DEVELOPMENT OF ULTRASONIC TOMOGRAPHY SYSTEM FOR LIQUID/GAS FLOW MEASUREMENT IN A VERTICAL COLUMN

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Development of Ultrasonic Tomography System for Liquid/Gas Flow Measurement in a Vertical Column

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Dengan nama Allah yang Maha Pemurah lagi Maha Penyayang.

To my beloved and supportive parents,

my brothers and sister,

and Intan Maisarah Bt. Abdul Rahim.

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LIST OF ABBREVIATIONS

Abbreviation		Definition
AC	-	Alternating Current
ADC	-	Analogue-to-Digital Converter
CAT	-	Computerised Axial Tomography
CPU	-	Central Processing Unit
CS	-	Control Signal
CT	-	Computerised Tomography
DA	-	Dielectric Absorption
DAQ	-	Data Acquisition System
DC	-	Direct Current
DCU	-	Digital Controller Unit
ECT	-	Electrical Capacitance Tomography
EIT	-	Electrical Impedance Tomography
EMT	-	Electromagnetic Tomography
EPR	-	Eminent Pixel Reconstruction
ERT	-	Electrical Resistance Tomography
GUI	-	Graphical User Interface
IC	-	Integrated Circuit
ICSP™	-	In-Circuit Serial Programming™
IPT	-	Industrial Process Tomography
LBP	-	Linear Back Projection
MATLAB	-	Matrix Laboratory
MCU	-	Microcontroller Unit
MIPS	-	Million Instruction Per Second

MRI	-	Magnetic Resonance Imaging
NMR	-	Nuclear Magnetic Resonance
Op-Amp	-	Operational Amplifier
PC	-	Personal Computer
PCB	-	Printed Circuit Board
PCI	-	Peripheral Component Interconnect
PET	-	Positron Emission Tomography
PT	-	Process Tomography
RISC	-	Reduced Instruction Set Computer
RS232	-	Recommended Standard 232
SHA	-	Sample and Hold Amplifier
SnH	-	Sample-and-Hold
TI	-	Texas Instruments
USB	-	Universal Serial Bus
UT	-	Ultrasonic Tomography
UTT	-	Ultrasonic Transmission Tomography

LIST OF SYMBOLS

Symbol		Definition
$\bar{A}$	-	Average Mean of Matrix A
$\bar{B}$	-	Average Mean of Matrix B
A_G	-	Percentage of Gas Area
Agas	-	Measured Gas Area
A_L	-	Percentage of Liquid Area
Aliquid	-	Measured Liquid Area
B (x,y)	-	EPR Marking Matrix
c	-	Velocity of Sound
C	-	Capacitor
C_{max}	-	Maximum Concentration
C_{Th}	-	Concentration Threshold
d	-	Diameter
dB	-	Decibel
E_a	-	Estimated Gas Area
F_c	-	Center Frequency
fps	-	Frames per second
Gas_Down_{xy}	-	Simulated Gas Bubble (Downstream)
Gas_Up_{xy}	-	Simulated Gas Bubble (Upstream)
Gas_{xy}	-	Simulated Gas Bubble
kHz	-	Kilohertz
L	-	Distance
M_a	-	Measured Gas Area
ME	-	Measurement Error

MHz	-	Megahertz
M_P	-	Maximum Total Pixels
$M_{Tx,Rx}(x, y)$	-	Normalized Sensitivity Matrices
N_{delay}	-	Number of Delayed Frames
nF	-	Nanofarad
$Pgas$	-	Gas Component Percentage
$Pliquid$	-	Liquid Component Percentage
P_r	-	Reflection Coefficient
P_t	-	Transmissions Coefficient
R	-	Resistor
Rx	-	Receiver
SimMap	-	Simulated Phantom Matrix
Sim_x	-	Simulation Profile
SnH	-	Sample-and-Hold
S_{TxRx}	-	Sensor Loss Voltage
t_s	-	Observation Time
Tx	-	Transmitter
V	-	Flow Velocity
V-	-	Inverting Input
$V(x,y)$	-	Concentration Profile
V+	-	Non-inverting Input
$V_{EPR}(x,y)$	-	Concentration Profile using LBP
$V_{LBP}(x,y)$	-	Concentration Profile using LBP
$V_{p\text{-}p}$	-	Voltage Peak-to-Peak
V_{ref}	-	Voltage Reference
$V_{ref\,TxRx}$	-	Reference Sensor Voltage
V_{Supply}	-	Voltage Supply

V_{TxRx}	-	Measured Sensor Voltage
Z	-	Acoustic Impedance
ρ	-	Density
τ	-	Transit Time
f	-	Frequency
α	-	Attenuation Coefficient
λ	-	Ultrasound Wavelength
$\circ$	-	Degree
μF	-	Microfarad
2D	-	Two Dimensional
3D	-	Three Dimensional

PEMBANGUNAN SISTEM ULTRASONIK TOMOGRAFI UNTUK PENGUKURAN ALIRAN CECAIR/GAS DALAM SALURAN MENEGAK

ABSTRAK

Aliran cecair/gas dua-fasa boleh didapati secara meluas dalam pelbagai aplikasi termasuk industri kimia dan petroleum. Pengukuran aliran dua-fasa adalah parameter yang penting untuk aplikasi yang memerlukan ketepatan pengukuran aliran. Aliran dua-fasa adalah fenomena yang sangat penting untuk sektor petroleum dan gas. Jika dibandingkan dengan aliran satu-fasa, ciri-ciri aliran dua-fasa adalah jauh lebih kompleks. Oleh kerana itu, peningkatan teknologi instrumentasi dan pengukuran aliran dua-fasa seperti penciptaan meter dua-fasa akan mempunyai peningkatan permintaan kerana akan memberi manfaat yang signifikan kepada banyak industri. Berdasarkan pada kelebihan teknik pengimejan tomografi, teknik pengesanan ultrasonik yang tidak menganggu proses aliran dapat direalisasikan. Litar elektronik digunakan untuk proses penghantaran dan penerimaan isyarat analog serta sistem perolehan data untuk pemindahan data kepada computer. Algoritma rekonstruksi imej yang sesuai juga penting untuk menyediakan akses visual kepada aliran cecair/gas dua-fasa sambil memberikan maklumat anggaran distribusi komponen untuk proses pemerhatian masa nyata. Ciri-ciri penting bagi pemilihan sensor telah diambil perhatian dan diseimbangkan antara frekuensi operasi yang tinggi untuk kepekaan yang lebih baik dan keluasan saluran menegak untuk mengelakkan isyarat pengukuran tidak dapat dikesan akibat redaman lengkap. Kualiti pengimejan pergerakan komponen cecair dan gas telah berjaya ditingkatkan melalui penggunaan algoritma baru Rekonstruksi Piksel Penting (RPP) jika dibandingkan dengan algoritma Unjuran Kembali Linear (UKL) yang umum. Kajian simulatif terhadap pengukuran halaju aliran dua-fasa cecair/gas untuk sistem ultrasonik tomografi satah berganda telah dijalankan. Dua cara berbeza berdasarkan penggunaan teknik korelasi-silang telah menunjukkan kesesuaian teknik tersebut untuk menganggarkan kelajuan aliran. Kualiti rekonstruksi imej terhadap aliran dua-fasa dilihat mempunyai kesan yang signifikan dengan menggabungkan algoritma RPP dengan teknik Penapisan Median yang mengabaikan bacaan piksel yang tidak serasi dengan keadaan sekitar. Gabungan algoritma RPP dengan teknik Penapisan Median dilihat memberi kesan yang signifikan dalam meningkatkan kualiti rekonstruksi imej dengan mengabaikan bacaan piksel yang tidak serasi dengan keadaan sekitar. Kelebihan lain akibat dari kombinasi tersebut adalah kesan yang halus terhadap rekonstruksi imej sambil memberikan gambaran komponen cecair dan gas dua-fasa yang lebih baik, malah hasilnya juga mempunyai bentuk dan saiz yang menghampiri keadaan sebenar aliran. Kaedah statistik linear juga diperkenalkan untuk menganggar nilai ambang-atas yang sesuai untuk pengimejan saiz komponen gas yang berbeza dalam saluran yang ingin dipantau terutama dalam kejayaan mengesan gelembung gas yang kecil. Keputusan yang diperolehi mungkin berguna bagi pemantauan aliran cecair/gas dalam pelbagai industri seperti proses campuran kimia, penghantaran bahan kimia atau pemantauan proses.

DEVELOPMENT OF ULTRASONIC TOMOGRAPHY SYSTEM FOR LIQUID/GAS FLOW MEASUREMENT IN A VERTICAL COLUMN

ABSTRACT

Liquid/gas two-phase flow widely exists in many applications including chemical and petroleum industries. Measurement of this two-phase flow is an essential parameter for these applications where accurate flow measurement is required. Two-phase flow, a phenomenon of critical importance to oil and gas sector where compared with single-phase flow, its flow characteristic is much more complex. Thus, the improvement of the instrumentation and measurement technology for the two-phase flow such as the development of two-phase flowmeters will have a growing demand since it will bring significant benefits to many industries. Based on the advantage of tomographic imaging technique, non-invasive ultrasonic sensing technique is realized by using electronic measurement circuits for transmitting and receiving the analog signals, data acquisition system for transferring the data to the PC and most importantly the suitable image reconstruction algorithm for providing visual access to the two-phase liquid/gas flow and estimating the component distribution for real-time measurement. The important characteristic for sensor selection is noted and balanced between high operating frequency for increased spatial sensitivity and the cross-sectional area of the vertical column to avoid undetected measurement signal caused by complete attenuation. The enhancement of liquid and gas component distribution imaging over the common Linear Back Projection (LBP) algorithm has been successful by implementing the new Eminent Pixel Reconstruction (EPR) algorithm. Simulative study on liquid/gas two-phase velocity measurement for dual-plane ultrasonic tomography system also has been made. Two different methods based on the use of cross-correlation technique have shown the usability of the technique for estimating the flow velocity. The image reconstructions quality of the two-phase flow is seen to have a significant increase by combining the EPR algorithm with Median Filtering technique that eliminated pixel values which are unrepresentative of their surroundings. Another advantage of such combination is the smoothen effect on the reconstructed images, resulting in better visualization of the two-phase liquid and components because the outcome have approximating shape and size if compared with the actual flow condition. Linear regression method are also introduced for configuring the appropriate threshold values for imaging different size of gas component inside the investigated column especially on the successful detection of small gas bubbles. The results obtained can be useful for the online monitoring of liquid/gas flow in many industrial processes such as chemical mixing process, fluid transportation or process monitoring.

CHAPTER 1

INTRODUCTION

The word 'tomography' which according to the Oxford English Dictionary means a technique for displaying a cross section through a human body or other solid objects using X-rays or ultrasound. The origin of the word 'tomography' is the combination of the word *tomos* which origins from Greek and the word *graphy*. *Tomos* means "a section" or "a cutting" while graphy is a technique of producing images. The Encyclopaedia Britannica describes tomography in a more application-orientated manner:

> A still more complex technique variously called computerised tomography (CT), or computerised axial tomography (CAT), was developed by Godfrey Hounsfield of Great Britain and Allan Cormack of the United States during the 1970s. Since then it has become a widely used diagnostic approach. In this procedure, a narrow beam of X-rays sweeps across an area of the body and is recorded not on film but with a radiation detector as a pattern of electrical impulses. Data from many sweeps are integrated by a computer, which uses the radiation absorption figures to assess the density of tissues at thousands of points. The density values appear on a television-like screen as points of varying brightness to produce a detailed cross-sectional image of the internal structure under scrutiny (Vol. 11, p. 837)

As it can be concluded from this description, tomography is often commonly perceived as an imaging tool for medical examination purposes. It has to be emphasized, however, that the concept of tomography and its non-invasive way of imaging are not restricted to the medical field. Over the last decade, tomography has been developed, into a reliable instrumentation tool for imaging numerous industrial applications. This field of application is commonly known as Industrial Process Tomography (IPT) or simply Process Tomography (PT). Process tomography consists of tomographic imaging of systems, such as process pipes in industry. In tomography the two-dimensional (2D) and even three-dimension (3D) distribution of some physical quantity in the object is determined. There is a widespread need to get tomographic information about process. This information can be used, for example, in the design and control of processes. Tomography involves taking measurements around the periphery of an object (e.g. process vessel or patient) to determine what is going on inside. The best known technique is CAT scanning in medicine, however process tomography instrumentation needs to be cheaper, faster and more robust (York, 2001).

External non-invasive sensors are used to detect signals from the investigated process, and the three dimensional material distribution or the velocity field is computed using the measured data. Process tomography is an area of rapid growth both in terms of research and applications. There are number of challenges remaining in this area including data processing for image reconstruction (Soleimani, 2008), and application of imaging modalities in a real applications. Process Tomography is undoubtedly providing new ways to look inside industrial processes, where in industry, seeing is believing. Process Tomography also becomes even more appealing since non-intrusive sensors are used to obtain the cross-sectional images.

Generally a tomography system can be built by mounting a number of sensors around the circumference of a vertical or horizontal pipe. The output signal from the sensors can be processed through a signal conditioning circuit and will be sent to the Personal Computer (PC) by means of any Analogue-to-Digital Converter (ADC). Data processing will be performed on the digitized signal from respective sensors that has been received by the PC. Finally the processed data will be used to reconstruct the cross-section flow image in the pipe. Information obtained from tomography systems will enable concentration, velocity and flow-rate to be determined over a wide range of flow regimes by providing better averaging in time and space through multi-projections of the same observation. Improvement of the quantity and quality of information is also expected in any applications in using tomography systems.

1.1 Background Problems

Previous research in adopting ultrasonic sensors in process tomography was introduced by Gai et al. (1989) when they documented their research on the non-invasive ultrasonic tomography fabrication technique. The history of ultrasonic tomography continues with the development that was focused to liquid/gas flow measurement (Xu et al., 1993; Xu & Xu, 1998; Xu et al., 1997). The latter system however implements invasive technique which is mostly not favoured by the industries. Additionally, the proposed technique by Xu et al. (1997) utilized high excitation voltage (around 200V) for the transmitter. This is however troublesome and the electrocution danger or technical breakdown would be dangerous if any fault accidentally appeared to be in the system. Nevertheless, the high excitation voltage has put a restriction on the system and also the application (Fazalul Rahiman, 2005).

The latest development on ultrasonic tomography by Fazalul Rahiman (2005) however have solved the earlier problems described. The implemented system have successfully developed an ultrasonic tomography system using low operating voltage transducers (20V) which has been proved to be sufficient for liquid/gas flow imaging as long as the acoustic energy could pass through the process vessel (Fazalul Rahiman, 2005). More importantly, the developed system has successfully implement 16-pairs of ultrasonic transducers for non-invasive ultrasonic measurement system. The non-invasive transducer fabrication techniques were realised by using silicon grease as the