Development of a Portable Real-Time Electrical Impedance Measuring System for Continuous Monitoring

Ramesh Kumar[1], Vevekanandam[1], Rajesh Dey[2],

[1]Lincoln University College, Malaysia

[2]Gopal Narayan Singh University, Sasaram, Bihar, India 821305

(rameshkumarmeena@gmail.com, vivekanandam@lincoln.edu.my, rajesh.dey@gnsu.ac.in)

Abstract:

Electrical impedance plays a crucial role in various fields such as biomedical applications, process control, microbiology, and chemical processes. Currently, impedance monitoring is performed manually, which is both time-consuming and labor-intensive. Considering the significance of impedance measurement, this paper aims to design and develop a real-time Electrical Impedance Measuring System capable of detecting impedance variations across a conducting region in terms of voltage. The system operates on the principle that when a fixed input current is applied to the cross-section of an object, the resulting output voltage is measured. The impedance is then determined as the ratio of this voltage to the applied AC current. This enables the assessment of conductivity in the targeted region where the known AC current is introduced. These impedance variations have significant applications, particularly in the biomedical field, including Electrical Impedance Tomography, respiratory monitoring, brain activity analysis, and pneumography. Designed for real-time data acquisition, the system allows for continuous long-term monitoring. Additionally, it is a cost-effective, flexible, and portable instrument with an integrated data acquisition system. A dedicated software application, developed using Visual Basic 6, facilitates seamless data capture on a PC.

Keywords: Electrical Impedance Tomography (EIT), Real-Time Monitoring, Portable Instrumentation, Impedance Tomography, Biomedical Applications

1. INTRODUCTION

Impedance refers to the opposition encountered when an alternating current (AC) passes through a subject. While it may seem similar to resistance, the two differ in their fundamental nature [1-3]. Resistance represents the opposition to direct current (DC), whereas impedance accounts for both resistance and reactance. Reactance specifically measures the opposition to AC due to capacitance or inductance [4-7]. Unlike resistance, which remains constant across frequencies, impedance varies with frequency because reactance is influenced by inductance and capacitance. This distinction is crucial in AC analysis and circuit design [8-9]. The most common method for measuring impedance is the constant current technique, where impedance variations are recorded over time. In this approach, a current (typically 5–20 mA at 20–100 kHz) is applied to the target region, and the resulting voltage signal along the current path is measured [10-11]. The amplitude of this signal is directly proportional to the electrical impedance of the segment, enabling the determination of the region's conductivity or resistivity. The voltage signal can be captured using either a two-electrode or four-electrode technique [12-15]. Depending upon location of:

a) Current feeding electrodes

b) Voltage measuring electrodes

There are various Electrical Impedance Measuring methods available:

1. Neighboring Method
2. Opposite Method
3. Cross Method
4. Adaptive Method

Due to better sensitivity of Opposite method and comparatively lesser computations involved, opposite method is used here. Electrical Impedance Tomography (EIT) employs various measurement strategies to reconstruct conductivity distributions within a given medium. The choice of measurement method significantly impacts the quality, sensitivity, and computational efficiency of the reconstruction process. The four commonly used EIT measurement techniques are the Neighboring Method, Opposite Method, Cross Method, and Adaptive Method. Each method differs in terms of electrode configuration and sensitivity distribution within the imaging domain [16-18].

The Neighboring Method, where adjacent electrodes are used for current injection and voltage measurement, provides uniform sensitivity but suffers from lower resolution in deeper regions. The Cross Method, which uses diagonal electrode pairs, enhances deeper sensitivity but results in complex image reconstruction. The Adaptive Method dynamically adjusts electrode configurations based on real-time feedback, offering flexibility but at the cost of increased computational demands [19-21].

Among these methods, the Opposite Method, where current is injected through two electrodes positioned opposite to each other while voltage is measured across another pair of opposite electrodes, proves to be particularly effective. This method provides better sensitivity to conductivity variations in deeper regions compared to the Neighboring Method, ensuring improved imaging quality [22-25]. Additionally, the Opposite Method requires fewer computations than the Cross and Adaptive Methods, making it computationally efficient without compromising accuracy. Given these advantages, this study adopts the Opposite Method as the preferred EIT measurement strategy to achieve an optimal balance between sensitivity, resolution, and computational efficiency [26-28].

2. Methodology

There are three objectives in this study, first is to design Hardware for *Real Time Electrical Impedance Measuring System, such as shown in figure 1* for acquiring Impedance Data points from a Model with 6 electrodes. For Data acquisition, Opposite Method is used here. Second is to develop hardware for *Data Acquisition System, such as shown in figure 2* so that the system becomes a complete Measuring system. Third objective is to develop software for Data Acquisition. Visual Basic 6 is used for this.

The following figure shows the fabricated impedance measuring system. Current and frequency selection provision is also kept here. The data which is captured from phantom is displayed on LCD [9-15].

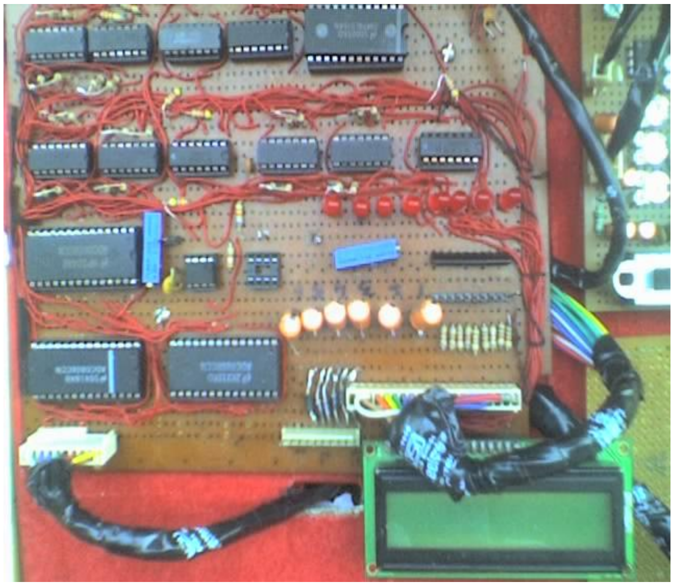

Figure 1: Fabricated *Real Time Electrical Impedance Measuring System*

Figure 2: *Fabricated Data Acquisition System*

The above figure shows the fabricated Data Acquisition System. This allows to store the impedance data points in microcontroller which can be further processed. After designing hardware of REAL TIME IMPEDANCE MEASURING system & DATA ACQUISITION System, we need to design a software for data acquisition so that the measured 9 data points can be retrieved in PC. The software is written in Visual Basic 6.

The software consists of several subroutines, each designed to perform a specific function for efficient operation and data management. One subroutine is responsible for setting the Real-Time Clock (RTC), ensuring accurate timekeeping for recorded data. Another subroutine facilitates the erasure of RAM, achieved by opening and transmitting a blank file to clear existing memory. Additionally, a dedicated routine captures output data from RAM, enabling further processing. Once the data is retrieved, another subroutine processes the RAM data, organizing it for meaningful analysis. To support in-depth evaluation, a reporting subroutine generates analytical reports based on the processed data. Lastly, a crucial subroutine is implemented to test the attachment, verifying the integrity and functionality of connected hardware components. These subroutines collectively enhance the software's efficiency and reliability.

3. Results And Conclusions

This system is tested with different models under different conditions viz. Papaya, plastic container, iron pipe etc. In this experimental work, an iron pipe with a diameter of 4 cm is analyzed under different conditions to study variations in impedance. The experiment is conducted by maintaining a constant current of 125 mA and a frequency of 450 Hz to ensure uniformity in measurements. In the first case, where the pipe is dry, the iron pipe, being a good conductor, offers minimal impedance to the flow of alternating current. As a result, the voltage drop across the pipe remains low due to reduced opposition to the current. The impedance data, recorded in terms of voltage (V), is displayed in the captured data window, serving as a reference for further comparative analysis under different pipe conditions.

Case 1- When Pipe Is Dry

Since iron pipe is a good conductor, so when an alternating current is passed through it, less impedance will be offered. This will yield to less output voltage. The impedance data points in terms of voltage (V) are shown in figure 3 of captured data window

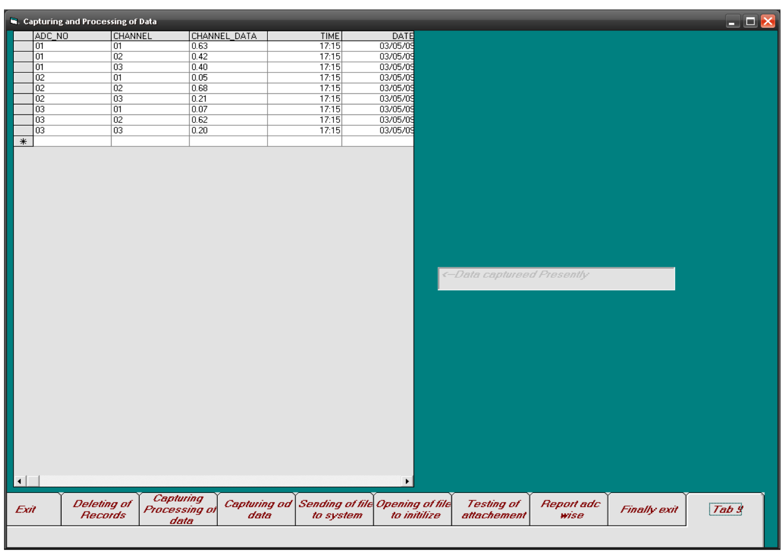

Figure 3: Voltage measurements in system

Case 2- When Water Is Flowing Continuously

In this case, water is continuously flowing in the pipe. As expected, the impedance offered in this case was comparatively less and so is the output voltage, such as shown in figure 4.

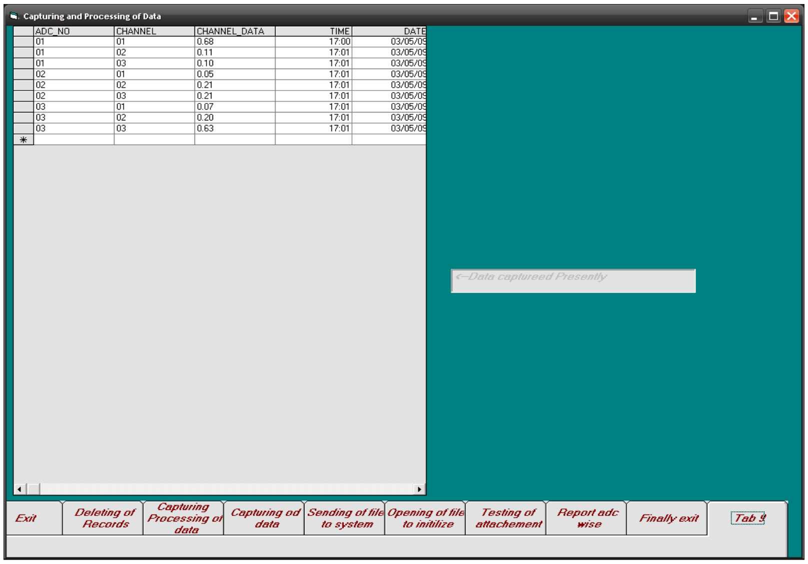

Figure 4: Voltage measurements in system

Case 3 -A 2.5 cm Diameter Plastic Pipe Is Dropped Into The Iron Pipe.

Here, a plastic pipe is placed inside the iron pipe. Plastic being an insulator, will offer more impedance and thus output voltage is expected to increase. This was observed true from the readings also which are shown in figure 5 given below.

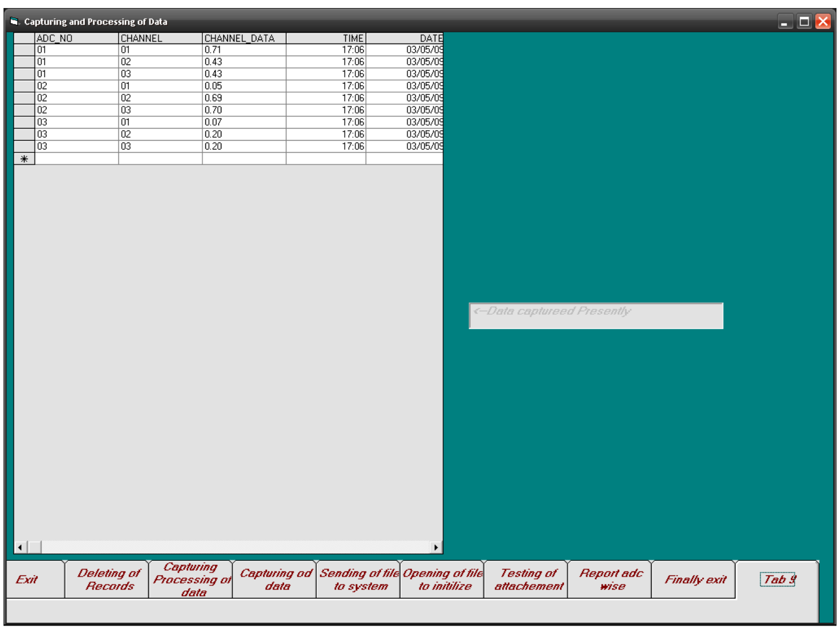

Figure 5: Voltage measurements in system

4. Conclusion

With the testing results it is proved that this designed system is sensitive to impedance changes. Impedance is the opposition encountered when an alternating current (AC) flows through a subject, incorporating both resistance and reactance. While resistance opposes direct current (DC) and remains constant across frequencies, impedance varies due to the frequency-dependent effects of capacitance and inductance. This distinction is essential for AC analysis and design. A common method for measuring impedance is the constant current technique, where a small AC current (typically 5–20 mA at 20–100 kHz) is applied to a specific region, and the resulting voltage is measured. Since the voltage amplitude is directly proportional to impedance, this allows for the assessment of conductivity or resistivity in the targeted area. The measurement can be performed using either a two-electrode or four-electrode technique, depending on the level of accuracy required.

5. Future Scope

Further work can be extended by using other Data acquisition techniques like Neighboring method, adaptive method, cross method etc. Beside this, due to limitation of time and unavailability of Serial ADC Chip the system is designed with 6 electrodes using parallel data acquisition, the same can be implemented for no. of electrodes like 8, 16, 32, 64 for better accuracy. The most important feature of this system is that it is a completely flexible Instrumentation System (with inbuilt DAQ) which can be used to measure any physical parameter. The only thing that has to be done is to connect the sensor according to application. Its software flexibility has led it to be used as an *All-Purpose Measuring System [21-28]*.

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