Resistivity Imaging of a Phantom with Irregular Inhomogeneities with 16 Copper Electrodes Based Sensory System in 2 Dimensional Electrical Impedance Tomography

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Abstract— In this paper, the fabrication of 16-copper electrode based electrical impedance tomography (EIT) system is fabricated. EIT is a tool for imaging the interior permittivity distribution of an object (stone/tumor) by measuring voltage at the surface. This method is useful for detecting the shape, size and position of unwanted lumps within a specified area. In order to understand the proposed work, a simulation study using Finite Element Method (FEM) based Multiphysics software has been performed, in which we have imaged perfectly the shape, position and sizes of both the regular and irregular shaped objects situated within a specified phantom area in a 2D plane. Simultaneously, we have developed a real-time system consists of 16 copper electrodes (placed equidistantly) detect non-conducting like plastic container in normal saline solution. We have injected a constant current to the phantom boundary and the surface potentials are being measured using neighbouring method. We have collected the output data sets and reconstructed the voltage density distribution plot using FEMM tool. The resulting images show that the resistivity profiles of the phantom for various events are successfully observed.

Keywords— Electrical Impedance Tomography (EIT), Finite Element Method (FEM), lumps, surface charge density

1. Introduction

EIT is a non invasive tool for imaging the interior permittivity distribution of an object by measuring voltage at the surface and then reconstructing it to an image. EIT depends mainly on the electrical properties of the materials, mainly conductivity of material which is placed inside the phantom under observation [1-3]. Harmful radiations are not involved in this process of imaging. For biomedical field it identifies information from the electrical properties of tissue [4]. It is an emerging methodology for use in medical applications. In the near future, there may be a possibility for the replacement of the conventional medical imaging techniques by EIT.

Computed Tomography (CT), Mammography, Magnetic Resonance Imaging (MRI), Positron Emission tomography (PET), Ultrasound and Thermal imaging are the conventional imaging techniques mentioned above [5]. All these techniques deals with either harmful radiations which may cause side effects to body tissues or very expensive.

Study of the impedance image reconstruction techniques with practical phantoms is necessary to analyze the performance of an EIT system. EIT systems with practical phantoms with saline and solid resistive materials are very popular [6]. EIT is very valuable due to its cost effectiveness i.e. it is affordable to common man and portability.

In this paper, firstly the FEM Multiphysics based simulation studies were performed and then real time implementations of EIT system with 16 copper electrode system were fabricated. An EIT system composed of two parts, a data acquisition hardware and an image reconstruction software [7, 8].

Fig. 1 shows the basic block diagram of EIT system. It is mainly comprised of
i) an array of electrodes, attached to the surface of the phantom and the normal saline as a conducting medium
ii) a voltage source (0-15V), which applies an dc voltage to the electrodes and measures the resultant voltage distribution on the surface of the phantom.
iii) an image reconstruction algorithm, which reconstructs images from the voltage difference as measured from the surrounding electrode array.
iv) a user interface (display, hardcopy, keyboard, storage facilities, etc.) to enable an easy user access to the image analysis.
II. Experimental Details

A. FEM Based Study

(a) Model Definition
This model solves Gauss’ law with \( \rho = 0 \). Using Poisson’s equation we have \[ \nabla (\varepsilon \varepsilon_0 \nabla V) = -\rho \] (1)
where \( \varepsilon_0 \) is the permittivity of the free space and \( \varepsilon_r \) is the permittivity of the object which is in our investigation. Here a cylindrical space is considered which contains air with \( \varepsilon_r \) equal to 1 and the different objects with varying permittivity’s from 4 to 16 are considered. The voltage difference, is created by setting \( V = 0 \) volt on the bottom and \( V = 10 \) volt on top of the cylinder. On all the other boundaries, electric insulation condition as given in Eqn. 2 is used.
\[ n \cdot D = 0 \] (2)

(b) Model Designs

A slice of a cylindrical volume is considered with four objects of different shaped and of same height. These bodies are assumed to be lumps (tumors) inside the human kidney and having different permittivity ranging from \((30-80) \times 10^3\). An overall permittivity inside the block is taken equal to 100. The model is converted to 3D platform from the 2D design FEM platform. Extremely fine physics controlled meshing (details provided below) is applied and the experimental study has performed. An electrical potential of 10V is applied at the top surface of the block and on the bottom surface a ground potential of 0V is applied and other sides are kept insulated.

![Figure 3. Photograph of the constructed model with meshing](image)

Details of the meshing:
- Maximum element size: 0.038 cm
- Minimum element size: 0.001 cm
- Maximum element growth rate: 2.4
- Resolution of the curvature: 0.4
- Resolution of the narrow region: 0.7

(c) Results and discussions of FEM study

Details of the objects under consideration:

Table I

| Specifications of the constructed cylinder |
|------------------------------------------|
| **Radius(cm)** | **Height(cm)** | **Relative Permittivity(\(\varepsilon_r\))** |
|----------------|----------------|------------------------------------------|
| 1              | 0.2            | 100                                      |

Table II

| Objects shown in Fig. 1 | Specifications of the object (lumps) |
|--------------------------|-------------------------------------|
|                          | **Height(cm)** | **Relative Permittivity(\(\varepsilon_r\))** |
| 1                        | 0.2            | \(40.678 \times 10^3\)                        |
| 2                        | 0.2            | \(80.678 \times 10^3\)                        |
| 3                        | 0.2            | \(60.678 \times 10^3\)                        |
| 4                        | 0.2            | \(30.678 \times 10^3\)                        |

(values of relative permittivities obtain from [12])
Figure 4. Photograph determining the shape of the objects placed inside from the top of the cylinder by noting the surface charge density. It can be easily visualized from Fig.4, that the surface charge density is higher for the higher permittivity objects as expected. Fig. 4 shows the variation of electrical field along z-axis.

Figure 5. Photograph showing the variation of surface charge density, electric field (streamline density) along z-axis within the specified volume.

B. Implementation Of Real Time EIT System

The experimental set up developed by us consists of 16 copper electrodes, Single Pole Single Throw (SPST) slide actuated DIP switch-based multiplexers is used for electrode switching module which is operated manually for injecting current and measuring the voltage, a dc 0-15 V supply, XRT 111 as Voltage Control Current Source (VCCS), multiplexer for and arduino uno board for pc based data acquisition. The block diagram of the developed sensory system is given in Fig. 6 and the real time implemented system is provided in Fig. 7.

This real time implementation focuses on the EIT experiments performed using normal saline with 0.9 % of sodium chloride in a plastic container (phantom). The diameter of plastic container is 30 cm and height is 10 cm and the volume of normal saline used is 360 ml. Electrical conductivity of normal saline is 300 mS/m.

(a) Data Collection

The 16 copper electrodes are placed on phantom equidistantly and normal saline is used as a conducting medium. The non conducting impurities are inserted at different positions within the phantom in presence of normal saline water. Following the neighbouring pattern current injection protocol constant current of 1A is applied across two electrodes at a time but current can also be applied through opposite, cross and adaptive method [2, 7, 9, 10]. The setup of experiment is shown in figure 2. For example, in a set of 16 electrodes the current is applied between electrode pair 1-16 and the voltage is measured between 2-3, 3-4 and so on (excluding source pair electrodes). Thus the first 13 readings are obtained. The current source is then shifted to pair 1-2, 2-3 etc and the procedure is repeated to get the next set of 13 readings [7, 9, 10]. Then, the voltage difference is measured between adjacent electrodes [1, 9]. All these voltage readings are taken manually and it takes nearly 15 minutes to take one set of voltage readings. The non conducting impurity used in this experiment is plastic cylinder of 5cm diameter and 15 cm height. After taking all the voltage set readings finite element method is used for reconstruction of images.
III. Results And Discussions

The FEM based voltage density plots as obtained in Fig. 9(a,b,c), indicates the position of the impurity present within the closed specified phantom area. It is impossible to detect the actual size as well as the shape of the impurity present. The profile of the potential lines in the FEM graph is studied. It is visualize that when the non-conducting impurity is placed inside the phantom, the equipotential lines gets deviated and leave the non-conducting object. Thus, the voltage measured near impurity is high i.e. the conductivity is low.

IV. Conclusions

The Electrical Impedance Tomography is a non radiating, safe, portable and affordable imaging technique. The disadvantage of an EIT includes its poor spatial resolution. By increasing the number of electrodes the performance of EIT system can be improved. Due to the fixed size of the phantom circumference, the size of the electrodes can be kept optimum to achieve best resolution. The distribution of the colour profile in the voltage density plots of FEM graph indicates the presence, the type and the location of the unwanted lumps. This technique can be used for various applications ranging from monitoring the condition of human thorax during breathing, lung fluid detection, imaging of human brain and stomach for gall bladder stones, hyperthermia, foetal movement, imaging of intravascular hemorrhage in infants etc.

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