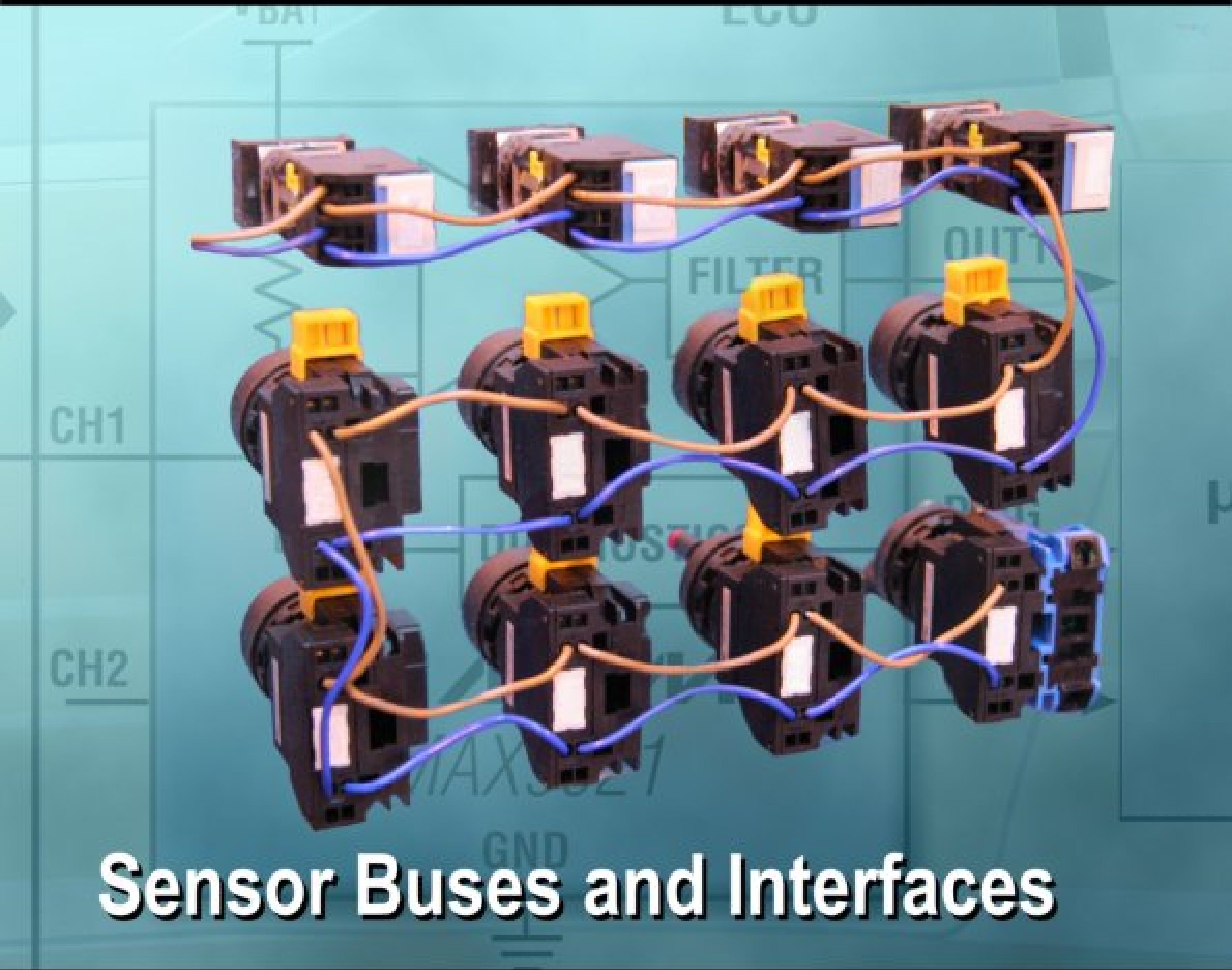
ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 116
5/10



Sensor Buses and Interfaces

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 116, Issue 5, May 2010

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA).
Available in electronic and on CD.

Sensors & Transducers Journal

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Volume 116
Issue 5
May 2010

www.sensorsportal.com

ISSN 1726-5479

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International Frequency Sensor Association (IFSA).

Sensors & Transducers Journal, Vol. 116, Issue 5, May 2010, pp. 76-82

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Two-Phase Flow Regime Identification by Ultrasonic Computerized Tomography

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Received: 30 March 2010 /Accepted: 24 May 2010 /Published: 31 May 2010

Abstract: This paper describes the development of ultrasonic computerized tomography for identifying the liquid and gas flow regimes. The work reported in this paper demonstrates image reconstruction techniques applied to an experimental vessel using non-invasive technique. The investigations were based on the transmission and the reception of ultrasonic sensors that were mounted circularly on the surface of an experimental vessel. The algorithms used to reconstruct the concentration profile for two-phase flow using fan-shaped beam scanning geometry were also presented. *Copyright © 2010 IFSA.*

Keywords: Ultrasonic imaging, Fluid flow measurement, Image reconstruction

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1. Introduction

The measurement of two-component flow such as liquid or oil flow through a pipe is increasingly important in a wide range of applications, for example pipeline control in oil exploitation and chemical process monitoring. Knowledge of the flow component distribution is required for the determination of flow parameters such as the void fraction and the flow regime. Real-time reconstruction of the flow image is needed in order to estimate the flow regime when it is continuously evolving. Real time process monitoring plays a dominant role in many areas of industry and scientific research concerning liquid/gas two-phase flow. It is proved that the operation efficiency of such a process is closely related to accurate measurement and control of hydrodynamic parameters such as flow regime and flow rate [1]. Besides, monitoring in the process industry has been limited to either visual inspection or single point product sampling where product uniformity is assumed. This approach for the determination of fluid flow parameters of two-component flow is called flow imaging.

2. The Attenuation Model

The attenuation process may be modeled by Lambert's exponential law of absorption [2], where the ultrasonic energy intensity of transmitter and receiver are related as in Fig. 1 (where *L* represents the total path length) and its mathematical expression is given by Equation (1).

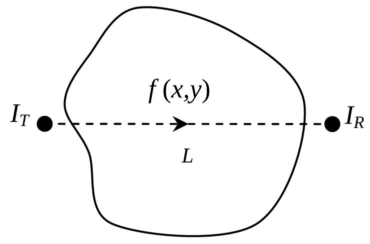


Fig. 1. The ultrasonic attenuation model.

$$I_R = I_T \exp\left(-\int_L f(x,y)\mathrm{dI}\right), \tag{1}$$

where I_R = the receiver intensity, I_T = the transmitter intensity, L = path length in the object field and $f(x, y)$ = the attenuation function by the object field.

At room temperature, both water (liquid) and air (gas) have acoustic impedance of 1.5 x 10^6 kg/m^{2}s and 430 kg/m^{2}s respectively. The reflection coefficient, R at the interfaces can be calculated as below:

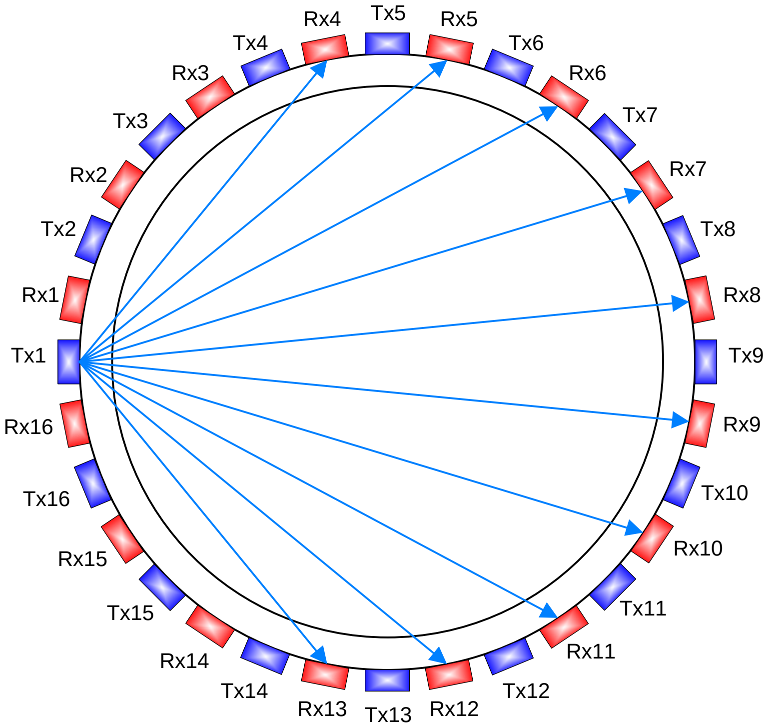
$$R_{\text{(water/air)}} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right] = \left[\frac{430 - 1.5\times10^6}{430 + 1.5\times10^6}\right] = -0.9994\times100\%, \\ = -99.94\%, \tag{2}$$

where Z_1 = the liquid (water) acoustic impedance (kg/m^{2}s) and Z_2 = the gas (air) acoustic impedance (kg/m^{2}s).

The negative sign indicates the reversal of the phase relative to the incident wave. In above calculation, it shows that due to the large different of acoustic impedance between the liquid and gas medium, therefore 99.94% of ultrasonic wave will be reflected at liquid/gas boundary and scattered within the liquid area.

3. Tomography Measurement Section

An acrylic pipe with a 115 mm outer diameter and a 6mm pipe wall thickness is used as the experimental vessel. Ultrasonic transducers will be evaluated by circularly arrayed 16-pairs (16-transmitters and 16-receivers) non-invasively on the surface of the experimental vessel. The active elements for these transducers are Piezoelectric Ceramic with a resonant frequency of 40 kHz. The measurement section is shown in Fig. 2.



(a)

(b) (c)

Fig. 2. The measurement section: (a) Projection geometry; (b) Transducer ring; and (c) Transducer arrangement.

The Tx1, Tx2, Tx3 and etc. represents the transmitters whereas the Rx1, Rx2, Rx3 and etc. represents the receivers. By using the transmission-mode method and the fan-shape beam projection technique, the ultrasonic transmitters will transmit pulses at 40 kHz through the process vessel to the point of interest. Each transmitter excited will emit two cycles of tone burst of 40 kHz at 20Vp-p. These transducers having divergence angle, α of 125^o resulting each projection from the transmitting transducers cover up to 10-channels of the receiving transducers. A total of 16 observations were made in one scan, hence 160 independent measurements were obtained.

When the components to be imaged are gases, there may be no directly transmitted signals from the transmitter to the receiver because of the obstacles. By reflecting against the pipe wall or multiple reflections on the gas component surfaces, the receiver may still detect some signals, at later time though because direct transmission takes the shortest path and hence the shortest time [3]. When a pulse is transmitted from the transmitter, for each receiver there is a specific observation time at which the transmitted pulse should arrive. This time is the shortest time and the path between the transmitter and receiver is a straight line. This observation time for each receiver is recorded and programmed onto the microcontroller.

The basic hardware preparations are the signal generator, signal conditioning circuit and the data acquisition system as interfacing peripheral. The electronic system required for controlling the ultrasonic transducers as recommended by Plaskowski *et al.* [4] should has four main functions that are:

a. Supplying pulses to activate the transmitting sensors should ideally be software controlled so that the timing of the pulses can be easily varied and the synchronization is ensured.

b. Amplifying the analogue signals from the receiving sensors.

c. Reshaping the received analogue signals into digital pulses which preserved the time of arrival information.

d. Interfacing to the digital computer for control of pulses generations and image reconstruction from received data.

Based on the above criteria, the electronic measurement system has been designed and the block diagram for the electronic measurement system is shown in Fig. 3.

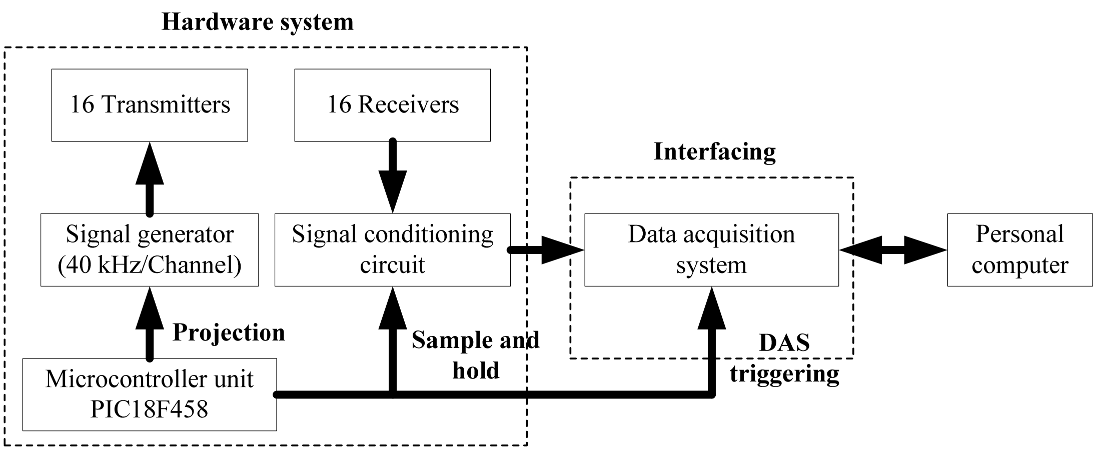


Fig. 3. The electronic measurement system block diagram.

The microcontroller will generate a dual frequency signal namely the minor and the major frequency. The minor frequency is the 40 kHz ultrasonic signals with a duty cycle of 50% at each pulse. The major frequency is the 150 Hz signal which is for the reverberation effects delay of the receiver before the next transmitter are being excited. The reverberation effects delay is needed to avoid the overlapping echoes at the receivers due to two separate ultrasound excitations. Fig. 4 shows the ultrasonic computerized tomography system used for liquid and gas flow regime identification.

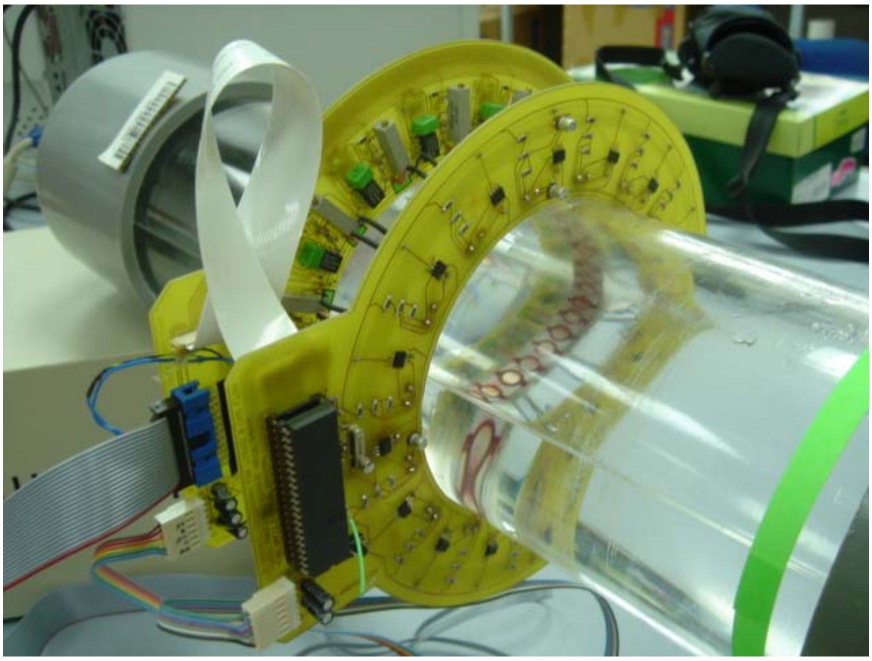


Fig. 4. The ultrasonic computerized tomography system.

4. The Image Reconstructions

In Linear Back Projection algorithm (LBP), the concentration profile is generated by combining the projection data from each sensor with its computed sensitivity maps [5]. The modeled sensitivity matrices are used to represent the image plane for each view. To reconstruct the image, each sensitivity matrix is multiplied by its corresponding sensor loss value; this is same as back project each sensor loss value to the image plane individually [6]. Then, the same elements in these matrices are summed to provide the back projected voltage distributions (concentration profile) and finally these voltage distributions will be represented by the color level (colored pixels). This process can be expressed mathematically as in Equation (3) [6]:

$$V_{LBP}(x,y) = \sum_{Tx=1}^{16}\sum_{Rx=1}^{16} S_{Tx,\,Rx} \times \overline{M}_{Tx,\,Rx}(x,y)\,, \tag{3}$$

where $V_{LBP}(x, y)$ is the voltage distribution on the concentration profile matrix, $S_{Tx,Rx}$ is the sensor loss value and $/M_{Tx,Rx}(x, y)$ is the normalized sensitivity matrices.

The Hybrid Reconstruction algorithm (HR) is based on the previous development by Ibrahim [7]. This algorithm determines the condition of projection data and improves the reconstruction by marking the empty area during image reconstruction. As a result, the smearing effects caused by the back projection technique are reduced. The projection data obtained by Ibrahim [7] is based on the sensor value. Later, Chan [6] had used a different approach where he used the signal loss measurement instead of direct projection data in order to reconstruct the fan-shaped beam image using optical tomography. He claimed that this method is easier to implement compared to the original method. The HR is obtained by multiplying the concentration profile obtained using the LBP with the HR masking matrix. The HR masking matrix was obtained by filtering each of the concentration profile element. If the concentration profile element is larger or equal to ¾ of the maximum pixel value, then the masking matrix element for the corresponding concentration profile element is set to one otherwise it is set to zero. The mathematical model for HR is shown in Equations (4) and (5).

$$V_{HR}(x,y) = B_{HR}(x,y) \times V_{LBP}(x,y) \tag{4}$$

in which:

$$\begin{aligned} B_{HR}(x,y) = 0 &\Rightarrow V_{LBP}(x,y) < P_{Th} \\ B_{HR}(x,y) = 1 &\Rightarrow V_{LBP}(x,y) \geq P_{Th} \end{aligned} \tag{5}$$

where B_{HR} (x, y) is the HR masking matrix, P_{Th} is the pixel threshold value (¾ of the maximum value), V_{LBP} (x, y) is the reconstructed concentration profile using LBP and the V_{HR} (x, y) is the improved concentration profile using HR.

5. Results and Discussions

Static experiments were carried out to estimate the performance of the system presented. Initial studies showed that this method is effective and feasible, but further investigations should be continued to extract more quantitative information. Several experiments on the stratified and annular flows have been carried out. The images captured using the LBP and the HR are shown in Fig. 5.

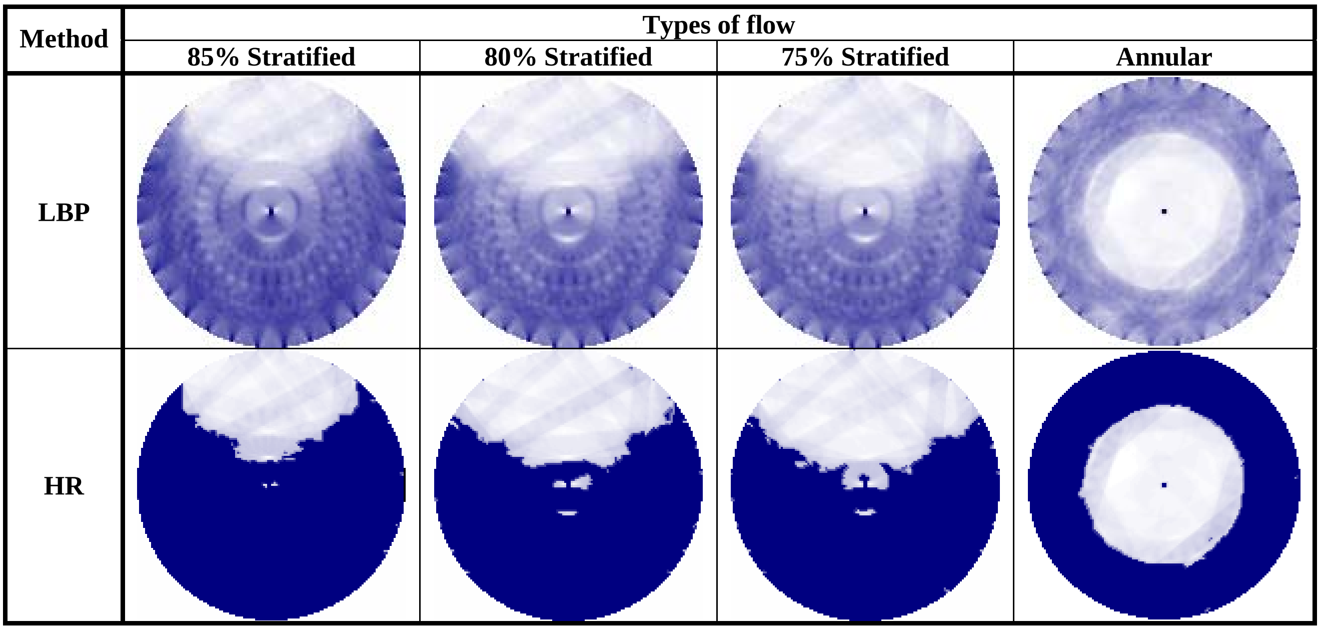


Fig. 5. The liquid and gas flow regimes.

The developed ultrasonic computerized tomography was capable of identifying the liquid and gas flow regimes. The system is however needs further improvement on the sensors modeling in order to obtain optimum results but, the present setup performance is sufficient enough for used on liquid and gas flow regime identification system.

References

[1]. R. Abdul Rahim, M. H. Fazalul Rahiman, and K. S. Chan, Monitoring Liquid/Gas Flow Using Ultrasonic Tomography, in *Proc. of the 3rd International Symposium on Process Tomography*, Lodz, Poland, 2004, pp. 130-133.

[2]. B. S. Hoyle and L. A. Xu, Ultrasonic Sensors, in Process Tomography: Principles, Techniques and Applications, R. A. Williams and M. S. Beck, Eds. *Butterworth-Heinemann*, Oxford, 1995, pp. 119-149.

[3]. H. Gai, Y. C. Li, A. Plaskowski, and M. S. Beck. Flow imaging using ultrasonic time-resolved transmission mode tomography, in *Proc. of the IEE 3rd Int. Conf. Image Processing and Its Application*, 1989, pp. 237–241.

[4]. A. Plaskowski, M. S. Beck, R. Thron, and T. Dyakowski, Imaging Industrial Flows: Applications of Electrical Process Tomography, *IOP*, Bristol, U. K., 1995, pp. 76–160.

[5]. T. R. McKeen, and T. S. Pugsley, The Influence of Permittivity Models on Phantom Images Obtained From Electrical Capacitance Tomography, *Measurement Science Technology*, 2002, Vol. 13, pp. 1822–1830.

[6]. K. S. Chan. Real-Time Image Reconstruction for Fan Beam Optical Tomography System, *M. Eng. Thesis*, Universiti Teknologi Malaysia, Malaysia, 2002.

[7]. S. Ibrahim, Measurement of gas bubbles in a vertical water column using optical tomography, *Ph. D. dissertation*, Sheffield Hallam Univ., Sheffield, UK, 2000.

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