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ULTRASONIC TOMOGRAPHY SYSTEM FOR LIQUID/GAS FLOW: FRAME RATE COMPARISON BETWEEN VISUAL BASIC AND VISUAL C++ PROGRAMMING

RUZAIRI ABDUL RAHIM[1*], NORKHARZIANA MOHD. NAYAN[2] & MOHD. HAFIZ FAZALUL RAHIMAN[3]

Abstract. In order to process and simulate a tomography system, it has been found that Visual C++ programming has an advantage one step ahead compared to Visual Basic programming. Besides having an ability of higher processing speed, Visual C++ also encapsulates an extended function compared to Visual Basic. Real-time simulation of ultrasonic tomography system applied to liquid and gas flow has been implemented by previous researcher using Visual Basic 6.0 software programming. The program was excellent but unfortunately, the processing speed was not fast enough. Therefore, Visual C++ is expected to achieve a higher processing speed than Visual Basic. The main purpose of this research is to construct and develop a tomogram for visualizing the liquid and gas flow using Visual C++ software. By using a suitable image reconstruction algorithm, the tomogram will be interfaced with a tomography measurement system and a personal computer using Keithley DAS-1802HC interfacing card. By using Visual C++ programming software, the results showed an improvement in the image reconstruction speed and therefore, a high-speed measurement of ultrasonic tomography system could be achieved.

Keyword: Ultrasonic tomography, image reconstruction, ultrasonic sensor

Abstrak. Simulasi masa nyata bagi sistem tomografi ultrasonik yang diaplikasikan kepada aliran cecair dan gas terdahulu menggunakan program perisian Visual Basic 6.0. Namun begitu, kelajuan bagi pemprosesan adalah tidak memberangsangkan. Oleh yang demikian, Visual C++ dijangkakan dapat memberikan kelajuan pemprosesan yang lebih baik berbanding Visual Basic. Tujuan utama penyelidikan ini dijalankan adalah untuk membangunkan sebuah tomogram untuk menggambarkan visual bagi aliran cecair dan gas menggunakan perisian program Visual C++ dalam sistem ultrasonik proses tomografi. Dengan menggunakan algoritma pembinaan imej yang sesuai, tomogram tersebut akan diantaramukakan dengan sistem pengukuran tomografi dan juga komputer menggunakan kad pengantaramukaan Keithley DAS-1802HC. Dengan menggunakan perisian program Visual C++, keputusan yang diperoleh menunjukkan peningkatan kelajuan pemprosesan algoritma pembinaan imej dan sekaligus pengukuran menggunakan sistem tomografi ultrasonik yang lebih laju telah dicapai.

Kata kunci: Ultrasonik tomografi, pemprosesan imej, sensor ultrasonik

[1,2&3] Control & Instrumentation Engineering Department, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[*] Corresponding author: Email: ruzairi@fke.utm.my

1.0 INTRODUCTION

Tomography is an interdisciplinary field that is concerned with obtaining cross-sectional images of an object. The word "*Tomography*" is derived from the Greek language, *Tomo,* which means cutting section and *graph,* which means picture. Therefore, the tomography process can be defined as a process of obtaining plane section images of an object. From the Oxford English Dictionary; tomography means:

> *"Radiography in which an image of a predetermined plane in the body or other object is obtained by rotating the detector and the source of radiation in such a way that points outside the plane give a blurred image. Also in extended use, any analogous technique using other forms of radiation."*

From an engineering perspective, tomographic technology involves the acquisition of measurement signals from sensors located on the periphery of an object, such as a process vessel or a pipeline. This reveals information on the nature and distribution of the components within the sensing zone. Most tomographic techniques are concerned with abstracting information to form a cross sectional image and also the derivation of information relating to two or three dimensions.

Process tomographic instrumentation must be relatively low cost and be able to make measurements rapidly. Using an array of sensors placed around the periphery of a process vessel, it is possible to image the concentration and movement of components inside. Measurements are reconstructed to form two- or three-dimensional images, providing information to monitor processes and improve yields, quality, efficiency, and overall control. Process tomography can be applied to many types of processes, and unit operations, including pipelines, stirred reactors, fluidized beds, mixers, and separators. Depending on the sensing mechanism used, it is non-invasive, inert, and non-ionizing. It is therefore, applicable in the process industry.

A simple tomography system can be built by mounting a number of sensors around the circumference of a vertical pipe. The output signal from the sensors will be sent to the computer via an interface card. The computer will receive the signal from the respective sensors to perform data processing and finally, construct a cross-sectional flow image in the pipe. With further analysis, the same signal can be used to determine the concentration, velocity, and mass-flow rate profile of the flows.

In the process industry, information describing material distribution and validating internal modes of the process are necessary for the optimum design and operation of process equipment. Hence, there is a need for the process engineer to visualize the inside of the mixing vessel or reactors, thus relevant measurement techniques are necessary.

It is important to monitor a flow in order to ensure the efficiency of a process plant. Moreover, it is also important to have a high-speed measurement in order to provide users with maximum productivity. Therefore, a method of measuring a concentration profile in industrial vessels should be investigated. During the earlier stage, the capability of performing ultrasonic measurement system by Mohd Hafiz Fazalul Rahiman [1] is limited because the processing speed of the system is not fast enough. When there is a system that could perform higher processing speed, it will provide a higher frame rate. The system will accomplish real-time processing speed for the reconstructed image. Furthermore, image reconstruction visualization with a higher processing speed will reduce the measurement error. Therefore, further research is needed to reduce the time for processing the image and to enhance the performance of this measurement procedure.

2.0 ULTRASONIC TOMOGRAPHY

Ultrasonic sensors have been successfully applied in flow measurement, non-destructive testing and are widely used in medical imaging [2]. Ultrasonic tomography made use of ultrasonic transmitting and receiving sensors that are axially spaced along the flow stream. The sensors do not obstruct the flow. As the suspended solids' concentration fluctuates, the ultrasonic beam is scattered and the received signal fluctuates in a random manner about a mean value. This type of sensor can be used for measuring the flow velocity. Two pairs of sensors are required in order to obtain the velocity using cross-correlation method. Ultrasonic sensor propagates acoustic waves within a range of 18 kHz to 20 MHz.

Wherever there is an interface between one substance and another, the ultrasonic wave is strongly reflected. However, it is difficult to collimate and problems occur due to reflections within enclosed spaces, such as metal pipes [3]. There are two types of ultrasonic signals that are usually used. They are the continuous signal and the pulsed signal. The pulsed system will be used to avoid the standing wave patterns that can exist within the pipes. Using the ultrasonic method in air is very inefficient due to the mismatch of the sensors' impedance as compared with air's acoustic impedance. New types of sensors are continually being developed but the effective ones are expensive. The design of this sensor is critical when it is needed to reduce any sensor's ringing [4]. Both the transmitter and the receiver electronics are relatively sophisticated compared to the electrical charge sensor [5].

Ultrasonic techniques are used to make measurements in many areas of science and technology. The majority of publications on ultrasonic tomography are concerned with medical or NDT (non-destructive testing) applications. Asher [6] summarized the use of ultrasonic sensors in the chemical and process industries. In Plaskowski *et al.*[7], the authors pointed out the special difficulties in multi-phase flow imaging.

The basic theory in ultrasonic has been well developed and ultrasonic instrumentation is widely used. Schueler reviewed the history of acoustic imaging and the fundamentals of digital ultrasonic imaging [8]. At the same time, an interesting paper was published by Schafer and Lewin [9] in which, the authors thoroughly described the design, construction, and development of the front-end hardware of a digital ultrasonic imaging system. The recent trend in front-end hardware has been new sensor material development and further implementation of integrated circuit techniques.

Apart from searching for new materials, many researchers have been investigating improved methods of acoustical impedance matching between the media in order to reduce the attenuation. Another active area is to shape or guide the ultrasonic beam by using acoustic lenses [10]. Phased array sensors [11] are attracting more attention because the associated electronics has improved greatly in the past 10 years, although the narrow beam angles from a phased array are not suitable for imaging high-speed flows, where a wide beam is needed to cover the pipe area.

3.0 HARDWARE DESIGN

Figure 1 shows an overview of the system. The ultrasonic tomography system has been successfully developed by the previous researcher and for performing the real-time image reconstruction, a software program using Visual Basic has been implemented. The main purpose of this tomography process is to visualize the internal flow or the process in a pipe or plant using electronic measurement system for liquid/gas flow. In this case, a pipe is used as the prototype. The pipe is placed vertically and liquid flows inside it.

An array of 32 ultrasonic sensors is mounted equal-spaced around the circumference of the vertical flow pipe. 16 of the ultrasonic sensors are transmitters and another 16 sensors acted part as receiver. These sensors will generate electric signal representing the flow inside the pipe. These signals are then fed to the data acquisition system (DAS) and then to the computer to reconstruct the image of the internal flow inside the pipe.

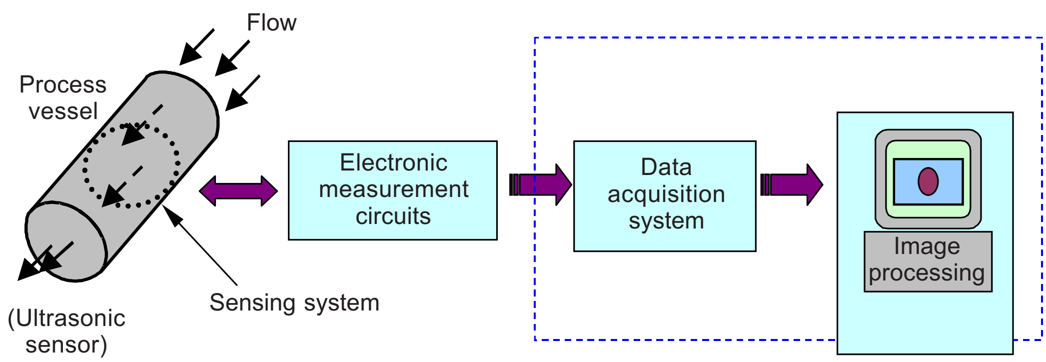

Figure 1 The ultrasonic tomography system block diagram

3.1 Sensing System

In this project, 16 pairs of ultrasonic sensors (receiver-transmitter pair) are placed on the plane, perpendicular to the length of the pipe. This arrangement is shown in Figure 2. The circle shows the cross-section of the pipe. The sensors are designed to identify

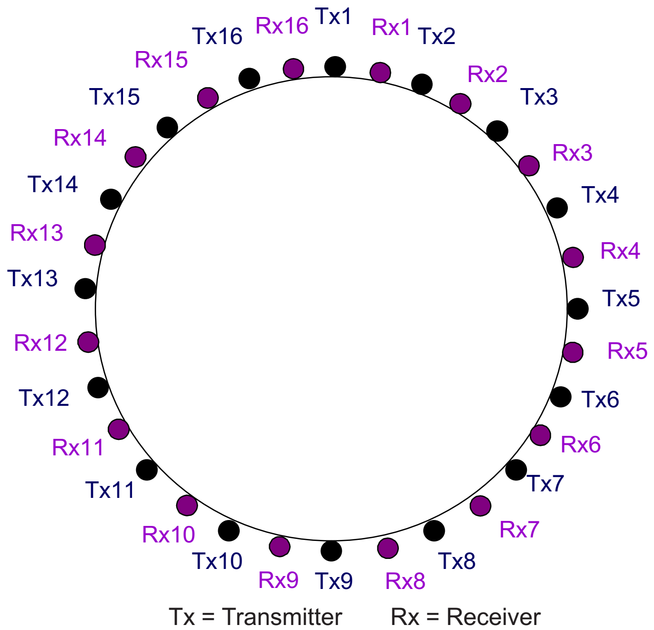

Figure 2 The arrangement of the ultrasonic transmitters and ultrasonic receivers

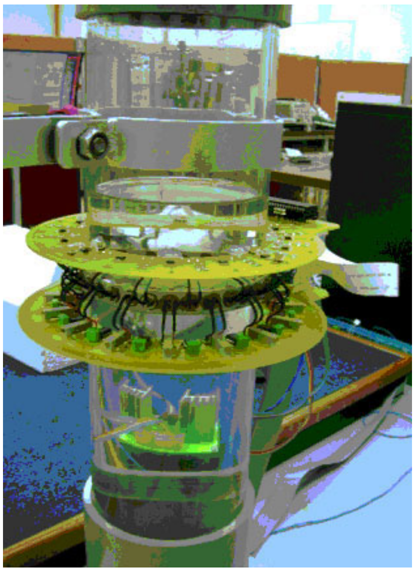

Figure 3 The ultrasonic tomography system

the flow pattern and measure the cross-sectional void fraction. The hardware is capable of producing data at 62.5 frames per second, but data transmission and image reconstruction make it only possible to observe images at maximum of 10 frames per second (by using 32 × 32 pixels image resolution). Figure 3 shows the ultrasonic tomography system that has been successfully developed.

4.0 IMAGE RECONSTRUCTION

In this project, the tomographic images are derived using a back projection algorithm. In order to derive this algorithm which provide the solution to the inverse problem, the forward problem must be solved first. In the forward problem, sensors are modeled individually to produce the corresponding sensitivity map respectively. These maps are then used to solve the inverse problem such as to derive the linear algorithm. The solution of the inverse problem will be applied to construct an image of flow concentration.

4.1 The Forward Problem

The forward problem determines the theoretical output of each sensor when the sensing area is considered to be two-dimensional. In order to calculate the sensitivity model for each sensor, the cross section of the pipe is mapped into a rectangular array, which consists of 32 × 32 pixels as shown in Figure 4.

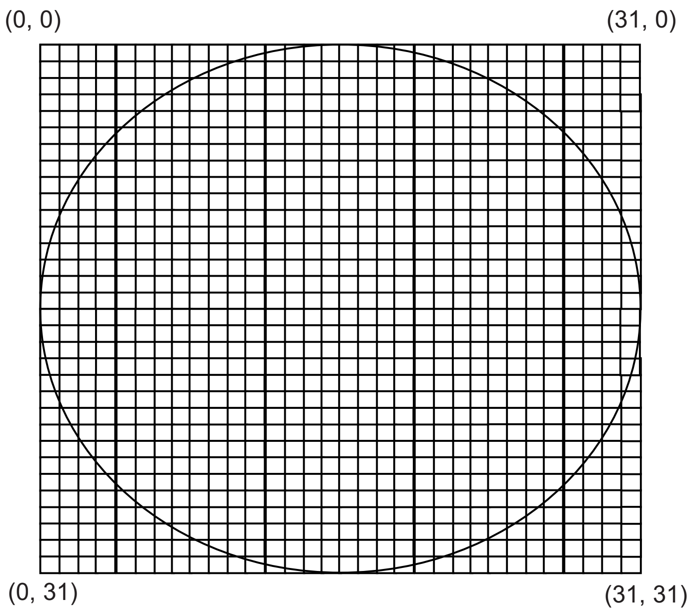

Figure 4 Image plane model for 32 × 32 pixels tomogram

The forward problem can be solved by using analytical solution of sensitivity maps which produces the sensitivity matrices. Each transmitting sensors is virtually excited and the affected pixels are taken into account. Calculation of the sensitivity matrices is already done by the previous researcher [12] to develop the image reconstructions in Visual Basic programming. In this project, the sensitivity matrices are reused to develop the image reconstruction in Visual C++ application program.

4.2 The Inverse Problem

The inverse problem is used to determine from the system response matrix (sensitivity matrices), a complex transformation matrix for converting the measured sensors value into pixels that is the tomogram [13]. The linear back projection algorithm will be produced. The linear back projection algorithm is obtained by summing the respective pixel of the concentration map for all sensors.

5.0 SOFTWARE DEVELOPMENT

Software development is a process of identifying the problem and then solving it using programming application program. Therefore, it is very important to decide which programming method is best to be applied.

In this research, the problem is to synchronize data from hardware to be processed in the software. Moreover, the application program has to be programmed with full attention in order to make sure the image processing speed will increase more than the previous application program. In order to serve this purpose, an application program is developed offering high speed of image processing data measurement from several sensors between a very short interval and in a real time mode. The working procedure of this program is collecting the online data from the sensors through an interface card, Keithley DAS-1802HC and manipulates the data from averaging until displaying it on the screen. The most important factor to be considered is the program must have a higher processing speed than previous application program that had been developed. Therefore, the most suitable developer software to be used is Microsoft Visual C++.

5.1 The Application Program

At the main frame, the application program functions were arranged in few subroutines as in Figure 5. The tasks for each subroutine are as follows:

(i) DAS acquisition - Basic application program commands for real time monitoring.
- Initialization button is to initialize the software and hardware before the data to be acquired and manipulated by the software.

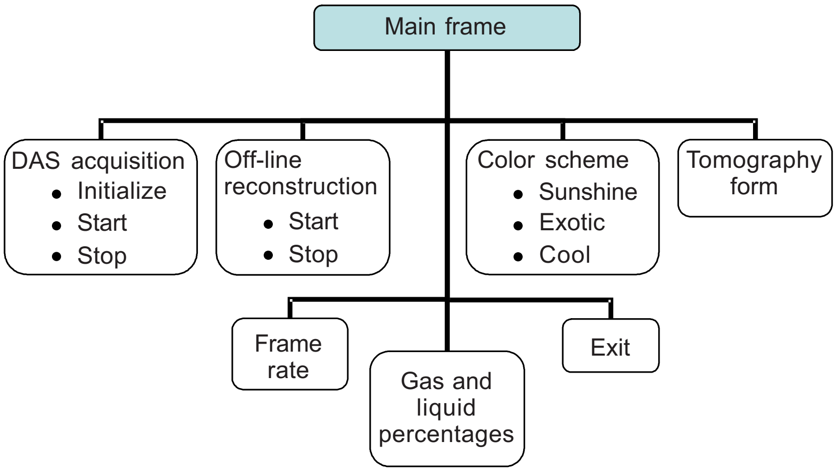

Figure 5 The application program distribution chart

- Start/Stop button is used to instruct the application program to start or stop from collecting data and also reconstruct the image. The stop button is also used to hold the current image being displayed on the tomogram.

(ii) Off-line reconstruction - Commands for the off-line reconstruction algorithm.
(iii) Color scheme - Color index selection for the tomogram visualization.
(iv) Tomography form - The tomogram visualization.
(v) Frame rate - The image processing speed calculated for the current tomogram displayed (unit in frames/seconds).
(vi) Gas and liquid percentages - Percentages of gas and liquid distribution in the visualized tomogram.
(vii) Exit button - Enable user to simply quit the application program.

The GUI for the ultrasonic tomography system is shown in Figure 6.

5.1.1 Application Program Architecture

Figure 7 shows the flow chart of the application program. Once the application program is loaded, the system initially goes through initialization process to configure the DAS-1802HC interface card.

When the initialization task is successfully executed without any error, the system will start to collect a large amount of data from 16 sensors via the interface card. The collected data has to go through many processes before the concentration image can be successfully displayed. In the beginning, the collected data will be used to solve the forward and inverse problem. The solution of the problem is then shown as the result of the system, which will be discussed in detail in the following section. Basically, the manipulated data will be used to generate the concentration profile that is to be displayed.

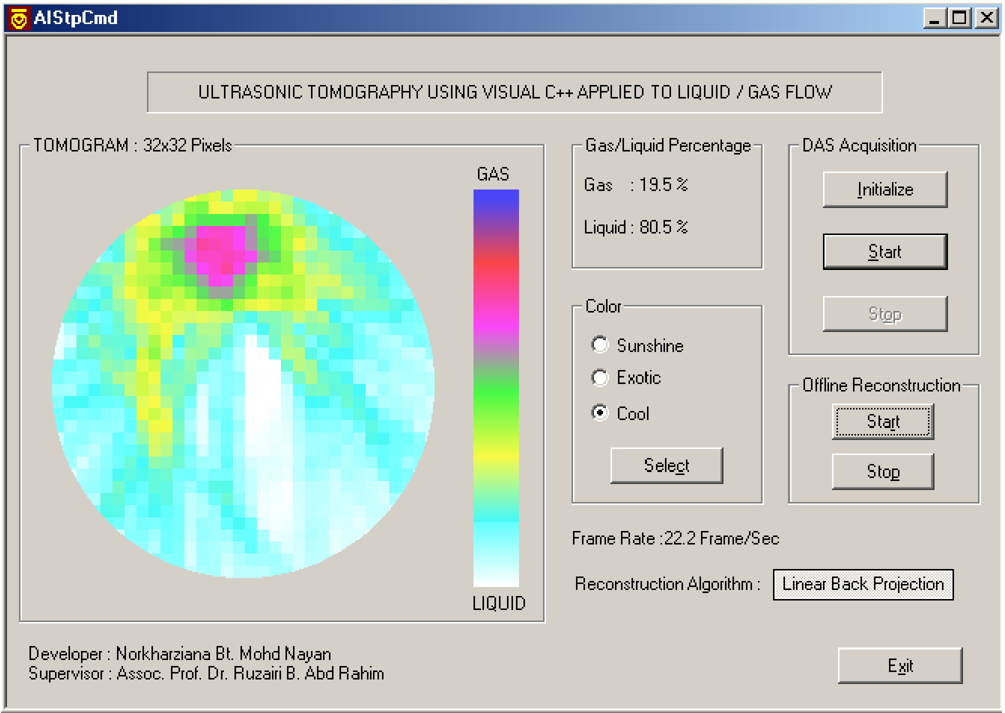

Figure 6 Application program GUI

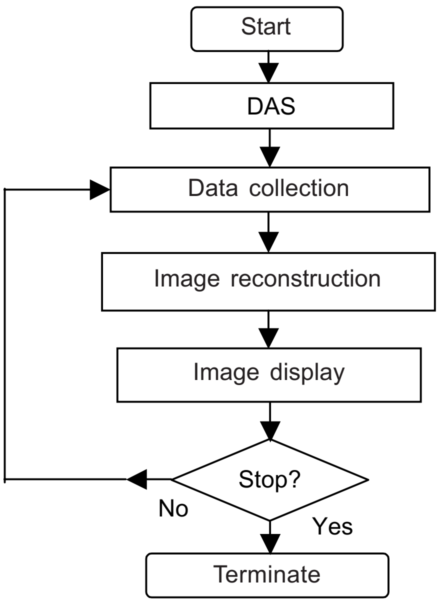

Figure 7 Application program flow chart

As long as the application program is not instructed to terminate or hold, the program execution will be returned to the data collection task again to collect data and complete the cycle. The program will repeat the cycle until it is instructed to hold the current tomogram displayed or to terminate.

5.1.1.1 Initialization Task

The main purpose of the initialization is to configure the interface card and the components implemented in the program synchronously into proper operating modes so that they can work together. The initialization task will configure the memory locations that are used by the program instruction during data manipulation. Subsequently, the interrupt level, DMA level and global gain will be configured according to the default setting mode.

5.1.1.2 Data Collection Task

After being initialized, the application program will firstly instruct the data collection task to start collecting data. Before the application program performs any data collection task, the scan channel will be set to 16. Then, promptly data collection will be performed and saved the data into a memory location reserved for a channel 0 for further instruction. The channel will be incremented for the next channel and perform data scanning and followed by saving data into another memory location. The scanning of the channel will be stepped from start channel (channel 32) to stop channel (channel 47). When the stop channel is reached, the data collection task will reload to the start channel. On the following cycle, all the data are collected from each channel. This collecting and adding 16 data are collected for each channel.

5.1.1.3 Calibration

It is very important to ensure that the measurement and visualization of the tomogram display is accurate and reliable. In order to achieve that purpose, a data manipulation task with calibration must be performed. By using another program, data from each sensor will be captured and saved in another file. The calibration is done by setting a full liquid flow in the experimental pipe and measure the voltage of each receiver for each transmitter projection. The calibration can be described in Figure 8.

5.1.1.4 Programming Architecture

This task becomes the most important task since the main function of the application program is to generate a concentration map of flow in a pipe, calculate the liquid and gas distribution percentages as well as the image process speed calculation. This task will perform calculations in order to solve both forward and inverse problem. The main programming architecture flow chart is given in Figure 9.

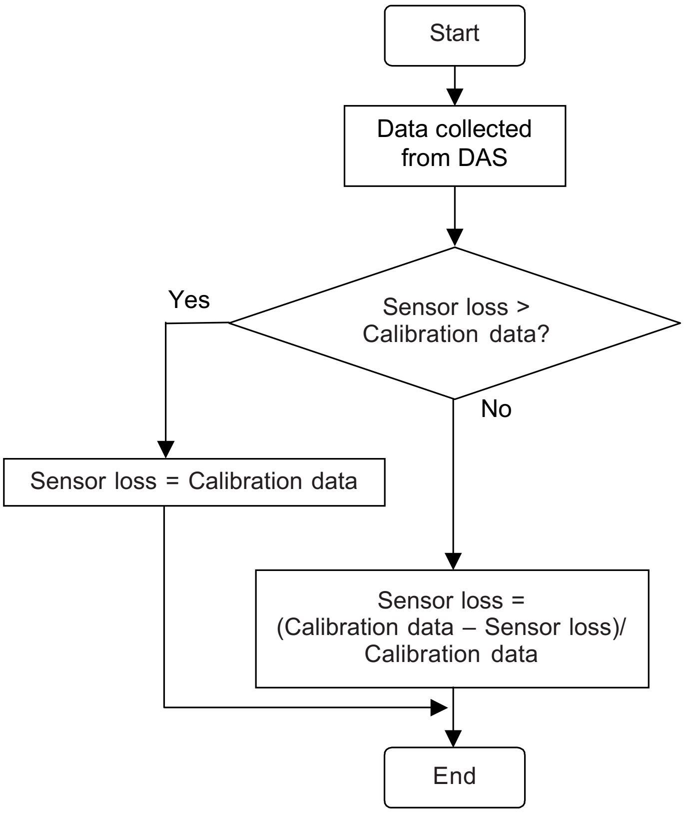

Figure 8 Calibration task flow chart

From data acquisition after the initialization, the data will be acquired from the ultrasonic tomography system. Then, the data acquired will be used to draw the tomogram using Linear Back Projection algorithm. After that, the frame rate for the image processing speed and the liquid and gas percentages will be displayed on the application program. Figure 10 shows the details of Draw Image LBP subroutine.

The tomogram drawing was accomplished by using bitmap method. The DDB (Device Dependent Bitmap) method is used to perform fast bitmap drawing. The 32 × 32 square matrix of concentration profile obtained from the image reconstruction algorithm which is calculated by the application program was stored in FanBeamMap (32, 32) array. Each profile in the FanBeamMap (32, 32) array is converted into a color level according to the profile value.

Next, each profile containing the color level information is extracted onto the screen using the SetBitmapBits function. The SetBitmapBits function will set the bits of bitmap to the bit values. To calculate the tomogram refresh rate or known as frame rate, the GetTickCount function is used to where it will retrieve the number of milliseconds that have elapsed since the current operation has started. Figure 11 shows the liquid and gas percentages together with frame rate calculation process.

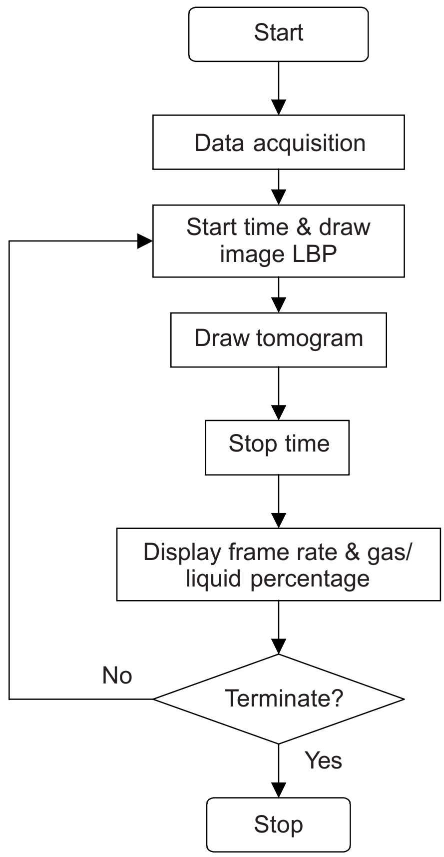

Figure 9 Main programming architecture

To ensure that the calculation of liquid and gas distribution is correct, a static modeling of the liquid and gas calculation is calculated in order to compare the theoretical result and the application program that has been developed. Gas in the liquid flow (Figure 12) is created using a test pipe with a diameter of 27 mm.

The gas and liquid calculation by using software is as follows:

$$\text{Gas percentage} = \frac{\sum \text{Value in each pixel}}{\sum \text{Max. value in each pixel}} \times 100\% \quad (1)$$

where:

(i) Value in each pixel depends on the attenuated voltage obtained by the receiver.
(ii) Maximum value for each pixel is 255. Therefore, the sum of maximum value in each pixel is 261 120.

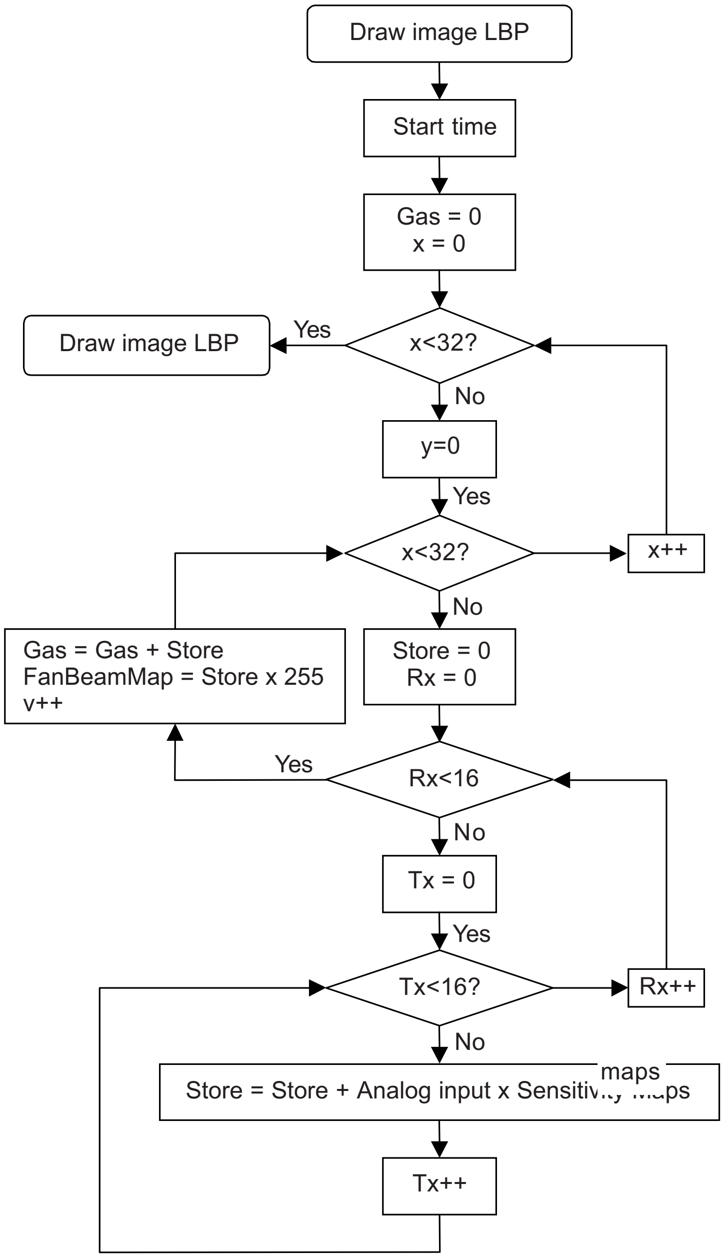

Figure 10 Draw image LBP subroutine

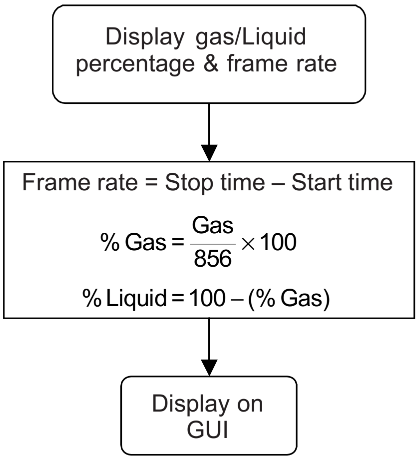

Figure 11 Calculation of gas and liquid percentage and frame rate subroutine

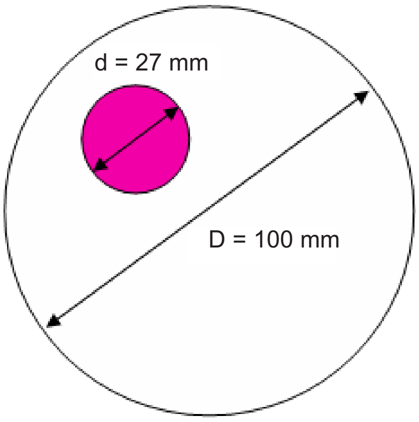

Figure 12 The static model to calculate the liquid and gas percentages

Meanwhile, the liquid percentage is obtained by simply deducting the normalized gas concentration by 100. By using static model, the gas percentages in the experimental pipe can be obtained by using the following equation:

$$\text{Gas percentage} = \frac{A_{Liquid} - A_{Gas}}{A_{Liquid}} \times 100\% \tag{2}$$

5.1.1.5 Image Display Task

Before the concentration profile in the previous map can be displayed, the application program must identify the display format. As default, the application program will display the map in "cool" color index unless the user chooses to change the color index. After displaying the corresponding color index, the application program will generate the normalized sensor voltage for each sensor.

User can choose either to run the program in on-line (real-time) measurement or the off-line reconstruction image by clicking the Start control button in Offline Reconstruction panel or clicking the Initialization control button in the DAS Acquisition panel.

5.1.1.6 Graphic User Interface

Figure 6 shows the Graphic User Interface (GUI) displaying a tomogram with 32 × 32 pixels image resolution. For the analysis of results, the same programming and GUI have been developed with different type of image resolution that is 8 × 8 pixels image resolution, 16 × 16 pixels image resolution, 64 × 64 pixels image resolution, and 128 × 128 pixels image resolution.

6.0 RESULT ANALYSIS

Experiments have been performed using various color indices to observe the visualization of the gas and liquid flow in the experimental pipe. During the experiment, a test pipe with a diameter of 27 mm was used to make the occurrence of the gas in the pipe that contains fill of liquid flow.

6.1 Experiment Results

By using 32 × 32 pixels resolution, the reconstructed images for the test pipe are shown in Figure 13 for cool color index; Figure 14 for exotic color index and Figure 15 for sunshine color index.

In order to determine the performance of Visual C++ on reconstructing real-time images, several image resolutions have been used. They are 8 × 8 pixels, 16 × 16 pixels, 32 × 32 pixels, 64 × 64 pixels, and 128 × 128 pixels. From the reconstructed images, the frame rates for each pixel resolution were captured. The results are shown in Figure 16.

From Figure 16, the frame rate values were represented by the graph in Figure 17 and they were compared with the existing application program using Visual Basic [12].

7.0 DISCUSSION

Different sets of color index will differentiate the image better. In this application program, gas and liquid distribution can easily be differentiated on the tomogram by using suitable color index. It also depends on the user perspective of viewing the image.

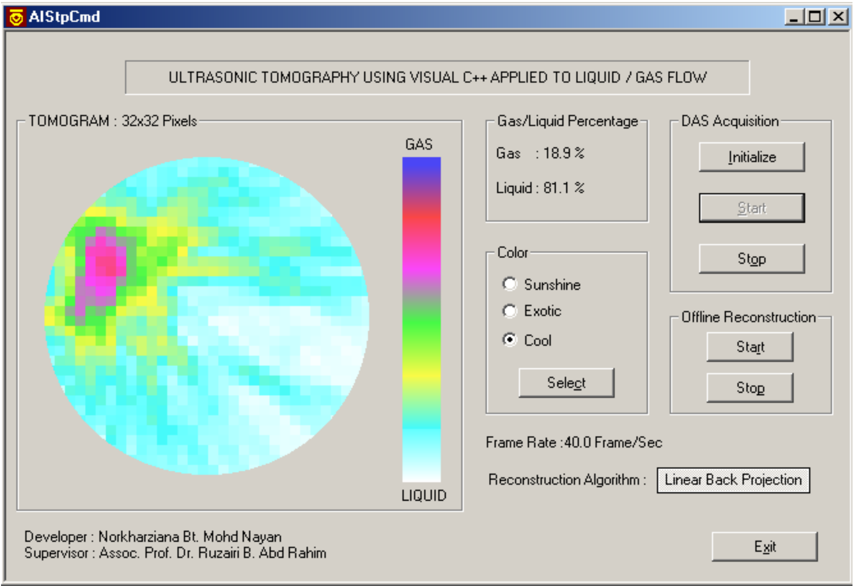

Figure 13 The tomogram image with cool color index

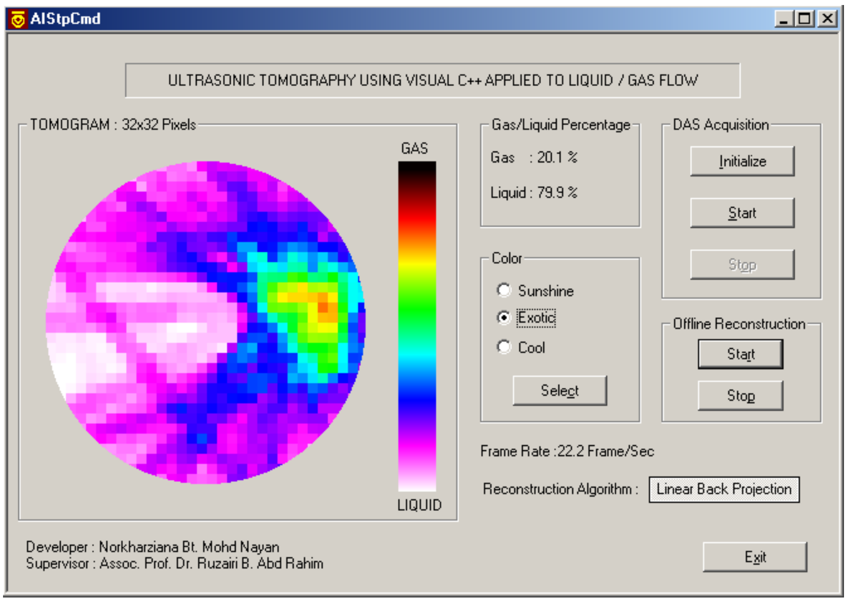

Figure 14 The tomogram image with exotic color index

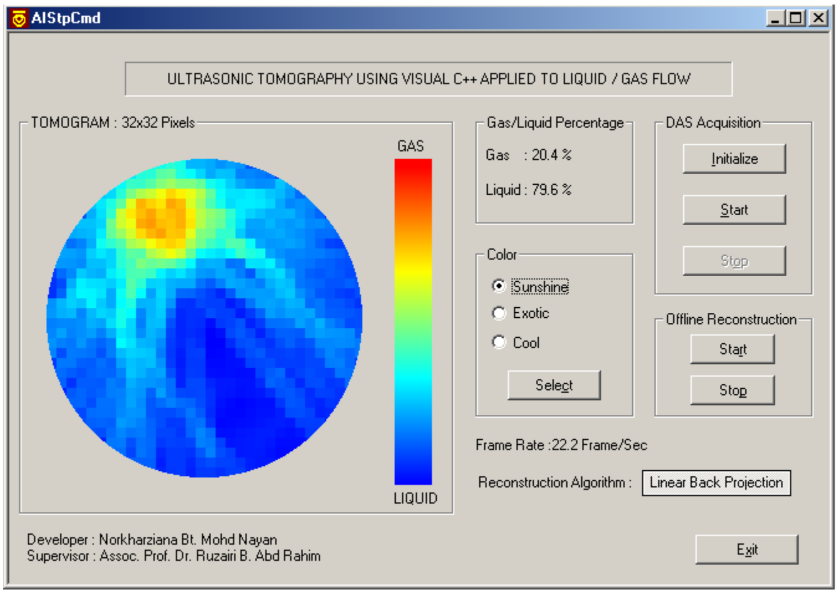

Figure 15 The tomogram image with sunshine color index

From various image resolution displayed; 128 × 128 pixels image resolution shows better image interpretation. Therefore, liquid/gas percentage calculation is more accurate. Unfortunately, the image processing time is very slow. Meanwhile, for the 8 × 8 pixels image resolution, it can be seen that the image visualized is very poor, but the frame rate is up to 1 Giga frame per second.

From the graphical comparison between Visual C++ application program and Visual Basic, it can be seen that Visual C++ has higher image processing speed compared to Visual Basic software.

From the static modeling that was used to calculate the distribution of liquid and gas flow visualized in the tomogram, the liquid and gas percentage achieved is 29.17% for gas distribution and 70.82% for liquid distribution in the experimental pipe. Meanwhile, from the application program, it showed that the liquid and gas percentage is in the average of 20% and 80% respectively. The difference between the programming calculation and the mathematical modeling calculation is due to calculation of pixel value on the program.

Higher resolution will reduce the measurement error, which is the error of gas and liquid percentage in the experimental pipe. This is because the gas and liquid percentage is calculated based on pixel value on the tomogram. Therefore, high resolution will reduce the measurement error. But, the smearing effect of LBP makes the error percentages increase. However, using better image reconstruction algorithm such as Hybrid Back Projection or Iterative Back Projection could cut down the smearing effects and therefore, reduce the liquid and gas percentages error.

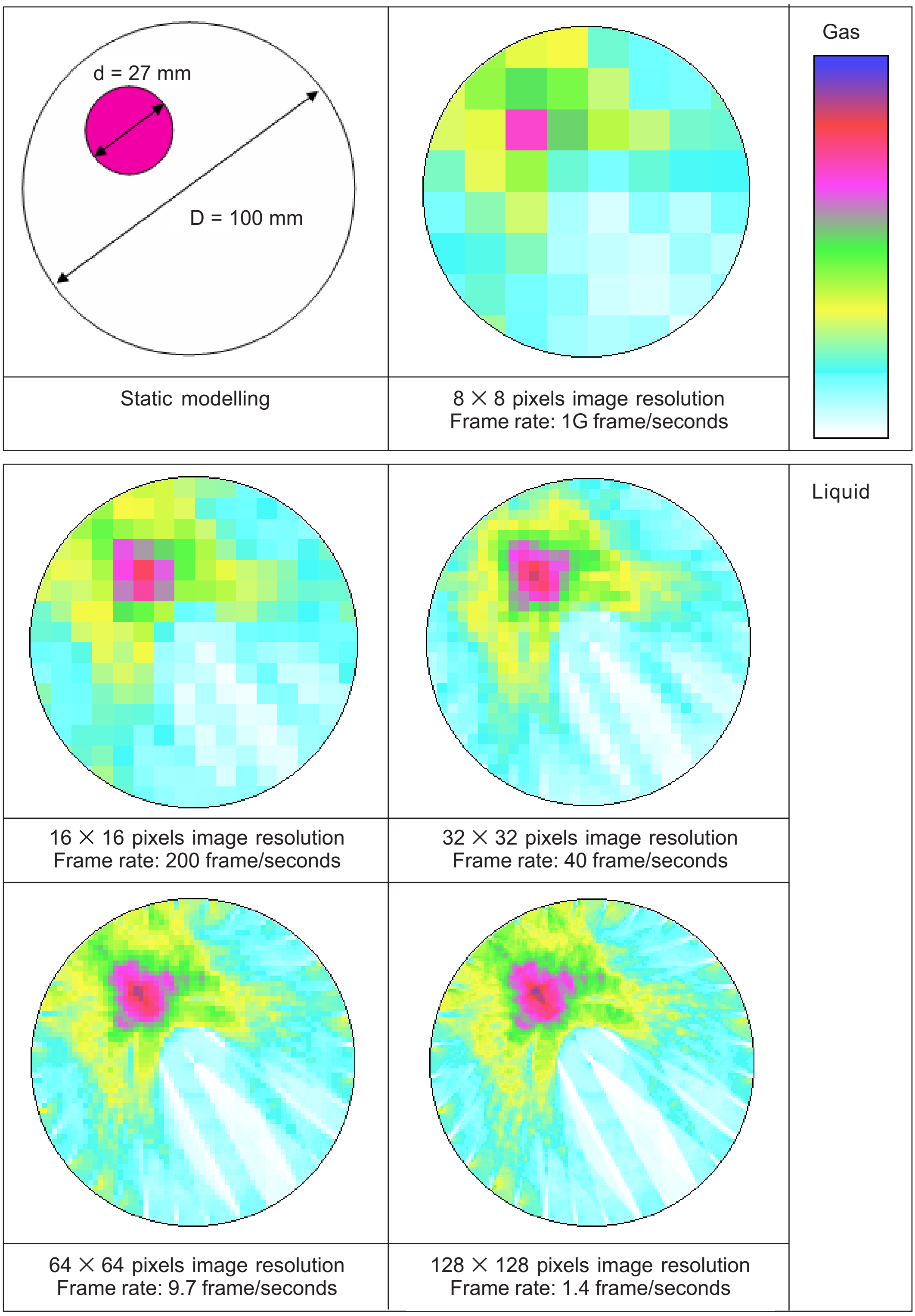

Figure 16 Results on static gas model with different image resolution

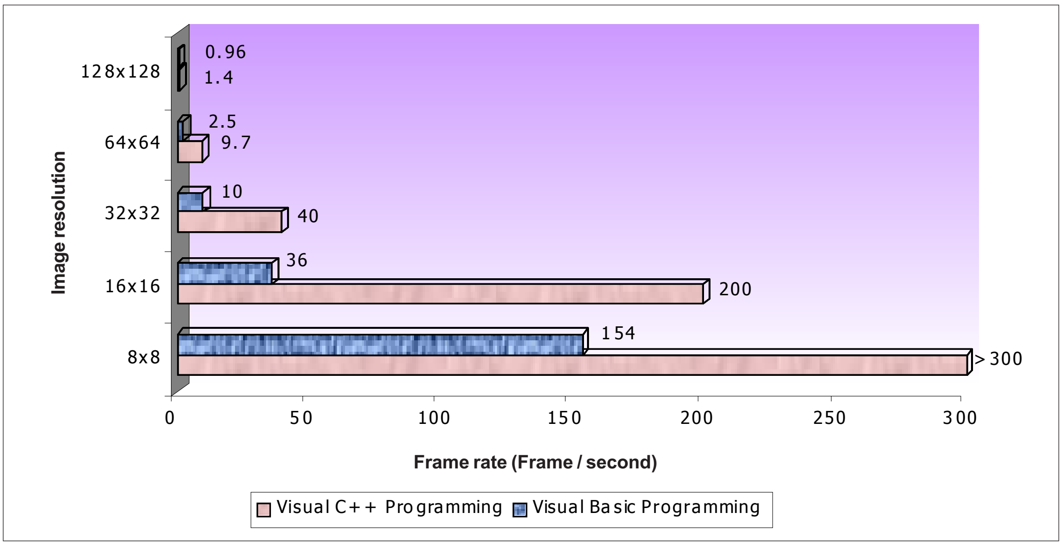

Figure 17 Frame rate comparison between Visual Basic and Visual C++

8.0 CONCLUSIONS

The ultrasonic tomography system for visualizing the real-time image of liquid and gas flow using Visual C++ software platform has been developed to visualize the internal flow of the experimental pipe. Compared to the previous results, it can be seen that the image processing speed has been increased by using Visual C++. Therefore, the performance of real-time image reconstruction has been improved.

Through the current research work, it is found that the importance of monitoring a flow is to ensure the efficiency of a process plant. Moreover, it is also important to have a high-speed measurement in order to obtain an exact visual of the corresponding flow. It has been found that the latest versions of software programming (Visual C++) have an advantage one step ahead compared to the older version of the programming (Visual Basic). Besides having an ability of higher processing speed, it also encapsulates an extended function rather than the older version. Therefore, a higher resolution at a higher speed measurement can be realized by using Visual C++ software programming.

REFERENCES

[1] Mohd Hafiz Fazalul Rahiman. 2003. Image Reconstruction Using Transmission-Mode of Ultrasonic Tomography in Water/Particles Flow. B. Sc. Thesis. Universiti Teknologi Malaysia.

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

[3] Sallehuddin Ibrahim. 2000. Measurement of Gas Bubbles in a Vertical Water Column Using Optical Tomography. Ph. D. Thesis. Sheffield Hallam University, UK.

[4] Gregory, I. A. 1987. Shot Velocity Measurement Using Electrodynamic Transducers. Vol. 1 & 2. Ph. D. Thesis. University of Manchester Institute of Science and Technology.

[5] Xu, L. A. 1987. Pulsed Ultrasound Cross-Correlation Flowmeter for Two - Component Flow Measurement. Ph. D. Thesis. University of Manchester Institute of Science and Technology, UK.

[6] Asher, R. C. 1983. Ultrasonic Sensors in the Chemical and Process Industries. *Journal Science Instrument Physics*. 16: 959-963.

[7] Plaskowski, A., M. S. Beck, R. Thron, and T. Dyakowski. 1995. *Imaging Industrial Flows: Applications of Electrical Process Tomography*. UK: IOP Publishing Ltd. 76-121.

[8] Schueler, C. F., H. Lee, and G. Wade. 1984. Fundamental of Digital Ultrasonic Imaging. *IEEE Trans. on SU*. SU-31: 195-217.

[9] Schafer, M. E., and P. A. Lewin. 1984. The Influence of Front-end Hardware on Digital Ultrasonic Imaging. *IEEE Trans on SU*. SU-31: 259-306.

[10] Hoyle, B. S. 1996. Process Tomography Using Ultrasonic Sensors. *Measurement Science Technology*. 7: 272-280.

[11] Xu, L. J., and L. A. Xu. 1997. Ultrasound Tomography System for Monitoring Bubbly Gas/Liquid Two Phase Flow. *IEEE Transactions on Ultrasonic, Ferroelectrics and Frequency Control.* 44(I).

[12] Mohd Hafiz Fazalul Rahiman. 2005. *Non-invasive Imaging of Liquid/Gas Flow Using Ultrasonic Transmission-mode Tomography*: M. Sc. Thesis. Universiti Teknologi Malaysia.

[13] Mohd Fua'ad Rahmat. 1996. *Instrumentation of Particle Conveying Using Electrical Charge Tomography*. Ph. D. Thesis. Sheffield Hallam University, UK.