An Experimental Study for Bio Impedance Tomography Technique

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Abstract: - A relatively new imaging technique called electrical impedance tomography (EIT) generates images of an object's internal impedance distribution. It achieves this by reconstructing impedance measurements obtained from the object's surface. The novel reconstruction of a numerically simulated object. This paper investigates an EIT method that employs a single current source, injecting electrical currents into the body via a pair of neighboring electrodes. Different from the conventional adjacent voltage measure pattern, the proposed combine measure pattern improves system signal-to-noise ratio through selecting the larger cross measure voltage signal and discarding the smaller signal. In electrical impedance tomography, current patterns are injected in to a subject and boundary voltages are measured. The reconstruction of a cross-sectional image of resistivity distribution requires an efficient data-collection and the FEM method to solve the equation. The FEM analysis software package was developed which includes an interactive graphical mesh and solving linear and non-linear equation using vector techniques.

Keywords: - Electrical impedance tomography, Finite Element Method, phantom, tomography

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1. Introduction

EIT systems utilize surface current application and voltage measurement to reconstruct an approximate map of the internal conductivity within a body [1-2]. This emerging technique offers a unique combination of advantages for internal imaging: it's non-invasive, low-cost, non-destructive, free of radiation, and enables visualization and measurement without interfering with the object's normal operation [3][4]. The Finite Element Method (FEM), employed for the forward solution, approximates a continuous system by transforming it into a discrete system composed of a finite set of elements and nodes, effectively creating a network or mesh [5-6]. FEM is a numerical technique used to find approximate solutions for both partial differential equations and integral equations. Its solution strategy involves either fully eliminating the differential equation or converting the PDE into an approximating system of ordinary differential equations [7-8].

2. Hardware part

This work centered on the hardware implementation of electrical impedance tomography. Following this, experiments and feto-maternal monitoring were conducted using the developed system [1-6]. Physiological parameters (fetal heart rate, uterine contraction, fetal temperature) and morphological parameters (fetal movement, IPG) were calculated. The EIT system's final step is image reconstruction, where an algorithm processes the acquired data to form an image. Figure 1 provides a top-down view of the system's block diagram, revealing its core components: digital and analog circuits, an array of electrodes functioning as EIT sensors, and a PC. Specifically, the system's analog hardware consists of a precise current source and a data acquisition unit, while a microcontroller unit handles the digital aspects [9-10].

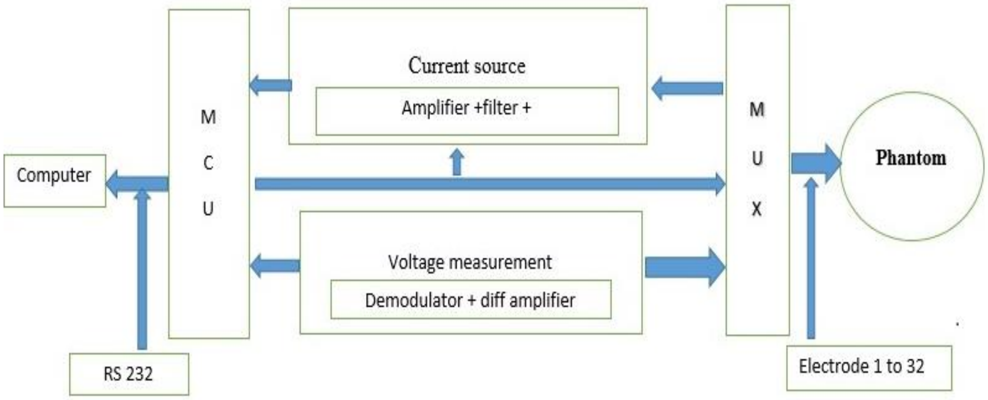

Figure 1 : Hardware Flow digram of the proposed System

The hardware architecture of an EIT system integrates several key components. It includes a phantom (the object under investigation), an electrode configuration that defines electrode placement for current injection and voltage measurement, and a current source to deliver controlled currents [11]. A multiplexer module manages electrode connections, routing signals and allowing sequential selection of electrode pairs for sensing and injection. Finally, a control unit/MCU (Microcontroller Unit) orchestrates the entire system, synchronizing current injection, electrode selection, and voltage measurements [11-12]. The voltage measurement unit in an EIT system accurately detects and amplifies the small voltage differences that appear on the phantom's surface due to injected currents. These measurements are then sent to a PC, often via an RS232 cable, for processing and image reconstruction. The PC acts as the central hub, managing data acquisition, processing, and visualization. It receives the voltage data, applies advanced reconstruction algorithms to create impedance images of the phantom's internal conductivity, and allows users to control EIT hardware parameters like current amplitude and electrode stimulation patterns. Ultimately, the control unit orchestrates the process, the voltage measurement captures the response, and the PC facilitates communication, processing, and image generation, enabling non-invasive internal imaging [9-15].

2.1. Phantom with Electrode Configuration

A phantom serves as a model object, examples including a human body, plastic pipe, glass tank, or papaya. When creating a phantom for EIT imaging, the initial step is to select a material that ideally remains invisible in the resulting EIT images [13]. This process is crucial for developing reliable quantitative data processing protocols for both 2D and 3D EIT object scanning. This study utilized a phantom with 32 electrodes arranged in a specific configuration. Generally, increasing the number of electrodes allows for more independent measurements, leading to a better-constrained system and potentially higher confidence and resolution in the reconstructed resistivity distribution [14-15]. However, practical wiring limitations often restrict the number of electrodes that can be manually attached. Figure 2 illustrates this setup. Various electrode materials are employed in EIT systems, each offering distinct electrochemical properties and biocompatibility characteristics. Among the commonly used types are Ag-AgCl electrodes, known for their stable and low impedance interface with biological tissues, minimizing polarization artifacts and providing reliable measurements. Copper electrodes represent another option, often chosen for their good electrical conductivity and relatively low cost, although they may be more susceptible to corrosion and polarization compared to Ag-AgCl [16-17].

2.2. Electrode Belt

Figure 2 displays an electrode belt designed to fit the dimensions of the phantom. Thirty-two electrodes are positioned equidistantly along the centerline of an elastic band. This design allows for an equal increase in the spacing between adjacent electrodes when the belt is stretched [2-3]. The belt is secured around the phantom using a pair of connecting hooks. Figure 2 shows the fabricated electrode belt, which utilizes Ag-AgCl electrodes. To facilitate easy replacement, the electrodes are attached to the band using a button-like structure.

2.3. Current source

Accurate current sources are essential for EIT systems, needing a wide frequency range and the ability to handle significant variations in load impedance. A common and straightforward approach to achieve a constant current involves using positive and negative feedback around a high-gain operational or instrumentation amplifier [18]. Specifically, current sources in EIT systems must be capable of delivering alternating current ranging from 0.1 mA to 1 mA across a frequency band of 10 to 100 kHz, while also accommodating load impedances between 100 Ω and 10 kΩ. Furthermore, to function effectively, their output impedance should ideally exceed 100 kΩ. Therefore, a well-designed current source for EIT should meet all of these criteria.

2.4. Multiplexer module

As illustrated in the figure 2, an EIT system can employ a high-speed multiplexer module featuring 32 outputs. This multiplexer module utilizes the analog multiplexer ADG506AKN. For a 32-electrode EIT system, eight integrated circuits of this multiplexer are necessary. Above IC, four are dedicated to the current source's injection and sink ports, while the remaining four are for voltage measurement. The multiplexer enables the sharing of both the current source and the voltmeter among multiple electrodes. The control unit (MCU) acts as the central orchestrator of the EIT hardware. It governs the multiplexer to configure electrode states for current injection and voltage measurement, and establishes RS-232 communication with a PC (often running MATLAB or LABVIEW) for data exchange. The MCU also provides real-time measurement feedback via an LCD and manages the Analog-to-Digital Converter (ADC) as a slave device using handshaking and interrupt signals for accurate voltage acquisition. Following the voltage acquisition, these measured values, initially stored in the microcontroller's registers, are then transmitted to the connected computer via the RS-232 serial communication protocol, typically utilizing a 9-pin COM port for this data transfer.

3. Experimental Setup

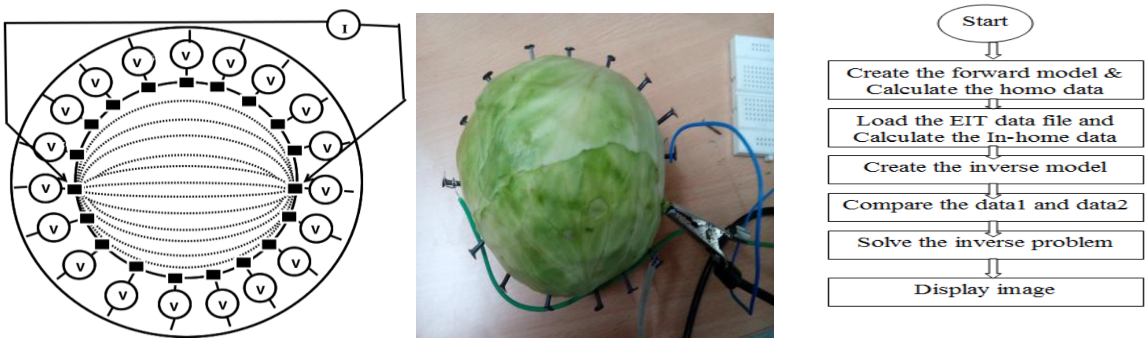

Figure 2. Electrode configuration, Phantom and Flowchart of the algorithm

When building a phantom, such as the cabbage used in this study, the initial step involves selecting a material appropriate for EIT imaging. Ideally, the phantom (such as shown in figure 2) itself should not produce a visible signature in the resulting EIT images. This process is part of developing a robust quantitative data processing protocol for 3D EIT object scanning [13]. In a typical experimental setup, the first step is to acquire a phantom (the object of interest) [20]. Subsequently, an image of this phantom is constructed by placing electrodes along its surface, injecting current through some electrodes, and measuring the resulting voltages at others [5]. The simulation phantom employed in that work was restricted to two and three dimensions and featured a circular boundary. A circular finite element model with an 18.2 cm diameter, comprising a specific number of nodes and elements, was utilized. Sixteen electrodes were positioned at equidistant intervals along the boundary, indicated by bold lines in the representation [2].

4. EIT Image reconstruction

Tomographic images are typically generated through the application of specific image reconstruction algorithms. The process of reconstructing an image of an object from a collection of its cross-sectional projection data presents a distinct processing challenge [11]. To develop algorithms for the inverse problem in tomography, solving the forward problem is essential. This research addresses sensor modeling to build a simulated tomographic environment [15]. This simulation specifically replicates a system employing multiple fan beam projections with characteristics akin to the physical hardware. The primary goal of this simulation is to accurately predict the sensor readings that would be observed for various flow models within the real hardware system [13]. MATLAB was used to process the EIT voltage data [11].

5. Results

EIT images were generated using a defined current driving and voltage measuring approach. This utilized an adjacent pattern, where current was injected between two adjacent electrodes, and the resulting potential differences were measured across the remaining electrode pairs. A full set of measurements was taken using 16 coplanar electrodes, which also served for current injection. Figure 3 illustrates the voltage distribution curves obtained for all 16 electrodes under these conditions, with the applied signal frequency ranging from 10 kHz to 100 kHz [5].

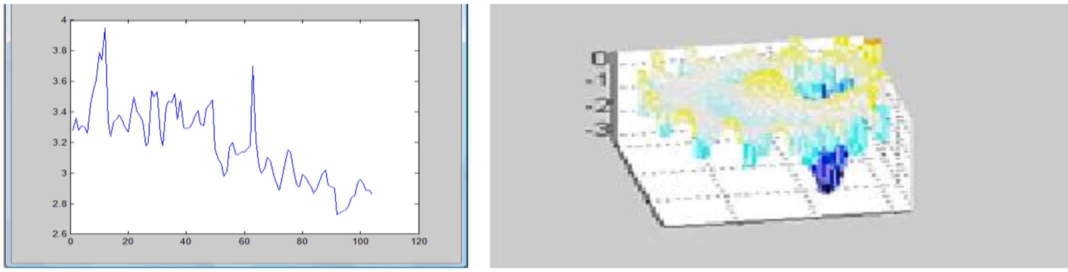

Figure 3: Data Distrubution and Final image for Phantom used using EIT

For the simulation, a simplified two-dimensional isotropic cross-section of a phantom with a diameter of 21.3 cm was employed. The reconstructed impedance images for the phantom's interior were derived from various data collection methods, including the conventional adjacent method. However, due to the limited dataset of only 104 measurements acquired by the conventional adjacent method, the resulting reconstructed impedance image exhibits a significant ill-posed problem. Figure 3 displays the final output of the simulation or M-file program, showcasing the reconstructed 2D or 3D image alongside different mesh models. This figure 3 presents the final image obtained for the phantom. The forward solution calculates the potential distribution within the object and the resulting voltages on the electrodes. These potential distributions are computed based on the mesh and electrode placements, as depicted in the forward model. The final simulation stage yields the 2D or 3D image, the clarity of the reconstructed image in Figure 3 improves with an increasing number of finite elements used in the simulation.

6. Conclusion

EIT is an imaging modality with significant applications in both industrial and medical fields. A core challenge in EIT is image reconstruction, which primarily involves determining the impedance, particularly the resistivity distribution, by solving the inverse problem. In our work, we first established the forward problem to calculate the potential distribution using the Finite Element Method [7]. To achieve this, we developed a phantom model and designed reconstruction algorithms using MATLAB. The necessary data for this process was acquired using specialized data acquisition software and hardware.

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