APPLICATION OF TRANSMISSION-MODE ULTRASONIC TOMOGRAPHY TO IDENTIFY MULTIPHASE FLOW REGIME

Y. Abdul Wahab[1], R. Abdul Rahim[2], M.H. Fazalul Rahiman[2], and M.A.Ahmad[1]
[1] Control and Instrumentation Research Group, Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, 26600, Pekan, Pahang, Malaysia
(Tel : +609-4242152; E-mail: yasmin@ump.edu.my)
[2] Process Tomography Research Group, Department of Control and Instrumentation Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
(Tel : +607-5537801; E-mail: deanrmc@utm.my)

***Abstract*- This paper presents an application of ultrasonic tomography where the main objective is to identify the multiphase flow regime which is liquid, gas and solid at once. The system was designing non-invasively by using offline method. The transmission mode with fan shaped beam back projection had been implemented for sensing purposes where 8x8 projections were produced. Beside, the linear back projection (LBP) algorithm was implemented in the software system for the image reconstruction part. Experiments show that the multiphase flow regime for liquid, gas and solid at once can be identifying by using ultrasonic tomography. The results of experiments and possible future improvement were also discussed.**

***Keywords*—Ultrasonic tomography, Transmission mode, Linear Back Projection (LBP) algorithm.**

I. INTRODUCTION

In process and chemical industries, multiphase flow plays an important role. A monitoring system that can be applied non-invasively is very important in multiphase flow system where it should be able to provide information about the composition of the multiphase system. Tomography is the most beneficial technology that can be applied to solve the problem. An ultrasonic tomography is one of the techniques that have been successfully used in industries in other to monitor the actual process material such as in pipeline and vessel. Of course, the installation of ultrasonic tomography will not interrupt the process being examined.

The goal of ultrasonic tomography is to reconstruct the spatial distribution of some acoustic parameter of an object using ultrasonic measurements [1]. It has been widely used in medical and successfully applied in pipeline and vessel. In [2], the authors point out an interested paper where they present the real time transmission tomography for two component bubbly gas/liquid flow. By using a binary logic filtered back projection algorithm, the results got more faster compare with the binary logic back projection. Beside, Warsito *et al.* [3] presented transmission-mode method for measuring the cross-sectional distribution of gas and solid hold-ups in slurry bubbles. They proposed ultrasonic computed tomography to develop non-invasive techniques for gas-liquid-solid system. However, even the research focus on gas-liquid-solid system, the tomogram that has been shown on this paper is presents in separately which are liquid/gas and liquid/solid not gas/liquid/solid at once. Authors in [4] had focused the application of ultrasonic technique and statistical approach in other to investigate the phase holdup in multiphase flows. The approach shows that it was reliable to measure gas and liquid holdups under high liquid velocity conditions within the two-phase and three-phase circulating fluidized beds as well.

Recent years, applications of process tomography as a robust non-invasive tool for direct analysis of the characteristics of multiphase flows have increased in number [5]. As most sensors currently used in multiphase flow meters are affected by the distribution of components in the mixture, tomography imaging may possibly improve the accuracy and provides a wider measurement range. In addition, the overall anticipated affects are improvements in product yield and uniformity, minimized input process material, reduced energy consumption and environmental impact, and the lowering of occupational exposure to plant personnel [6].

In this research, different approach was implemented by using ultrasonic tomography where the liquid, solid and gas can be identified at once.

II. ULTRASONIC TOMOGRAPHY SYSTEM

Ultrasonic waves are high (“ultra”) frequency sound (“sonic”) waves: they vibrate at a frequency above 20 kHz which are too fast to be audible to humans [7]. The potential benefits are, it is possible to gain an insight into the actual; secondly, since ultrasonic tomography is capable of on-line monitoring, it is the opportunity to develop closed loop control systems and finally, it can be non-invasive and possibly non-intrusive system [8]. By using transmission mode and fan shaped beam projection technique, the 16 sensors consist of 8 transmitters and 8 receivers with beam angle 125° each were put side by side non-invasively along the periphery of the outer of pipe wall (acrylic pipe). The fan shape beam geometry that firstly introduced by the Xu *et. al*. was implementing in this research. The fan shaped beam was chosen because of the cover area is bigger for the receiver to receive a signal that transmit by the transmitter. The example of single scanning geometry by using fan shaped beam projection can be seen in Fig. 1.

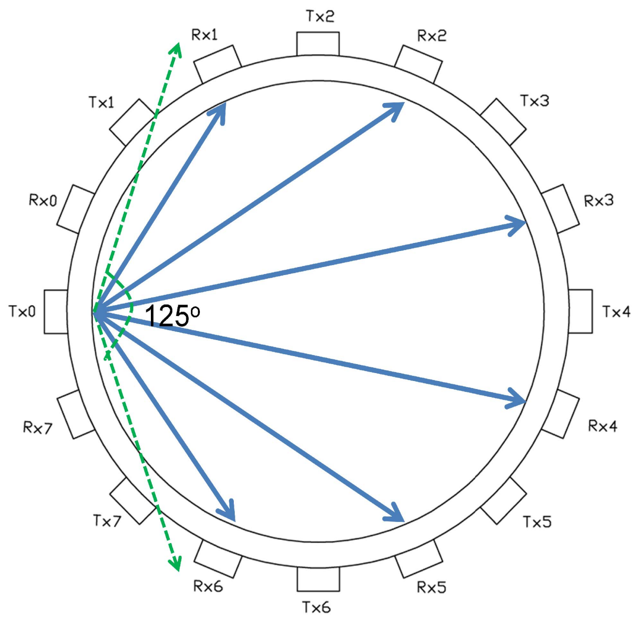


Fig. 1. Single Scanning Geometry using Fan Shaped Beam Projection

For the purpose of this research, the ultrasonic tomography system has been designed. This ultrasonic tomography system as shown in Fig. 2 consists of hardware system and software system. The hardware system was including the ultrasonic sensor setup and electronic measurement setup. Meanwhile, the programming for microcontroller unit and the image reconstruction that used to get the tomogram were implemented in the software system.

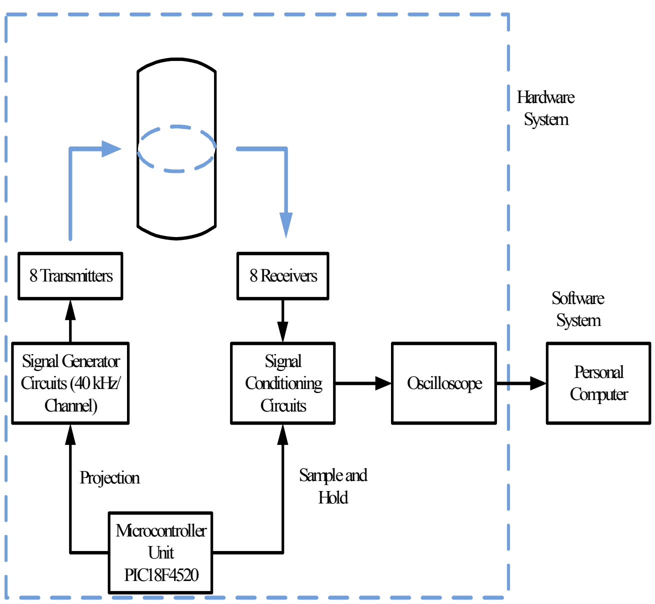


Fig. 2. Ultrasonic Tomography System

The hardware system includes the Microcontroller Unit (PIC18F4520), signal generator circuit and signal conditioning circuit. A PIC18F4520 microcontroller will be used to transmit and control the projection of 40 kHz pulses to the signal generator circuit. A function of signal generator circuit here is chosen to be a comparator. Then, the signal generator circuit will transmit the signal to the transmitter. After transmitter transmits the ultrasonic wave through the acrylic pipe, then the signal will receive by receiver. The received signals will then amplify to an appropriate voltage level.

Note that, when the pulse transmitted by 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 and the first highest peak for each receiver are recorded and then programmed into the microcontroller. The time is named as time-of-flight (TOF) as shown in Fig. 3.

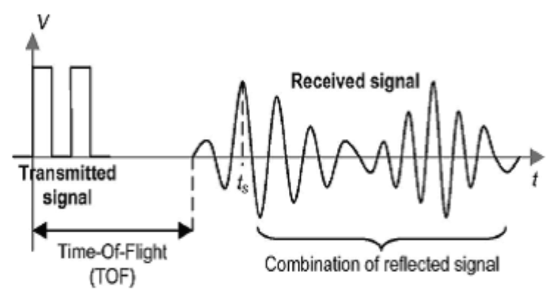


Fig. 3. Example of Transmitted signal and Received signal

In this research, an offline method was applied. A sample and hold technique is used to capture (sample) the received signal under observation time. This signal also will be hold to a certain delay that control by microcontroller. Simultaneously, the reading of holding voltage that took peak to peak from the oscilloscope is then taken manually and will be used for image reconstruction part.

III. IMAGE RECONSTRUCTION ALGORITHM

The linear back projection (LBP) algorithm that has been used successfully recently was used in this research. It was originally developed for X-Ray tomography, and it has also an advantage of low-computational cost. This LBP algorithm is computational straight forward to implement and is a popular method for image reconstruction [9]. The back projection means that a pixel-based approach that basically consists of summing up the contribution of single measurements to the pixel values in the measurement plane [10]. In this method, a large number of ultrasonic transducer is necessary to obtain a good spatial resolution. Sensitivity maps were derived for an individual sensor that used by the LBP algorithm in other to obtain the concentration profiles from measured sensor values.

The process of obtaining concentration profile using LBP can be expressed mathematically as shown in equation:

$$V_{LBP}(x,y) = \sum_{Tx=0}^{7} \sum_{Rx=0}^{7} S_{Tx,Rx} \, x \, \overline{M}_{Tx,Rx} \quad (1)$$

$$S_{Tx,Rx} = V_{ref\ Tx,Rx} - V_{Tx,Rx} \quad (2)$$

Where $V_{LBP\ (x,y)}$ is the voltage distribution that obtained using linear back projection algorithm, $S_{Tx,Rx}$ is the sensor loss voltage of transmitter (Tx) and receiver (Rx), $\overline{M}_{Tx,Rx}(x,y)$ is the normalized sensitivity maps, $V_{ref\ Tx,Rx}$ is reference voltage for the projection of Tx-th to Rx-th, and $V_{Tx,Rx}$ is the sensor value for the projection of Tx-th to Rx-th.

In this research the reference voltage is obtained during the full liquid flow. This calibration data is needed during the image reconstruction process for extracting the sensor loss information. Beside, the sensor loss values calculated also must be in the normalized value because it will multiple in the normalized sensitivity map. In addition, the back projected data values are smeared back across the unknown density function (image) and overlapped to each other to increase the projection data density. The smearing effects is the side effect of the LBP since each pixels are summations of the back projected signals. Hence, in this case, the 'wrong' pixels are summed twice by the value of the smearing effect. This produce ambiguous image since the reconstructed image may represent two, three, our four pixels [11]. The flow chart of the algorithm is shown in Fig. 4 as below:

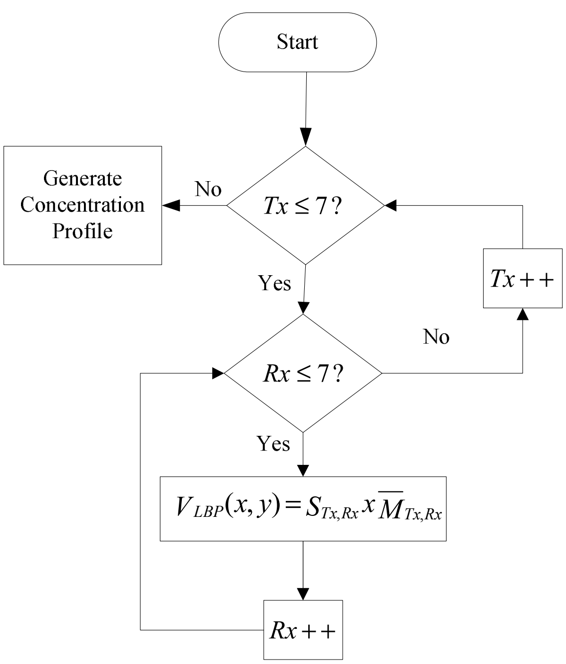


Fig. 4. Flow Chart of LBP Algorithm

The concentration profile obtained was represented by 32x32 of square matrix. The profile values were converted into color levels (also known as tomogram). The tomogram drawing was accomplished using Bitmap method. Fig. 5 shows the color levels. The white color represents the low concentration and the blue color represents the high concentration. The low concentration means the overlapping of data projected was small and vice versa.

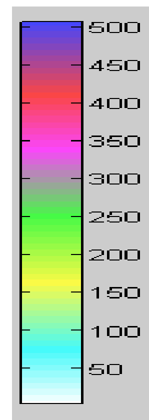


Fig. 5. The Color Levels

IV. RESULTS AND DISCUSSION

Some experiments had been conducted in this research. Materials and diameter used for gas and solid medium as shown in Table 1. The acoustic impedance of PVC pipes that used for this purpose was neglected so that the ultrasonic can penetrate through the PVC pipes.

Table 1. Material and Diameter used for the Project

Material	**Diameter**
Gas(Air)	25mm
Gas(Air)	20mm
Solid(Cement)	25mm
Solid(Cement)	20mm
Solid(Wood)	Width=30mm,Height=20mm

The full liquid means the pipe was full with water without any gas or solid at all. The different of acoustic impedance between the pipe and water was not too much and allows the transducer to penetrate through the pipe wall and travel to the respective receivers through the water. As shown in Fig. 1, only 6 receivers will receive the signal since the beam angle of transducer is 125°. Another two receivers outside from the beam angle were neglected due to the lamb wave. From Fig. 5, the concentration profile give the high concentration with the highest value is 511 and the color is blue. This value is obtained because in this position there is no obstacle. Noticed, the color at the center in Fig. 5 is white causing by the limited projection in this project. Thus, there is no ultrasonic projection travel on that area. The full liquid measurement will be used as a reference for others experiment. Beside, the position of the pipe in vertical condition also makes the full liquid was used as a basic flow for the other experiments.

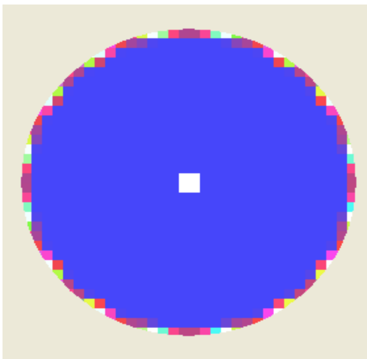
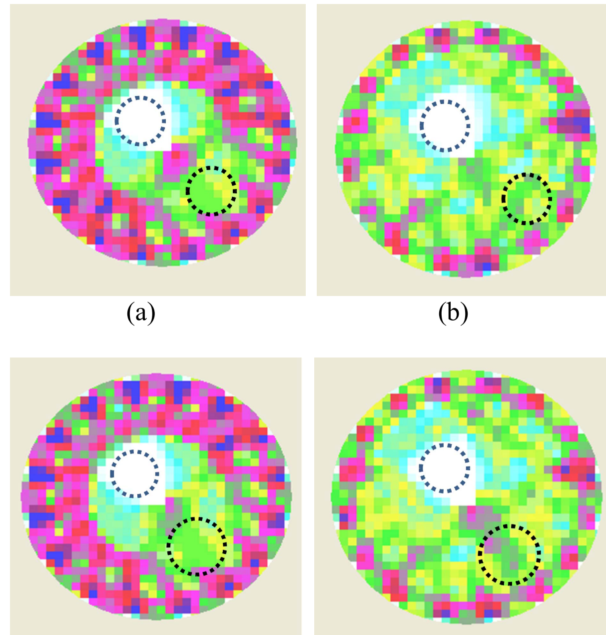


Fig. 5. Tomogram of full liquid

In other to make sure whether the experimental results got can be confirmed or not, the test profile was done first. Then, the results of test profiles become a reference for the experimental results. When the three phase flow experiments had been conducted, the results shows that the ultrasonic tomography cannot identify clearly the tomogram for full liquid with gas and cement. It only can recognize clearly the location of gas but not for the cement. By doing a test profile, the different between location area of gas and cement can be identified. However, after experiments were conducted, the tomogram got indicate that it cannot identify the exact location of cement but the gas location can be seen obviously. The different sizes of gas used can be seen in the Fig. 6 and Fig. 7 where the area of 20 mm gas used was smaller compare to the area of 25 mm gas during the experiments. But not for the different sizes of cement that used as a solid medium. It is due to the ultrasonic wave that absorb the cement and influence the tomogram obtained even the mismatch of acoustic impedance between air cement is almost 99.98%.

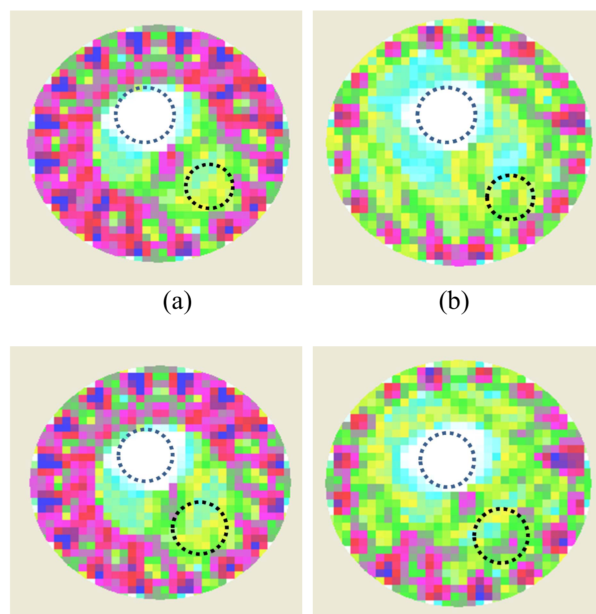
If this happened, it not will complete the objective of the project. Thus, the experiment was proceeding by using a wood as a solid medium. The mismatch of acoustic impedance between the air and wood is 99.43%. From Fig. 8 the tomogram got can be identifying the location of gas and solid. It also follows the tomogram of test profile. The tomogram got also shows that the better image can be obtained for three phase flow when the wood used as a solid medium. As general, the results obtained from the experiment shows that the tomograms were not very clear even it can identify the location of gas and solid. The algorithm used which is LBP algorithm itself produce the smearing effect for all tomogram obtained in the project. Thus, it cannot give an exactly the real shape of the object that we want. The limited projection used which is 8x8 projections also influence the results obtained. Beside, the position of the medium inside the pipe during the experiment which is not exactly same as the test profile also influences the results.



(a) (b)

(c) (d)

Fig. 6. Full Liquid with gas (20mm) and solid. (a) Test profile of gas and solid (20 mm) ; (b) Experimental result of gas and solid (20 mm); (c) Test profile of gas and solid (25 mm) ; (d) Experimental result of gas and solid (25 mm).

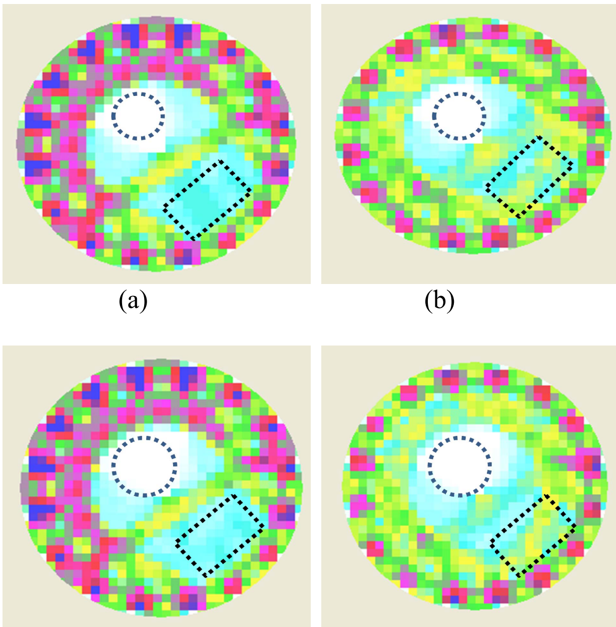


(a) (b)

(c) (d)

Fig. 7. Full Liquid with gas (25mm) and solid. (a) Test profile of gas and solid (20 mm) ; (b) Experimental result of gas and

solid (20 mm); (c) Test profile of gas and solid (25 mm) ; (d) Experimental result of gas and solid (25 mm).



(a) (b)

(c) (d)

Fig. 8. Full Liquid with gas (20 mm and 25mm) and wood. (a) Test profile of gas (20mm) and wood ; (b) Experimental result of gas (20mm) and wood; (c) Test profile of gas (25 mm) and wood ; (d) Experimental result of gas (25 mm) and wood.

V. CONCLUSION

The objective of this research generally had been achieved. The non-invasively application and ultrasonic propagation with transmission mode and fan shaped beam projection was profitably implemented and made use to identify the multiphase flow regime. Beside, the hardware fabrication of ultrasonic transducer also effectively implemented. The multiphase flow which are liquid, gas and solid can be identified and displayed at once. However, the algorithm used which is LBP algorithm has some disadvantages and limited projection influence the results obtained. It also was limited to certain material used for solid medium. A very important part is the mismatch of acoustic impedance between the materials used must be known first before proceeding to the next steps. By simply increasing the projection of the ultrasonic system, for example 16x16 or 32x32 projection instead of 8x8 projections, a clearer image can be obtained and the spatial resolution of reconstructed image can be reduced. Beside, other image reconstruction algorithm like Hybrid Binary Reconstruction or others can be applied since LBPA is proved having smearing effects on the reconstructed image. An ultrasonic sensor with wider beam angle can be applied for more coverage of the projected signal since the current ultrasonic sensors angle is 125^{o}. However, advance investigation should be continued to extort more quantitative information.

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