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Development Eit System

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Abstract: Electrical Impedance Tomography (EIT) is a non-invasive imaging technique for examining the electrical properties of tissues, with applications in biomedicine due to its affordability, portability, and safety. However, EIT systems often involve costly or complex hardware, limiting accessibility for in-lab experimentation. This project introduces an efficient, easily replicable EIT hardware system designed for frequencies between 1 kHz and 50 kHz, aimed at making EIT more accessible for proof-of-concept validations. The system optimizes performance while minimizing costs, using modern integrated circuits and a lock-in amplifier for compact signal filtering and DC output generation. Comprehensive schematics, manufacturing files, and fabrication procedures are provided to simplify replication and further development. The hardware is experimentally tested and validated through data comparison with simulations and inclusion detection in biological tissues.

Keyword: Electrical Impedance Tomography (EIT), Open-source hardware, Multiplexer, Current detector, Phantom, Peak detector, power supply, Low pass filter, Band pass filter.

I. INTRODUCTION

Electrical Impedance Tomography (EIT) is an emerging imaging technique that has significantly developed over the past two decades. It utilizes low-amplitude AC signals delivered through electrodes to create a map of a medium's admittivity, making it particularly effective for imaging human tissues, including the lungs and brain. EIT is valued for its portability, cost-effectiveness compared to traditional imaging methods, and the safety of low-amplitude electrical signals, unlike X-rays. However, EIT has lower spatial resolution than techniques like MRI and CT and is sensitive to disturbances due to its ill-posed nature, requiring high accuracy in hardware measurement systems.

In EIT, the subject is surrounded by electrodes that apply and measure electrical signals. A large number of measurements are performed using a 4-pole technique, applying a constant current between two electrodes and measuring the resulting voltage across other pairs. This process is repeated with different current injection pairs. The collected data is post-processed to reconstruct the admittivity map, either through absolute reconstruction with a single measurement set or differential reconstruction using reference measurements, often preferred for its robustness against modeling errors.

The software component involves finite element meshing, regularization tools to manage the ill-posed problem, and minimization techniques. EIDORS is a widely used open-source software for addressing the direct and inverse problems of EIT. While several commercially available EIT systems exist, their high costs (often in the thousands of euros) and lack of adaptability for specific applications limit accessibility. Lower-cost electronic boards, such

as the STEMLAB by RedPitaya, offer potential for building EIT systems, yet still require additional hardware for independent electrode management.

Previous research has proposed various EIT hardware designs, including low-cost, high-speed options without provided schematics, and more complex systems requiring numerous electronic components. The need for efficient, affordable hardware is particularly important for research laboratories focused on concept validation without the precision of expensive professional devices. This paper presents a fully documented open-source hardware design for EIT, providing schematics that can be easily reused and modified. The design emphasizes assembly ease and a minimal component count while ensuring measurement quality, critical for reliable reconstruction due to the ill-posed nature of the problem. A lock-in amplifier circuit facilitates compact and efficient signal filtering and demodulation. Comprehensive manufacturing procedures and usage instructions are included, enabling users to perform measurements effortlessly. This development aims to create an affordable, replicable EIT hardware system that supports broader access, innovation, and practical applications of this valuable imaging technology.

II. LITERATURE SURVEY

This paper presents a high-resolution 2D electrical impedance tomography (EIT) system using an FPGA-based acquisition setup with a tunable current source, capable of achieving over 500 fps with 32 electrodes and 2400 fps with 16 electrodes at 500 kHz. It integrates a Nvidia Jetson Orin GPU for parallel high-speed image reconstruction, utilizing algorithms such as Linear Back Projection, Tikhonov regularization, and Gauss-Newton. Experiments show a speed-up of at least four times over traditional PCs, achieving over 2500 fps with a 16-electrode, 8192-mesh system, making it suitable for high-speed and 3D EIT applications. [1]

Reconstruction of Electrical Impedance Tomography (EIT) images based on the Expectation-Maximization (EM) method involves iterative updating to estimate unknown conductivity distributions within a medium. The EM algorithm is particularly useful in dealing with the ill-posed nature of the EIT problem, as it maximizes the likelihood of observed data (i.e., voltage measurements) given an estimated model of conductivity. During each iteration, the Expectation step (E-step) calculates the expected log-likelihood based on current conductivity estimates, and the Maximization step (M-step) updates these estimates to maximize this likelihood. This process continues until the model converges to a solution that accurately represents the internal impedance distribution. The EM method is advantageous for its robustness in handling noisy data and under-determined systems, making it a viable choice for improving the accuracy of EIT image reconstructions. [2]

Sensor-based image reconstruction in Electrical Impedance Tomography (EIT) using open-source technology utilizes affordable platforms like Arduino or Raspberry Pi for hardware and software tools like Python for image processing. These open-source systems enable cost-effective and customizable EIT setups, making the technology more accessible for research and educational purposes. While ideal for low-budget applications, further optimization is needed for high-resolution and real-time imaging tasks. [3]

In the study by Varun Kumar Tiwari, titled "A Novel Neural Network-Based Data Acquisition System Targeting High-Speed Electrical Tomography Systems," the author proposes an innovative approach to enhance the data acquisition process for electrical tomography. This system leverages neural networks to optimize the collection and processing of measurement data, aiming to achieve high-speed performance essential for real-time imaging applications. By integrating advanced machine learning techniques, the proposed data acquisition system enhances the accuracy and speed of image reconstruction in electrical tomography, overcoming the limitations of traditional methods. The results demonstrate significant improvements in data processing efficiency, paving the way for more effective and rapid imaging solutions in various practical applications. [4]

Electrical Impedance Tomography (EIT) has seen significant advancements and applications in recent years, particularly in real-time imaging of internal conductivity distributions. In medicine, EIT is used for non-invasive monitoring of lung function and brain activity, enabling continuous patient observation. Industrially, it aids in process monitoring and quality control in sectors like oil and gas and food processing. Recent developments in reconstruction algorithms, including deep learning techniques, have improved image accuracy and speed, while open-source technology has made EIT systems more accessible. The integration of EIT with other imaging modalities further enhances its diagnostic capabilities, highlighting its versatility and potential for ongoing innovation. [5]

Developing and Evaluation of an Electrical Impedance Tomography System for Measuring Solid Volumetric Concentration in Dredging Scale focuses on creating an EIT system to monitor solid volumetric concentrations in dredging operations. The system employs multiple electrodes to measure the electrical impedance of sediment mixtures, providing real-time insights into solid particle concentrations. The development includes hardware design, electrode configuration, and advanced signal processing for accurate image reconstruction. Evaluation tests in real-world dredging scenarios assess the system's accuracy and sensitivity. This EIT system enhances operational efficiency and environmental management in dredging projects by enabling precise monitoring of solid concentrations. [6]

Electrical Impedance Tomography (EIT) is making significant strides in both research and clinical applications. The development of affordable and open-source EIT hardware, such as Arduino-based systems, is improving accessibility for users. High-speed acquisition systems using FPGA and GPU technologies show promise, although they require specialized knowledge to implement. Methods like expectation maximization enhance image quality, while sensor-based techniques effectively aid in cancer detection. However, challenges remain, including complexity, measurement sensitivity, and specific application limitations. Continued advancements in EIT technology will be essential for expanding its use and improving its reliability in various fields.

III. PROPOSED MODEL

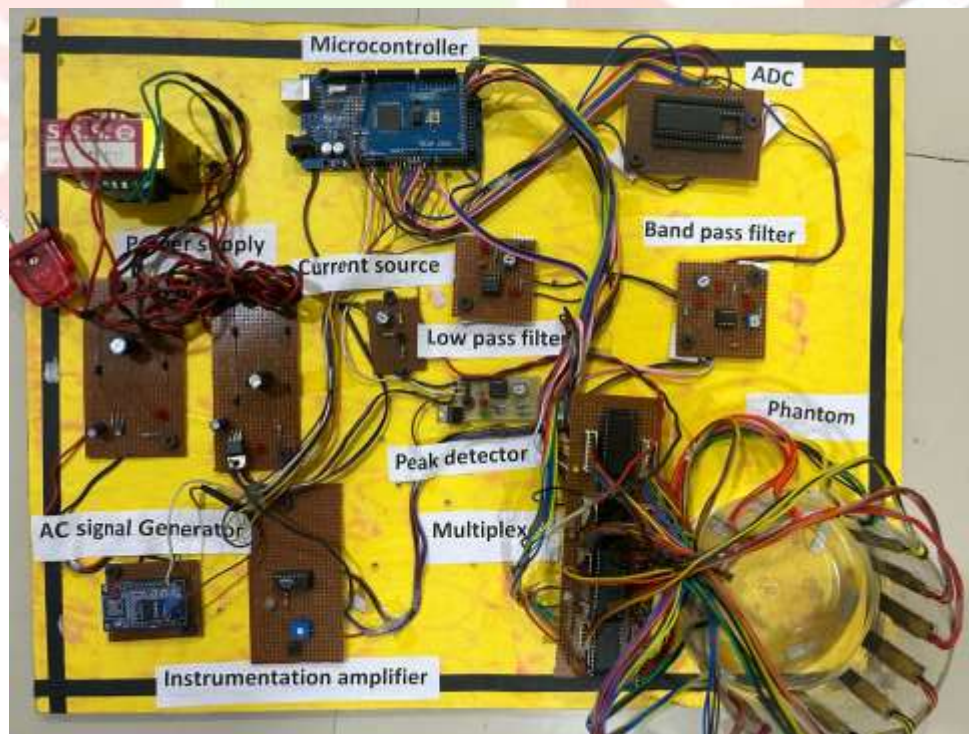


Fig.1: EIT working model

1. **Power supply:** A 230v AC supply is connected to the transformer then bridge rectifier and rectifier gives pulsating output then capacitor and voltage regulator LM1117 ic and output voltage is 2.5V.
2. **Peak detector:** Its circuits are used to determine the peak (maximum) value of an input signal. It stores the peak value of input voltages for infinite time duration until it comes to reset condition. The peak detector circuit utilizes its property of following the highest value of an input signal and storing it.
3. **Low-Pass Filter:** A low-pass filter is used to remove high-frequency sounds from an audio signal. It is called a low-pass filter because it allows low-frequency signals to pass through, while attenuating higher-frequency signals.
4. **ADC:** The ADC converts the analog voltage into a digital value. The function used in order to obtain the value of an analog signal is `analogRead(pin)`. This function converts the value of an analog input pin's voltage and returns a digital value from 0 to 1023, relative to the reference value.
5. **Bandpass Filter:** A bandpass filter is an electronic circuit that allows a specific range of frequencies to pass through while attenuating frequencies outside that range.
6. **Multiplexer:** A multiplexer is useful for reducing the number of wires or channels needed to transmit or process multiple signals. By using a multiplexer, you can combine several signals into one and send it over a single wire or channel.
7. **Instrumentation Amplifier:** The importance of an instrumentation amplifier is that it can reduce unwanted noise that is picked up by the circuit. The ability to reject noise or unwanted signals common to all IC pins is called the common-mode rejection ratio (CMRR). Instrumentation amplifiers are very useful due to their high CMRR. Instrumentation amplifiers are precision, integrated operational amplifiers that have differential input and single-ended or differential output. Some of their key features include very high common mode rejection ratio (CMRR), high open loop gain, low DC offset, low drift, low input impedance, and low noise.
8. **Phantom:** A calibration phantom is often a cylinder, or plate with densities values. They are utilized in quality control to ensure images are reconstructing the imaged phantom to the correct density values. Deviation from these values can indicate a need for imaging equipment service.

Hardware is developed by following steps:

- Connect power to the hardware: GND, 12 V and 5V.
- Connect the low frequency generator to the VCC input
- Connect the digital signals (0 V/5 V) to the control part of the switch matrix. These signals will select the current injection and voltage measurement electrodes.
- Connect the measuring device to the output of the lock-in amplifier filter. An Arduino may be suitable, but it is advisable to use a device with a 14-bit resolution
- Connect the object (phantom or tissue) to be imaged to the 16 electrodes arranged around the vessel or the object.
- Turn on the power supply and the low-frequency generator.

- Set the low-frequency generator to, for example, 5V at 10kHz to generate a 1mA current at 10kHz through the current injection electrodes.
- Refer to the multiplexer truth table to select the right electrode combinations. Use the digital signals to select the current injection electrodes and another digital signals to select the voltage measurement electrodes.
- Allow the signal to stabilize before taking measurements (wait time depends on the low-pass filter tuning).
- Get your measurement and save it
- Repeat steps 8-11 for different combinations of current injection and voltage measurement electrodes (up to 16 electrodes, rotating between all combinations).

IV. RESULT & DISCUSSION

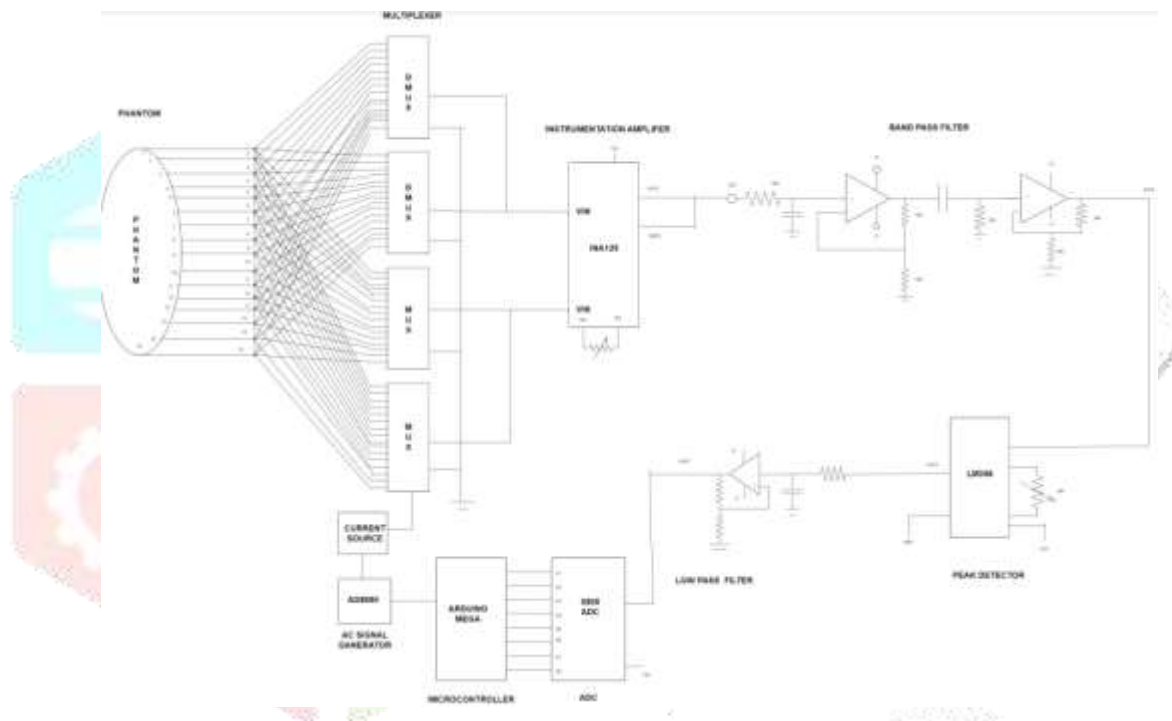


Fig.2: Circuit diagram

The EIT system utilizes 16 electrodes around a cylindrical water tank (phantom) to measure electrical impedance and reconstruct internal images. Current is injected and boundary voltages are measured using four 16 x 2 multiplexers (IC74151), where two multiplexers control current injection and the other two handle voltage measurement, thus reducing the number of hardware components required. The excitation signal is generated by a Direct Digital Synthesis (DDS) module (AD9850), capable of producing high-resolution signals up to 40 MHz. The current source is implemented using a Modified Howland Current Source (MHCS), based on an AD9850 instrumentation amplifier and LM358 operational amplifier, allowing for adjustable current amplitudes of 1 mA, 3 mA, or 6 mA. Alternatively, a transistor-based current injection method is used for precise control of the injected current. In this method, a voltage-controlled current source (VCCS) is built using transistors that regulate current flow into the electrodes based on the control voltage from the DDS signal. After current injection into the phantom, the voltage drop across the unknown impedance is first amplified by an AD9850 instrumentation amplifier, with a variable resistor controlling the gain. The signal is then filtered by an 8th-order Chebyshev band-pass filter (BPF), removing noise and unwanted frequencies. It is subsequently amplified by an AD8221 inverting amplifier, bringing the signal output to around 5V. Since the signal is sinusoidal, a peak detector (AD8022)

converts it to a DC signal by capturing the peak value of the waveform. The DC output is then smoothed using a low-pass filter (LM358) with a 159 Hz cut-off frequency, reducing ripple and noise. The peak voltage is then measured by an ADS1115 ADC, operating in differential mode, which converts the signal into a 12-bit digital output for further processing. Power for the system is supplied by a $\pm 9\text{V}$ DC source from DIGILENT, while $\pm 2.5\text{V}$ regulators (TPS72325DBVT and TPS73225DBVT) provide power to the multiplexers, making the system highly efficient and suitable for low-cost EIT applications that require precision in both current injection and voltage measurement.

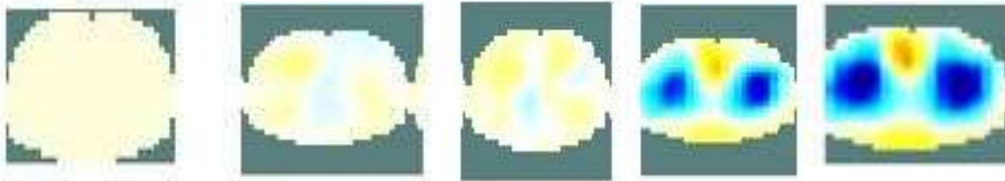


Fig.3: Simulation result

- This image shows a uniform color with no noticeable variations, indicating that the initial reconstruction does not yet reveal any internal structure or impedance differences. This might be the starting point, where no objects or anomalies have been detected in the phantom. It likely represents the baseline state before any significant processing.
- Slight variations in color begin to emerge, suggesting the early detection of impedance differences within the phantom. The presence of faint colors indicates that the algorithm has started identifying areas with slight conductivity differences, but the internal structure is still unclear.
- The contrast increases, with more defined areas of varying color. This indicates that the reconstruction algorithm is picking up more significant impedance variations, which may correspond to distinct objects or regions within the phantom. The image is beginning to form discernible internal features, showing a progression in the reconstruction accuracy.
- The image now shows even stronger contrast and clearer regions of color, potentially highlighting two distinct areas within the phantom. These darker and lighter regions could represent objects or areas with higher or lower conductivity, providing a more detailed view of the internal structure. This stage likely corresponds to a more refined reconstruction where impedance differences are becoming more pronounced.
- This is the most detailed and highest-contrast image in the sequence. The colors are much more vibrant, with clearly defined regions, which could represent two high-conductivity areas surrounded by lower-conductivity regions. This final image likely represents the most accurate reconstruction in the sequence, with the algorithm having achieved a precise depiction of the internal impedance distribution.

V. CONCLUSION

This project presents an open-source and easily replicable hardware solution for Electrical Impedance Tomography (EIT), aimed at making this valuable imaging technique more accessible and practical for broader use. The developed hardware, designed to operate within a frequency range of 1 kHz to 10 kHz, addresses the high costs and complexity typically associated with EIT systems, thereby lowering the barrier to entry for researchers and practitioners. The emphasis on using cost-effective components and modern integrated circuits, such as a compact lock-in amplifier, ensures a balance between performance and affordability. Detailed schematics and manufacturing files are provided to facilitate replication and customization by the community. Experimental validation of the hardware demonstrated its capability to accurately reconstruct inclusions in biological tissues, aligning closely with simulation results and confirming its reliability and effectiveness. By providing a practical and affordable EIT solution, this project promotes wider adoption and further innovation in the field, ultimately contributing to advancements in biomedical imaging and diagnostics.

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