Phantom Experimentation and Initial Observations in Electrical Impedance Tomography

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Abstract- Electrical Impedance Tomography offers an inexpensive and portable measurement instrument for monitoring of electrical conductivity for medical and industrial type phantom. This paper presents a simple hardware of EIT system. Also presents experimentation on different phantoms, through this system. The number of electrodes may be used 4, 8, 16, 32, etc. and can be used according to requirement and diameter of the object. But the selection of high number of electrons, obtains higher resolution, more clarity of image. And also presents of graph and data according to experimental study of phantom/object.

Keywords: - Electrical Impedance Tomography, Phantom,

1. INTRODUCTION

Bioimpedance techniques has evolved over several decades as a promising imaging modality for non-invasive conductivity measurement [1]. The concept of impedance-based imaging can be traced back to the early 20th century when researchers explored electrical properties of biological tissues, which is also called Electrical Impedance Tomography (EIT). The Foundation for Modern EIT was presented in the 1970s and 1980s, when Sheffield University developed one of the first EIT systems for medical applications, particularly in the monitoring of pulmonary function. Over time, advances in computational power and electrode design have improved EIT resolution and reconstruction algorithms, making it more applicable to real-time image in medical and industrial fields [2-3].

Bioimpedance techniques play a crucial role in EIT, as measure the electrical properties of biological tissues to differentiate between various structures and conditions. EIT Techniques such as tetrapolar impedance measurement, where four electrodes are used to inject current and measure voltage, were widely used for medical diagnosis. Multi-frequency bioimpedance analysis allows the differentiation of tissue types based on frequency-dependent conductivity variations [4-5]. Electric impedance spectroscopy further refines this process, analyzing the impedance on a variety of frequencies, allowing a better characterization of cellular and tissue properties. These techniques increase EIT' ability to detect physiological changes, making it valuable for applications in pulmonary images, brain monitoring and cancer detection [6-8]. Recent innovations integrate machine learning and deep learning methods to improve image reconstruction, making EIT a more reliable and accurate tool for biomedical and industrial applications. EIT is a non-invasive imaging method used in both medical and industrial applications. It operates by applying alternating currents, usually in the milliampere range and frequencies between 10 kHz and 100 kHz, through electrodes placed on the surface of a subject (or phantom). The resulting voltage measurements are then used to reconstruct an image of the subject's internal conductivity distribution [6-7]. This reconstruction process involves an algorithm that calculates the conductivity from the measured boundary data. The figure 1 illustrates a typical EIT system block diagram.

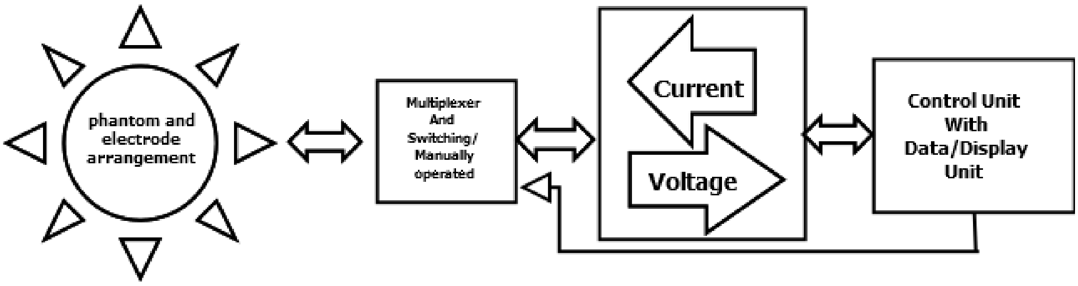


Figure 1 : EIT system

Electrical impedance tomography syetm has various practical applications according to field, e.g. in medical field (long term monitoring, detection of cancer, monitoring for internal bleeding, gastric emptying, imaging of lung problems [7-10]) due to the changes in bio-electrical properties among tissues and impedance distribution can shows the physical and practical properties of the Subject and in industrial field (Process control, real time monitoring of process plants such as mixers and conveyors, quality control and fault detection for various materials, geological exploration) and also used for educational and laboratory designing [8-10]. EIT system has many advantages, e.g. non-invasive, low cost, fast response, portable, radiation free, safe and it is suitable for ambulatory monitoring and beside measurement. It is easy to be operated and maintained.

EIT has been extensively studied as a non-invasive imaging technique for assessing the electrical conductivity distribution within a given medium. Studies highlight its advantages in medical imaging, particularly for lung function monitoring, brain activity detection, and cancer diagnosis, due to its portability, low cost, and real-time imaging capability [12-14]. The research also explores its applications in industrial environments, such as detecting structural defects in materials and monitoring the distribution of fluids in pipes. Several studies emphasize that resolution and accuracy of the EIT image depend on factors such as electrode configuration, signal processing algorithms and medium conductivity being analyzed [15-17]. Recent advances in hardware and software techniques, including machine learning based image reconstruction methods, significantly improved the reliability and accuracy of EIT systems. However, challenges such as misplaced problems and noise sensitivity remain key areas of ongoing research.

2. Methodology

The Bioimpedance Methodology Study involved manually conducted measurements using a phantom conductive configuration, electrode matrix and data acquisition. The electrodes were evenly placed around the phantom and the controlled AC currents were injected while voltage differences were recorded [18-20]. The acquired impedance data were processed and reconstructed in conductivity maps using image reconstruction algorithms. Variations in electrode configurations and phantom properties were analyzed to optimize accuracy and resolution, contributing to the advancement of image techniques based on bioimpedance for medical diagnosis [21-25].

2.1. Phantom

The initial and crucial step in building an EIT phantom involved the selection of a material with appropriate characteristics of electrical conductivity. This selection process is critical because the chosen material directly affects the accuracy and reliability of the EIT image technique. The phantom serving as a controlled experimental model, is essential for the development and validation of robust data processing protocols. These protocols are vital to accurately reconstruct the images of the electrical measurements obtained during EIT scanning [22-21].

2.2. Electrode Configuration

The performance of an EIT system is influenced by the number and arrangement of electrodes placed in the phantom, common settings employ 4, 8, 16 or 32 electrodes, among others. A higher electrode count allows for a larger number of independent electrical measurements, which strengthens system restrictions and finally results in a more accurate and higher image of internal resistivity distribution [4-8].

2.3. Data Acquisition and measurement

To perform the acquisition of EIT data, a constant current origin and current generator is used to inject a controlled configuration into the phantom. An oscilloscope and multimeter are used to monitor and accurately measure the applied current and the resulting voltage potentials [10-13]. The voltage data acquisition process involves sequentially applying a predetermined current through different electrode pairs and measuring voltage to all electrodes for each current injection. This sequential process, viewed in Figure 2, is essential to generate a comprehensive data set. There are several data acquisition strategies, including neighboring, crossed, opposite and adaptive methods, each with its own advantages [9-12].

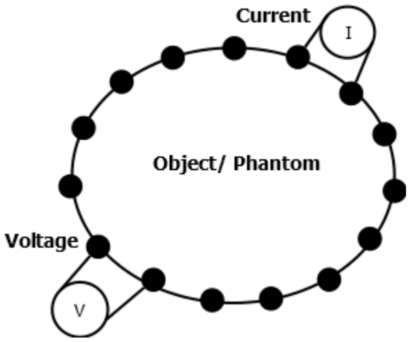


Figure 2: The Electrode Configuration

EIT data acquisition employs various techniques to inject current and measure tensions between the electrodes placed into a phantom. The neighboring method uses adjacent electrodes for current injection and measures between successive neighboring pairs. The cross method injects current between more distant electrodes to obtain a more uniform current distribution. The opposite method applies the current through diametrically opposite electrodes, using a nearby electrode as a voltage reference and measuring stresses of the remaining currents without current. Finally, the Adaptive Method injects current through all electrodes simultaneously, requiring independent current generators for each electrode, allowing for a more comprehensive dataset [8-13].

3. Experimental Work

The experimental work focused on bioimpedance as well EIT, where manual measurements were performed to analyze tissue conductivity and impedance variations. Electrodes were strategically placed on the subject to capture electrical signals, and impedance data were recorded across multiple frequencies. The collected data were processed to reconstruct conductivity maps, allowing for visualization of internal structures and anomalies. Various electrode configurations and signal processing techniques were tested to optimize accuracy and resolution. The findings contribute to advancing non-invasive diagnostic techniques using bioimpedance-based imaging.

To conduct an EIT experiment, a phantom is prepared, and electrodes (either needle or iron nail type) are positioned around its circumference, such as shown in figure 3. An AC current source, implemented using operational amplifiers to convert voltage to current, is employed to inject a current within the milliampere range and at frequencies between 10 kHz and 100 kHz. Subsequently, voltage measurements are recorded from the other electrodes. These measurements are then processed to reconstruct an image representing the conductivity distribution within the phantom.

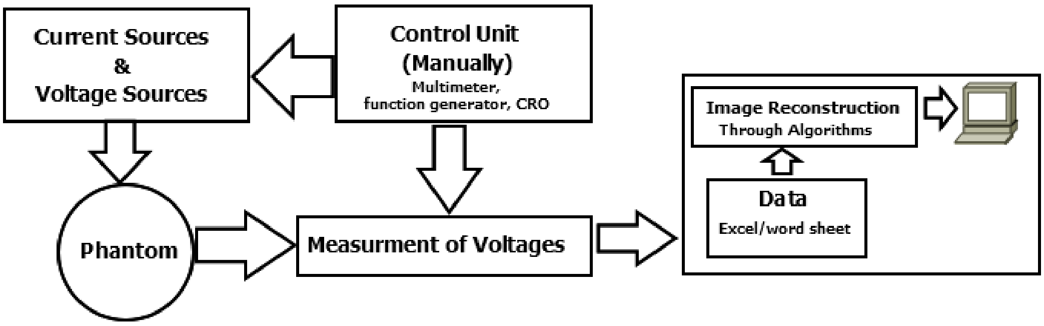
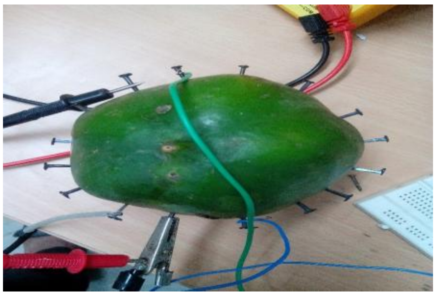


Figure 3 : Block Diagram of the Experimental work

3.1. Experiment I

In this experiment, a papaya was selected as a phantom due to its anatomical resemblance to the human stomach. Electrodes were strategically placed around the papaya's circumference, and an AC current, ranging from 0.6 mA to 1 mA with a frequency between 30 kHz and 50 kHz, was applied. Voltage potentials were subsequently measured using a multimeter and the opposite method of EIT data acquisition. The experimental configuration is illustrated in the accompanying figure 4.

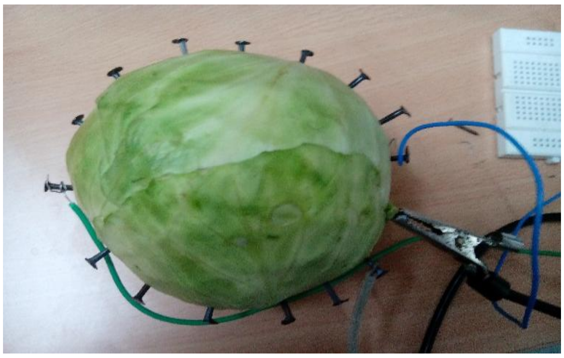


Diameter	8.6 CM
Weight	421 G
Materials	Papaya
No of Electrode	16
Type	Fully conductive

Figure 4: Complete Demsostartion of the experiment I such as phantom, setup and Specifications

Experiment II

For Experiment II, a cabbage phantom was used to simulate EIT imaging. Electrodes were positioned around its perimeter, and an AC current within the range of 0.6 to 1 mA, at frequencies of 30 to 50 kHz, was injected. The resulting voltage potentials were then measured using a multimeter, employing the opposite method. The experimental setup is depicted in the figure 5.



Diameter	8.6 CM
weight	421 G
Materials	Cabbage
No of electrode	16
Type	Fully conductive

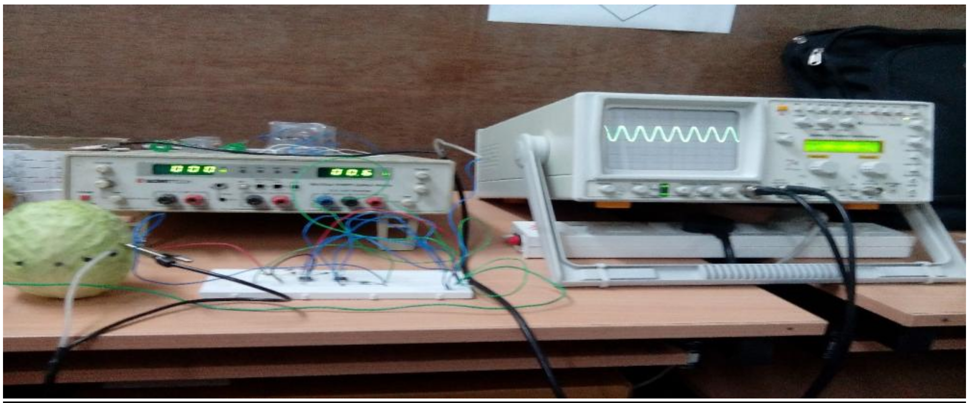
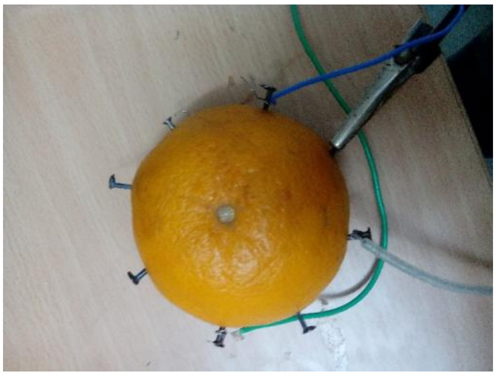


Figure 5: Complete Demsostartion of the experiment II such as phantom, setup and Specifications

3.2. Experiment III

In Experiment III We have taken Orange used as a phantom and inserted electrode on its boundary and after that applied current through some electrode using Current source then calculated potential of other electrode through the multimeter. In this experiment used Current is 0.6 mA to 1 mA with Frequency 30 kHz to 50 kHz. Show in figure 6.



Diameter	5.6 CM
Weight	156 G
Materials	Orange
No of Electrode	08
Type	Fully conductive

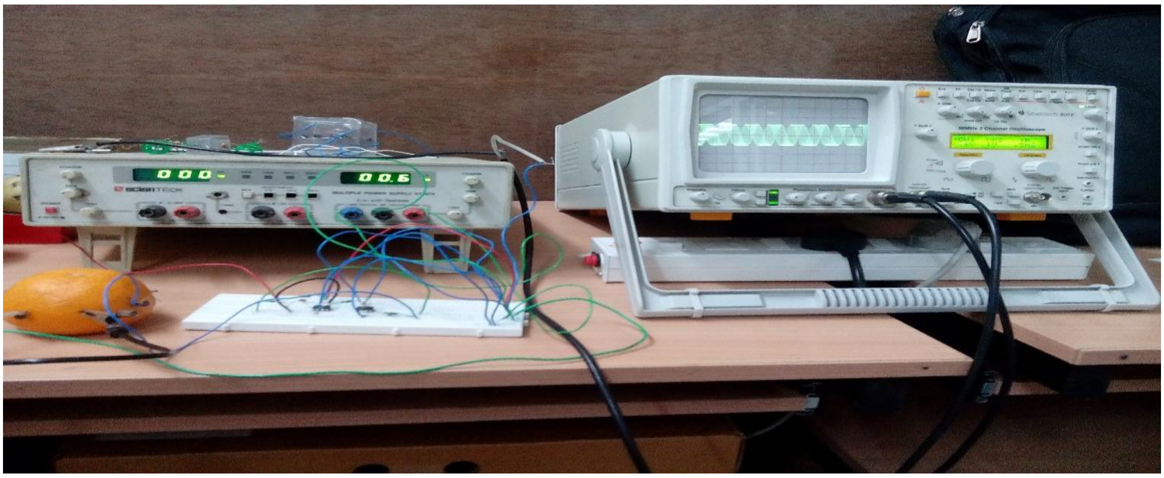
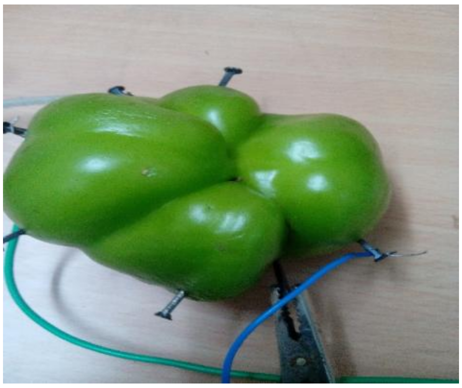


Figure 6: Complete Demsostartion of the experiment III such as phantom, setup and Specifications

3.3. Experiment VI

In Experiment III We have taken Orange used as a phantom and inserted electrode (eight electrode) on its boundary and after that applied current and calculated potential of another electrode through the multimeter. In this experiment used Current is 0.6 mA to 1 mA with Frequency 30 kHz to 50 kHz. Show in figure 7.



Diameter	4.8 CM
Weight	74 G
Materials	Capsicums
No of electrode	8
Type	Fully conductive

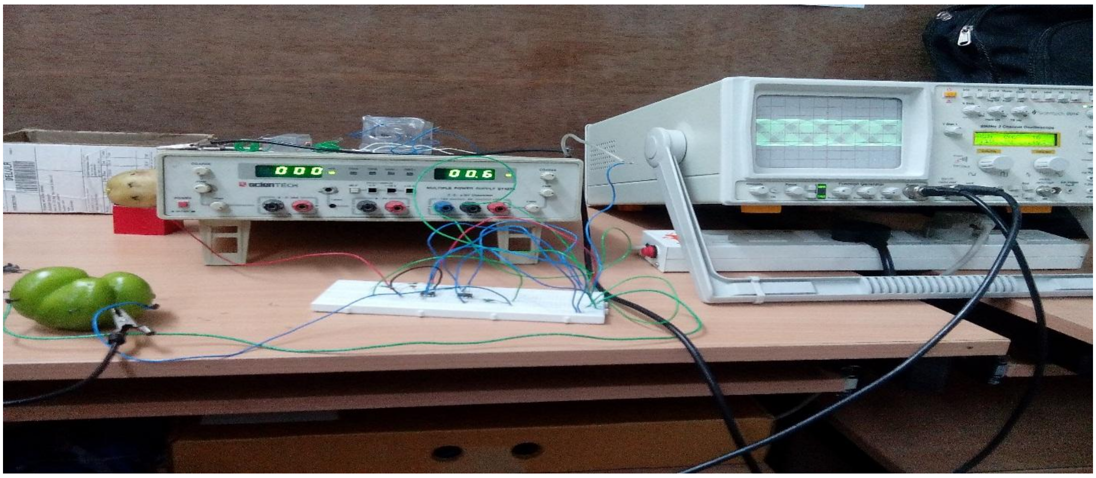


Figure 7: Complete Demsostartion of the experiment IV such as phantom, setup and Specifications

4. Results

Table 1: Impedance variation as per the different phantoms through EIT methodology

Phantom 1		
Current location	**Voltage measurements**	
Electrode (1-3)	Electrode (2-4)	2.31 mv
Electrode (2-4)	Electrode (1-3)	2.34 mv
Phantom 2		
Current location	**Voltage measurements**	
Electrode (1-3)	Electrode (2-4)	1.75 mv
Electrode (2-4)	Electrode (1-3)	2.11 mv
Phantom 3		
Current location	**Voltage measurements**	
Electrode (1-3)	Electrode (2-4)	3.5 v
Electrode (2-4)	Electrode (1-3)	3.05 v
Phantom 4		
Current location	**Voltage measurements**	
Electrode (1-3)	Electrode (2-4)	1.77 mv
Electrode (2-4)	Electrode (1-3)	2.22 mv

This experiment involved a comprehensive analysis of data acquired from various current injection patterns and electrode configurations. For each distinct electrode position, a series of thirteen voltage measurements were meticulously recorded, utilizing both a multimeter for precise voltage readings and a CRO for visual waveform analysis. The CRO provided real-time visualization of the output voltage waveforms, enabling a detailed examination of signal characteristics. Furthermore, the measured output voltages were systematically compared and correlated with the corresponding positions of the electrodes, allowing for a thorough evaluation of the spatial distribution of electrical potential within the phantom. This comparative analysis facilitated the identification of patterns and relationships between electrode placement and voltage distribution, crucial for accurate image reconstruction.

5. CONCLUSION

The main objective of this experimental investigation was to acquire precise impedance data from a variety of object materials. This data is crucial for understanding and improving EIT performance. It is important to recognize that the fundamental assumption of EIT, that current driving is confined to a single plane, does not accurately represent complex current flow within a real three-dimensional volume conductor. Consequently, the physical geometry of the phantom and the configuration of its sensor matrix play a key role in the quality and accuracy of reconstructed images.

Specifically, the accuracy and resolution of the EIT image reconstruction are strongly influenced by various Phantom design parameters. These parameters include, among others, the height of Phantom, the number of electrodes used, the materials of which the electrodes are built, the geometric shape of the electrodes, their width and the precise positioning of the electrode matrix around the phantom. To address these critical factors, this study focused on examining the electrical responses of the phantom to variations in electrode geometry. By systematically changing and analyzing these geometric configurations, intend to achieve a deeper understanding of their impact on impedance measurements [24-26]

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