SENSORS & TRANSDUCERS

ISSN 1726-5479

vol. 148

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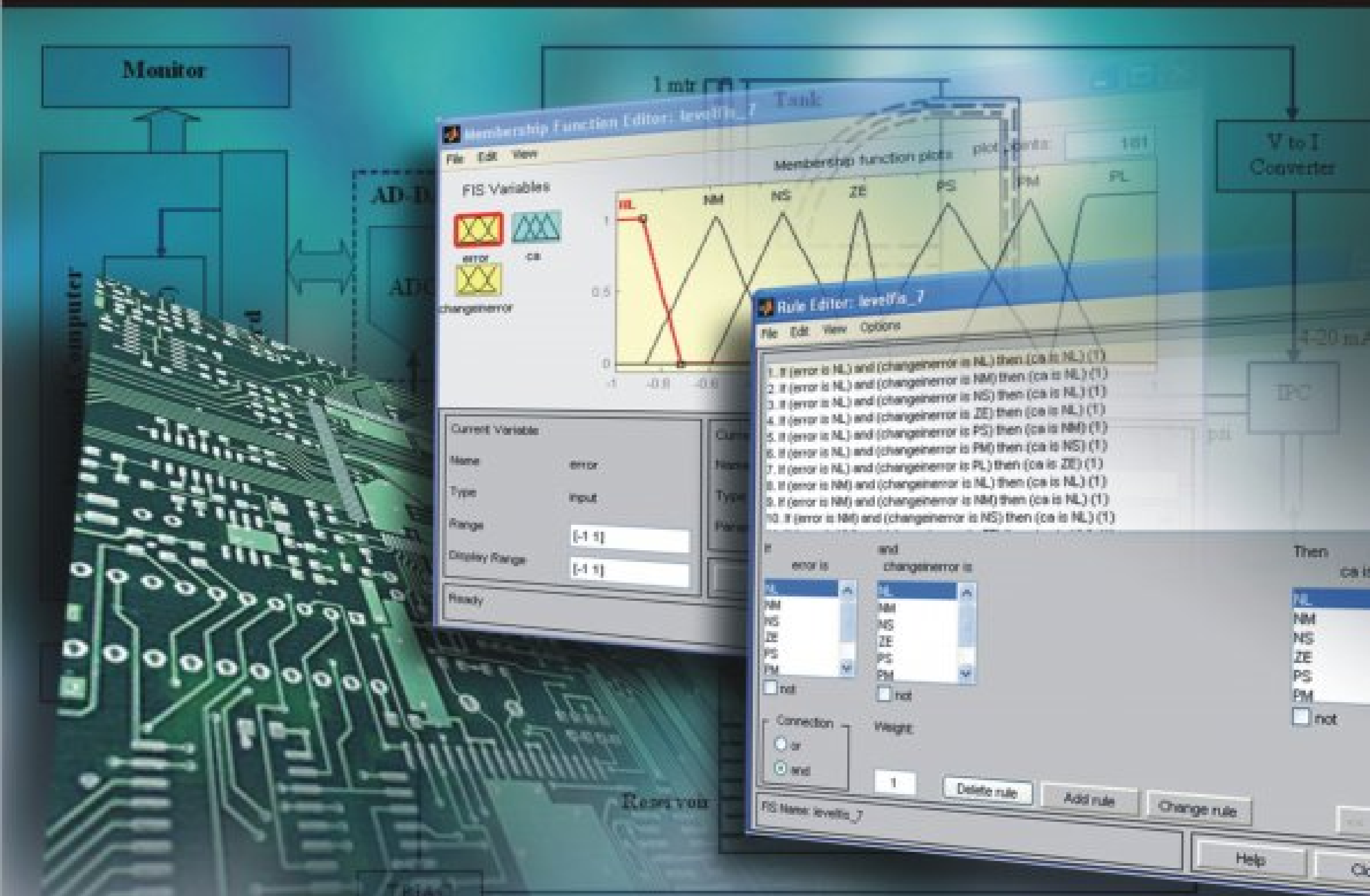

Sensor Instrumentation, Data Acquisition Systems and Virtual Instruments

International Frequency Sensor Association Publishing

Printed in the USA.

Sensors & Transducers

Volume 148, Issue 1
January 2013

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 both: print and electronic (printable pdf) formats.

Sensors & Transducers Journal

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Volume 148
Issue 1
January 2013

www.sensorsportal.com

ISSN 1726-5479

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Sensors & Transducers, Vol. 148, Issue 1, January 2013, pp. 33-39

Sensors & Transducers
ISSN 1726-5479

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Ultrasonic Tomography Imaging for Liquid-Gas Flow Measurement

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Received: 6 June 2012 /Accepted: 24 January 2013 /Published: 28 January 2013

Abstract: This research was carried out to measure two-phase liquid – gas flow regime by using a dual functionality ultrasonic transducer. Comparing to the common separated transmitter–receiver ultrasonic pairs transducer, the dual functionality ultrasonic transceiver is capable to produce the same measurable results hence further improvises and contributes to the hardware design improvement and system accuracy. Due to the disadvantages and the limitations of the separated ultrasonic transmitter–receiver pair, this paper presents a non-invasive ultrasonic tomography system using ultrasonic transceivers as an alternative approach. Implementation of ultrasonic transceivers, electronic measurement circuits, data acquisition system and suitable image reconstruction algorithms, the measurement of a liquid/gas flow was realized. *Copyright © 2013 IFSA.*

Keywords: Tomography, Ultrasonic, Two phase flow, Flow measurement, Transceiver.

1. Introduction

This research aims to develop a non-invasive ultrasonic tomography system and to develop application to reconstruct images of a two-phase liquid – gas flow system. Similar research in non-invasive method of ultrasonic tomogram fabrication technique was introduced [1]. The development on ultrasonic tomography has shifted to focusing on two-phase liquid–gas flow. This system implemented invasive method which is not appropriate practically in most industries [2]. This system requires high excitation voltage (200 V) to transmit ultrasonic signals via a transmitter. Such high voltage has many restrictions in terms of safety and cost.

A common ultrasonic tomography system uses a separated type of ultrasonic transmitter and ultrasonic receiver with a specified frequency range. Such system raises some difficulties and disadvantages such as; i) More space required to mount more sensors, ii) More sensors will cost higher expenses and iii) Accuracy of the system will decrease.

To overcome the above mentioned problems, this research implemented the use of ultrasonic transceiver replacing the use of separated ultrasonic transmitter–receiver pair. Hence, such system can improve the accuracy of measurement and uses less space compare to the separated transmitter–receiver pair.

2. Ultrasonic Sensor and Hardware Configuration

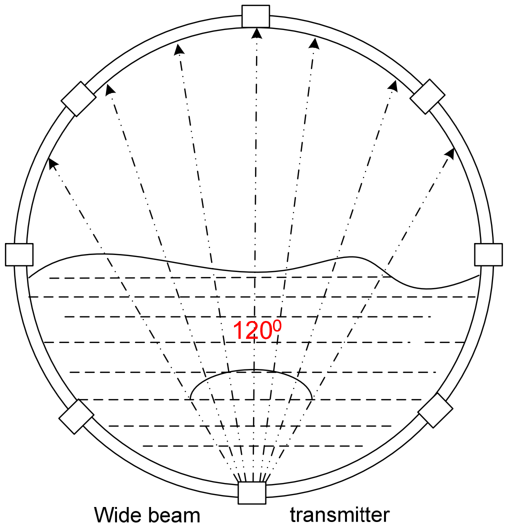
Ultrasonic waves are high (ultra) frequency sound (sonic) wave which vibrate at a frequency above 20 000 vibrations per second or 20 kHz. The behavior of ultrasonic is similar to audible sounds but has a much shorter wavelength. Most ultrasonic waves can be described in terms of harmonic (sinusoidal) waves. The ultrasonic waves can only propagate through the medium of solid, liquid or gas but not in vacuum.

There are several types of ultrasonic transducer available in the market with different range of frequencies. A good tomography sensor should possess some important features such as non-invasive and non-intrusive. It should not necessitate rupture of the walls of a pipeline and does not disturb the nature of the process being examined [3]. For this reason, ultrasonic transceivers as shown in Fig. 1 were employed in this research.

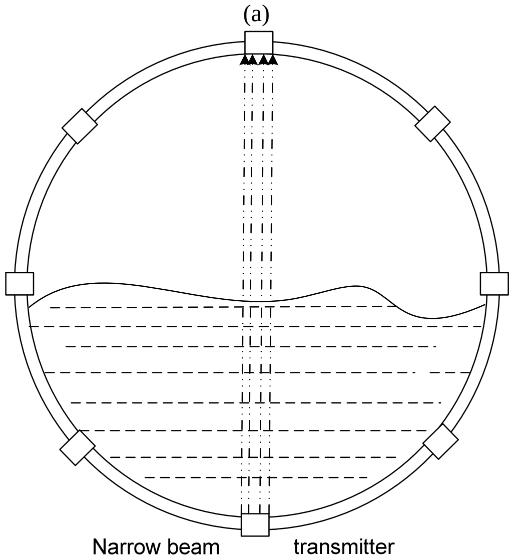
Fig. 1. Ultrasonic transceiver sensors.

The ultrasonic transceiver (as in Fig. 1) is a type of transducer that converts electrical energy into high frequency sound waves and also converting sound waves back to electrical energy. It contains piezoelectric crystal materials that have the ability to transform mechanical energy into electrical energy and vice versa [4]. This sensor is suitable for non-invasive measurements and it is low cost. Its flat main surface makes it easy to be mounted on an acrylic pipe.

In most non-destructive testing or medical applications, an object or field of interest is irradiated from a single viewpoint, usually with a narrow beam of ultrasonic acoustic energy [5]. The ultrasonic transceiver implemented in this research utilizes an angle of 120^0 degree wide beam. Fig. 2 illustrates the comparison between wide beam and narrow beam ultrasonic projections.



(a)

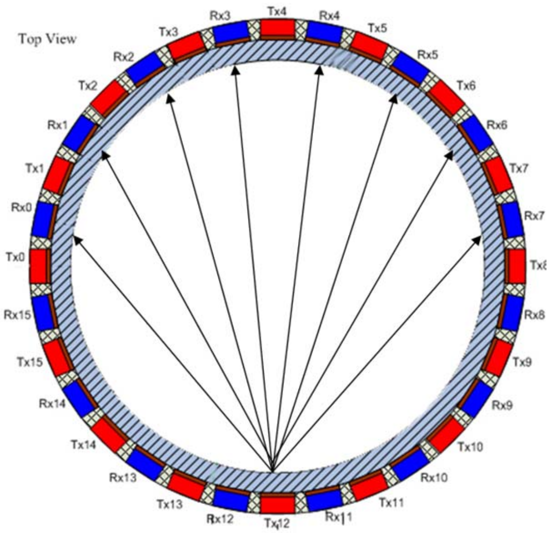


(b)

Fig. 2. (a) Wide beam, and (b) narrow beam projections.

Ultrasonic transceivers are dual functional sensors. It can function as a transmitter (TX) or receiver (RX) at one time, which makes it preferable to use for less number of these sensors can be used to produce the same or even better results comparing to the use of common separated transmitter–receiver transducer.

The sensor configuration of a transceiver and common transducer surrounding a pipe surface was compared and illustrated as in Fig. 3. Separated transmitter-receiver pair needs to be sequentially arranged. Each transmitter will require a receiver mounted next to it while using ultrasonic transceivers only requires a switching method to switch select the transceivers.



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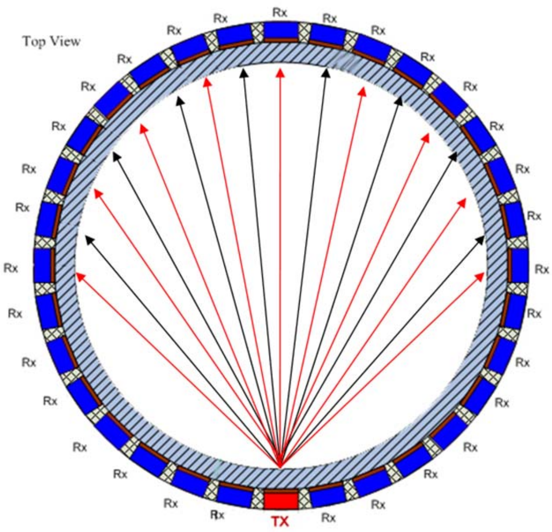


(b)

Fig. 3. Sensor configuration comparison; (a) Separated transmitter–receiver setup, (b) Transceiver setup.

All 8 transceivers are firmly mounted on the acrylic pipe surface. This was done by using a sensor jig to hold firm all the sensors [7] surrounding the acrylic pipe as in Fig. 4. All sensors are evenly placed to ensure the better receiving signals are captured. Correct and precise positioning of the sensors is crucial to obtain accurate results.

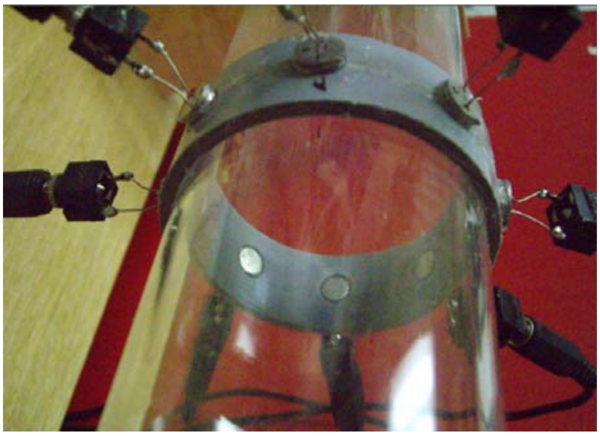
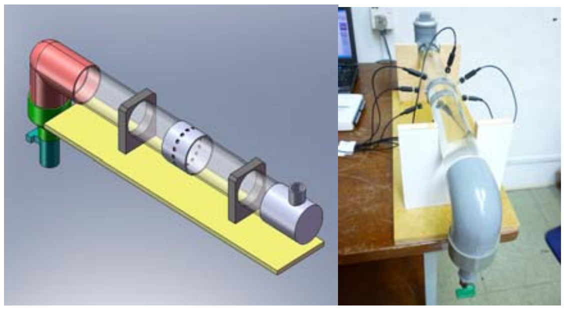


Fig. 4. Sensor jig design.

In order to fabricate a precise hardware system, the whole hardware system was designed in 3D using Solidwork software as in Fig. 5 (a) while Fig. 5 (b) is the actual hardware system used in this research.



(a) (b)

Fig. 5. Acrylic pipeline for tomography system, (a) 3D drawing, (b) fabricated experimental setup.

3. Software System

In this research, signal data from hardware system was synchronized with a software system developed to process the incoming ultrasound signal. For an ultrasonic receiver to receive ultrasound signals, the ultrasonic transmitter will require pulse tone to transmit ultrasound signals. This can be done by generating 40 kHz pulse wave via a microcontroller [8]. By using a Peripheral Interface Circuit (PIC) microcontroller, an external wave signal generator will not be necessary. Hence, it could highly decrease the cost and the hardware size of this system.

Pulse waves are sent to all 8 channels via Port B of the microcontroller which has 8 input-output (I/O) pins for 8 channels. The transmitted 40 kHz pulse wave signal was captured using an oscilloscope as shown in Fig. 6 below. These pulses will vibrate the sensor surface and produce sound wave at 40 kHz to a located receiver.

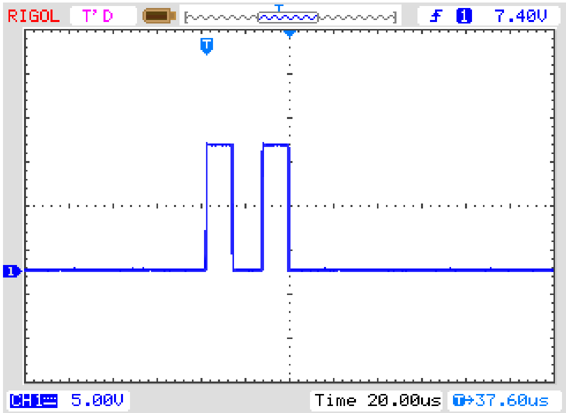


Fig. 6. 40 kHz Pulse Signal.

The transmitted ultrasound wave signal can be captured by the transceivers which are switched to receiving mode (RX). The captured acoustic wave response is shown in below Fig. 7.

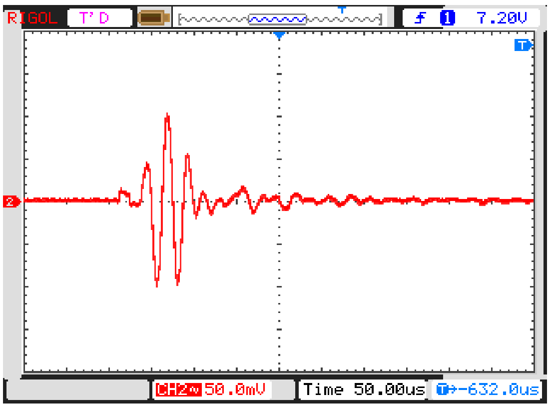


Fig. 7. Response signal at receiver.

The received signal will then be amplified via a signal conditioning circuit before reconstructing images. The ultrasonic signal conditioning circuit is shown in Fig. 8. The ultrasonic signal conditioning circuit consists of two major components where the first component is the amplifier and the second component is the signal processing circuit. The first part was built using the audio operational amplifier, LM833. This op-amp is a high speed op-amp with excellent phase margin and stability. The amplifier was designed in two stages with inverting amplifier connection. The first stage is the pre-amplifier with gain AA = -150 and the second stage is to amplify with gain AB = -150. A single gain is not sufficient enough to analyse the obtained signals.

Therefore, the received signals are amplified twice. The processed signal will then be used to reconstruct images representing the two phase liquid–gas flow.

3.1. Data Acquisition

In this research, the NI-USB 6218 data acquisition device (DAQ) from National Instruments were used. This device is connected via Universal Serial Bus (USB) to a computer. To work along with this device, Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) from National Instruments was used. The NI-USB 6218 will acquire all signals via its analogue input pins and store it in a binary text file for the image reconstruction process.

The DAQ program will only take place if the assigned external trigger pin (PFI0) from the device is triggered. This process was carried out by using the same microcontroller used to control the transceivers switching sequence to trigger NI-USB. Fig. 9 shows the data acquisition block diagram using LabVIEW software while Fig. 10 illustrates the flow chart of the data acquisition process.

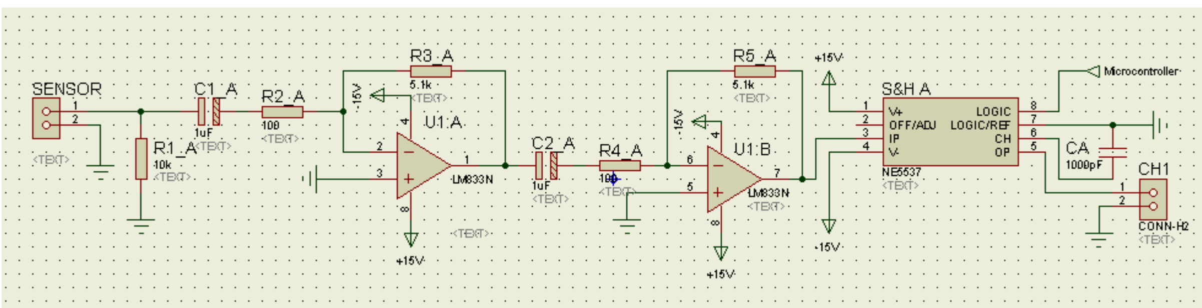


Fig. 8. Ultrasonic signal conditioning.

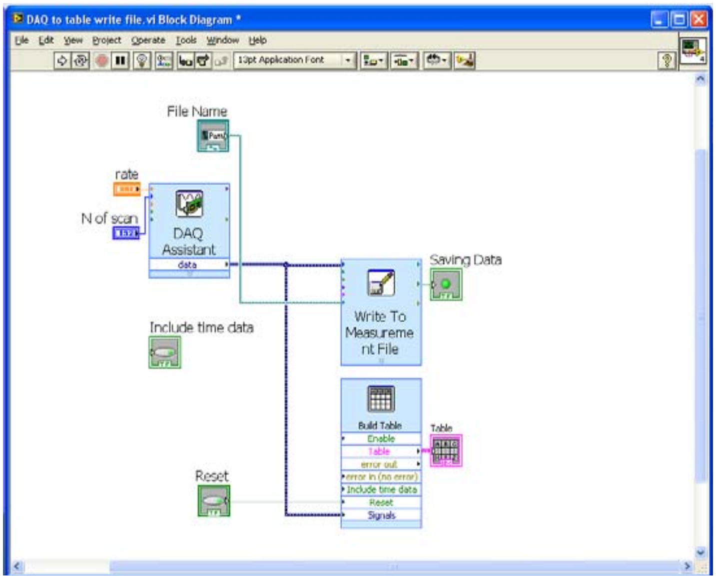


Fig. 9. NI-USB block diagram program in LabVIEW.

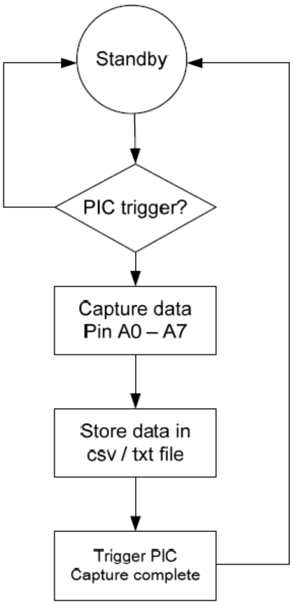


Fig. 10. The data acquisition flow chart.

4. Image Reconstruction

The final part of the system is to evaluate the obtained measurement data from the signal conditioning circuit. By using Linear Back Projection (LBP) algorithm, the flow regime image can be reconstructed. This method is computationally straight forward to implement besides low computation cost and is a widely preferable method for image reconstruction.

The measurements obtained at each projected data are the attenuated sensor values due to object space in the image plane. These sensor values are then projected back by multiplying with the corresponding normalized sensitivity maps using the below equation:

$$V_{LBP}(x,y)=\sum_{Tx=1}^{8}\sum_{Rx=1}^{8} S_{Tx,\,Rx}\times \overline{M}_{Tx,\,Rx}(x,y)\,, \qquad (1)$$

where $V_{LBP(x,y)}$ is the voltage distribution obtained using LBPA, $S_{Tx,Rx}$ is the sensor loss voltage of the transmitter (Tx) and receiver (Rx) and $M_{Tx,Rx}(x,y)$ is the normalized sensitivity maps. The flow chart to apply the LBPA program can be illustrated as in Fig. 11.

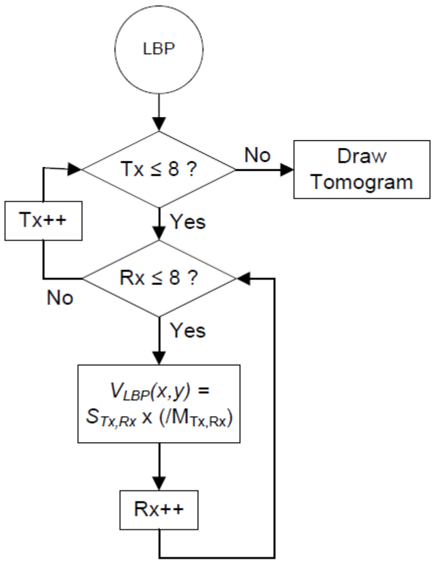


Fig. 11. Linear back projection algorithm application flow chart.

The forward problem will determine the theoretical output of each sensor when the sensing zone area is considered two dimensions. This can be solved by using the analytical solution of sensitivity maps which produce the sensitivity matrices [9]. The tomogram images are then reconstructed on the mapped sensitivity map to visualize the two phase liquid-gas flow.

Firstly, the cross section of the pipe must be mapped onto a 32 × 32 rectangular arrangement sum of 1024 pixels as shown in Fig. 12. This setting is suitable of producing a frame per second imaging [10].

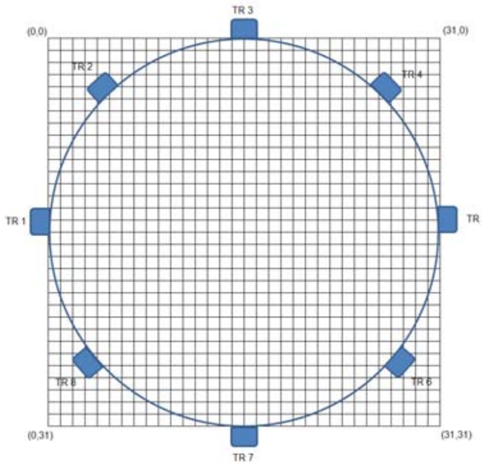


Fig. 12. Image plane model for 32×32 pixels transceiver tomogram.

The mapping configuration for the transceivers will differ from the common separated transmitter–receiver pair type of the ultrasonic transducer where the total of 16 sensors will be involved to be mapped (8 unit transmitters and 8 unit receivers). Fig. 13 below shows the image plane model for the 16 ultrasonic common type transducers where each transmitter and receiver is located side by side in sequence.

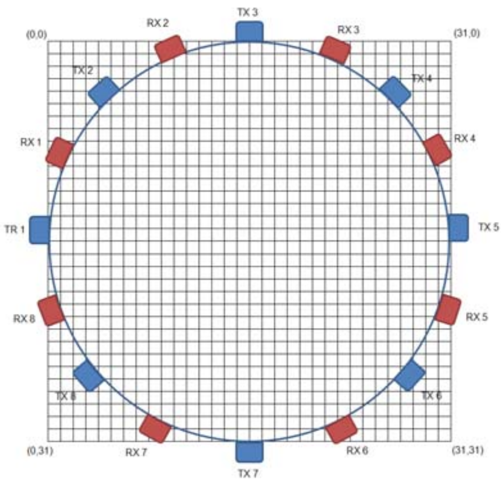


Fig. 13. Image plane model for common ultrasonic transducer.

The mapping process and sensor arrangement (as in Fig. 12 and Fig. 13**)** shows that the use of ultrasonic transceiver arrangement has more space available for the extra number of sensors to be mounted while the use of common separated transmitter-receiver sensor are very limited due to space constrain on the pipe surface.

4. Result and Discussion

The liquid–gas flow regimes are identified by placing the acrylic pipeline horizontally such that the gas phase (air) flows in the upper section of the pipe and the liquid (tap water) in the lower section. A horizontal pipe with a static liquid model and empty air are used to carry out measurements on two phase liquid–gas flow. Four types of measurement were carried out; i) full flow, ii) three quarter flow, iii) two quarter flow and iv) one quarter flow.

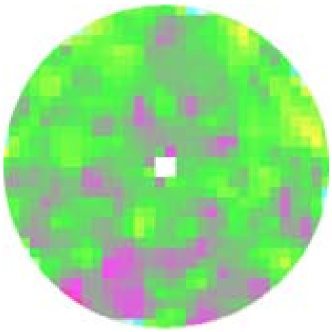
The final reconstructed tomogram results are shown in below Fig. 14.

The reconstructed images using the Linear Back Projection (LBP) technique results in blurring the object image. The blurring is due to the projection along straight lines and the smearing effect. The distribution of the intensity is centre symmetrical and dependent on the projection angle where the blurring function is the inverse of the corresponding pipe radius.

One of the methods to reduce the blurring is by using the Hybrid Binary Reconstruction Algorithm (HBRA). This algorithm has the advantage of correcting and improving the stability and repeatability of the reconstructed images [11]. This procedure is only appropriate for two-phase flow imaging in cases where the phases are well separated such as liquid-gas flow [12]. Since the use of transceivers has more spaces for more sensors to be installed, increasing the amount of sensors will contribute for better image resolution and better results.

5. Conclusion

This research shows that this system is able to detect the presence of two phase liquid–gas flow in pipelines. From the image result which has been successfully generated, the use of only 8 transceivers can produce the same result as 16 pairs of separated transmitters–receivers. The separated ultrasonic transmitter-receiver transducer which is commonly used in ultrasonic tomography measurement requires larger space to mount it on the surface of the pipeline. This is due to the needs of having extra pairs of transmitter–receiver where each of these transmitters–receiver pairs has only a single function, either to transmit or receive only. Comparing to the use of the transceivers, 8 units of ultrasonic transceivers could perform measurements as the performance of 16 pairs separated transmitter–receiver.



(a) Full flow image

(b) Three quarter image

(c) Two quarter image

(d) One quarter image

Fig. 14. Tomogram images for four flow measurement conditions.

Acknowledgements

The authors would like to thank the Faculty of Electrical Engineering, Universiti Teknologi Malaysia and Process Tomography and Instrumentation Research Group (PROTOM-i) for discussions that have been useful in this paper.

References

[1]. H. Gai, Y. C. Li, A. Plaskowski, and M. S. Beck, Flow imaging using ultrasonic time-resolved transmission mode tomography, in *Proceedings of IEEE 3rd International Conference on Image Processing and its Application,* 18-20 July 1989, pp. 237–241.

[2]. Sanderson, M. L. and Yeung, H., Guidelines for the Use of Ultrasonic Non-invasive Metering Techniques, *Flow Measurement and Instrumentation*, Elsevier, Vol. 13, 2002, pp. 125-142.

[3]. S. Zdzislaw, R. Zbigniew, K. Adam, O. Janusz, L. Mieczyslaw, Impedance Tomography System, in *Proceedings of 3rd International Symposium on Process Tomography*, Lodz, Poland, 2004, pp. 147-150.

[4]. R. A. Williams, M. S. Beck, Process tomography-principles, techniques and applications, *Butterworth-Heinemann*, Oxford, 1995, pp. 119-149.

[5]. J. Krautkramer, H. Krautkramer, Ultrasonic Testing of Materials, 4th Edition, New York, *Springer-Verlag*, 1990.

[6]. A. Al-Salaymeh, F. Durst, Development and Testing of a Novel Single-Wire Sensor for Wide Range Flow Velocity Measurements, *Measurement Science Technology*, Vol. 15, 2004, pp. 777–788.

[7]. Henriksen, Erik Karl, Jig and Fixture Design Manual, *Industrial Press*, 1973, pp. 1.

[8]. M. H. Fazalul Rahiman, R. Abdul Rahim, F. R. Mohd Hezri, T. Mazidah, Ultrasonic Transmission-Mode Tomography Imaging for Liquid/Gas Two-Phase Flow, *IEEE Sensors Journal*, Vol. 6, Issue 6, 2006.

[9]. W. Warsito, L.-S. Fan, Measurement of Real-Time Flow Structures in Gas–Liquid And Gas–Liquid–Solid Flow Systems Using Electrical Capacitance Tomography (ECT), *Chemical Engineering Science*, Vol. 56, Issues 21–22, 2001, pp. 6455–6462.

[10]. R. Abdul Rahim, Ultrasonic Tomography System for Liquid/Gas Flow: Frame Rate Comparison Between Visual Basic and Visual C++ Programming, *Jurnal Teknologi*, Vol. 44, D, 2006, pp. 131–150.

[11]. M. H. Fazalul Rahiman, R. Abdul Rahim. A Novel Hybrid Binary Reconstruction Algorithm for Ultrasonic Tomography, *Sensors & Transducers*, Vol. 89, Issue 3, 2008, pp. 93-100.

[12]. A. Plaskowski, M. S. Beck, R. Thron, T. Dyakowski, ImagingIndustrial Flows: Applications of Electrical Process Tomography. U. K: *IOP Publishing Ltd*, 1995.

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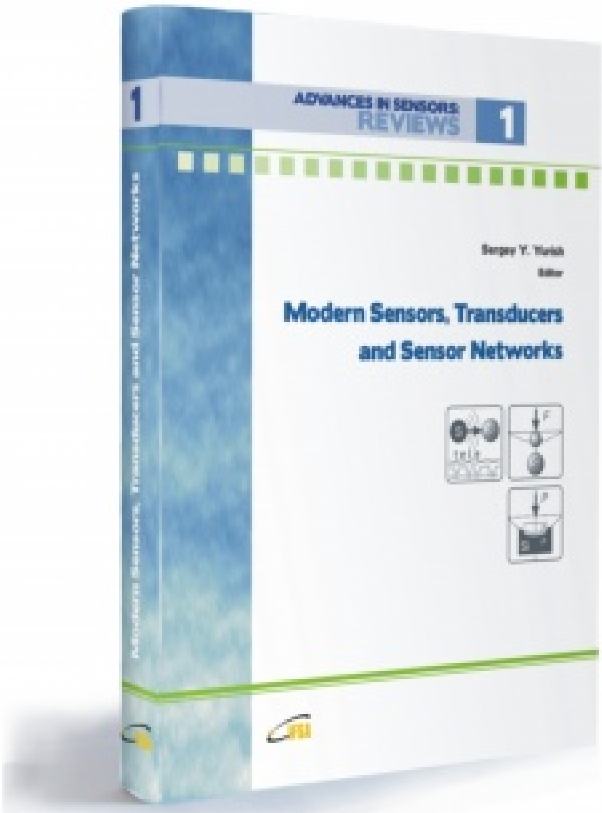

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