Image Reconstruction and Resolution via Electrical Impedance Tomography

by

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Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

SEPTEMBER 2012

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. William Pao)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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VYNER VIVIAN RAYA

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Abstract

Electrical Impedance Tomography (EIT) is the cheapest imaging method known but with a questionable ability to produce reliable image. Improving the resolution and the quality of the reconstructed image will be the ultimate aim of this project. Image of better quality is achievable with the incremental number of electrodes used. A better image quality is possible with the utilization of a finer-meshed Finite Element Model (FEM) in solving forward problem of the algorithm involves. Further improvement on the images is attainable with the application of image post-processing of Matlab, in which an image of better contrast and noise-free is reconstructed. We are now one step closer in establishing EIT as a reliable imaging technique in the future.

Chapter 1: Introduction

1.1 Project Background

Electrical impedance tomography (EIT) involves the acquisition of conductivity measurements from the electrodes located on the periphery of an object. From the conductivity measurements, the information regarding the nature and distribution of components within the measured zone can be revealed. EIT, like any other tomography and imaging techniques are interested in abstracting information to form a cross sectional image. EIT utilize a parallel array of electrodes usually arranged circularly around the measuring zone, and current injections to explore the entire cross section of the object.

Image reconstruction is another vital part of EIT. Image reconstructions are heavily influenced by forward-problem solving and inverse mathematics. EIT problems are usually non-linear and due to that condition, many algorithms emerged and still emerging to further improve the problem solving and ultimately producing a higher quality image. EIT not able to produce a high quality and sufficient resolution are the reason why EIT is still not up in the market yet. EIT images are tipped to be able to be improved of its quality either by improving measurement techniques, mathematical algorithm used, and the post-image processing.

Electrical Impedance Tomography is non-invasive in which is one of the key requirements of a tomography. Some imaging techniques such as X-ray utilizes radiation source which is highly penetrative and arguably can deteriorate health over time. EIT being non-invasive and non-intrusive will not pose any health-threats and indeed can be labeled as safe.

EIT are comparatively and significantly cheaper than other existing commercial imaging technique such, due to its very simple instrumentations. EIT usually made up of electrodes and current injectors for measurement purposes, and CPU for signal reconstruction, image interpretation and reconstruction, as well image-displaying hardware. The instrumentations will be discussed in detailed in the next chapter. Due to its simple instrumentation, EIT holds an advantage of being cost effective compared to other imaging techniques.

1.2 Relevancy and Feasibility of the Project

EIT are cost effective and should be further researched and improved upon until its commercialization. The section where EIT can be improved is the image quality and its resolution. A study on how to improve the resolution of the image produced can enable EIT to be more reliable in imaging.

1.3 Problem Statement

Electrical impedance imaging uses the concept of voltage measurement acquired from the boundaries of a conductive volume. However, the images produced are very crude and blur with results often dependent on the conductivity of the medium.

1.4 Objectives

- To reconstruct forward image via Electrical Impedance Method
- To investigate the response and resolution of the image due to voltage perturbation in a highly inclusion material.
- To improve the quality and resolution of the constructed images.

1.5 Scope of studies

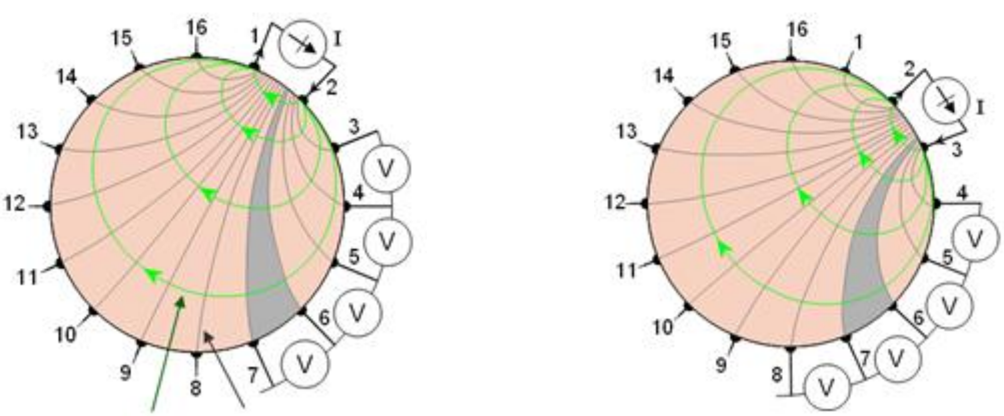
The focus of the project will be on enhancing the image quality. EIT involves injecting the current and measurement of conductivity, as well as proposing mathematical algorithm to improve the solution of image reconstruction. However, this project will not be doing any measurement process, as well as the improvement of the mathematical algorithm to be used in solving. Instead, this project will be utilizing a ready-made data from previous studies and enhancement of the image will be conducted via Matlab. The resolution of the image can be done via mesh refining, contrast enhancement and filtering.

Chapter 2: Literature review

Electrical impedance tomography involves a lot of activities from current injection and measurement until image reconstruction. Along the way, there are many other things that are needed to be explained such as the measurement methods, mathematical problem and solver. How image is reconstructed including the involvement of Finite Element Method and multiple solvers will be explored as well in this chapter.

2.1 Impedance Measurement Methods

In electrical impedance tomography, array of electrodes are set around the volume conductor of interest. Electric current will be fed through an emitter electrode and flows into a receptor electrode, and simultaneously all the remaining electrodes will be measured of its voltage. As described earlier, when the current is fed in a certain electrode, voltage should be measured through different pairs of electrodes to prevent error due to contact impedance which will contribute to a certain resistivity. Cheng et al (1990) alleged that voltage from current carrying electrodes should be included to obtain the greatest sensitivity to changes in the resistivity of the body. One of the methods in which electrical impedance may be measured is neighboring method.



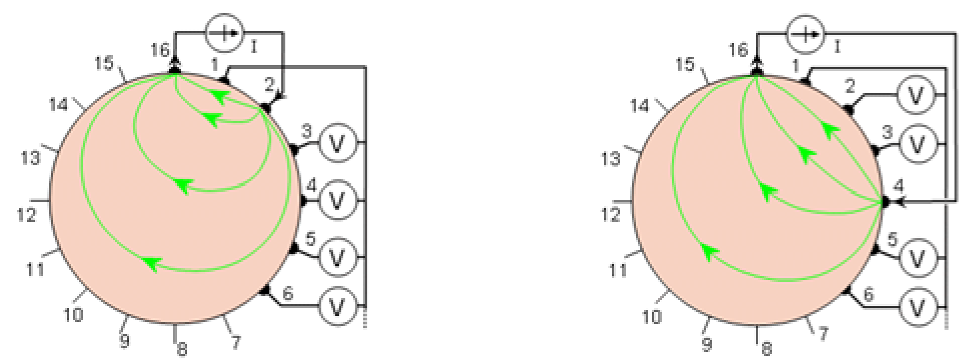
(a) The first four voltage measurements for the set of 13 measurements. Brown and Segar (1987)

(b) Another set of 13 measurements is obtained by changing the current feeding electrodes. Brown and Segar (1987)

Figure 2.1 Neighboring Methods

Figure 2.1(a) illustrates the neighboring method for a volume conductor with 16 equally spaced electrodes. The current is applied through electrode 1 and 2, the voltage is measured successively with electrode pairs 3-4, 4-5,…15-16. The process is repeated with subsequent pairs of electrode as shown in Figure 2.1(b), and repeated until current is fed through electrode 1 and 16.

The second method is called Cross Method as suggested by Hua et al (1987). The adjacent electrodes, for example 16 and 1, are selected for current and voltage reference electrodes, respectively. The other electrode which is electrode 2 will be connected with electrode 16 for current flow. The successive 13 electrodes will be measured of its voltage based on voltage reference electrode of number 1. This is shown in figure 2.2(a). The procedure is repeated with the current flows through electrode 16 and 4, while voltage measurement will be carried out with the same voltage reference that of electrode 1. This can be seen with reference to Figure 2.2(b).

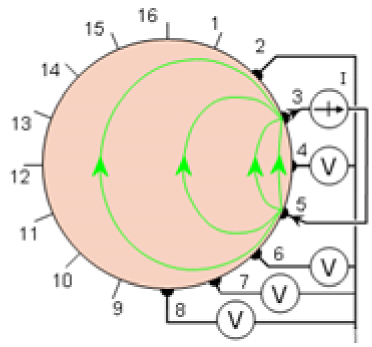


(a) The 1st Steps. Hua et al (1997)

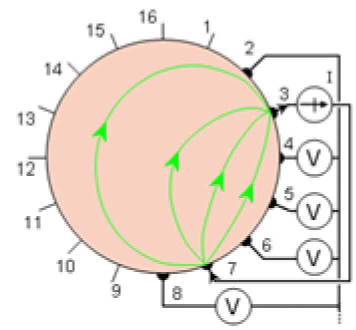
(b) The 2nd steps. Hua et al (1997)

Figure 2.2 Cross Methods

The measurement sequenced is again repeated using electrode 3 and 2 as current and voltage electrode respectively. Apply current through electrode 5, simultaneously measure the voltage successively for other remaining 13 electrodes with electrode 2 as voltage reference, as shown in figure. The procedure is repeated with applying current to electrode 7, and successively repeat this procedure for electrode 9, 11, …, 1 based on electrode 3 as current reference. Measure the voltage of remaining 13 electrodes with electrode 2 as voltage reference. The steps are shown in Figure 2.2(c) and (d).



(c) The 3rd step. Hua et al (1997).



(d) The 4th step. Hua et al (1997).

Figure 2.2 Cross Methods

Hua et al (1987) suggested another method called the opposite method. For this alternative, current is injected from one electrode to another diametrically opposite electrode. The electrode next to the current-injecting electrode is used as voltage reference. The rest are then measured of its voltage based on the voltage-referred electrode.

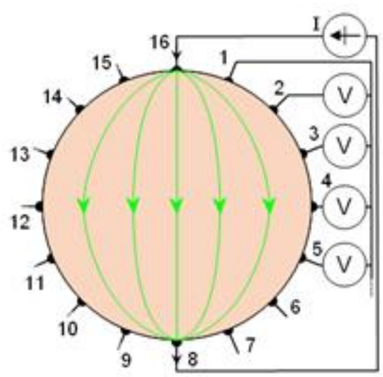


Figure 2.3 Opposite method of impedance data collection. Hua et al (1997).

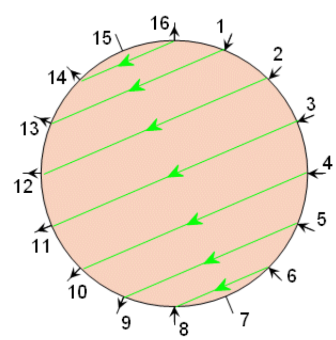


Figure 2.4 Adaptive method of impedance data collection. Gisser et al (1987).

The fourth method is proposed by Gisser et al (1987) which is called the adaptive method. In this method, current is injected through all electrodes. When measuring voltage, it is measured with respect to a single grounded electrode. When 16 electrodes were used, the number of first set of voltage measurement for a certain current distribution is 15. The process is repeated for another 15 sets. This can be seen on figure 2.4. Although more complicated, this method gives the best distinguishability and is the most versatile method of data collection (Lean et al, 2007).

2.2 Physical Design of EIT Equipment or Tools

Electrical Impedance Tomography creates images of the inner structure of a body using rings of ECG like electrodes on the sample (Holder, 2003), as illustrated in figure 5. An EIT system usually has a box of electronics and a PC. Typically the system is a 16 electrode EIT-phantom, with current injected at the phantom boundary using a current injector in order to create images of conductivity changes in the body (Newell et al, 2003). Traditional EIT systems inject current patterns in a serial manner and the impedance is computed from the collected data (Rubinsky et al, 2007).

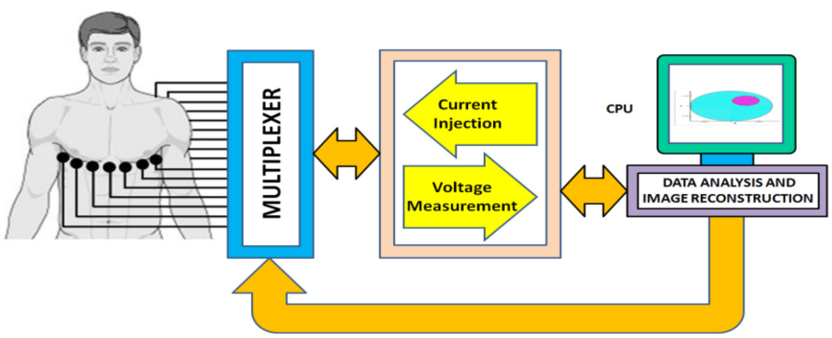


Figure 2.5 Medical EIT schematic: Electrode array attached to the patient's body. Bera and Nagaraju (2009)

Current will be injected with a certain frequencies and the differential potential developed at the voltage electrodes are measured. The developed potential is passed through the instrumentation and solved using the Finite Element Method in MATLAB, in which the differential potentials are numerically calculated using the forward solver.

2.3 Instrumentation Involved in EIT for Image Construction.

EIT system is developed with an analog instrumentation, a phantom with electrode array which acts as the EIT sensors, and a personal computer with image reconstruction algorithm (Nagaraju, 2009). Analog instrumentation of EIT includes constant current injector, voltage measuring device or data acquisition system, and electrode switching module. However, electrode is the basic element in the system. The electrodes act as a converter that converts the current into ionic current in an electrolyte. The electrodes also will be the measuring instrument in data acquisition. A Voltage Controlled Oscillator (VCO) generates a sinusoidal voltage signal as waveform using generator to be fed to Voltage Control Current Source (VCCS. The VCCS will convert voltage into desired current. The instrument amplifier will send the measured voltage to signal conditioning block for further adjustment before feeding into DAS processing.

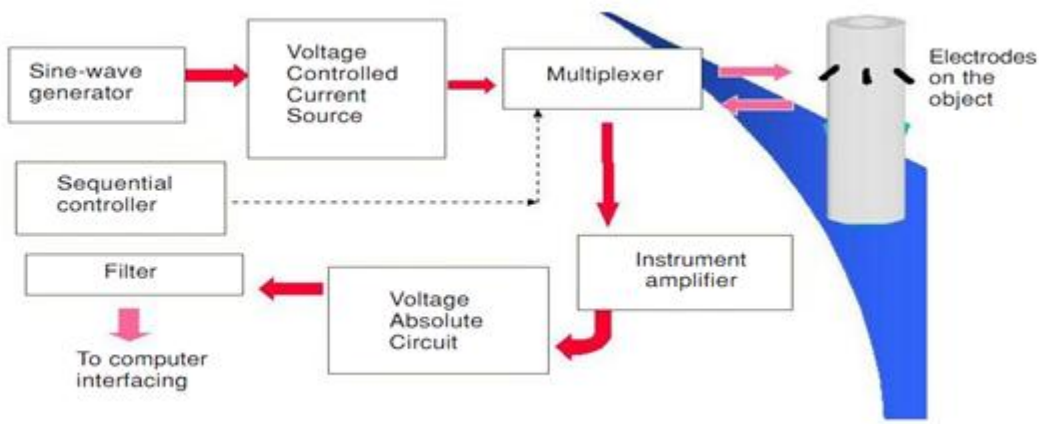


Figure 2.6 Block diagram of an EIT hardware system. Lean et al (2003)

2.4 Forward Mathematical Problem of EIT and Image Reconstruction

EIT is a soft-field tomography modality where the image reconstruction is formulated as a non-linear least-squares model fitting problem (Bayford, 2009). In order to reconstruct an image, three main steps will be taken: forward solving, computation of the Jacobian, and the computation of the conductivity update.

Finite Element Method (FEM) is usually used in forward solving that produces solution of a sparse linear system. FEM discretize the imaging domain to solve associated Partial Differential Equations (PDEs) that will linearize the system. In solving partial differential equations, it is aiming to create an equation that approximates the equation to be studied. The equation created must be stable, meaning that errors in the input do not accumulate and cause the resulting output to be meaningless.

The system of sparse equation then can be solved by direct or indirect iterative method. Direct solvers make use of matrix factorizations and once it is accomplished, multiple solutions for different right hand sides can be computed with very little cost (Borsic, 2009), as illustrated in the figure 2.7. The Jacobian matrix was calculated and assembled using a standard differentiation technique, and directly used. However, direct solvers require more memory than iterative solver due to factorized matrix storage. In context of tomographic applications, the same forward problem is solved for several excitations, and direct solvers can be faster than iterative solvers.

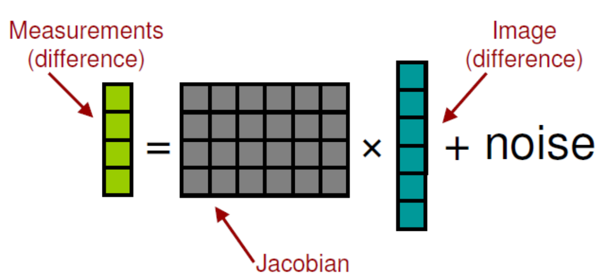


Figure 2.7 Direct method solving illustration

In iterative solving, a measured data will be retrieved from EIT electrodes and will be compared to the simulated data solved via finite element model. The simulation data will be updated for a few iterations of its conductivity distribution until it approximates with the real measured data. This can be illustrated in the figure 2.8. In other perspective, the jacobian matrix will be changed of its resistivity values at different iterations, and consequently updating the resistivity distribution. Starting from a crude approximation, it is iterated until they are halted. Consequently, it will create a situation in which the user can choose either a less accurate solution but can be calculated quickly, or a very accurate solution that are longer to be calculated.

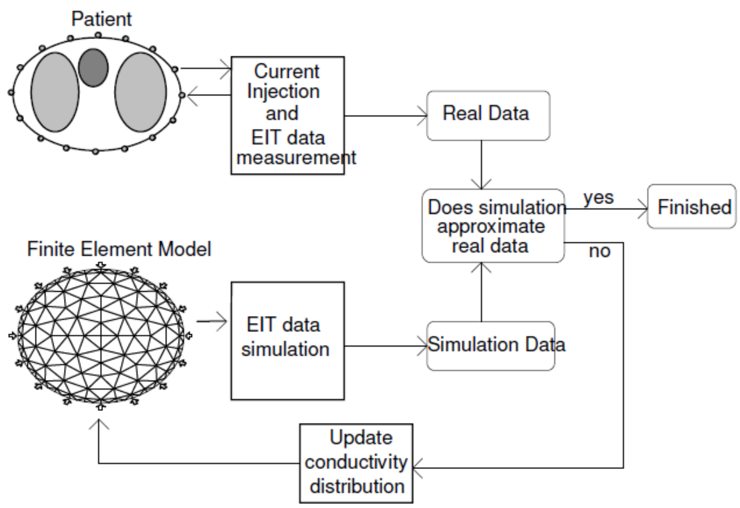


Figure 2.8 Iterative method solving illustration

2.5 Inverse Mathematical Problem and Regularization

The inverse problem is to determine the resistivity distribution from a finite number of boundary voltage measurements, by updating the resistivity distribution in response to an error formed by the difference between computed voltage values (via forward-problem solving) and the measured values. If this error is smaller than a prescribed error limit, the resultant resistivity distribution is considered acceptable.

Due to the highly ill-posed nature of the inverse problem in EIT, a lot of regularization technique has been proposed to obtain a stable solution. The image reconstruction of EIT is usually formulated as non-linear least squares Tikhonov regularized inverse problem:

Tikhonov Regularization Method (TRM) is the popular choice in solving the inverse problem but it is still sensitive to the choice of regularization parameter (Zhao et al, 2010). However, a novel algorithm, Level Set Method (LSM) which is based on TRM has been proposed to solve the problem of EIT.

Zhao et al (2010), has proposed the algorithm and summarized it as follows,

(a) EIT forward problem is solved by FEM to calculate the value of electrode voltages and consequently obtain the approximate conductivity distribution in the interior of volume.
(b) The object function ψ is minimize based on LSM to get level set function- by iteration process of searching the boundaries between different regions of the object.
(c) Calculate the interior conductivity distribution of the object by TRM.

2.6 Preconditioning of algorithm

A sufficiently fine meshed model, up to 100,000 nodes or more are preferable to properly capture the shape of the domain and of the electrodes. However, the sparse linear system can be too large to be handled by direct method such as Cholesky decomposition. Hence, the linearized forward problem will be solved using the Conjugate Gradient Method, with algebraic multi-grid (AMG) pre-conditioner. This CG method is a low-storage method and has computational advantage when involving FEM with large number of freedom. In other words, the solution of the forward problem is computationally intensive.

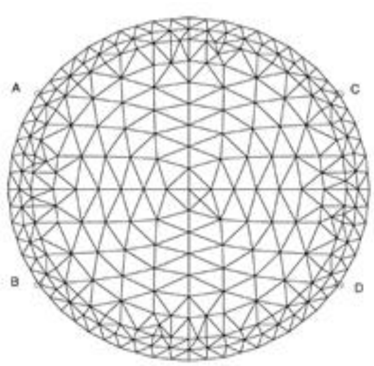


Figure 2.9 Circular domains with triangular finite elements (coarse mesh). Zhao et al (2010)

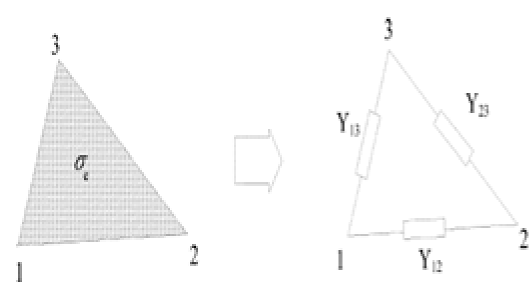


Figure 2.10 A linear triangular finite element is viewed as an electrical circuit. Zhao et al (2010)

In Preconditioned Conjugate Gradients (PCG), it is an iterative algorithm that generates a sequence of solutions which minimize the least square residual. The algorithm requires a matrix to be positive-defined for the iteration to be able to converge. For each iteration, only a single matrix-vector multiplication is required. The rate of convergence can be improved in a drastic way if the system is properly preconditioned. When preconditioning is applied, the algorithm converges in just a few iterations.

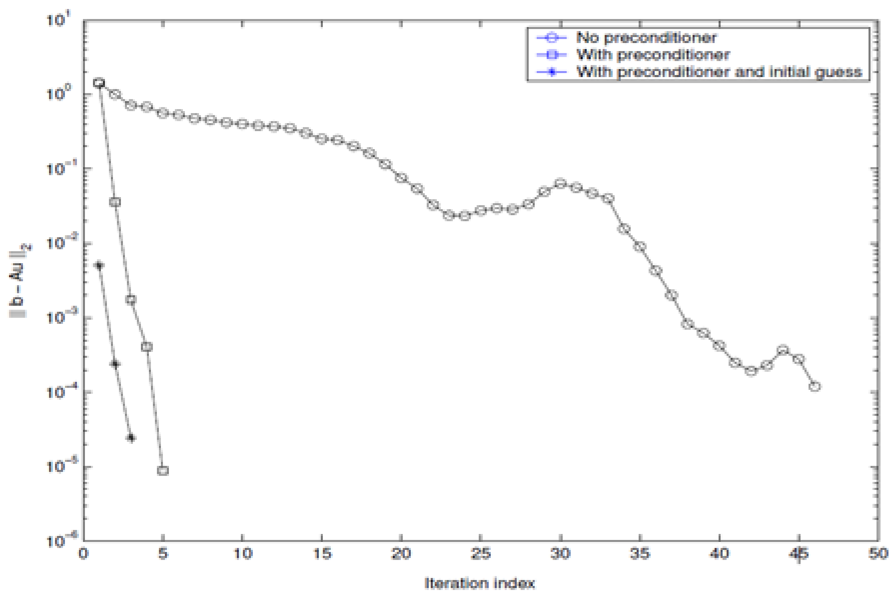


Figure 2.11 The impact of preconditioning and initialization on the convergence rate of the CG iteration. Borsic and Bayford (2009)

Chapter 3: Methodology

3.1 Summary of Project Activities

Table 3.1 Summary of Project Activities

Pre-Image-reconstruction works	Methodologies
Preliminary Research & Background Study	a) Literature Review
Analysis of the retrieved codes.	a) Programming codes in retrieved is tested in Matlab. b) Images can be constructed based on the codes
Selection of the appropriate target image/subject for images reconstruction.	a) Various case were studied and it is decided that only 2D image to be selected.
Study of what improvement that can be done to improve the image resolution	a) Various ideas are identified to improve the resolution of the image. b) Various types of ways to improve the images via post-processing techniques.

3.2 Research Flow Chart

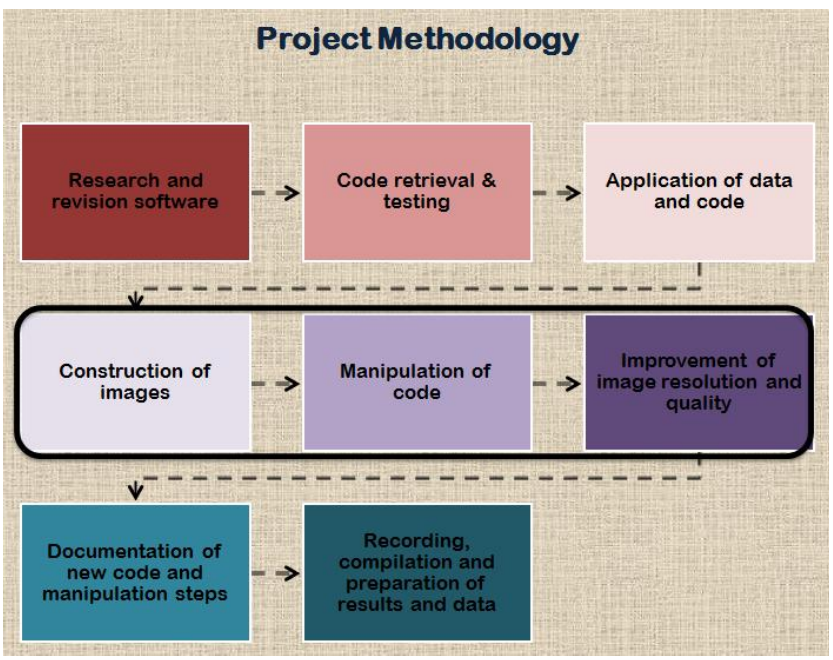


Figure 3.1 Research Flow Chart

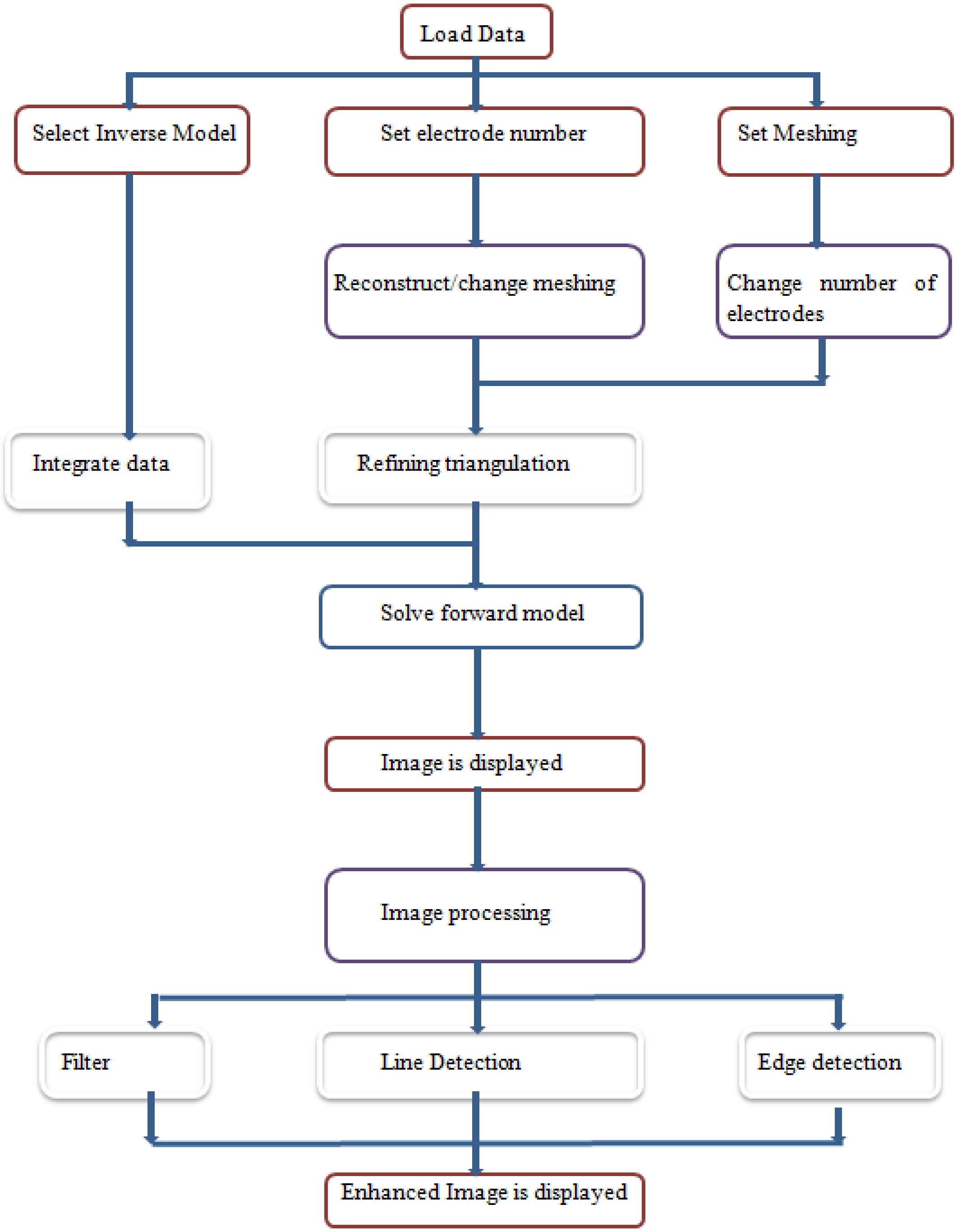


Figure 3.2 Research Flow Chart

3.3 Gantt Chart

Table 3.2 Gantt charts

No.	Detail/week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic	x	x													
2	Preliminary Research Work		x	x	x	x										
3	Software (Matlab) re-learning/revision				x	x										
4	Finding and retrieval of the code (Trial & Error)					x	x	x	✳							
5	Submission of extended proposal defence						x									
6	Proposal defence									x	x					
7	Reconstruction of image											x	x	x	✳	
8	Submission of interim draft report														x	
9	Submission of interim report															x

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Investigate image resolution via resistivity manipulation	x	x	x	✳											
2	Improving image quality anf resolution					x	x	✳		x	x					
3	Submission of progress report									x						
4	Slides and report preparation									x	x	x				
5	Pre-SEDEX Poster & Presentation(Internal Examiner)											✳				
6	Submission of Draft Report to Supervisor												x			
7	Submission of Dissertation(soft bound)& submission of Technical Paper(Supervisor)													✳		
8	Oral Presentation(2 Internal Examiners & 1 Supervisor)														x	
9	Submission of 3 Hard bound Dissertation															✳

✳ Denotes milestones in Gantt Chart.

3.4 Methodologies (Detailed explaination)

In this project, the electrical impedance tomography will not be done in real-time. The electrical result potentials were measured, and the process might be repeated for numerous different configurations of applied current. The data obtained, which is a forward problem, will be applied for modeling and mathematical calculation that ultimately will be used to reconstruct images.

In this research however, the data is already prepared and we will only apply the data and the ready-made algorithm to reconstruct image. However, certain changes in the algorithm such as refining the meshing of the Finite element model will be done to improve the resolution of the images, using Matlab software.

The methodology will be explained better with reference to the objective of this research paper.

- **To reconstruct forward image via Electrical Impedance Method**

In order to reconstruct an image, we need to retrieve and load the data of the image that we are interested in. From there, the stimulation pattern will be set. An inverse model will be selected by choosing the preferable model (which Finite Element Model of different meshing and parameter such as number of electrodes) that is readily prepared. A forward modeling will be solved (calculation of conductivity in boundary and interior part) to normalize the data to get the desired image. The image then can be displayed by solving the inverse model.

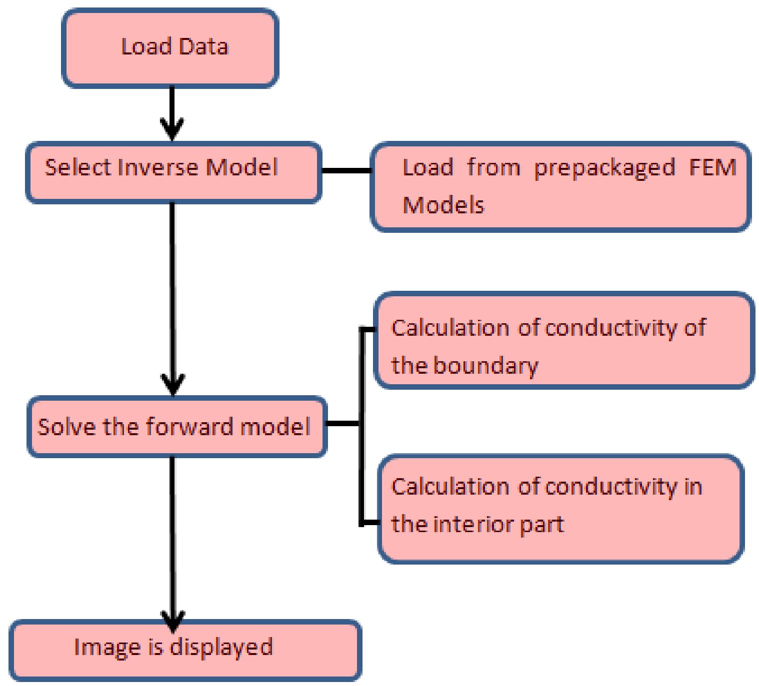


Figure 3.3 Flow chart of how forward image is reconstructed.

- **To investigate the response and resolution of the image due to voltage perturbation in a highly inclusion material.**

One of the manipulations that are proposed in this research project is by changing the Finite Element Method of the inverse model. This can be done by changing the meshing of the Finite Element Model. We set the inverse model to be of the number of electrode preferred and the preferred model of meshing. The Finite element model will then be used, and integrated with a prepared data. The data will settled on the points of which it is equivalent to the finite element model used. The finer the meshing, the finer the triangulation of the finite element, and there will be more 'electric circuit' that can be calculated and determined of its conductivity. We will then replace the current inverse model with the finer mesh and repeated the procedure until the finest mesh available. The image will be reconstructed and be shown.

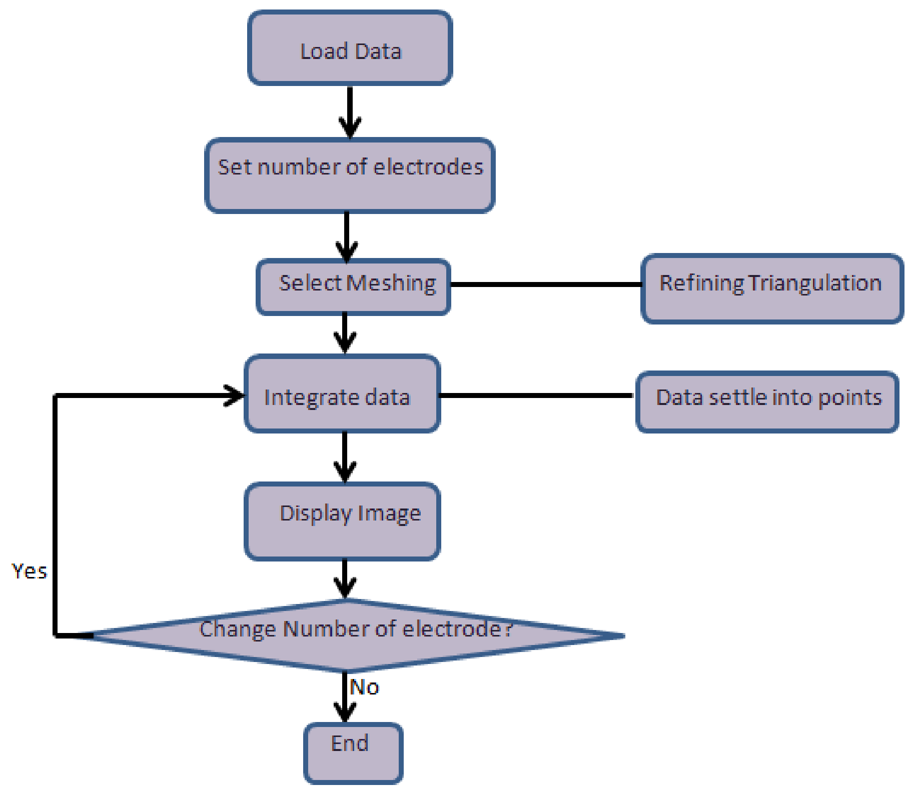


Figure 3.4 Flow chart of image reconstruction and changes of meshing is applied.

Another manipulation that is proposed is changing the number of electrode but using the same meshing. Repeat the procedure as the first manipulation, but instead of changing the meshing, the number of electrode is changed incrementally. The image is reconstructed and the sensitivity of the image will be studied.

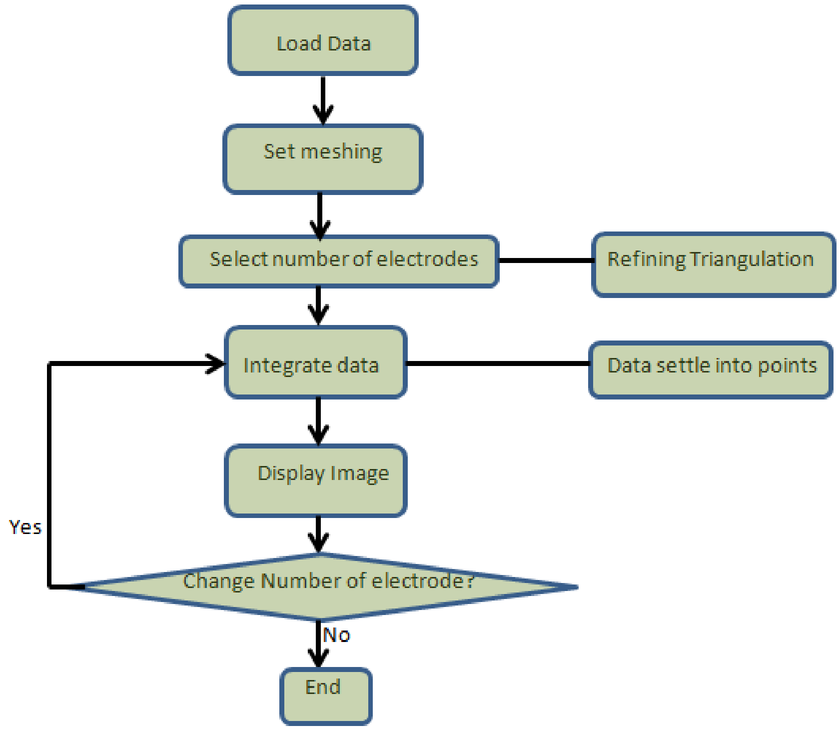


Figure 3.5 Flow chart of image reconstruction and changes of number of electrode is applied.

- **To improve the quality and resolution of the reconstructed images.**

After data manipulation and a desired (highest resolution) image is obtained, the image can be further improved using image processing toolbox of Matlab. Image color enhancement and contrast enhancement can be done. Filtering is also suggested to reduce the noise pollution on the images.

The contrast enhancement of the reconstructed images can be done by three techniques,

(a) imadjust- mapping the values of the input intensity image to new values. 1% of the data is now saturated at low and high intensities of the input data.

(b) histeq- performs histogram equalization. It transforms the values so that the histogram of the output image approximately matches specified histogram (uniform distribution by default).

(c) adapthisteq performs contrast-limited adaptive histogram equalization. It operated on small data regions (tiles) rather than the entire image. Each tile's is enhanced resulting in the histogram of each output region approximately matches the specific histogram (uniform distribution by default).

Other improvement that we can exert on the image is filtering. One of the filtering that we can use is Gaussian filter in which we can smooth the image. The process of smoothing suppresses the noise and cause small fluctuations. In terms of the frequency domain, this process suppressed high frequencies. Gaussian filters will prevent overshoot to the step function input while minimizing the rise and fall time. Gaussian filters can also be used to detect edges in images (edge detection).

The process of edge detection attenuates high fluctuations in color. In the frequency domain, this process attenuates the high frequencies. The edges for each color layer (red, green, and blue) are extracted, and the edge intensity images are placed in a matrix which will resemble a multi-dimensional color image, as shown in Equation (1).

An edge in an image may point in any directions, so four filters can be used to detect horizontal, vertical and diagonal edges in the blurred image. The edge detection operator such as Roberts, Prewitt, and Sobel, returns a value for the first devative in the horizontal direction (Gx) and horizontal direction (Gy). The edge gradient and direction can be determined via formula shown in equation (2).

$$\mathbf{B} = \frac{1}{159}\begin{bmatrix} 2 & 4 & 5 & 4 & 2 \\ 4 & 9 & 12 & 9 & 4 \\ 5 & 12 & 15 & 12 & 5 \\ 4 & 9 & 12 & 9 & 4 \\ 2 & 4 & 5 & 4 & 2 \end{bmatrix} * \mathbf{A}. \tag{1}$$

$$\begin{aligned} \mathbf{G} &= \sqrt{{\mathbf{G}_x}^2 + {\mathbf{G}_y}^2} \\ \mathbf{\Theta} &= \operatorname{arctan}\left(\frac{\mathbf{G}_y}{\mathbf{G}_x}\right). \end{aligned} \tag{2}$$

The edge direction angle is rounded to one of four angles representing vertical, horizontal and the two diagonals (0, 45, 90, and 135 degrees). The resulting image then can be displayed and shown.

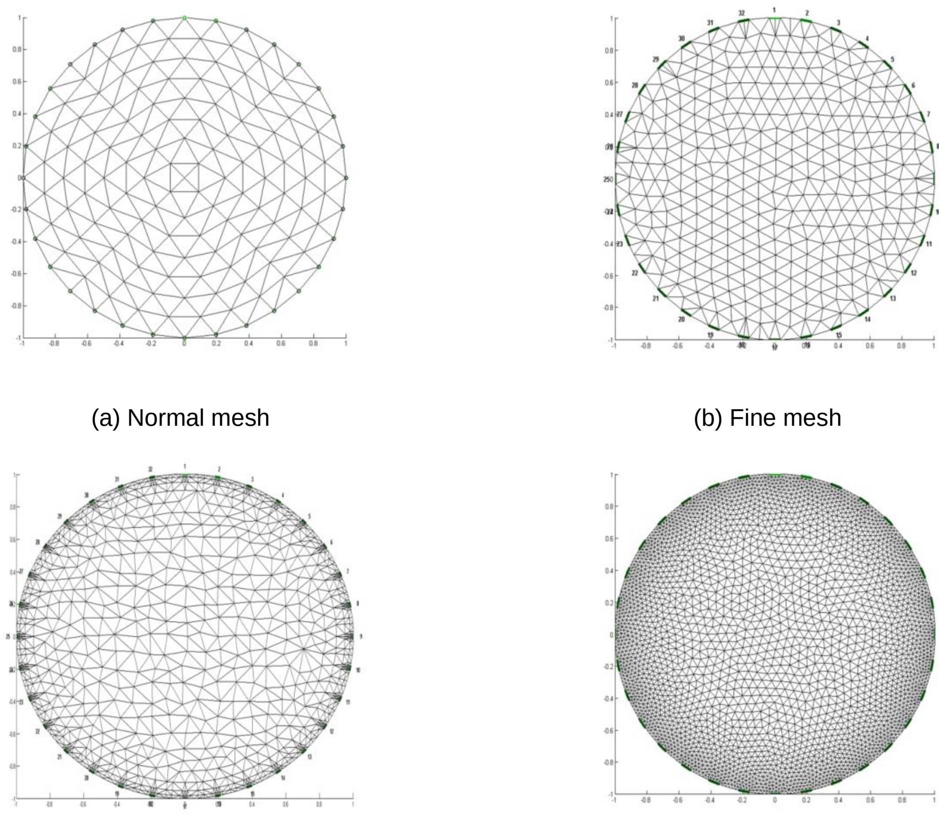
Chapter 4: Results

In order to reconstruct an image, inverse model is chosen and forward solving will be done. Finite Element Model (FEM) will be utilized and forward-solved.

For better understanding, we will explain each result and findings based on the objectives of the project.

4.1 To Construct Forward Image Via Electrical Impedance Method

Before we can reconstruct an image, we need to build a Finite Element Model that will be used for forward solving. Finite Element Model is the first step to image reconstruction and it is possible that it comes with different meshing and number of electrode. The accomplishment in building the FEM itself is the pioneer result. Below are some examples of forward model that has successfully being build:



(a) Normal mesh

(b) Fine mesh

(c) Finer mesh

(d) The finest mesh

Figure 4.1 Examples of Forward Element Models that will be used and solved to reconstruct images.

For the next test, we are to include a sample with 'lung' and 'pancreas' to be detected and to produce image via electrical impedance tomography. A set of data is already prepared and inserted into the Matlab software, solving the finite element model and the image can be reconstructed.

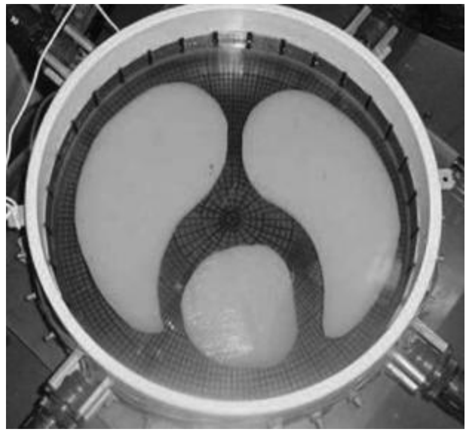


Figure 4.2 Phantom tank for data acquisitions

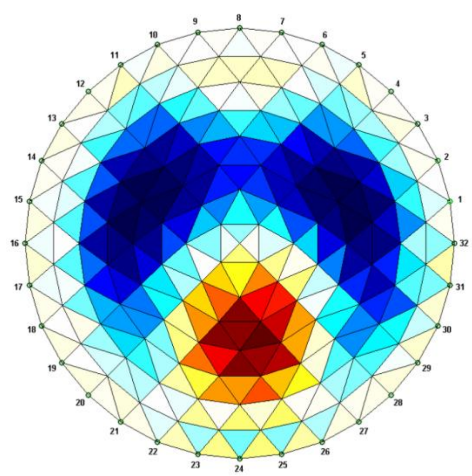


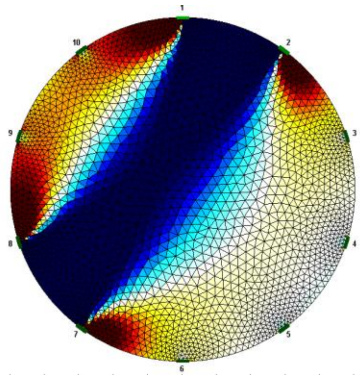
Figure 4.3 Reconstructed image based on the sample

The second part of the result will be based on our second objective which is

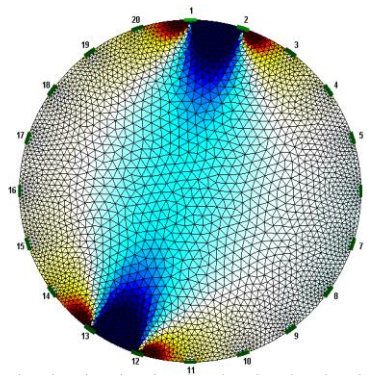
4.2 To investigate the Response and Resolution of the Image due to Voltage Perturbation and Data Manipulation in a Highly Inclusion Material

Here there will be two parts of investigation; the first investigation is to determine the resolution of images when the number of electrodes is increased but using the same meshing FEM.

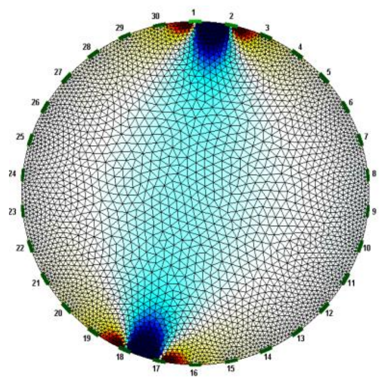
The electrodes will be started with 10 and will be increased in the increment of +10 and the resolution of the image is observed.



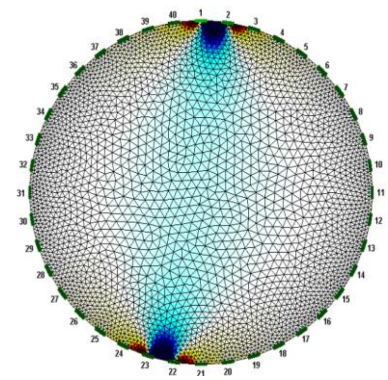
(a) 10 electrodes,



(b) 20 electrodes



(c) 30 electrodes



(d) 40 electrodes

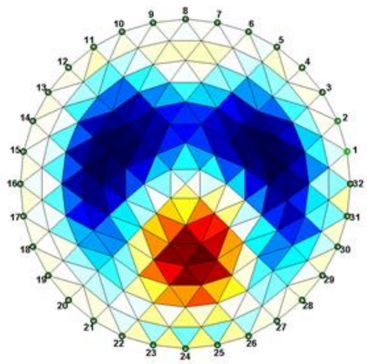
Figure 4.4 Changes in sensitivity and resolution of the image as the number of electrodes are increased.

It is observed that, as the number of electrodes increased, the sensitivity of the image is decreasing (notice that the bluish line in the middle of the image is fading, proving there is nothing but current injection and reception across the model). When sensitivity is decreased, it means that the resolution of the image is increasing.

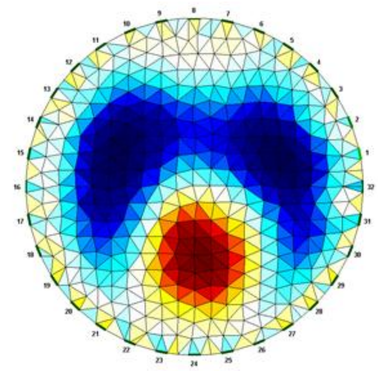
The conclusion for the first part is that as the number of electrodes is increased, there will be slight changes in meshing (finer), finer mesh even at slightest will increase the triangulation that can be measured and filled with data. Adding the number of electrodes can be one of the steps to be taken to improve the quality of image.

What if the electrode is set to be the fix variable and the manipulated variables will be the meshing of the FEM?

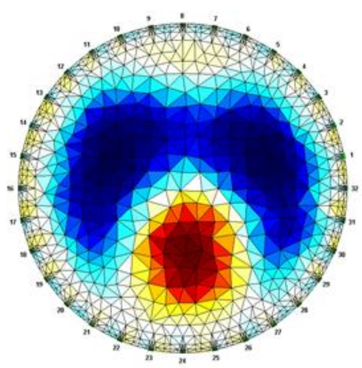
It is observed that, the finer the meshing, the better the image is in revealing its interior parts. By having more meshing, there are more ‘pixels’ that can carry data to be shown and perceived as images. This can be explained by the increment of the triangulation in the model and more conductivity can be measured. The image resolution can be future improved by using a finite element with a finer meshing.



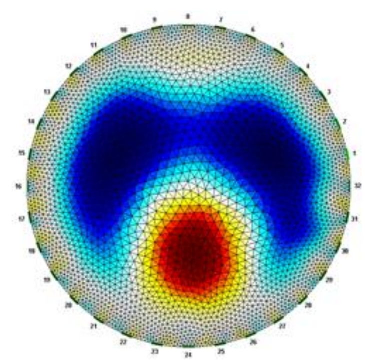
(a) Reconstructed image with normal meshing



(b) Reconstructed image with fine meshing



(c) Reconstructed image with finer meshing



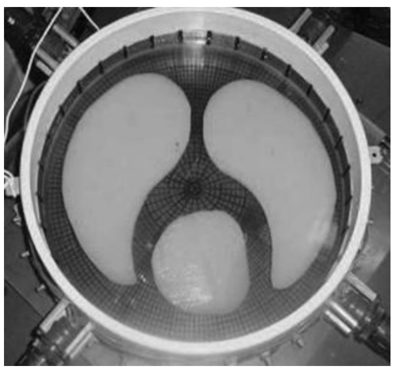
(d) Reconstructed with the finest meshing

Figure 4.5 Comparison between different meshing of the reconstructed images

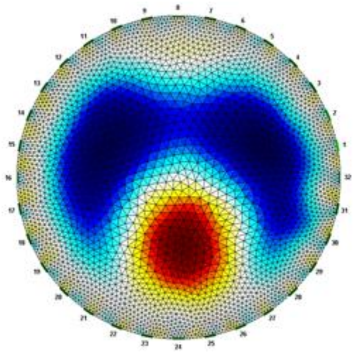
The third part of the experiment is to achieve the third objective of this project which is:

4.3 To improve the quality and resolution of the constructed images.

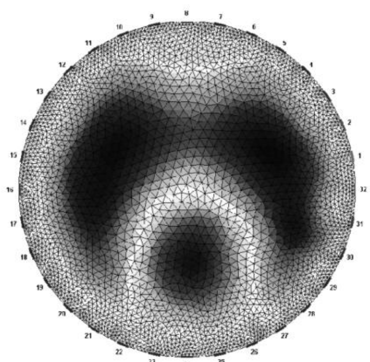
The reconstructed image is then being enhanced of its contrast via Image Processing Toolbox of Matlab, the contrast enhanced image has significantly improved the image especially the center of the image. We can observe that the separation between 2 ‘lungs’ at the center are more obvious compared to the original reconstructed image. The image quality is commendable but the images are still having shadowy part at the edge of the 'lungs'. In order to eliminate the shadowy part which is due to the noise effect, we are to implement filtering via Gaussian Filter. After filtering, we reconstruct the images using line detection as well as the edge detection. It is observed that the image produced is clearer and the shadowy 'noise' part is eliminated. The image produced is quite similar to the sample image; however the lung size is somewhat smaller than the sample. That leaves room for improvement in terms of producing image with higher similarities.



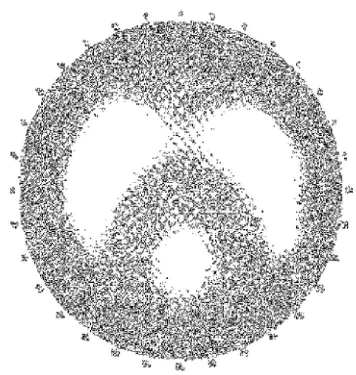
(a) Sample



(b) Reconstructed image with the finest meshing



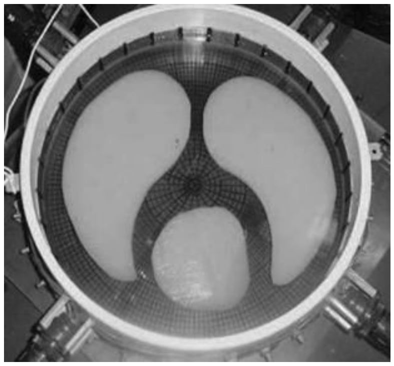
(c) Contrast enhanced image



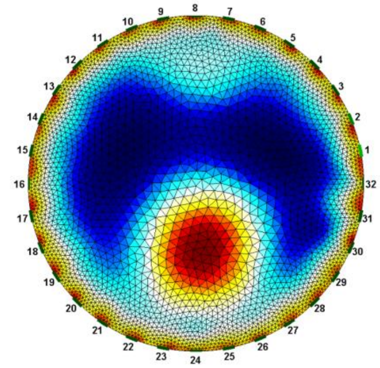
(d) Filtered image

Figure 4.6 Enhanced image (difference imaging)

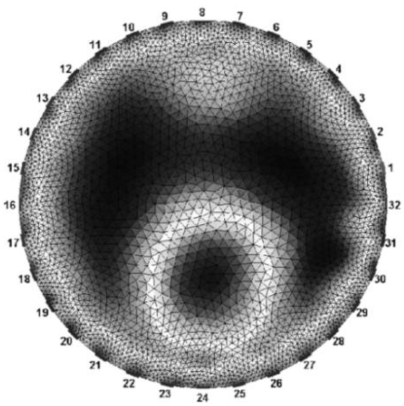
The above figure shows an image reconstruction via difference imaging or direct method. Difference imaging is when one measures the conductivity of the electrodes, and the measurement is compared to the algorithm created from the finite element model. The detected difference is then used directly to reconstruct the image. Absolute imaging on the other and is more accurate as it will compare an approximate solution with the measured conductivity to reconstruct the images. More iteration is done in absolute imaging for more accuracy.



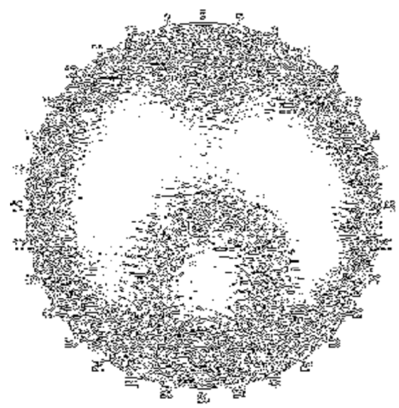
(a). Sample image



(b) Reconstructed image with even finer meshing



(c) Contrast enhanced image



(d) Filtered Image

Figure 4.7 Enhanced image (absolute imaging)

Based on the figure 4.7, we can see that the reconstructed absolute image is better when compared to the difference image of figure 4.6 in terms of the similarities between the sizes of the ‘lungs’. The reconstructed image went through the same process in which it is contrast-enhanced and ultimately filtered of its ‘shadowy’ noise effect. Figure 4.7 (d) looks almost similar to the sample image although not entirely or perfectly accurate. This is due to the fact that that the reconstructed image is still not of the highest quality. Since this project is dealing with an already-prepared data and the data can only be improved mathematically, it imposed a limitation to this project. Problems such as noise existence will always be around and is not possible to be eliminated by just doing image enhancing.

Chapter 5: Conclusion

The project indeed serves the purpose of improving the image quality of the reconstructed image based on the algorithm and measured data available. In this project, there are few suggestions on how to improve the image reconstruction, such as increasing the number of electrodes used and also the meshing of the finite element model used. There are two conclusions that can be derived from the previous statement: (1) The higher the number of electrodes used, the better is the image resolution; (2) The finer the meshing of the finite element model used, the better is the resolution of the reconstructed image.

The image can be further enhanced by post-image processing in Matlab. The image can be enhanced of its contrast to create a sharper image. The sharpened image are consequently being filtered using Gaussian filter, with edge and line detection to be carried out next the image quality produced are significantly enhanced. Another conclusion that can be stated is that the image can be reconstructed via difference imaging and absolute imaging, with the later ones proved to be a better image creator and produce result that is much more similar to the sample image.

Suggestions for improvement and future studies

Electrical Impedance Tomography as per mentioned is consisting on two major procedures; the measurement procedures, and image reconstruction activities. In this project, the focus is on image reconstruction: on how to improve the resolution of image, and how to enhance the reconstructed images. The limitation of the project is at the initial part of the project in which the data provided or the available algorithm is not good enough.

A lot of development can be undertaken to improve EIT: EIT instrumentations can be made of a more advanced technology such as better electrodes or frequency. The preparation of the EIT measurement experiment can also be improved, such as the changes in the salinity of the solution used to create a better medium for current flow. Improvement for post-measurement would be mathematics: Reconstruction algorithm used to solve the forward problem can be reformed for a better image construction. Reformation of pre-conditioning of algorithm can also be done to ultimately meliorate the image outcome. Consequently, a good data can be acquired for better image reconstruction in which can be further improved using methods discussed in this project.

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