UTM UNIVERSITI TEKNOLOGI MALAYSIA

COLLABORATIVE RESEARCH GRANT (CRG) PROPOSAL

A **TITLE OF PROPOSED RESEARCH:**
Tajuk penyelidikan yang dicadangkan :

TOMOGRAPHY LAB-ON-CHIP FOR MICROSAMPLE IMAGE RECONSTRUCTION

B **RESEARCH INFORMATION /** *MAKLUMAT PENYELIDIKAN*

Executive Summary

Microfluidic has been widely applied in the application of fluid monitoring, cell culture measurement, environmental and chemical analysis. The emergence of microfabrication has brought biomedical and chemical analysis to the next level where it promises portability, high throughput, and high detection sensitivity. Aside from measurements data, images of the reactions within the microdevice provides vast information. Images are now capture using confocal microscopy with limitation to a few hundred depths of the microchannel. Furthermore, in mixing analysis, fluorescent dyes are required to be added into the fluid to obtain images from the microfluidic device. For continuous monitoring of reaction within the microdevice especially for biomedical analysis which normally needs longer reaction period camera recording require massive storage facilities. Therefore this project proposes to integrate planar tomography system within the microfluidic platform to reconstruct images of the samples within the microchannel. Commonly, the samples within the microdevices can be catergorized to conductive and non-conductive materials. Soft field tomography systems such as Electrical Resistive Tomography (ERT) and Electrical Capacitive Tomography (ECT) offer detection for conductive and dielectric materials respectively. These soft field tomography systems require similar sensor array as the electrodes for detection and measurement. Subsequently these measurements can be processed to generate images related to the medium activities within the sensing area. The sensors detect and obtain data for 2D images reconstruction that representing activities in the flow chamber that replacing scope instruments. Validation of experimental results can be done with Finite Element Modelling software such as COMSOL Multiphysics. FPGA processing unit is used as control unit and data acquisition unit for collecting data for image reconstruction. This project provide alternative monitoring methods for microfluidic device and promotes a new multi-disciplinary research field that can benefits not only microfluidic analysis but provide opportunities to test the limit of tomography in microplatform.

Project Concept and Rationale

This program creates a multidisciplinary collaboration between micro and nanotechnology with the tomography system. This collaboration will benefit the micro and nano device development and also potentially to create multi-disciplinary projects that can allow emergence of new cutting edge technology in Malaysia.

Tomography is a technique of obtaining a cross section images of an object or closedpipelines [1] via sensor array invasively or noninvasively. A tomography system normally comprises an array of sensors which producing slice of a picture, a signal conditioning unit to handle the signal from the sensor and a data acquisition (DAQ) system to transfer the data to the computer for further process. The most common tomography systems are using Xray and Magnetic Resonance Imaging (MRI) in medical field to diagnose lung disorders and other relevant symptoms [2]. Due to the demand from medical diagnosis rapid development of tomography was initiated for medical applications. [3]. As for the industries, tomography is used to describe the characteristic of flow components such as gas, liquid and solid within a pipelines noninvasively[4].This is an important measurement because the safe and profitable operation may well depend on the capabilities of an instrument in terms of accuracy, sensitivity, range, time response and robustness harsh measurements within the pipeline. However, the process tomography systems are limited to macro scale measurement in the industry. As the quick emergence of lab on chip (LOC) application [5] within the medical, environmental analysis and cell culture field [6], great demand of LOC devices for microsample analysis has been significantly increased over the year. LOC platform promises high throughput, reduction of chemical response [7]. Therefore by integrating miniaturized sensor arrays and tomography measurement within the chip, it able to offer great potential in microscale medical diagnosis, chemical analysis, environmental analysis, application and single cell measurement. Sun et.al. has reported an on chip design of impedance tomography to reconstruct the image of the growth of biological cell [8]. This study applied the concept of miniaturized tomography system where the system is able to provide two dimensional image for cell culture. Related research of miniature tomography has also been carried out by Pititheerapab et al. [9] where the study is to produce animal bones with the use of 3D modeling application. The developed system has an ability to create 3D images of small objects. Planar tomography was also applied into the system to detect breast cancer. This is Lvaro Diaz Bolado [10] who has reported in towards tomography system of planar microwave for breast cancer early detection. The planar microwave tomography advantages for early stage detection are presented. wave used in planar ultrasonic tomography was conducted by D.S Ko [11]. Planar tomography microdevices have been widely used for medical application. For instance in the application of the xray, gastrointestinal endoscope medical data registration, treatment

monitoring. In addition, planar tomography is also applied in science and biology especially for chemical analysis. Simulation of electrode planar is done to identify the optimum geometries of small scale tomography planar electrode array is also use to study the electrical field distribution to verify the experimental result [13-14]. On top of that, planar tomography system utilizing ECT technique within miniaturized device has reported to be feasible for image reconstruction for sample within a chamber of size 2 cm in diameter [15].

Previous studies have shown the feasibility of planar tomography system used in image reconstruction and this project proposes the in depth study of the performance and the limit of the planar tomography system within micro-platform. The research work is to be studied numerically by using the COMSOL Multiphysics software and experimentally. These research works involve the development of microfluidic devices, tomography techniques, data acquisition system and image reconstruction algorithm. The findings of this research program provides an innovative alternative for microsamples monitoring using scopeless tomography techniques which will provide great offers for future onchip detections for medical diagnosis, chemical analysis analysis applications.

References:

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Objectives:

1. To investigate the feasibility of microchip based planar tomography for microsample multiphase flow image reconstruction.
2. To study the limit of detection of soft field tomography namely ECT and ERT for lab-on-chip applications numerically and experimentally.
3. To characterize the planar sensor array for soft fields microfluidic tomography systems.
4. To analyse and evaluate the reconstruction image for microsample of tomography LOC under dynamic flow condition.

Description of Research Program

The program consists of four key themes namely LOC Design and Development, Controller and Data Acquisition System, Signal Conditioning and Image Reconstruction Method, and Simulation Modelling Verification and Device Characterization. This program will be led by four project leaders according to the theme from UTM, UTHM, UniMAP and UMP. The overall idea of the program is to investigate the feasibility of tomography system to Lab on Chip platform in order to reconstructed images of the samples within the microfluidic device. The projects involve an overall design of microfluidic platform and planar electrodes for tomography sensing where the materials used in the development of the device is integrated with custom designed controller, data acquisition system, signal conditioning and image reconstruction. The complete device will be characterized to investigate the feasibility and limit of detections of tomography within microdevice platform.

1. Microfluidic Device Design and Development (Project Leader: Dr. Leow Pei Ling, UTM)

This research theme investigates the compatibility and feasibility of tomography system on the miniaturized and micro platform as known as Lab on a Chip (LOC). In this part, the design of the microfluidic device with 8-electrode and 16-

electrode array are designed using CAD with carefully consider the cross-talk issue of the electrodes within the sensing area which will contribute directly to the accuracy of the image reconstruction. The design of the microfluidic channel is required to fulfill the laminar profile and the hydrodynamic properties of the fluid. The commonly used microfludic design with single- and double-inlet microchannels are designed and studied. The device is fabricated for device characteristic study and for experimental tests.

2. **Controller Unit and Data Acquisition System (Project Leader: Assoc. Prof. Ir. Dr. Mohd Hafiz Fazalul Rahiman, UniMAP, UTM Member: Dr. Jaysuman Pusppanathan and PM. Dr. Sallehuddin Ibrahim)**

The quality of the image reconstruction is highly dependent on the electrical measurement at the electrodes and the sensitivity map. The synchronization of the electrodes switching configuration and the data acquisition require fast speed and high processing rate. To ensure fast processing rate for the data acquisition by using embedded system such as FPGA. The data acquisition system will control the switching configuration of the electrodes utilizing fan beam projection techniques. Fan beam projection technique provides higher resolution of images with equal number of electrodes sensor arrangement [57]. For single excitation, this technique excites single transmitter electrode and connects the rest of the receiver electrodes sensor (detector) to ground. Multiple projections from different angles are taken by switching the transmitter and detector until all sensors has been excited to form an image. As fan beam projection provides higher number of measurement as compared to parallel projection with equal number or sensor, a better quality of image can be expected. This is because high number of measurement increases the resolution of the system. Besides, this technique covers wider area of inspection during measurement which produces more accurate and better images. Once the measurement data is collected from the sensor, the measurement data is then process using image reconstruction algorithm to generate images.

3. **Signal Conditioning and Image Reconstruction Method (Project Leader: Dr. Elmy Johana Mohamad, UTHM, UTM Member: Dr Anita Ahmad and Dr Khairul Hamimah Abas)**

Tomographic reconstruction uses the measured signal or the integrals value obtained from the sensor to the cross-sectional distribution of the physical properties of the object being image. Numerous reconstruction algorithms available for the image reconstruction process in tomography system for instance the back projection technique and the iterative method. The implementation of back projection algorithm and the iterative reconstruction techniques have become the standard in most applications. Back projection algorithm retrieve data in the same line as the original data is projected. For back projection, the measurements obtained at each projection are projected back along the same line, assigning the measured value to each point in the line. Meanwhile, the iterative algorithm is based on calculating capacitance values from the permittivity distribution of the current image. The most commonly used reconstruction technique in industry tomography is said to be the linear back projection (LBP) algorithm. Although it has some limitations in terms of accuracy and spatial resolution, it is well suited for fast dynamic processes like multiphase flow, and widely used for on-line image reconstruction as it is numerically simple and computationally fast. LBP can be viewed as a weighted back-project or 'smearing' of each one of the normalised measurements along its sensing zone, given by the corresponding sensitivity map. To reconstruct images, each sensitivity map is multiplied by its corresponding sensor reading. The reconstructed image is to be display online via graphical user interface.

4. **Simulation Modelling and Device Characterization (Project Leader: Dr. Yasmin Abdul Wahab, UMP, UTM Member: Dr Rashidah Arsat, PM. Ir. Dr. Herlina Abdul Rahim and Pn. Shahrulnizahani Mohammad Din)**

The conceptual design of the microdevice and the geometrical of the planar electrodes are to be investigate via modelling simulation. The developed tomography system is highly dependent on the LOC design and the planar electrodes functionality. The electric field, charge distribution and electric profile are crucial in ensuring the samples within the micro sensing area is feasible to be detected. The simulation model will provide range of measurement magnitude as reference for optimizing the hardware design for the LOC, control unit, data acquisition system, signal conditioning and processing and image reconstruction of fluids in single or multiphase condition. This study is important to verify experimentally the feasibility of the use of tomography system within micro platform. The experimentally obtained results are to be further verify with theory and numerical simulation method by using COMSOL Multiphysics. The study involves resolution and electrical field strength within a small measurement area as well.

Research Methodology

As refer to the flow chart in Figure 1 (please refer to attachment), the four theme within the program is executed in parallel by each project leader and team from the designated universities at the begining of the program. The initial test platform of the microdevice is proposed to be a 1 mm × 1 mm cross section channel with a round shape chamber of diameter range from 5 mm to 10 mm which yield volume 200 µL to 800 µL. An 8- and 16- planar electrodes are designed and used as the sensor array for the tomography system. The design of the electrodes will consider the cross-talk effect and the planar electric field effect on the data measurement. The proposed soft field tomography systems are using electrical capacitive and electrical resistive measurements.

The parameters of the designed microdevice and sensor array are to be simulated via Finite Element Modelling (FEM) technique and also verified experimentally. The UTM research team will focus on the design and development of the device and UMP research team will produce simulation model based on the design provided by UTM members. Based on the sensor arrays and UniMAP research team will design the controller circuit for the switching configuration of the sensor array and also the data acquisition for the measurements. The research members from UTHM will focus on finding suitable image reconstruction methods for the data obtained from the microsensor array. A graphical user interface (GUI) will be designed to provide monitoring display of the reaction within the sensing chamber.

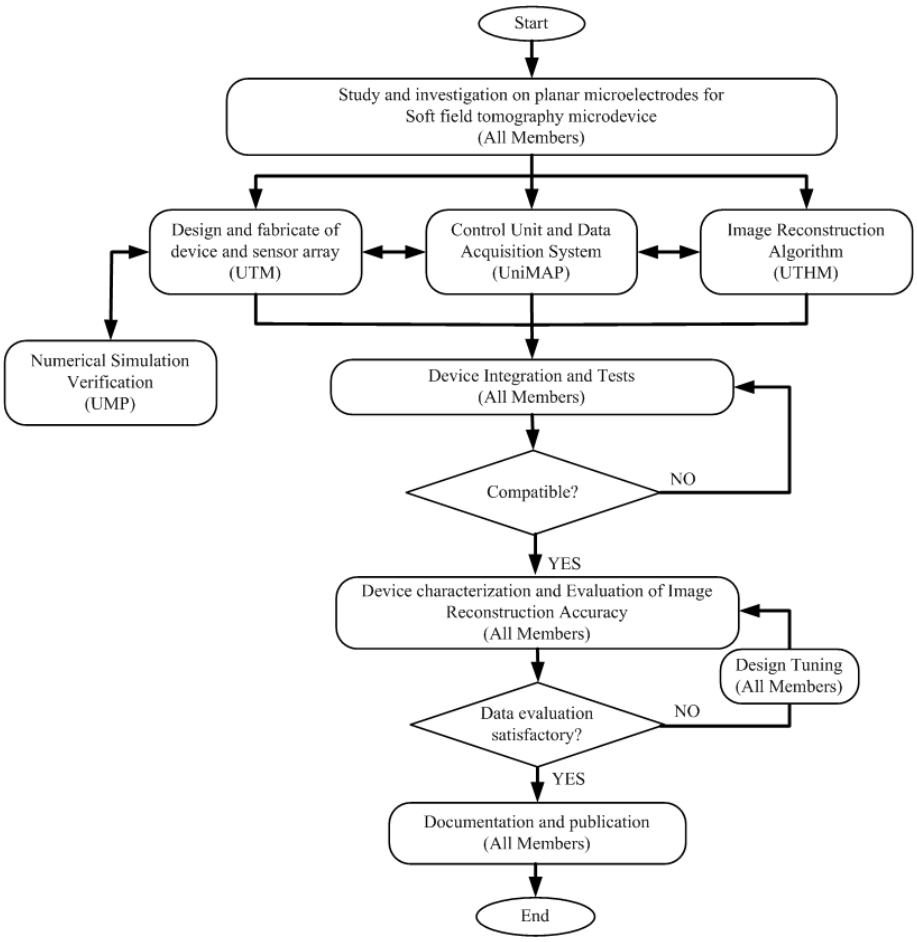

Figure 1: Program Flowchart

Each of the projects will be integrated and tested with standard samples such as water, oil, yeast cell and solvents. The characterization and limit of detection of the planar tomography system within the microdevice platform will be studied. The reconstructed images will be evaluated and studied for accuracy and validity for design tuning and improvement. The process of the research work and also involvement of the each team in the research is labelled in the process within the flow chart.

Gantt Chart:

NO	DESCRIPTION	YEAR 1												YEAR 2											
		Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20
1	Conceptual design of microchannel and planar electrodes	UTM																							
2	Simulation Modelling study of planar electrodes		UMP					i																	
3	Design and development of Control unit			UniMAP																					
4	Development and fabrication of Tomography LOC device				UTM								ii												
5	Signal Conditioning and Processing				UTHM																				
6	Development of Data acquisition system							UniMAP																	
7	Image Reconstruction Algorithm									UTHM					iii										
8	Device assembly and integration												UTM and All Members						iv						
9	Test and Debug																	All Members							
10	Device characterization and evaluation																		UMP and All Members					v	
11	Meeting/ Documentation																								

	Milestone	Date
i	Completion of LOC and Planar Sensor Array Design	Apr-19
ii	Completion of LOC and Planar Sensor Fabrication	Sep-19
iii	Completion of Control Unit, DAQ system and Image Reconstruction Algorithm	Nov-19
iv	Completion of tomography LOC system integration	Mar-20
v	Completion of device characterization and evaluation	Aug-20

B RESEARCHERS TRACK RECORDS

	Researcher (Role)	Affiliation *email*	Expertise	Journal (Scopus)	Citation	h-Index
(i)	Dr. Leow Pei Ling (Program Leader)	FKE, UTM leowpl@utm.my	Instrumentation and Lab-On-Chip/ Microfluidic	41	203	8
(ii)	AP. Ir. Dr. Mohd Hafiz Fazalul Rahiman (Project Leader)	Sc. Mech. Eng, UniMAP hafiz@unimap.edu.my	Ultrasonic, Process Tomography, Sensor and Instrumentation, IoT	134	625	14
(iii)	Dr. Elmy Johana Mohamad (Project Leader)	FKEE, UTHM elmy@uthm.edu.my	Instrumentation and Measurement, Process Tomography (ECT)	45	185	10
(iv)	Dr. Yasmin Abdul Wahab (Project Leader)	FKEE, UMP yasmin@ump.edu.my	Process Tomography (ERT, UT, ET), Image Reconstruction, Sensor and Instrumentation	17	70	5

C EXPECTED OUTPUT

1. Novel theories/New findings/Knowledge : *Soft Field Tomography Lab on Chip*

2. Research Publications : *8 Scopus Index Journals*

3. Specific or Potential Applications : *Medical/ cell culture microfluidic devices*.

4. Number of PhD and Masters (by research) Students : *2 Master (by research) students*

D BUDGET

Breakdown:

	Budget Details	Year 1	Year 2	Total
	Project 1: UTM			
1.	Vote 11000 - Salary and wages (1000/ month) & Fees	13,000.00	13,000.00	26,000.00
2.	Vote 21000 - Travelling and Transportation/	1,500.00	1,500.00	3,000.00
3.	Vote 27000 - Research Materials & Supplies	3,000.00	3,000.00	6,000.00
4.	Vote 28000 - Maintenance and Repair	1,000.00	1,000.00	2,000.00
5.	Vote 29000 - Professional Services	2,000.00	1,000.00	3,000.00
	Project total:	**20,500.00**	**19,500.00**	**40,000.00**
	Project 2: UniMAP			
1.	Vote 11000 - Salary and wages	10,000.00	10,000.00	20,000.00
	Project total:	**10,000.00**	**10,000.00**	**20,000.00**
	Project 3: UTHM			
1.	Vote 11000 - Salary and wages	3,600.00	3,600.00	7,200.00
2.	Vote 21000 - Travelling and Transportation/	1,000.00	1,000.00	2,000.00
3.	Vote 27000 - Research Materials & Supplies	4,000.00	4,000.00	4,000.00
4.	Vote 29000 - Professional Services	1,500.00	1,300.00	2,800.00
	Project total:	**10,100.00**	**9,900.00**	**20,000.00**
	Project 4: UMP			
1.	Vote 11000 - Salary and wages	3,600.00	3,600.00	7,200.00
2.	Vote 21000 - Travelling and Transportation/	1,500.00	1,500.00	3,000.00
3.	Vote 27000 - Research Materials & Supplies	1,500.00	1,500.00	3,000.00
4.	Vote 29000 - Professional Services	1,000.00	1,000.00	2,000.00
5.	Vote 35000 - Accessories and Equipment	4,800.00	0.00	4,800.00
	Project total:	**12,400.00**	**7,600.00**	**20,000.00**
	Program total:	**55,000.00**	**45,000.00**	**100,000.00**

Overall:

	Budget Details	Year 1	Year 2	Total	Percentage
1.	Vote 11000 - Salary and wages (1000/ month)	30,200.00	30,200.00	60,400.00	60%
2.	Vote 21000 - Travelling and Transportation/	4,000.00	4,000.00	8,000.00	8%
3.	Vote 27000 - Research Materials & Supplies	8,500.00	8,500.00	17,000.00	17%
4.	Vote 28000 - Maintenance and Repair	1,000.00	1,000.00	2,000.00	2%
5.	Vote 29000 - Professional Services	4,500.00	3,300.00	7,800.00	8%
6.	Vote 35000 - Accessories and Equipment	4,800.00	0.00	4,800.00	5%
	Project total:	**55,000.00**	**45,000.00**	**100,000.00**	**100%**

Appendix

Projects' Gantt Chart

PIC	NO	DESCRIPTION	18 Oct	18 Nov	18 Dec	18 Jan	18 Feb	18 Mar	19 Apr	19 May	19 Jun	19 Jul	19 Aug	19 Sept	19 Oct	19 Nov	19 Dec	20 Jan	20 Feb	20 Mar	20 Apr	20 May	20 Jun	20 Jul	20 Aug	20 Sept
Project 1 (UTM)	1	Conceptual design of microchannel and planar electrodes							i																	
	2	Development and fabrication of Tomography LOC device												ii												
	3	Device testing																		iv						
	4	Device assembly and integration																								
	5	Device characterization and evaluation																							v	
	6	Meeting/ Report/ Documentation																								
Project 2 (UniMAP)	1	Study and Understanding Overall Project Design Concept																								
	2	Design and development of Control unit																								
	3	Development of Data acquisition system														iii										
	4	Systems assembly and integration																		iv						
	5	Test and Debug																								
	6	System Evaluation																							v	
Project 3 (UTHM)	1	Study of Overall tomography LOC design concept																								
	2	Signal Conditioning and Processing																								
	3	Image Reconstruction Algorithm														iii										
	4	Caliration, test and tuning																		iv						
	5	Systems assembly and integration																								
	6	Image reconstruction Evaluation																							v	
Project 4 (UMP)	1	Study of Overall tomography LOC design concept																								
	2	Modelling and Simulation (sensors and device)							i																	
	3	Experimental measurement (Tomography LOC sensor array)																								
	4	Systems assembly and integration																		iv						
	5	Test and Debug																								
	6	Device characterization and evaluation																							v	