# UNSTRUCTURED ELECTRICAL IMPEDANCE TOMOGRAPHY USING AD HOC SENSOR NODE

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THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH
2019

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I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references which have been duly acknowledged.

18 June 2019

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# ABSTRACT

Electrical Impedance Tomography (EIT) is a simple solution for obtaining information about the interior of an object or a process through performing voltage measurements, whereby interior conductivity distribution in an object can be reconstructed in a form of tomograms. EIT has many applications in areas such as medical, geophysical, and industrial process, where it has shown various potential over existing tomographic modalities. However, the main drawback has been low spatial resolution towards the center of the object. The objective of this project is to obtain EIT measurements from the interior of the object under test, through the employment of ad hoc internal electrodes, in an effort to acquire data that were unobtainable through conventional EIT system. To achieve this objective, a prototype of an ad hoc EIT sensor is designed. The ad hoc EIT sensor is battery powered. The sensor node is attached with two pairs of electrodes. The sensor integrated circuit is designed to enable current injection and voltage measurement from within the medium using the two pairs of electrodes. One pair performs current injection, while another pair measures localized voltage difference. The role of the two pairs are interchangeable by using analog multiplexers. The sensor integrated system consisting of a current source, voltage sense, multiplexers, and microcontroller unit, were simulated and tested. The ad hoc sensor prototype was experimented on homogeneous medium and inhomogeneous medium of tap water and saline. The results show a feasible means of acquiring EIT data from the interior of the object.

## *ABSTRAK*


### *TOMOGRAFI IMPEDANS ELEKTRIK YANG TIDAK BERSTRUKTUR DENGAN PENGGUNAAN NOD SENSOR AD HOC*

*Tomografi Impedans Elektrik (EIT) adalah penyelesaian mudah untuk mendapatkan maklumat mengenai bahagian dalam suatu objek atau proses melalui pengukuran voltan, di mana taburan kekonduksian dalaman dalam objek boleh dibina semula dalam bentuk tomograms. EIT mempunyai banyak aplikasi dalam bidang seperti proses perubatan, geofizik, dan perindustrian, di mana ia telah menunjukkan pelbagai potensi ke atas modaliti tomografi yang sedia ada. Walau bagaimanapun, kelemahan utama adalah resolusi spatial yang rendah ke arah pusat objek. Objektif projek ini adalah untuk mendapatkan pengukuran EIT dari bahagian dalam objek di bawah ujian, melalui penggajian elektrod dalaman ad hoc, dalam usaha memperoleh data yang tidak dapat dikesan melalui sistem EIT konvensional. Untuk mencapai matlamat ini, satu prototaip sensor EIT "ad hoc" telah direka. Nod sensor tersebut telah dipasang dengan dua pasang elektrod. Litar bersepadu sensor direka untuk membolehkan suntikan semasa dan pengukuran voltan dari dalam medium menggunakan dua pasang elektrod. Satu pasangan melakukan pembekalan arus manakala pasangan lain mengukur perbezaan voltan setempat. Peranan kedua-dua pasangan ini boleh ditukar dengan menggunakan multiplekser analog. Sistem bersepadu sensor; yang terdiri daripada sumber semasa, rasa voltan, multiplekser, dan unit mikrokontroler, telah disimulasikan dan diuji. Prototaip sensor "ad hoc" telah diuji pada medium homogen sederhana dan tidak homogen air paip dan masin. Hasilnya menunjukkan cara yang mungkin untuk memperoleh data EIT dari bahagian dalam objek di mana maklumat biasanya cenderung tidak dapat dikesan atau rosak oleh bunyi.*

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| **AC** | - | Alternating Current |
| **ACT** | - | Adaptive Current Tomography |
| **ADC** | - | Analog-to-Digital Converter |
| **APT** | - | Applied Potential Tomography |
| **CEM** | - | Complete Electrode Model |
| **CMOS** | - | Complementary Metal-Oxide-Semiconductor |
| **CMRR** | - | Common Mode Rejection Ratio |
| **CFD** | - | Computational Fluid Dynamics |
| **CT** | - | Computed Tomography |
| **DAQ** | - | Data Acquisition |
| **DC** | - | Direct Current |
| **DDS** | - | Direct Digital Synthesis |
| **DSP** | - | Digital Signal Processing |
| **EIDORS** | - | Electrical Impedance and Diffuse Optical Reconstruction Software |
| **EIT** | - | Electrical Impedance Tomography |
| **ERT** | - | Electrical Resistance Tomography |
| **EUSART** | - | Enhanced Universal Synchronous Asynchronous Receiver Transmitter |
| **FVR** | - | Fixed Voltage Reference |
| **FEM** | - | Finite Element Method |
| **FET** | - | Field Effect Transistor |
| **GIC** | - | Generalized Impedance Converter |
| **GPIO** | - | General Purpose Input/Output |
| **HCS** | - | Howland Current Source |
| **IA** | - | Instrumentation Amplifier |
| **IC** | - | Integrated Circuit |
| **ICSP** | - | In-Circuit Serial Programming |
| **IHCS** | - | Improved Howland Current Source |
| **IHCSB** | - | Improved Howland Current Source with Buffer |

| | | |
|---|---|---|
| **ITS** | - | Industrial Tomography System |
| **JFET** | - | Junction Gate Field-Effect Transistor |
| **LC** | - | Inductor-Capacitor |
| **LCT** | - | Low Cost Tomography |
| **LIN** | - | Local Interconnect Network |
| **MRI** | - | Magnetic Resonance Imaging |
| **MSSP** | - | Master Synchronous Serial Port |
| **NIC** | - | Negative Impedance Converter |
| **PC** | - | Personal/ Portable Computer |
| **PWM** | - | Pulse Width Modulation |
| **PWG** | - | Programmable Waveform Generator |
| **RC** | - | Resistor-Capacitor |
| **RIDAM** | - | Reduced Internal Drive-Adjacent Measurement |
| **ROM** | - | Read-Only memory |
| **SCI** | - | Serial Communications Interface |
| **SNR** | - | Signal-to-Noise Ratio |
| **TINA** | - | Toolkit for Interactive Network Analysis |
| **VCCS** | - | Voltage Controlled Current Source |
| **2D** | - | Two-dimensional |
| **3D** | - | Three-dimensional |
| **UCT** | - | University of Cape Town |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A_{CL}$ | - | Closed loop gain of operational amplifier |
| $A_{CM}$ | - | Common-mode gain |
| $A_D$ | - | Differential gain |
| $C_S$ | - | Stray capacitance |
| d | - | Distance of the ad hoc sensor from vessel wall |
| G | - | Gain of the instrumentation amplifier |
| J | - | Electric current density |
| $\sigma$ | - | Electric conductivity |
| $\vec{E}$ | - | Electrical field |
| E | - | Electrode |
| L | - | Number of electrodes |
| h | - | Height of the ad hoc sensor from surface |
| I | - | Electric current |
| $I_L$ | - | Load current (Current injected into the load) |
| $I_S$ | - | Source current (Current generated by current source) |
| $V$ | - | Voltage |
| $V_L$ | - | Load voltage |
| $V_1$ | - | Voltage measured on first electrode |
| $V_2$ | - | Voltage measured on second electrode |
| $V_{in}$ | - | Input voltage from voltage source |
| $V_{in+}$ | - | Voltage input to the positive terminal of operational amplifier |
| $V_{in-}$ | - | Voltage input to the negative terminal of operational amplifier |
| $V_D$ | - | Differential voltage |
| $V_{CM}$ | - | Common-mode voltage |
| $V_O$ | - | Output amplified voltage |
| $Z_O$ | - | Output impedance |
| $Z_L$ | - | Load impedance |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Electrical Impedance Tomography (EIT) is an imaging modality whereby an interior conductivity distribution of an object is obtainable through current injections and voltage measurements using deployed electrodes. In a typical EIT system, an array of electrodes is attached on the periphery of the object and electrical current is injected through a pair of electrodes whereby voltage measurement is performed on the remaining pairs of electrodes in the array.

EIT has gained popularity in three major areas namely medicine, geophysics and industrial process. The popularity of EIT technology has been due to its cost effectiveness, portability, non-intrusiveness and it does not produce hazardous radiation as compared to other tomographic modalities (Holder, 2005).

In most cases of EIT, electrodes attached on the boundary of the object perform differential voltage measurement as developed on the object boundary. Schlebusch and Leonhardt (2013) explored various electrode arrangements such as ring, linear and matrix arrangement. Ring arrangement has been the conventional arrangement of choice in most EIT implementation where electrodes are attached around the object. Multiple rings and semicircle have also been used in an effort to effectively utilizing the usable areas on the periphery of the object under test and hence optimizing results.

Despite various methods to optimize measurements through electrode placement on the periphery (Huang *et al.* 2008), the desirable information in the central region of the object remains largely unobtainable (Zhang *et. al.* 2014).

This research investigates using ad hoc EIT sensor whereby the ad hoc sensor node is deployed within the phantom vessel to perform EIT measurement from interior of the medium. The sensor node is flexible to assume any location within the medium.

The ad hoc sensor is equipped with two pairs of electrodes which act as a current source and voltage measuring system. This allows for current injection and voltage sensing to be performed from any location within the vessel. The role of the electrode pairs are exchangeable, whereby in each measurement, one pair of electrode is functioning as a current injecting pair while the other pair measures localized differential voltage. This approach aims to acquire localized voltage measurements from the interior of the vessel, especially central locations.

## 1.2 Problem statement

The Electrical Impedance Tomography (EIT) reconstruction problem is an ill-posed one, whereby there are insufficient measured boundary voltage to recover unknown conductivity within the interior of the object under test. This means that for any given measurement precision, there are arbitrarily large changes in the conductivity distribution that are undetectable by boundary voltage measurements. The favorable effort to solve this problem has been increasing the number of measurements through increasing number of boundary electrodes available. However, the issue is more that the measured data should be unique and accurate to be consistent with a conductivity distribution within the object. One of the limitations of boundary measurement approach is that the electrodes are usually located around the periphery of the object (process vessel), hence limiting the location where the changes in conductivity in the medium can be detected and measured. The constraint of measurements to the boundary of an object results to low spatial resolution especially towards the center of the object (process vessel), which results in misrepresentation of the conductivity distribution on reconstructed tomograms. This leads to misleading results and interpretation of a process. Therefore, there is a need to invade the interior of the object under test (process vessel) by deploying ad hoc electrodes such that the area where measurements are