

ON CHIP PLANAR CAPACITANCE TOMOGRAPHY FOR TWO-PHASE
FLUID FLOW IMAGING

NUR ADILA BINTI MOHD RAHMAN ALI

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ABSTRACT

This thesis presents the development of an on-chip planar electrical capacitance tomography (ECT) of two-phase liquid flow in a pipe. This miniaturized planar ECT device was developed based on LabVIEW-based microfluidic device concept. Microfluidic device is a portable device that integrates different laboratory activities within a small platform that handles micro-scale liquid and it is normally used for all applications in analysis and detection. To visualize the condition within the reaction chamber an external optical instrument such as a micro-camera is used in the device to observe the flow. Furthermore, a camera that is attached to the optical sensor is used to collect data to monitor and intensify the process in order to analyze the data in a recorded video. The objective of each of these operations is to provide visualization via planar electrode array where the electrical data obtained can be directly related to a computer. This is achieved through a technique utilizing capacitance measurement within the microfluidic device platform of liquid flow analysis. To reconstruct a planar ECT sensor, a measured variation in the capacitance of a plate within the sensor area. Eight planar electrodes were arranged on a printed circuit board with dimensions of 5.00 cm by 2.08 cm. The channel width distributed all around 16 channels of the sensor area. Simulation was conducted in COMSOL Multiphysics to determine the design parameters of the microchannel and polydimethylsiloxane (PDMS) microchannel was fabricated using casting method. The integration of planar electrode sensor to the PDMS microchannel of the microdevice which allows two-phase liquid flow to flow in and out of the sensor chamber. A new projection technique was used for data collection method. A two-phase flow was simulated in Micro-Optical Visual Basic and Linear Back Projection algorithm implemented on the image reconstruction process. A portable data acquisition (DAQ) system in a personal computer and a data measurement software was developed for online measurement. Two-phase liquid-air and liquid-liquid data were tested. The data were loaded into the sensor chamber at a constant flow rate. The reconstructed data were compared to the real data captured by the camera and the evaluation of the two-phase liquid flow in a pipe was tested. At a flow rate of 12.03 l/min, the accuracy of the developed sensor in reconstructing water-air flow data was nearly 97.9% while the accuracy of the reconstructed oil-air flow data was nearly 94.3%. The study showed that the liquid concentration affects the reconstruction of the capacitance value with the liquid concentration. The reconstructed correlation coefficient showed good agreement with the comparison of the camera captured data. This study showed that the miniaturized planar ECT is suitable to capture the dynamic flow behavior within a sensor chamber.

ABSTRAK

Tesis ini bertujuan untuk menganalisis metode otomatisasi dalam sistem ECT pada sistem industri. Penelitian ECT dilakukan dengan menggunakan *Lab-on-chip* LOC sebagai alat ukur. Penelitian ini adalah penelitian terapan yang bertujuan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Pada penelitian ini dilakukan analisis terhadap sistem ini dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Penelitian ini dilakukan dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Penelitian ini dilakukan dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis.

Penelitian ini bertujuan untuk menganalisis metode otomatisasi dalam sistem ECT pada sistem industri. Penelitian ECT dilakukan dengan menggunakan *Lab-on-chip* LOC sebagai alat ukur. Penelitian ini adalah penelitian terapan yang bertujuan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Pada penelitian ini dilakukan analisis terhadap sistem ini dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Penelitian ini dilakukan dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis. Penelitian ini dilakukan dengan menggunakan alat ukur yang akurat dan efisien. Selain itu, penelitian ini juga dilakukan untuk mengetahui kemampuan sistem ini dalam melakukan pengukuran secara otomatis.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	i
	LIST OF FIGURES	ii
	LIST OF ABBREVIATIONS	vi
	LIST OF SYMBOLS	vii
	LIST OF APPENDICES	viii
1	INTRODUCTION	
	1.1 Re ea ch Bac o nd	1
	1.2 P o le State ent	3
	1.3 Re ea ch O ective	4
	1.4 Re ea ch Sco e	5
	1.5 The i O tline	6
2	LITERATURE REVIEW	
	2.1 Int od ction	8
	2.2 P oce To o a h	8
	2.3 Cla i ication o To o a h I a in	11

	Principle	
	2.3.1 Hand Field To o a h	11
	2.3.2 Soft Field To o a h	12
2.4	The Advantage and the Disadvantage of ECT	13
	State	
2.5	Lab on Chip and Microfluidic	15
	2.5.1 LOC with Electrical To o a h	17
	2.5.2 LOC with Electrical Capacitance	18
	To o a h	
2.6	Capacitance Measurement of Planar Electrode	20
2.7	Theoretical Protection Technique	23
2.8	Linear Reconstruction Algorithm of ECT	25
	State	
2.9	Linear Reconstruction in Linear Back	26
	Projection LBP Algorithm	
	2.9.1 The Forward Pole	27
	2.9.2 The Inverse Pole	28
2.10	Summary	29
3	DEVICE FABRICATION AND DEVELOPMENT	
3.1	Introduction	30
3.2	Research Flow Chart	30
3.3	Nominal Standard of the Optimal Geometric	32
	Miniaturized Planar To o a h	
	3.3.1 The Optimal Electrode Selection of	33
	Planar Electrode Array	
	3.3.2 The Optimal Height of Sensing Channel	33
	of Planar Electrode Array	
3.4	Fabrication of Micro Device	36
	3.4.1 Fabrication of Planar Electrode Array	36
	3.4.2 PDMS Micro Channel Development	38
	3.4.3 Integration of Planar Electrode Array and	41
	PDMS Micro Channel	

3.5	Mic o Device Bondin Te t	42
3.6	Mic o Device Re eata ilit Te t	44
3.7	Po ta le Data Ac i ition S te Develo ent	45
	3.7.1 Switchin Ci c it	47
	3.7.2 Ca acitance Mea e ent and A li ie Ci c it	49
	3.7.3 A ol te Val e Ci c it	50
	3.7.4 A d ino Me a Mic o Cont olle	51
3.8	S a	52
4	MINIATURIZED PLANAR ECT DEVICE CHARACTERIZATION	
4.1	Int od ction	54
4.2	Ca acitance Detection Cha acte i tic	54
4.3	Si nal Mea e ent Cha acte i tic	56
4.4	Plana Elect ode E citation Volta e and F e enc S l	59
4.5	Mic o Cha acte i ation	61
4.6	The E ect o Vol et ic Flow Rate to Si nal Mea e ent	63
4.7	S a	65
5	ONLINE MULTIPHASE FLUID DYNAMIC MONITORING	
5.1	Int od ction	66
5.2	I a e Recon t ction Al o ith St d	66
5.3	Sen itivit Di t i tion and Sen itivit Ma	67
5.4	G a hical U e Inte ace o Online Monito in	70
	5.4.1 To o a Di la Inte ace	71
	5.4.2 Data Di la Inte ace	72
5.5	S te Cali ation	74
5.6	I a e Recon t ction o Two- ha e Flow Sa le	79

5.6.1	Detection Ability of Miniaturized Planar ECT Senses	82
5.6.1.1	Quantitative Detection in Sensing Channel	82
5.6.1.2	Size of Sample	84
5.6.1.3	Flow Rate in Response Time	87
5.6.2	Lithium-Gallium Infrared Reconstruction	90
5.6.3	Infrared Lithium-Lithium Infrared Reconstruction	92
5.6.4	Microscopic Lithium-Lithium Infrared Reconstruction	94
5.7	The Effect of Lithium Concentration Ratio to Infrared Reconstruction	96
5.8	Summary	98

6 CONCLUSION AND FUTURE WORKS

6.1	Conclusion	100
6.2	Significant Research Direction	102
6.3	Future Recommendation	103

REFERENCES

Apendice A-E	113-123
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LIST OF TABLES

TABLE NO.	TITLE	PAGE
5.1	The nction o e in t tton	73
5.2	Mea ed e o o ai a le at di e ent ad ant in en in cha e	83
5.3	The ea ed and the e centa e e o o wate in wate - ai low ea e ent	90
5.4	The ea ed and e centa e e o o oil in wate -oil low ea e ent	94

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Selection of an inductance method in accordance to the method adapted by Bec and Williams	10
2.2	Electrical field of a parallel plate electrode	21
2.3	Illustration of dielectric ion and electric field lines of a parallel plate electrode	21
2.4	Capacitance of a parallel plate electrode within a configuration of 4-electrode	22
2.5	Projection technique used in the parallel plate electrode and electrostatic field projection	23
3.1	Reach of low charge	31
3.2	Standard model of a parallel plate electrode within a channel of a top view and front view	32
3.3	Electric field distribution in ECT of a parallel plate electrode with a plate and with two-plate electrode with water and oil	34
3.4	Electric potential across a parallel plate electrode with various height and electrode length with a ratio of length:width with a plate and with two-plate electrode with water and oil	35
3.5	CAD drawing with dielectric ion in a parallel plate electrode	37
3.6	The indicated parallel plate electrode	38

3.7	The 3D a te te late a d awin with di en ion a icated te late	39
3.8	The develo ent oce o PDMS ic o channel	40
3.9	Final e lt o the develo ed ic o device	41
3.10	Mic o device ondin te ti a e a at i t da a te th ee da	42
3.11	Mic o device ondin condition at t in a e e i ental et and te t e lt	43
3.12	The elect ode con i ation a i t e citation la t e citation	44
3.13	Re eata ilit te t o the ic o device	45
3.14	ECT en in od le loc dia a	46
3.15	Switchin ci c it	47
3.16	Ti in dia a o witchin ci c it	48
3.17	Ca acitance ea e ent and a li ie ci c it	49
3.18	A ol te val e ci c it	50
3.19	A d ino ic ocont olle loc dia a	52
4.1	E e i ental et o ca acitance detection cha acte i tic	55
4.2	Standin ca acitance o di e ent t e o dielect ic ate ial wate l co e ol tion ai and oil	56
4.3	E e i ental et o i nal ea e ent anal i	57
4.4	Volta e val e o wate a le ac o en o a a	58
4.5	Volta e val e o wate a le ac o en o a a with di e ent volta e l	59
4.6	Volta e val e o wate a le ac o en o a a with va io e enc lie	60
4.7	a Pe i taltic do in and DC oto eed cont olle	62
4.8	Vol e low ate o cha acte i ation o ic o	62
4.9	Volta e val e o wate a le with va io vol et ic low ate	63
4.10	Volta e val e o wate oil l co e ol tion and ethanol	64

	at 12.03 l/ in	
5.1	The e a le o ac o ection 87	67
5.2	a Sen itivit a and elect ode con i ation o elect ode ai E_0 - E_1	69
5.3	S a e en itivit at i o iniat i ed lana ca acitance to o a h	69
5.4	PC GUI nit ca t e	70
5.5	GUI di la a to o a and colo a	71
5.6	Ta lated data	72
5.7	Sen o volta e ea e ent o 8-elect ode ECT en o	73
5.8	U e in t	73
5.9	Sen in cha e d in cali ation a ai and wate	75
5.10	Cali ation o ai a le	76
5.11	Cali ation o wate a le	76
5.12	Sen in cha e d in cali ation o oil	77
5.13	Cali ation o oil a le	78
5.14	Sen in cha e d in cali ation o l co e ol tion	78
5.15	Cali ation o 100 l co e ol tion a le	79
5.16	E e i ental et o i a e econ t ction o two- ha e l id low anal i	80
5.17	Pi el n e in	81
5.18	Q ad ant in en in a ea	82
5.19	To o a with di e ent location o the wate -ai a le at di e ent ad ant o en in a ea	83
5.20	Detection a ilit o the te to detect di e ent wate e centa e in wate -ai ea e ent	84
5.21	Act al and econ t cted i a e o wate e centa e within the en in cha e	85
5.22	Detection a ilit o the te to detect di e ent oil e centa e in wate -oil ea e ent	86
5.23	Act al and econ t cted i a e o oil e centa e within the en in cha e	87

5.24	To o a o wate -ai low ea e ent with di e ent low ate	88
5.25	Mea ed e o o wate -ai a le o di e ent low ate	89
5.26	Recon t cted i a e o wate -ai a le a eal i a e and to o a	90
5.27	To o a o wate -ai low ea e ent	91
5.28	To o a o wate -oil low ea e ent	93
5.29	To o a o wate - l co e ol tion low ea e ent	95
5.30	To o a o wate - l co e low ea e ent with di e ent li id concent ation	97
5.31	Volta e ea ed with di e ent concent ation	98

LIST OF ABBREVIATIONS

ADC	-	analog to digital converter
CT	-	Coil-terminated Transmission Line
DAQ	-	data acquisition system
ECT	-	Electrical Capacitance Transmission Line
EIT	-	Electrical Inductance Transmission Line
ERT	-	Electrical Resistance Transmission Line
FEM	-	finite element method
	-	frequency
GUI	-	Graphical User Interface
HR	-	hydrodynamic interaction
ILBP	-	Iterative Linear Back Projection
ILH	-	impedance
LBP	-	Linear Back Projection
LCR	-	Inductance Capacitance Resistance
LOC	-	localization
1/ in	-	milliliters per minute
MRI	-	Magnetic Resonance Imaging
NMR	-	Nuclear Magnetic Resonance
PCB	-	printed circuit board
PDMS	-	polydimethylsiloxane
PET	-	Position Emission Tomography
RF	-	radio frequency
PT	-	Process Tomography
RGB	-	red green blue
R	-	receive electrode

S/	-	Sie en e ete
T	-	t an itte elect ode
USB	-	Unive al Se ial B
V .	-	volta e ea -to- ea

LIST OF SYMBOLS

A	-	act al i a e
a	-	hal a o the elect ode
C	-	inte -elect ode ca acitance at i
C_f	-	eed ac ca acitance
C_x	-	ca acitive e on e
E	-	n e o elect ode
$E_{i/j}$	-	elect ic ield di t i tion
ϵ_r	-	dielect ic con tant
ϵ_o	-	elect ic con tant
\mathbf{K}	-	e ittivit at i
ℓ	-	len th o elect ode
M	-	n e o inde endent ea e ent
M	-	n e o individ al tandin ca acitance
N	-	n e o i el
R	-	econ t cted i a e
R_f	-	eed ac e i tance
S	-	en itivit at i
S^{-1}	-	inve e en itivit at i
S^T	-	t an o e en itivit at i
w	-	width o the elect ode
ω	-	an la e enc
ϕ	-	otential di t i tion
θ	-	otation an le

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Li t o P lication	113
B	Sen itivit Ma	115
C	Sche atic Dia a o DAQ S te	118
D	A d ino Mic ocont olle Codin	121
E	I a e Recon t ction Codin	123

CHAPTER 1

INTRODUCTION

1.1 Research Background

Microfluidic or lab on chip (LOC) has been introduced by Manz in 1990's for chemical applications in liquid chromatography [1]. Since then it has become a leading technology that is widely used in biomedical and chemical analysis, medical diagnosis and cell culture [2]. LOC is a miniaturized device that integrates various laboratory activities such as sample preparation [2], DNA analysis [3, 4] and biochemical detection [5] within a single chip. Due to the miniaturized LOC device, one can achieve high throughput and high detection sensitivity. It is not the capability of handling an extremely low liquid volume where detection in volume concentration can be made. The size of LOC devices are now all in millimeter to a few centimeter. The size of the miniaturized device is not the concentration of the reagents or chemical solution matters. Besides, LOC device has the ability to carry out a large number of high surface-to-volume ratio and reduced reaction time which lead to effective control compared to other conventional analytical methods.

LOC devices are now all integrated microchannel with microreactors [6], microchambers, microfluidic reaction columns or analysis. Various detection methods have been reported, the common one are optical sensor detection, droplet [7] and electrode or electrical sensor [8]. As the size of the device decreases to miniaturized level, the integration of optical sensor

diagnostic and limited. Hence, continuous measurement in electrode is operative. Electrode can be divided into various types and have according to the need of the detection. Various measurement can be done in electrode such as electrochemical detection, capacitance or impedance measurement. However, due to the measurement in electrode are provided 1D measurement and often the data can be obtained into a form of a graph within the chart. The continuous 2D data can be obtained will enhance the application of LOC.

Process of a graph PT is defined as an approach of obtaining correlation of an object with the natural state of the process. It provides real-time information on the internal state of process in various form of a graph and the information is integrated. In earlier works, PT is one of the techniques that have established a good relation in medical field of diagnosis. In medical application, the continuous graph CT can be X-ray to obtain correlation of a non-invasive X-ray and Magnetic Resonance Imaging (MRI) is intended to diagnose and other relevant factors.

Since then, a rapid development of a graph technique has been initiated and has been applied in various applications and several works that are working. Depending on the application, various measurement methods such as electrostatic, electrical, optical and acoustic measurement. Electrical measurement is the most popular measurement in industrial process of low voltage measurement and intrinsically safe. Electrical measurement is the change of the electrical field distribution within the measurement cell can be obtained on impedance, capacitance or resistance measurement. A new type of a graph modalities electrical capacitance tomography (ECT) has been the most suitable to the measurement in a low cost and resistance to high temperature.

Either in medical or forensic industries to which has been used in large scale in other sectors to date due to their high speed and high volume available. Recent interest in the large scale detection is due to the application of initiated to which increase in volume over the last few years. However, in industrial applications to the environment provide in the diagnostic data where accurate identification is difficult to achieve. The integration of the toxicologic techniques into a parallel laboratory environment of detailed analysis which a 2D image can be obtained.

1.2 Problem Statement

Due to the increase in availability of the application of solid state microarray technology in cell based medical diagnosis chemical and biological analysis solid state LOC technology has been widely applied. In solid state microarray technology and miniaturization allow for the identification of a wide range of chemical and biological analytes. A lot of medical and biological analysis is being conducted in microarrays which is the combination of the whole process to take place. For example in cell culture in microarrays the cell are cultivated under controlled conditions which are able to maintain the consistency of the culture condition. The duration of cell growth is the combination of the time of cell and continuous monitoring is needed to observe the cell behavior.

In cell culture in the cell are placed in a cell incubator to provide the ideal condition. In conventional cell culture in microarray technology the conventional method to observe the cell behavior. However, it is difficult to get the microarray inside the microincubator due to its size and the microarray has to be removed from the incubator for microarray evaluation. An optical instrument which a microarray is needed to provide visual information of the reaction has occurred within the microarray. Microarray with camera are available and large to a large extent. The entire process is carried out to

integrate electrical impedance tomography into solid-state technology to produce a device where the electrical signal data can be easily stored in the computer.

A major goal is to improve the detection in solid-state devices of microanalyses to provide 1D data illustrated in a graph. Nevertheless, 2D tomography is important in the application of cell detection in medical analysis of the lithography area. The 2D tomography is helpful in visualization of the lithography area and more accurate estimation can be made. With microanalysis techniques, the initial energy of a beam can be integrated in a solid-state device. This solid-state device with the energy of a beam is a major goal to produce technology that allow the device to obtain 2D data. The initial energy of a beam device will produce 2D tomography that illustrate the state of the lithography area in a more detailed manner.

1.3 Research Objectives

The main aim of this research is to study the feasibility of a microanalyses device to produce two-dimensional low impedance. The specific objectives of the research are as follows:

1. To analyze an on-chip impedance tomography of two-dimensional low impedance connection.
2. To investigate the feasibility of impedance tomography electrode in a low impedance condition in finite element method (FEM) and experimental approach.
3. To develop a portable data acquisition system that provide online impedance tomography of the initial energy ECT energy.

The feasibility of impedance tomography energy in a microanalyses device. To accomplish the objective, an 8-electrode energy of a beam on impedance tomography energy was analyzed and integrated into solid-state technology. Besides a

o ta le data ac i ition DAQ te and an i a e econ t ction o a tilin Linea Bac P o ection LBP al o ith wa develo ed o online onito in . Li id- a and li id-li id a le we e ed in thi e ea ch to te t the ea i ilit o the develo ed te in econ t ctin i a e o two- ha e l id low a le .

1.4 Research Scopes

The ea i ilit o iniat i ed lana ECT te o two- ha e l id low i a in i inve ti ated. Thi e ea ch i divided into device a ication the develo ent o data ac i ition te and o twa e od le develo ent o i a e econ t ction oce . The a ication o ic o device con i t o the a ication o lana elect ode a a the a ication o ol e - a ed ic o channel and the inte ation o low ele ent within the chi - a ed to o a h te .

The lana elect ode a a which i de i ned a ed on elect ical ca acitance to o a h i a icated on inted ci c it oa d PCB in the conventional etchin techni e. Meanwhile a ol e a ed ic o channel i a icated in ca tin ethod o a id otot in . A 3D a te te late i a icated to e ed a a old and ol di eth l ilo ane PDMS i ed a the ain ate ial o the a ication o ic o channel. A o ta le data ac i ition te co i in o i nal conditionin ci c it and A d ino Me a act a the cont olle nit o the ECT te . Thi DAQ te ea e the chan e in elect ical a a ete within the en in a ea. The te collect and condition the data e o e it i ent to the cont ol co te o i a e econ t ction oce .

A o twa e od le o i a e econ t ction i develo ed in Vi al Ba ic 6.0 to allow online i a in o two- ha e l id low a le . Linea Bac P o ection al o ith i i le ented o i a e econ t ction oce d e to it i le t ethod which allow a t co tational ti e. The econ t cted i a e a e ve i ed a ed on the eal ti e i a e ca t ed d in e e i ental wo . The alit o

reconstructed image analysis is based on image-based analysis where the image is compared between the real and reconstructed image pixel by pixel. For the explanation on image-based method is discussed in Chapter 5. Two-dimensional low angle were used to test the feasibility and the accuracy of the method.

1.5 Thesis Outlines

This thesis consists of five chapters. The first chapter is the introduction that contains a brief overview and a definition on the research project. This chapter discusses on the background of the problem to tackle the objective and the scope of the research.

Chapter 2 covers an overview in the fundamental concept and theories of X-ray diffraction. The application of X-ray diffraction technology on X-ray diffraction is based on X-ray diffraction analysis reviewed and the image reconstruction process is explained thoroughly.

Chapter 3 discusses the simulation of the optical properties of the initiated channel to X-ray diffraction in finite element method (FEM). The approach used to simulate the channel and X-ray channel are discussed in detail. The feasibility of the developed X-ray device and the development of DAQ system are presented.

Electrical characterization of the developed device is presented in Chapter 4. This chapter discusses the characterization of the device to measure electrical channel in the low angle.

In Chapter 5 the image reconstruction of two-dimensional low angle is presented. The analysis of the image reconstruction of low-angle and low-angle-low-angle

analytical procedures based on the accuracy of the test. The detection ability of the test is evaluated and discussed.

Chapter 6 concludes the overall work in this thesis. Significant contributions to the field and ideas for future development are stated in this chapter.

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