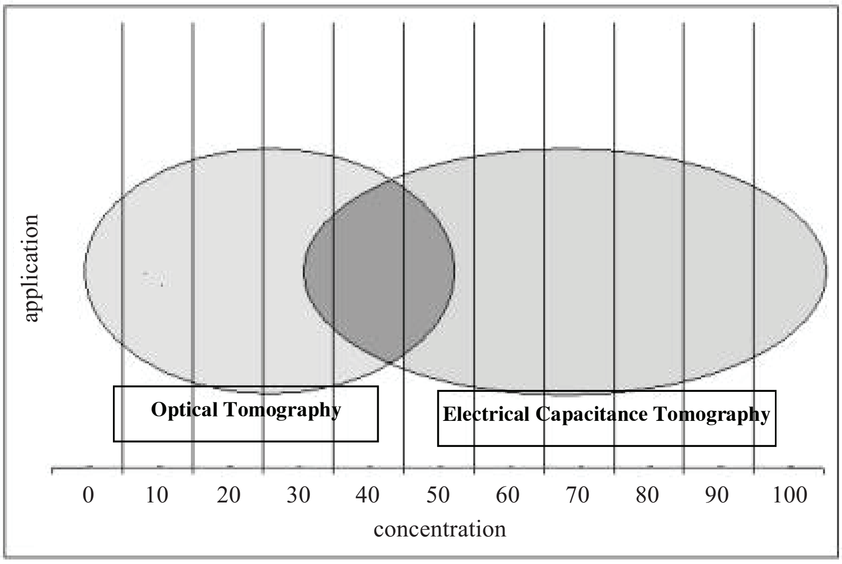


Fig. 2. Application of DMT sensor

The Dual Modality Reconstruction (DMR) is derived based on the adjusting pixel values of p_i^C as the detect regions (area). Where the concentration is lower $p_i^C \leq 35\%$ and p_i^C labelling detects area and this ith pixel did't consider into account and applied the p_i^O. Meanwhile for $p_i^O \geq 35\%$ the ith pixel follows the p_i^C.

The DMR algorithm is being developed using C++ programming language. The flow chart representing the steps involved in the algorithm is shown in Figure 3.

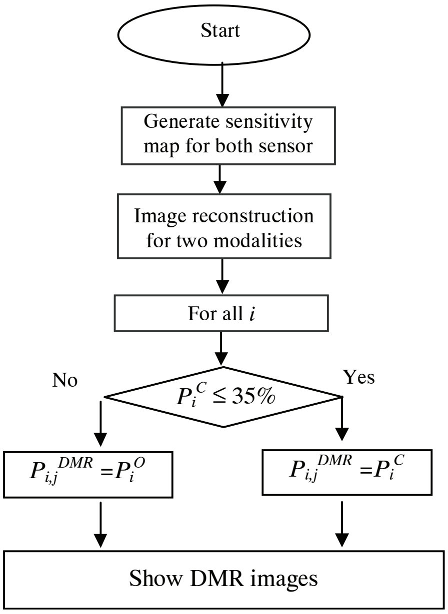
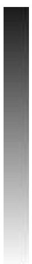
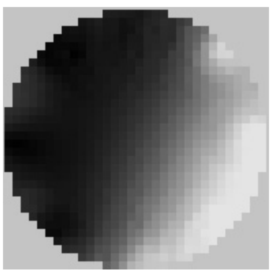
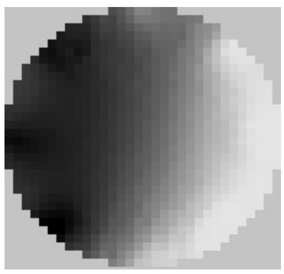
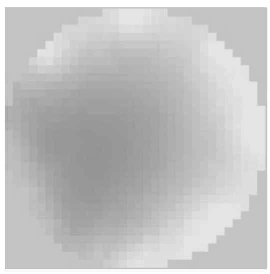


Fig. 3. Flow chart for DMT algorithm

3. Result and discussion

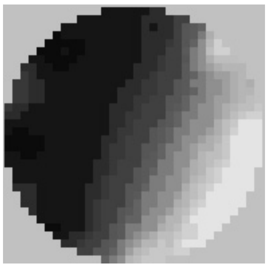
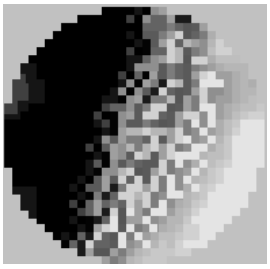
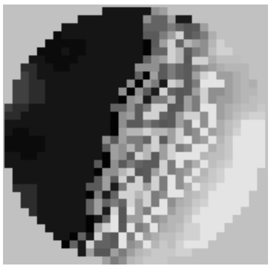
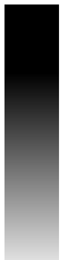
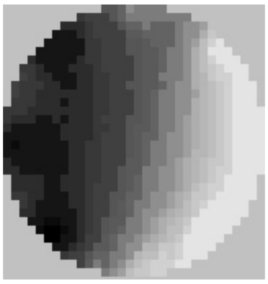
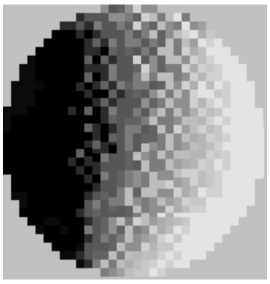
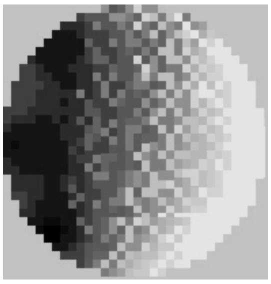
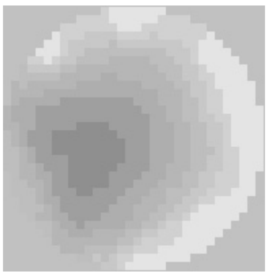
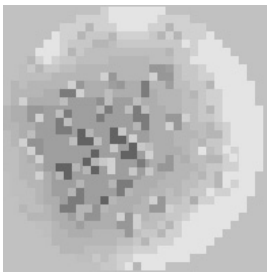
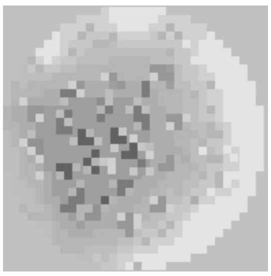
The simulation result utilized by IBP for electrical capacitance sensor is shown in Table 2. The resulting images from ECT image (colour GRB 24-bits) show the boundary condition of concentration distribution. For the low distribution below 35% the result shows the blurred image.

Table 2
Images reconstruction for electrical capacitance sensor

Concentration	ECT image (grey-scale)		
 1 0			

As can be seen in Table 3, image fusion produced by DMR algorithm is characterized by a greater sharpness. For row no 1 in Table 2, the result of image fusion shows high quality image in full range distribution. For row no 3, the image fusion also shows the high quality image in low distribution.

Table 3
Images reconstructed by DMT algorithm.

	ECT image	OT image	Image fusion	
1				
2				
3				

4. Conclusions

A development of new DMR algorithm has been discussed. The simulation result from the dual sensor tomography shows that the dual sensor system enables to produce high quality image and sharpness in full range distribution.

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