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Software Contributions to the Development of a Low-Cost Chest Electrical Impedance Tomography Harness for Fitness and Telemedicine

By

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Abstract

This thesis presents a series of software contributions designed to enhance the development of a low-cost chest Electrical Impedance Tomography (EIT) harness for fitness and telemedicine applications. EIT offers a non-invasive, radiation-free imaging technique, primarily utilized for monitoring lung health, wellness, and fitness. The centrepiece of this research is the design and development of a cost-effective, wearable chest EIT harness that incorporates 32 self-abrading ECG type electrodes. This innovative approach has the capacity to significantly impact and potentially revolutionize fitness tracking and telemedicine sectors.

The project's primary objectives included designing a user-friendly graphical user interface (GUI) which would enable skilled and unskilled users to identify poor contact electrodes and perform self-abrasion. More specifically, the project first aims to develop a user-friendly GUI that connects to an EIT Device and can be ported to a smartphone. Secondly, the project aims to enable the GUI to present the electrodes to the user on a virtual 3D human chest and assess whether the user has positioned their electrodes appropriately for sufficient skin contact. These aims were achieved as seen by the creation of the application, the displaying of the electrodes, and the designing of the image reconstruction plots.

Further, the software was adapted to enable operation on less powerful devices such as Raspberry Pi, which will allow the software to be ultimately used on smartphones., bridging the gap towards its ultimate utilization on smartphones. Moreover, an enhancement was implemented in the EIT software to support real-time EIT image reconstruction from single and dual rings of 16 electrodes, thus improving image quality.

Despite certain limitations encountered with the 32-electrode system and performance differences between PC and less powerful platforms, significant strides were made in enhancing accessibility and user-friendliness. Key findings indicate opportunities for further improvements in hardware, software optimization, and GUI personalization.

This research has not only expanded the potential applications of EIT technology but has also underscored the areas where further development is needed to achieve an efficient, user-friendly, and portable EIT harness for fitness and telemedicine markets. It lays a solid foundation for future endeavours in making EIT imaging more accessible and applicable for everyday use.

Contents

1. Introduction

1.1 Orientation:

Electrical impedance tomography (EIT) provides a non-invasive, radiation-free approach to lung imaging, allowing for future use in the fields of health monitoring, wellness, and fitness. The primary goal of this project was to design a cost-effective, wearable chest EIT harness equipped with 32 self-abrading ECG type electrodes that can easily be used in fitness and telemedicine applications. By integrating a user-friendly GUI and a portable image collection and reconstruction software, the proposed harness aimed to make lung imaging accessible to both skilled and unskilled users for the fitness and telemedicine markets.

1.2 Background

1.2.1 Background and Importance of Electrical Impedance Tomography (EIT):

There are two main types of EIT imaging methods, absolute ETI and time-difference EIT. Absolute EIT is a non-invasive imaging technology that uses harmless electrical currents to produce images of bioimpedance distribution within a body region [1]. Time-difference ETI occurs when the EIT can capture real-time changes in bioimpedance. This is useful because it adds a dynamic dimension to its imaging capabilities by monitoring changes in bioimpedance over time [2]. It is an interdisciplinary area that draws on mathematics, physics, and clinical sciences to generate images based on variations in the electrical conductivity of tissues in a body or materials in each volume. EIT applies an electric current and measures voltage across a sequence of surface electrodes, enabling it to detect changes in electrical properties that occur due to physiological changes or differing tissue properties [2].

Biomedical applications of EIT are increasingly becoming established in routine clinical use, with clinical chest EIT systems now commercially available. Examples of its use include monitoring of ventilation and imaging of lungs, heart, blood flow, brain, nerves, and cancerous tissue. Notably, the COVID-19 pandemic highlighted the critical role of EIT in managing ventilated patients in intensive care [2].

In addition to biomedical applications, the principles of EIT are also applied in geophysics, aiding in the detection of metallic ores, groundwater, and for imaging and monitoring of structures like bridges and embankments. Similarly, in process tomography, EIT is used to monitor pipes and mixing vessels [3].

This technology holds promise in the medical field as it is non-invasive, compact, and potentially cost-effective compared to other conventional medical imaging devices. However, it is critical to acknowledge that EIT imaging is of lower spatial resolution and subject to many sources of interference all of which are factors that contribute to the challenges faced in achieving reliable time-difference image reconstruction. Furthermore, increasing the number of electrodes does not necessarily improve the spatial resolution, as the pathways of the current flow are influenced by the varying properties of the tissue in those areas [3].

Nevertheless, research comparing regional impedance changes in EIT with lung density measurements using CT have shown a strong correlation, indicating that regional relative impedance changes detected by EIT are closely associated with regional lung volume changes observed by CT. This further highlights the potential utility of EIT in biomedical applications. [3]

Nonetheless, with continuing advancements in the field of EIT use, there are opportunities to address these methodological limitations and broaden the applications of EIT. It is an exciting time for researchers and clinicians interested in the development and application of this technology, with a growing community providing support and fostering innovation. The future will undoubtedly bring further improvements to EIT, potentially increasing its reliability, reproducibility, and range of applications.

1.2.2 Overview of EIT in Lung Imaging:

EIT systems typically function by applying AC currents across pairs of electrodes, based on a protocol and measuring voltages across the remaining ones. When used for imaging lung ventilation, EIT operates by quantifying changes in lung tissue aeration during the breathing process. This allows clinicians to obtain images representative of ventilation distribution at the bedside. The changes in lung gas content modify its impedance and consequently, during mechanical ventilation, lung impedance is closely tied to the degree of inflation. Despite its potential, current commercially available EIT scanners often suffer from low spatial resolution, which limits the precision of the images. [4]

From the electronics perspective, EIT systems typically apply currents across pairs of electrodes and measure the voltages across the remaining electrodes, allowing for a full set of measurements or an "EIT data frame." The development of robust, user-friendly EIT electronics is crucial for routine clinical use, with requirements such as rapid electrode placement and detection and reporting of disconnected electrodes.

Image reconstruction in EIT is a significant challenge due to the ill-conditioned and often ill-posed nature of the underlying equations [4].

EIT has proven useful in patients with Acute Respiratory Distress Syndrome (ARDS). This is because EIT enables visualization of the effects of mechanical ventilation directly and non-invasively at the bedside. [5]

Further, in ARDS patients, EIT can non-invasively visualize the effects of mechanical ventilation. It has the potential to help clinicians adjust ventilation parameters and manage treatment. EIT can detect changes in regional ventilation reflecting the extent of lung injury and the effects of ventilation, including the application of Positive End-Expiratory Pressure (PEEP) and recruitment manoeuvres [6].

In addition, EIT is also being investigated for bedside monitoring of lung gestation in pre-term neonates. Disorders related to lung growth, maturation, and control of breathing are significant problems faced by neonatologists, and EIT could potentially provide non-invasive, continuous monitoring of these parameters [5].

Despite the potential of EIT, EIT is developing and hence, is faced with several technical challenges such as low spatial resolution, interference from other medical devices in the Intensive Care Unit (ICU), and these systems assume a standard chest shape to reconstruct images in real-time. [5] All of which need to be further explored and analysed.

Despite these challenges, EIT offers numerous potential applications, such as detecting pulmonary emboli and monitoring pneumothorax drainage, due to the high contrast between air and surrounding tissue [7]. There has been particular interest in using EIT for monitoring lung maturation and oxygen requirements in preterm neonates, where it presents a safe, non-invasive alternative to traditional monitoring methods.

With ongoing research and technological advances, EIT could provide additional tools to optimise the management of patients with respiratory conditions. However, further improvements are required to overcome the existing limitations and validate the clinical impact of EIT-based protocols.

1.2.3 Previous Attempts/Experiments Exploring Portable EIT Solutions:

A review of the existing literature unveils various endeavours to design cost-effective, reliable, and user-friendly electrical impedance tomography (EIT) solutions. This exploration has prompted the development of a range of systems, each addressing different facets of EIT technology. These facets encompass portability, ease of use, cost-efficiency, and specific applications.

However, these solutions have come with a set of inherent pros and cons. While the benefits of chest EIT include its cost-effectiveness and the ability to continuously monitor lung function, a critical disadvantage is its relatively poor spatial resolution. Nonetheless, even with this limitation, it still offers a unique advantage in the realm of telemedicine by providing a portable device that delivers lung imaging where no other solutions currently exist.

Another key area of consideration has been the application of electrode rings in EIT systems. Current systems predominantly use a single ring of electrodes, but the potential for enhancing the resolution along the z-axis exists in theory by implementing multiple rings. However, this approach comes with its own set of challenges and is a topic of ongoing research and development.

One study showcases the development of a portable EIT system tailored for lung function assessment and suitable for home use. This system is compact and lightweight, comprising a console and a 16-channel electrode belt. Further, it can be powered either from a mains supply or a Li-ion battery. A distinguishing feature of this design is its compatibility with a mobile application, allowing users to self-administer tests and capture data. Furthermore, it includes a cloud-based processing pipeline, making it ideal for telemedicine applications. The system's functionality extends beyond mere data collection; it is also capable of producing functional maps to help detect and monitor changes in lung diseases such as COPD. While this system is particularly important for its focus on lung function, its application could potentially be extended to other chronic diseases, given that changes in bioimpedance could be indicative of various health conditions [8].

Another experiment addresses the development of an EIT system, notably using a Raspberry Pi 4 (RPi4) as an embedded system. This solution also places a high emphasis on portability, reliability, and cost-effectiveness, but uniquely addresses the need for a low-cost system capable of image reconstruction. The authors describe a system capable of achieving satisfactory results, comparable to those of a personal computer but with a significantly lower energy consumption, making the system portable and reliable. The system uses three novel algorithms that are efficient enough to run on the RPi4. The proposed system is demonstrated to have applications in mechanical ventilation, the food industry, and structural health monitoring. In addition, the study lays out opportunities for further optimization and improvement, particularly in areas such as the calibration process and more precise impedance measurements [9].

Both projects present significant advancements towards the realization of portable and affordable EIT solutions, indicating the usefulness of such systems for various applications, from lung function assessment to industrial monitoring. The focus on self-administration and telemedicine applications in the first system represents an important step towards more accessible health monitoring, while the low-cost, reliable, and portable EIT system developed in the second study opens possibilities for various applications across industries. Nonetheless, despite the considerable progress, more work remains to be done in terms of precision, accuracy, and broader applications of these devices. Compared to these systems, the systems we follow in this experiment have two rings of electrodes, the software is user-friendly for both skilled and unskilled users, and we use novel electrodes that have been created out of Primasil.

Further, a thorough review of the existing literature shows various attempts to design cost-effective, reliable, and user-friendly EIT solutions. This exploration has prompted the development of a range of systems, each addressing different facets of EIT technology. These facets encompass portability, ease of use, cost-efficiency, and specific applications.

These solutions have come with a set of inherent pros and cons. The benefits of chest EIT include its cost-effectiveness and the ability to continuously monitor lung function in real time. However, a critical disadvantage is its relatively poor resolution. Nonetheless, even with this limitation, it still offers a unique advantage in the realm of telemedicine by providing a portable device that delivers lung imaging where no other solutions currently exist.

1.2.4 GUI and the Role of GUI in Medical Imaging Software:

A critical aspect of any medical imaging software is the graphical user interface (GUI). Graphical User Interface (GUI) is a form of user interface that allows users to interact with electronic devices through graphical icons and audio indicators, as opposed to text-based interfaces or typed command labels. In the context of medical imaging software, it serves as a visual bridge between the complex data and the user, facilitating the process of understanding and interpreting the information being displayed [10]. A well-designed GUI can make the process of imaging and data interpretation more user-friendly, particularly for non-expert users.

A GUI is crucial for the successful application of medical imaging software, particularly in non-clinical settings. A well-designed GUI simplifies complex operations, enabling non-experts to effectively utilize advanced imaging technologies like EIT [11].

a. **Types and Classification of Interfaces**: A variety of interfaces are used in software development, including the Web-User Interface (WUI), Hand-User Interface (HUI), Graphical User Interface (GUI), and Command Line Interface (CLI). In the context of medical imaging software, the GUI plays a crucial role as it enables direct manipulation and provides support for mouse use graphics, among other features.

b. **User-Centred Design**: The GUI must be designed with the user in mind. The considerations include user's characteristics, preferences, colour and navigation preferences, ergonomics, modular design, and ease of management. This allows for medical treatment to be more personalized. Moreover, the GUI should allow efficient problem-solving with minimal errors and time expenditure.

c. **Quality Evaluation Criteria**: GUI design quality can be evaluated based on various factors such as speed of visual elements drawing, frame rate, hardware resources requirements, ease of finding elements, time taken to learn the program, adaptation to user characteristics, and the number of errors when working with the interface.

d. **User Perception and Psychological Aspects**: Psychological aspects of user perception should be considered in GUI design. Users tend to be cautious of new elements, prefer familiarity, and find it challenging to use multiple devices simultaneously. Therefore, interfaces should be minimally invasive, use familiar graphical elements, require a minimal number of operations, and use colours and sounds that evoke positive responses.

e. **Specific Design Aspects for Medical Field**: In the context of medical imaging software, the GUI should consider the needs of different user groups such as administrators, diagnosticians, doctors, and laboratory assistants. Each user group should have a GUI with a minimum necessary set of functions. Text and numeric IDs should be minimized while graphic symbols and user-friendly icons should be maximized.

f. **Usability Testing**: Usability testing is a crucial part of GUI design, ensuring that the interface is user-friendly and functional for its intended users. It can provide invaluable feedback for further refinement of the GUI. Further, usability is essential to the willingness of users to use the interface.

g. **Graphical User Interface (GUI) Models**: The models of graphical user interfaces can be divided into programmer's models, user's models, and programming models. Each of these models considers different aspects and needs, creating a comprehensive understanding of the user-interface interaction.

The role of the GUI in medical imaging software is extensive and multi-faceted, with critical implications for user experience and functionality. It's not merely a way for users to interact with the software; it is also an important determinant of the software's success in both clinical and non-clinical settings. A well-designed GUI is crucial for making complex medical imaging software accessible and user-friendly for both skilled and unskilled users [11].

1.3 Purpose

1.3.1 Rationale - The Need for a Low-Cost, Wearable Chest EIT Harness

The ever-growing telemedicine market and increasing interest in personal fitness monitoring necessitate the development of a low-cost, wearable EIT system that can be operated by non-experts. Our project aims to address this need by designing a chest EIT harness with self-abrading ECG type electrodes and user-friendly software. Therefore, we wanted to create a portable, low-cost, self-abrading system which would allow inexpert users to achieve good electrode contact and adequate results.

In contrast to existing developments, our solution offers several additional features. It is designed to be portable and low-cost which will make it more accessible to a broader population. The self-abrading electrodes incorporated into our harness improve contact and signal quality and hence, the device will be more user-friendly, particularly for non-expert users. Moreover, we recognize the critical aspect of achieving good electrode contact for accurate imaging. Consequently, our system is designed to guide even an inexperienced user to establish proper electrode contact that will further simplify its use.

One of the key distinguishing features of our design is the use of two electrode rings. This represents a significant enhancement over current systems that typically use one ring of electrodes. The use of multiple rings offers potential for improved image quality by enhancing the resolution along the z-axis.

Finally, our project focuses on mobile integration that aims to equip the EIT harness with capabilities for operation via a smartphone. This not only enhances its portability but also significantly widens its accessibility and potential applications in the realm of telemedicine and personal fitness monitoring.

The need for a low-cost, portable, and easy-to-use EIT harness is apparent when considering the limitations of existing systems and the potential benefits of making lung imaging accessible to a wider population. This project seeks to fill this gap.

1.4 Purpose of the Study

Our primary goal is to create an affordable and portable EIT system that incorporates a wearable harness with 32 self-abrading ECG type electrodes. The specific objectives include:

1. Develop a user-friendly GUI that connects to an EIT Device and can be ported to a smartphone.
2. Enable the GUI to present the electrodes to the user on a virtual 3D human chest and assess whether the user has positioned their electrodes appropriately for sufficient skin contact.
3. Enhance EIT software to support EIT Image Reconstruction and assess the improvement in image quality.
    a. GUI Display of EIT Image Reconstruction from 1 Ring of 16 Electrodes in Real Time.
    b. GUI Display of EIT Image Reconstruction from 2 Rings of 16 Electrodes in Real Time.

2. Materials and Methods

This section provides an overview of the materials used and the methodologies followed during the development and implementation of the EIT harness, GUI, porting process, and system-on-chip development.

2.1 Developing the EIT Harness

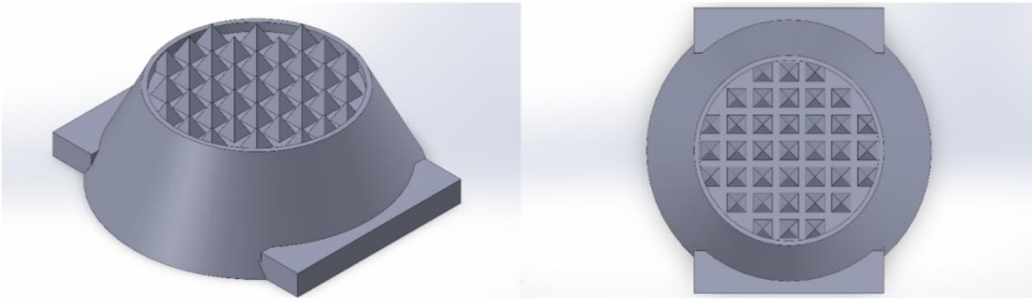
2.1.1 Designing the Harness

The harness design was guided by both functional requirements and user comfort, specifically targeting adaptability for various user scenarios. Jonathan Lam, the designer, prioritized the location of the harness in the 4-6th intercostal space to prevent interference from diaphragm and abdominal contents in EIT measurements.

Design investigations were carried out using a mock-up worn by multiple subjects performing commonly performed actions. This empirical method provided reliable and representative feedback from the target user group, informing development of the device. Furthermore, having real users try it on allowed for quantitative physical measurements to support this development process as well as allowed for an adequate understanding of comfort.

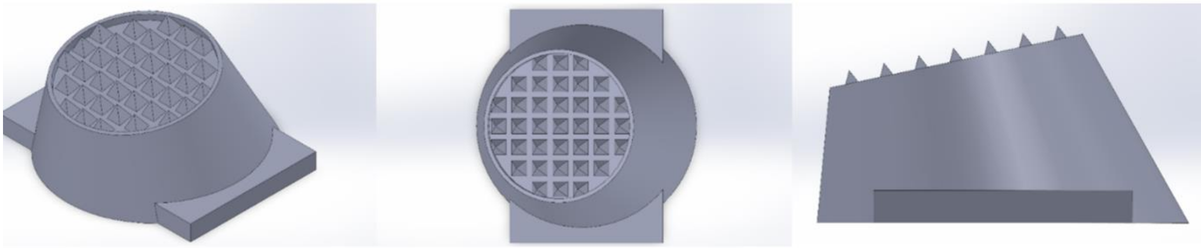
Three electrode designs were tested: apexes, flat depression, and midline electrodes (Fig. 1). Each design was evaluated for its abrasive properties and capacity for achieving sufficient skin contact. To assess the self-abrasive functionality, subjects were asked to rub the back of the electrodes, while the electrodes were placed on the skin of their hands. The various designs' abrasive qualities were then scored. According to the paper, after conducting 10 rubs, the individual scores were combined and then averaged across all participating subjects. This process allowed for a potential maximum score of 10 and a minimum score of -10. To evaluate the extent of skin abrasion, the affected area was examined for signs of redness or superficial skin scratches following the 10 rubs. Selected electrodes had abrasion scores of 9, 10, and 9.33 for the flat depression, flat, and midline electrodes, respectively, suggesting successful implementation of the self-abrading feature.

Flat Depression Electrodes:



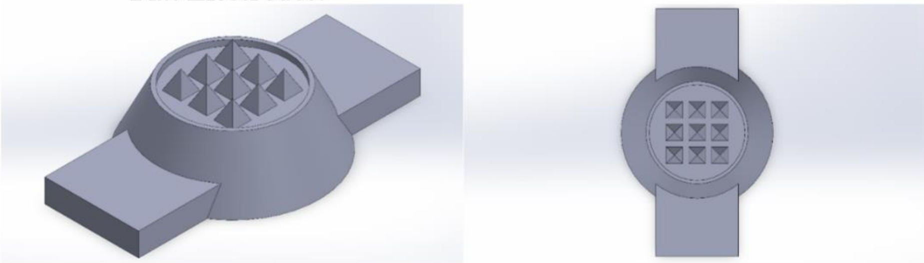
Completely flat but raised surface by 9.5mm, with a contact surface radius of 9.5mm used in axilla area. Abrasion score: 9

Midline Electrodes:



9.5mm contact surface radius with 6mm elevation of one side due to sloped contour of Medial Pectoral area and medial trapezius area. Tapered profile to prevent rocking and ensure abrading. Abrasion Score: 9.33/10

Flat Electrodes:



Electrode with a height of 6mm and contact surface radius of 5.8mm achieved an abrasion score of 10.

Figure 1: Shows the 3 Final Electrodes designs.

For the harness material, the team chose a conductive silicone rubber, based on its flexibility, cost-effectiveness, and suitable resistivity of ~0.05 Ωcm. Conductivity investigations involved increasing the percentage of carbon fibre within the silicone rubber with each trial, with tests conducted at frequencies representative of those needed in a working EIT system. The selected conductive silicone, Primasil PR610, exhibited extensible properties and an impedance that suggested it might meet the target of less than 5kΩ with further testing.

The harness design concluded with the assembly of a 16 electrode EIT belt featuring flat electrodes, which were formed and cured from the chosen Primasil conductive silicone. The belt was designed to connect to a small ASIC chip performing the EIT calculations and was fitted on a human with a chest diameter of 96cm. Though some issues were encountered with surface mis-contacts and the weight of the connection wires, these were addressed in situ, and the harness demonstrated its ability to be used for Thoracic EIT, producing an image representing a general increase in change of impedance across the imaging plane during inspiration.

Future work for the harness design includes creating and testing additional electrode shapes from Primasil conductive silicone, further investigating the impedance characteristics, and optimizing the harness design for improved skin contact and abrasion. The harness will also be incorporated into a comfortable and easy-to-wear shirt fabric for additional testing and development.

2.1.2 Incorporating the Self-Abrading Electrodes

The incorporation of self-abrading electrodes into the wearable EIT system presented an innovative approach to optimize user comfort and the efficacy of the EIT technology. The self-abrading nature of the electrodes was intended to provide continuous, high-quality contact with the user's skin without necessitating any additional preparation or discomfort.

In the development phase, various designs of the electrodes were evaluated through abrasion tests. These tests aimed to assess the abrasive quality of different designs, determining how likely each electrode would abrade the skin upon contact. However, these tests were indicative of the likelihood rather than the severity of abrasion, which was qualitatively gauged through visual inspection, examining for signs of redness or skin scratching.

While testing was conducted with PLA and PETG electrodes, the goal was to manufacture the electrodes using conductive silicone rubber because it is far more suitable for wearable devices due to its extensibility and flexibility. Thus, the abrasion results derived from these early-stage prototypes may have been slightly exaggerated. As such, future attempts at the design may require further abrasion tests using the desired silicone rubber electrodes.

The flat electrode design was selected for its high abrasion score and low volume, enhancing cost-effectiveness. However, research suggests that an increased electrode contact surface can decrease skin-electrode contact impedance [12]. Considering this, it may be worthwhile to investigate whether a wider flat electrode design may offer lower contact impedance and if this potential improvement outweighs the current design's material cost advantages.

One potential limitation in the design process was the limited number of subjects used to test the prototype. Only four subjects with minimal variation in physical characteristics were used, potentially limiting the design's applicability to a wider range of body types. To ensure broader applicability, further testing with a more diverse subject group is required.

In the subsequent process of creating a conductive silicone rubber, various compounds and mixing methods were used. Some combinations resulted in successful conductivity, while others did not. These variations may be attributable to the molecular characteristics of the components and the nature of the mixing process. Additionally, it was observed that the conductive properties of the silicone rubber were negatively affected by high concentrations of carbon fibre doping, indicating a need for balancing conductivity with the extensible and flexible properties of silicone rubber.

Finally, in the process of moulding and curing, Primasil PR610 was utilized as a potential electrode material. However, the curing process was found to be challenging due to the specific conditions required, including the need for a vacuum oven paired with pressure and high temperatures. Despite the challenges, some promising results were obtained, suggesting that with refinement, this material could be suitable for use.

Impedance and contact impedance tests on Primasil PR610 revealed its properties were within the acceptable range set for the project, showing promise for its use in electrode manufacturing. Despite the varying results due to potential experimental errors, the preliminary results were encouraging, paving the way for further investigations and refinements in the development of self-abrading electrodes for the wearable EIT system.

2.1.3 Introduction to EIT 32 Device from Sciospec:

The EIT 32 Hardware that will be used is by a company called Sciospec. Sciospec Scientific Instruments is at the forefront of electrical impedance technologies as it specializes in solutions for impedance spectroscopy and tomography, electrophysiological techniques, and electrochemical methods. Further, Sciospec's technology finds wide-ranging applications some of which include bio-analytics, medical research, material science, and component testing. A key element in its success is its ability to cater to diverse needs, from smaller scale biochip solutions and point-of-care services, to comprehensive, large-scale systems for automated industrial process control or pharmacological testing. Sciospec technology also forms the core of many products designed for bioanalytical and medical applications. This research project utilizes the EIT 32 Sciospec device, a leading product from Sciospec's range. The versatility of this device and its high adaptability make it an excellent choice for the exploration and experimentation at the heart of this study.

2.2 Building the User-friendly GUI

2.2.1 Prototype Design

The initial stage in the development of our novel bioimpedance monitoring app involves creating a comprehensive prototype design. This design provides an early visual representation of the final product. We utilized Figma for this purpose. Figma is a user-friendly interface design tool known for its capacity to facilitate collaboration and consolidate ideas effectively.

Fig. 2 provides a detailed look at the envisioned layout and functionality of our bioimpedance monitoring app. A prominent feature of this prototype is the interactive 3D chest model. Designed with precision and a high degree of detail, the 3D chest model aims to provide users with an intuitive and engaging way to interact with the bioimpedance data.

2.2.2 GUI Design and Functionality

The GUI has been designed to be intuitive and user-friendly. One of its main features is a rotation tool, allowing users to view the chest from various perspectives and gain a comprehensive understanding of the distribution of bioimpedance across the chest. The GUI shows the connection status of each electrode (green for connected, red for not connected).

The user interface includes three key buttons, each designed to offer a different aspect of bioimpedance monitoring. The first button labelled "Check Connection," allows users to inspect the impedance of each electrode present on the 3D chest model. The second button labelled "Adjust Connection," lets users re-check the connection until the impedance of all electrodes is working properly.

2.2.3 Impedance Display

The third button in our GUI, labelled "View Impedance," navigates the user to a real-time graphical representation of chest impedance. This live plot allows users to monitor bioimpedance changes as they happen, providing a tool for real-time data analysis and immediate medical response, if required.

It's important to note that the design showcased in the figure is a prototype and, therefore, subject to changes based on iterative user testing and feedback. The central goal of this design stage is to create a user-friendly, informative, and intuitive app that effectively visualizes bioimpedance data in real-time. The purpose of this is to enhance user experience and foster better understanding of bioimpedance measurements in clinical and biomedical engineering contexts.

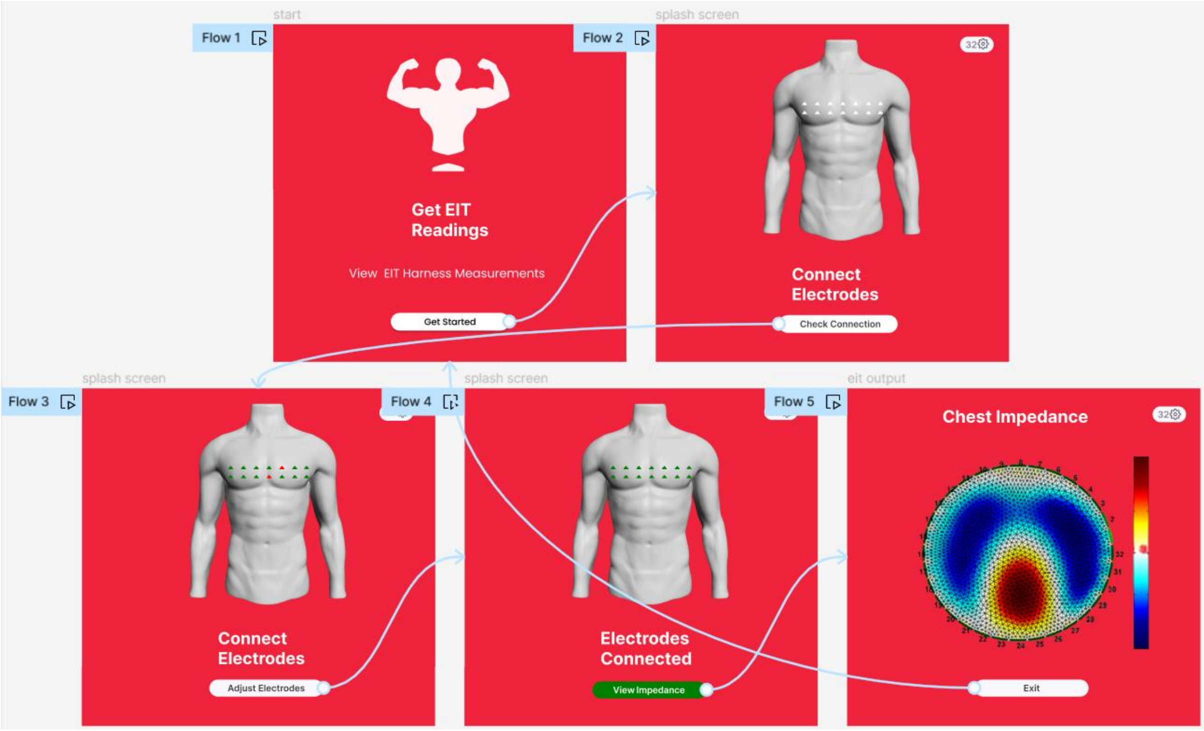


Figure 2: Application prototype design

2.2.4 Interface Design and User Experience

The design of our bioimpedance monitoring application places significant emphasis on the user experience (UX) and interface design. We aimed to create a user-friendly software interface that prioritizes simplicity and accessibility. Consequently, text and numeric IDs have been kept to a minimum while graphic symbols, carrying user-friendly labels, have been employed to create a more visually engaging and intuitive interface.

The GUI of the application has been designed with a key focus on simplicity and usability, catering specifically to non-expert users in a telemedicine setting. With a clean, intuitive interface, the GUI comprises should have only the necessary functions needed for the operation of the device, thereby minimizing complexity and potential confusion [11].

The design principle adhered to aims to make the user experience as seamless as possible, limiting the potential for errors while interacting with the software interface. This approach significantly enhances usability and productivity, making the application suitable for individuals without extensive technical or medical imaging backgrounds.

While plans exist for further customization to cater to different user groups, such as administrators, diagnosticians, doctors, and laboratory assistants, the current version of the software is primarily geared towards facilitating easy and effective use by non-expert users.

As described in our Software Detailed Design Document, the application was built using Python and the PyQt framework to offer a powerful yet user-friendly GUI. This GUI not only serves as the medium through which users interact with the Electrical Impedance Tomography (EIT) hardware but also provides additional features such as checking electrode connections and adjusting them if improper impedance readings are detected.

The software architecture follows the Model-View-Controller (MVC) pattern, facilitating a clean separation between the interface, data, and control logic. The interface, or the “view” in MVC, is built using the PyQt framework as this allows us to create a visually appealing and highly interactive GUI.

The user interface, (UI) of the application is made up of several components, each serving a unique function. Key components include a StackedWidget, enabling users to switch between different views or functionalities; QPushButton, enabling user interactions and triggering specific actions; QSlider, allowing users to adjust parameters within a specified range; FigureCanvas, facilitating the display of interactive plots and graphs; and ImageColorbar, providing a colour bar for the displayed images.

The design of the UI is such that users can effortlessly navigate through different pages, interact with the system via buttons, and adjust sliders to modify parameters. Visual aids like interactive plots and colour bars help users to understand the data being generated by the system.

Specific sequences of operations have been established for tasks such as checking electrode connections, adjusting electrodes, starting the measurement task, and closing the application. The reason for this is to further enhance user experience and minimize errors.

Overall, the user experience and interface design have been created to cater to the specific needs of our end-users while ensuring maximum functionality and ease of use. We strive to make the process of bioimpedance measurement as user-friendly and efficient as possible which will enable quick data interpretation and decision making.

2.2.5 The Role of Qt-Designer and Python in GUI Development

Python and the Qt-Designer were integral to the development of the GUI for this desktop application, which interfaces with a device measuring Electrical Impedance Tomography (EIT) readings.

Python was the primary language used to write the application because of its simplicity and flexibility. Its comprehensive set of libraries and modules, such as PyQT and SciPy, allowed for the implementation of various aspects of the software, including the Model-View-Controller (MVC) architectural pattern, electrode value adjustments based on impedance readings, and the display of images in the user interface.

Python's versatility and ease of use facilitated the development of numerous components of the application, including main.py, MainWindow class, Controller class, checkElectrodes module, presenter.py, and imagedisplay.py. These components range from handling the initiation of the application, managing the user interactions, managing the data flow and logic, presenting measurement data, and even handling the display of images.

The Qt-Designer was used in conjunction with Python to develop the user interface of the application. Specifically, it was used in the creation of the UI components within the ui_app.py module and the ImageColorbar class in the colorbar.py module. The Qt-Designer provides robust tools for creating a professional and user-friendly graphical interface that enhances the user experience. Its capabilities include designing multiple pages, implementing layout managers, labels, buttons, sliders, and other UI elements.

The graphical interface allows users to interact with the application and the EIT hardware device, check and adjust electrode connections, view impedance, and observe EIT measurements. The integration of Python with the Qt-Designer in the development process provided an effective solution to build a powerful GUI that is efficient and easy to use.

Thus, Python and Qt-Designer played crucial roles in GUI development, leveraging the strength of Python's simplicity and Qt-Designer's user interface design capabilities to create an effective solution for managing Electrical Impedance Tomography readings.

2.3 System-on-Chip Development with Raspberry Pi 4B

In the development of this project, the Raspberry Pi 4B was used as a system-on-chip solution to facilitate the simulation of the application running on a mobile platform. The underlying objective of this design choice was to mimic the scenario in which the EIT device (Scio spec) would wirelessly stream measurement data to a mobile device which is an important feature considering the absence of Wi-Fi or Bluetooth functionalities in the current EIT device.

The Raspberry Pi 4B, renowned for its compact size, versatility, and significant computing power, was chosen for its capability to handle the complex calculations and data processing demands associated with EIT measurements. As a single-board computer, the Raspberry Pi 4B acts as a mini-PC, running the Python GUI application and interfacing with the EIT device directly.

To emulate the intended mobile experience, a remote desktop approach was adopted. Users interact with the application as if it is on a mobile device, while the program is running on the Raspberry Pi 4B. This method, often referred to as “Wizard of Oz” prototyping, is a practical approach to user testing and design in cases where full hardware functionality is not yet available.

Furthermore, the Raspberry Pi 4B’s robust capabilities were leveraged to manage the EIT measurements, electrode connections, adjustments, and present the data in a comprehensible format to the user via the GUI. The Raspberry Pi 4B was instrumental in maintaining a portable, cost-effective, and versatile system for EIT imaging.

In essence, the integration of Raspberry Pi 4B in the system design offers a viable workaround to simulate the wireless data streaming capability from the EIT device to the mobile application. Its adoption underscores the potential of system-on-chip development in overcoming hardware limitations and facilitating more accessible and portable healthcare solutions.

2.4 Extending the EIT Software to 2 Rings

A central objective of this thesis was to extend the functionality of the existing Electrical Impedance Tomography (EIT) software to support 32 electrodes, equivalent to two rings of 16 electrodes each. The current EIT Device (Sciospec) has a capacity of 32 channels—two rings of 16 electrodes—thus the immediate focus was on effectively handling 32 electrodes. This extension from a single ring to two rings of electrodes allowed for more comprehensive imaging capabilities.

The current 16-electrode EIT system operates on a differential protocol, implying there are no reference electrodes. The electrical impedance is measured in a pattern across the electrodes, with the software algorithm processing the data to generate a 2-dimensional image of the conductivity changes within the body.

To extend the EIT software to accommodate 32 electrodes, we continued to use a differential protocol. However, we adopted the skip-4 injection and skip-3 measurement in-plane differential protocol [13]. (This protocol along with its corresponding Jacobian matrix was kindly prepared for me by my secondary supervisor Kai Mason). While there is no conceptual difference between the two cases, the number of measurements increased significantly, and the images shifted from 2-dimensional to 3-dimensional representations. This extension, despite its complexity, was essential to achieve more detailed and extensive imaging.

The process of extending the EIT software followed these steps:

1. **Calculate Jacobian from the Model**: This involves creating a matrix of partial derivatives for the electrode system. For the 16-electrode system, in two-dimension, the matrix was based on a triangular mesh whereas the 32-electrode system used, in three-dimension, the forward model is tetrahedral and then the mesh is converted to a coarser hexahedral mesh for reconstruction a hexahedral mesh. A crucial consideration here was the mesh choice. The

tetrahedral mesh requires more storage, around 10GB, compared to the hexahedral mesh which only required about 642MB. The exact reasons for this discrepancy are not fully understood, but the difference in storage requirements was significant.

2. **Down sample the Jacobian**: The Jacobian calculated from the fine tetrahedral or hexahedral mesh was down sampled to a coarse equivalent mesh. This step is crucial in managing computational complexity.

3. **Collect Data**: This is the stage where the EIT system measures impedance from the various electrode combinations.

4. **Perform Image Reconstruction**: The Jacobian's singular value decomposition was calculated. Then, the Moore-Penrose pseudoinverse was calculated using the singular value decomposition. A reconstruction matrix was then calculated using a value of the hyperparameter, which could be chosen using various methods. Multiplying the reconstruction matrix by input data gave the output for the reconstructed change in conductivity. This method known as the 0th Order Tikhonov Regularisation.

5. **View Reconstruction**: The final step was to view the reconstructed images. Since the Jacobian had been down sampled to a hexahedral mesh, the corresponding down sampled mesh was used for viewing the reconstruction.

This whole process could be implemented in both 2D and 3D. The only difference was the shift from tetrahedral to triangular and hexahedral to square when moving from 3D to 2D. Thus, the development of the 32-electrode EIT system and the extension of the EIT software to two rings was a natural extension of the existing technology, but also a significant advancement in terms of detailed and extensive imaging.

3. Results

3.1 User-friendly GUI and Image Reconstruction

Throughout the course of this project, a user-friendly graphical user interface (GUI) was developed to interact with an Electrical Impedance Tomography (EIT) device, specifically Sciospec. This section discusses the results of the project in alignment with the four project aims.

3.1.1. Building the GUI that interfaces with an EIT device (Scio spec):

The development of a Graphical User Interface (GUI) to interface with an EIT device was a critical component of this project. This interface provides a visually intuitive mechanism for users to interact with the EIT device, rendering it more accessible and user-friendly.

The GUI was designed to interface with the Scio spec EIT device specifically. It employs programmed algorithms to interact with the device's built-in functionalities and data acquisition systems. The GUI is programmed to only run when the EIT device is connected as this ensures that the system's resources are efficiently utilized. This aspect of the GUI was a notable achievement, with Fig. 3 illustrating the successful connection between the GUI and the EIT device.

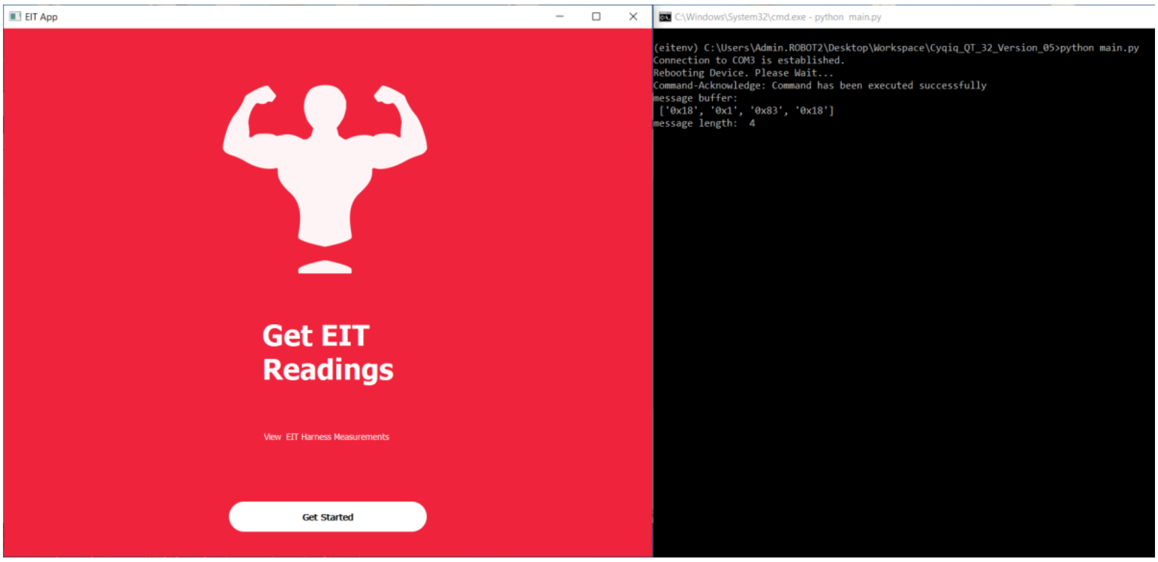


Figure 3: image of the EIT App running and proof of interface between the App and EIT Device (Scio spec)

3.1.2. GUI Display of a 3D chest with 2 rings of 16 electrodes:

In the context of this project, the EIT device was attached to a saline-filled tank equipped with two rings of 16 electrodes. This tank acts as a proxy for a human chest, and while it does not provide a perfect representation, it is a suitable and practical stand-in for the proof-of-concept and development phases of the project. This can be seen in fig. 4 where there is an image of the saline tank connect to the EIT 32 device and the human chest is displayed on the smartphone as it is connected to the Raspberry Pi.

The GUI displays a 3D depiction of the chest, with the positioning of the 32 electrodes clearly visible. This representation allows for a detailed visualization of the EIT system, including the layout of the electrodes on the chest, which is vital for understanding the system's operation. In addition, the GUI features an option to rotate the 3D model of the chest, facilitating the viewing of the electrode positions from various angles, (fig. 5). Although the system employs static images rather than a fully dynamic 3D model due to the complexity of the latter, it serves its purpose and presents potential for improvement in future iterations.

The system's "connect" feature allows users to ascertain the connection status of each electrode. It is programmed to determine the impedance of each electrode, changing the colour representation on the GUI accordingly. The system designates a green colour for electrodes with impedance below 5000 (indicating a proper connection) and red for those with impedance above 5000 (signifying a potential issue with the connection). This colour-coding system aids in troubleshooting and ensuring a reliable setup.

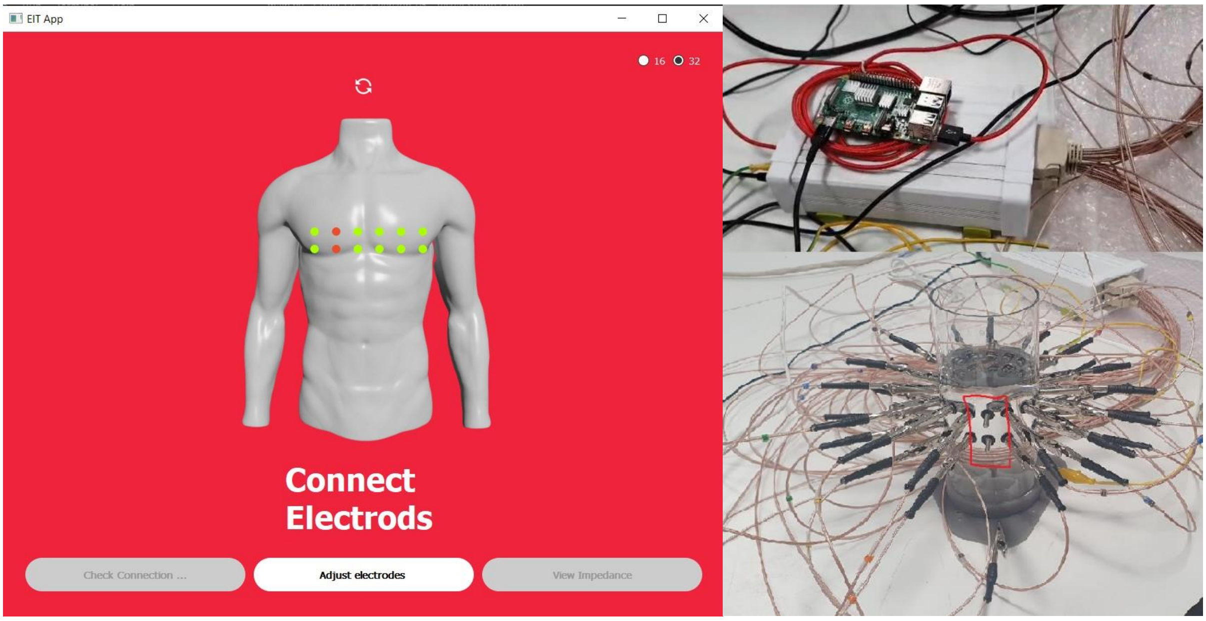


Figure 4: Image of the GUI Display of the 3D chest with 2 rings of 16 electrodes(left), image of the 32 EIT Device (Scio Spec) connected to the raspberry pi 4B (top right) and image of the saline filled tank connected to the EIT device (bottom right). In addition, 2 electrodes have been removed (electrodes 2 and 18) and as a result the 3D chest is able to display that those 2 electrodes need adjustment.

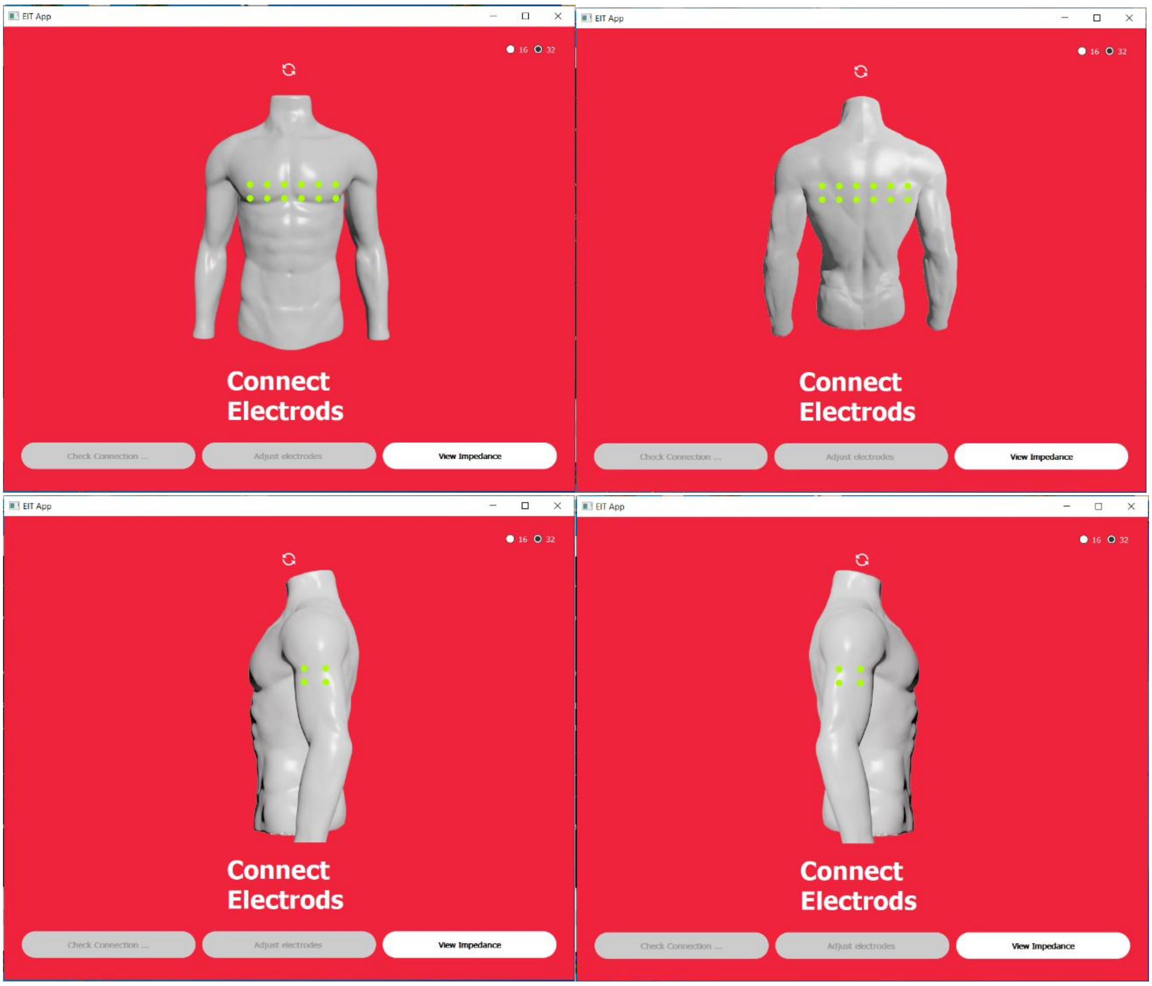


Figure 5: Shows images of all 4 angles of the rotated 3D chest showing the electrodes.

3.1.3. GUI Display of EIT Image Reconstruction from 1 Ring of 16 Electrodes in Real Time:

Upon pressing the “view impedance” button on the GUI, the program requests impedance measurements from the EIT device. These measurements are streamed in real-time from the saline-filled tank and collected by the program. The system then employs the reconstruction matrix, a key component in EIT image reconstruction, to convert the impedance measurements into pixel data for image generation. This mathematical process involves several steps including matrix multiplication, clipping the result to the colour modulation value, applying a colormap, and displaying the final image, (fig. 6).

The system’s ability to produce a 2D XY slice image with a resolution of 56 x 56 pixels, (fig. 7) real-time demonstrates the efficiency and effectiveness of the implemented algorithms. The reconstructed images refresh at a rate of approximately 10 frames per second, allowing users to observe changes in the saline-filled tank in near-real-time.

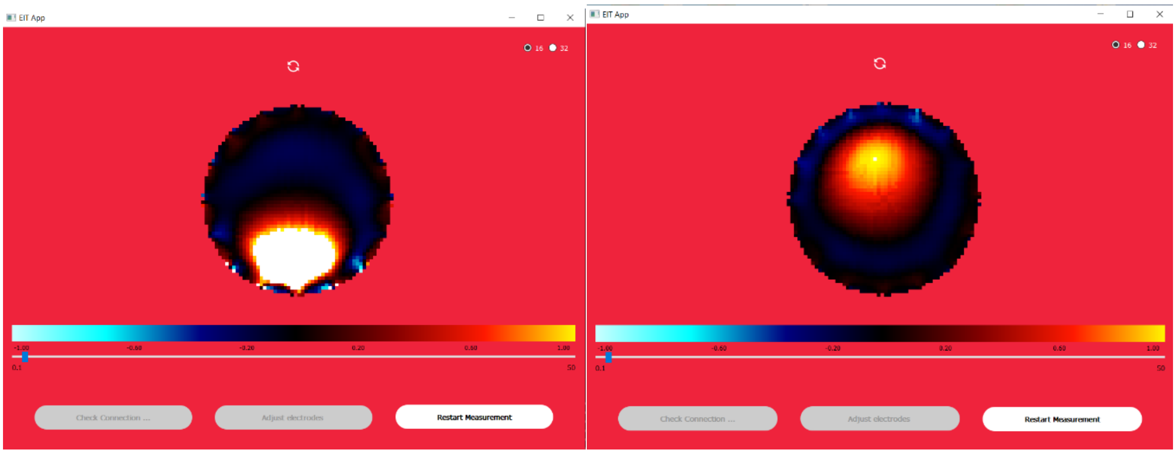


Figure 6: Shows images of the GUI’s Display of EIT Image Reconstruction from 1 Ring of 16 Electrodes in Real Time. In addition, the slider bellow the colour bar effects the brightness left of the image plots.

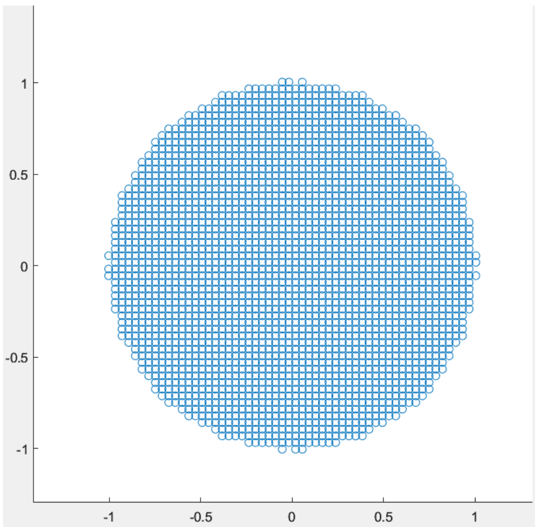


Figure 7: Shows the coordinates of each of the pixels (56x56) in a plot.

3.1.4. GUI Display of EIT Image Reconstruction from 2 Rings of 16 Electrodes in Real Time:

Expanding the system to handle two rings of 16 electrodes each, thus allowing for 3D EIT imaging, represented a significant advancement of the project. The process for this setup remains largely similar to the single-ring version, with the primary difference being the increased data input (32 x 32, or 1024, voltage measurements) and the size of the reconstruction matrix.

This expansion introduces a new dimension to the imaging capabilities of the system as it enables for the conversion the pixel data into a 3D representation with dimensions 18 x 18 x 48 pixels, (fig. 8). Despite the substantial increase in data, the system maintains its functionality and user-friendly interface however lower resolution compared to plotting with the single ring of 16 electrode system as overall there are more pixels to handle when plotting in 3D.

The updated GUI allows users to switch between three different views (XY, ZY, and ZX axes), (fig. 9), providing a comprehensive understanding of the scanned object in the saline-filled tank. This option was designed to have all 3 different image reconstruction in the same page and having the plots side by side. Conversely, I decided not to have 3 imaging reconstruction plots slices XYZ in one page because, firstly, this results in slower imager reconstruction speed (especially when this is running on a mini processor that the raspberry pi 4 has) and secondly, the page will have three sliders instead of one for each plot making the page more cluttered.

However, the transition to a 32-electrode system introduced challenges, particularly in the form of inaccurate voltage measurements from the EIT device when operating on two channels. After reviewing the Sciospec device documentation. This issue is due to the device's settings limitation, which significantly affected the accuracy of the impedance images compared to the single-ring setup.

According to the Sciospec's documentation it is stated that under the heading 'Set Single-Ended or Differential Measure Mode (0x08)' its quoted that "in the case of a 32-channel system it is only possible to differentially measure 16 or 32 channels in a circular arrangement, use single ended measurements for all other settings." Therefore, because of the EIT 32 Device limitations, I am unable to get accurate voltages measurements when using the skip-4 injection and skip-3 measurement in-plane differential protocol.

Resolving this challenge is a key objective for future development. Despite this, the system's ability to handle an expanded number of electrodes and produce accurate EIT images represents a crucial milestone in the project.

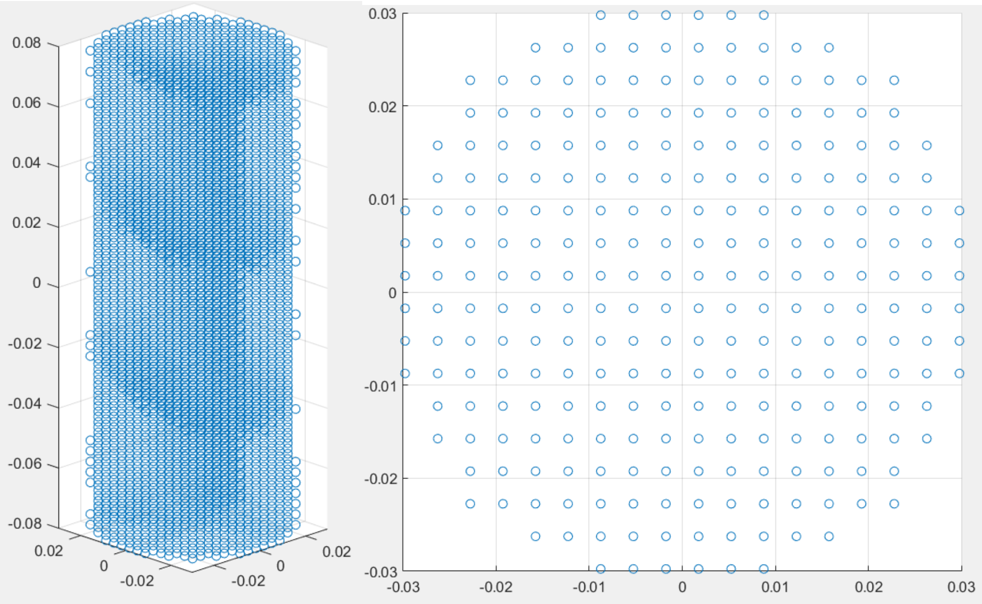


Figure 8: Shows the coordinates of each of the pixels (18 x 18 x 48) in a plot.

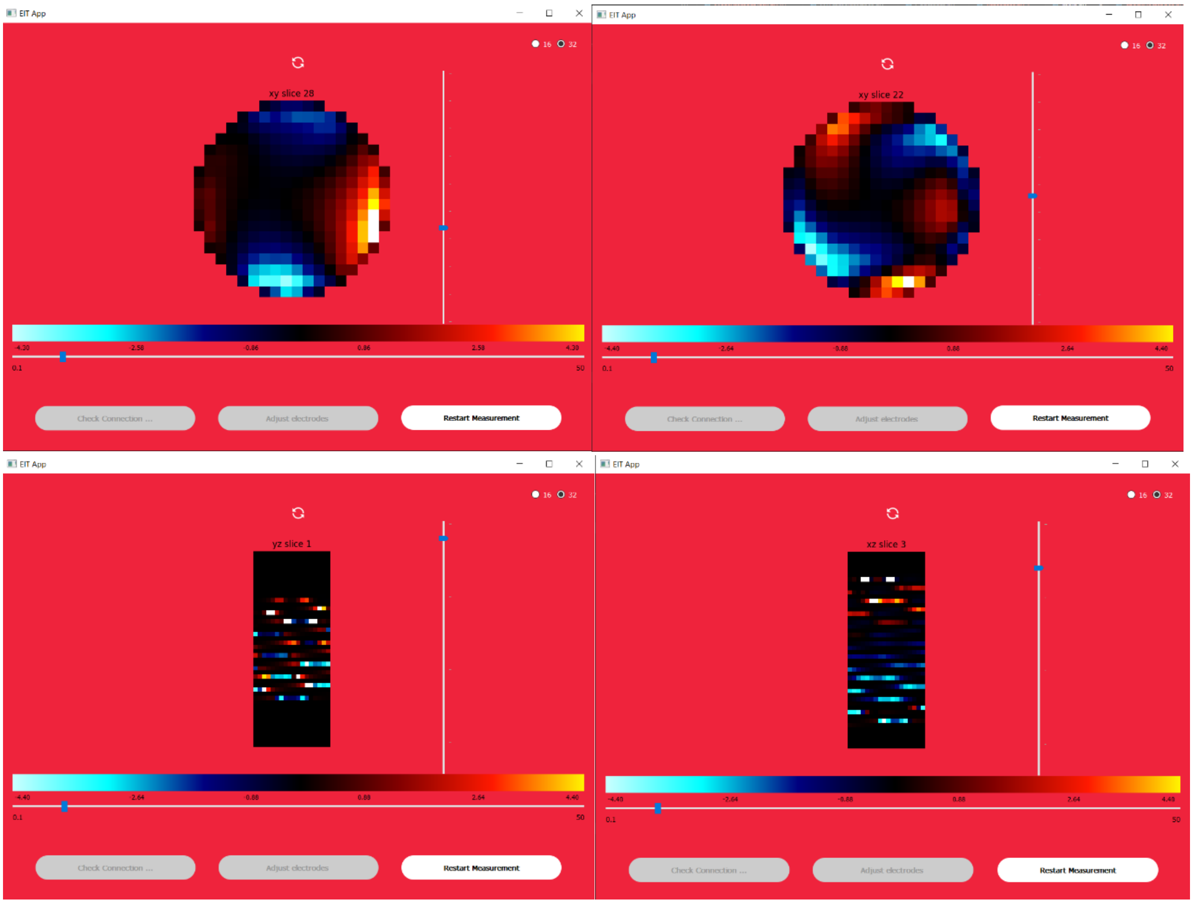


Figure 9: Shows imagers of all the 3 plots slices x-y axis (top left and right) y-z axis (bottom left) and x-z axis (bottom right). There is a rotation button above the plot that allows the users to change which plot is showing and slider on the left side.

3.2 Porting of EIT Software to Smartphone

The primary focus of this section is the transfer or “porting” of the EIT software, initially developed for a desktop or laptop environment, onto a Raspberry Pi, and by extension, a smartphone. This effort aligns with the aim to create a highly portable, user-friendly solution for real-time visualization of EIT impedance measurements.

3.2.1. Raspberry Pi as a Compact Computing Unit:

Raspberry Pi, a small and affordable computer, was chosen as the platform to host our software due to its compact size and impressive computing capabilities. As a single-board computer, it offers an array of I/O options that facilitate communication with various devices and peripherals, making it an ideal choice for the project. The Pi’s specification is it has a Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz.

Despite its compact size and low power consumption, the Raspberry Pi can run a fully-fledged operating system and is capable of executing complex software such as our EIT GUI program. This characteristic was crucial for our goal to deliver a portable solution for EIT measurements.

However, compared to running the program on a PC which obviously has a much more powerful processing capability. The pi’s live image plotting has a slower frame rate, which is to be expected.

3.2.2. Using Anaconda to Establish a Python Environment:

Our EIT software is a Python program. To ensure the program’s successful operation on the Raspberry Pi, we leveraged Anaconda – an open-source package management and environment management system. Anaconda simplified the process of setting up a Python environment by managing dependencies, installing the necessary libraries, and configuring the environment for our specific use case.

With Anaconda, we created an environment on the Raspberry Pi that perfectly matched our program’s requirements, and this allowed the EIT software to run seamlessly on the device. This environment isolation also reduced potential conflicts with other software or libraries installed on the Raspberry Pi which increased the robustness of our solution.

3.2.3. Xrdp for Remote Access:

Xrdp, an open-source remote desktop protocol server, was an important tool in making our GUI program accessible via a smartphone. Xrdp allows a remote device to establish a session with the Raspberry Pi, effectively enabling the device's screen to serve as a display for the Raspberry Pi.

Installing Xrdp on our Raspberry Pi allowed us to connect a smartphone to the Raspberry Pi remotely. Consequently, we could execute our program on the Raspberry Pi and visualize its operation on the smartphone’s screen. This setup enabled a Wizard of Oz style prototyping, where the program appears to run on the smartphone, while the processing is happening on the Raspberry Pi.

3.2.4. End Result - EIT Software on Smartphone:

The combination of the Raspberry Pi’s compact computing power, the Python environment established with Anaconda, and the remote access capabilities provided by Xrdp resulted in a highly portable, smartphone-accessible solution for our EIT software.

As displayed in figure 10, the user interface of our EIT software could be used comfortably on a smartphone screen, providing users with real-time EIT impedance measurements at their fingertips. This result signified a significant achievement towards our project aim and allowed us to push the boundaries of EIT imaging towards increased accessibility and ease-of-use.

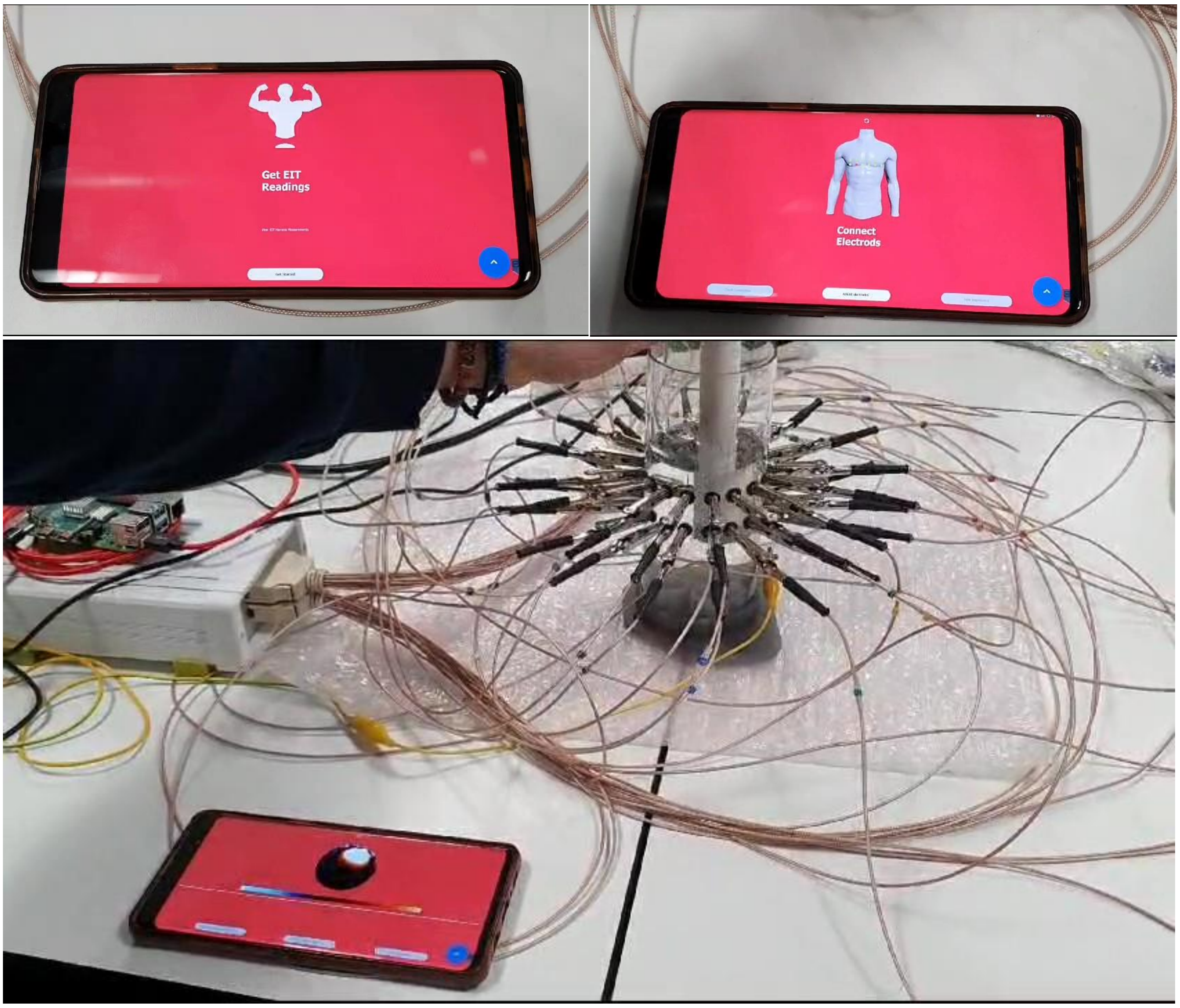


Figure 10: shows images of the complete program and device running on a smartphone.

3.3 Code Documentation (Software Design)

The purpose of this subsection is to provide a detailed design description for the development of this user-friendly desktop application that interfaces with a device measuring Electrical Impedance Tomography (EIT) readings. The application is built using the Python programming language and the PyQT framework for the graphical user interface (GUI).

3.3.1. Overview:

The application aims to enhance an existing Python application (GTK front-end) by changing its front end to a PyQT-based GUI and adding new features. The main objective is to create a user-friendly interface that allows the user to interact with the EIT hardware device and perform EIT measurements. The new features include checking electrode connections and adjusting them if improper impedance readings are detected.

3.3.2. Architecture:

The application follows the Model-View-Controller (MVC) architectural pattern. The main components are:

- Model: This includes the data structures and logic related to the EIT measurements, impedance calculations, and electrode adjustments.
- View: This represents the graphical user interface implemented using the PyQT framework.

- Controller: This acts as an intermediary between the model and the view, handling user interactions and updating the model and view accordingly.

3.3.3. Main Components:

3.1. main.py:

- This file contains the entry point of the application and initializes the main window.
- It creates an instance of the MainWindow class and starts the application event loop.

3.2. MainWindow class:

- This class represents the main window of the application and extends the QMainWindow class from the PyQt5 library.
- It initializes the UI components defined in the ui_app module using the Ui_MainWindow class.
- It creates an instance of the Controller class to handle user interactions and updates.

3.3. Controller class:

- This class acts as the controller in the MVC pattern and handles user interactions and updates the model and view.
- It receives references to the UI components and the MainWindow instance during initialization.
- It connects the UI components' signals to the corresponding slots for user interaction handling.
- It manages the initialization and configuration of the different pages of the application.
- It handles actions such as rotating the torso, checking electrode connections, adjusting electrodes, and starting the measurement task.
- It interacts with the model for generating and adjusting electrode values and assigns colours to the electrodes based on impedance readings.

3.4. checkElectrodes module:

- This module provides functions for generating and adjusting electrode values based on impedance readings.
- The generate_electrodes function generates initial electrode values and returns them along with an adjusted flag.
- The adjust_electrodes function adjusts electrode values based on impedance readings and returns them along with an adjusted flag.
- The return_electrodes function assigns values to electrodes based on the indices of electrodes to adjust.
- The get_impedances function interacts with the EIT hardware device to obtain impedance measurements.
- The module uses the Sciopy library for connecting to the EIT hardware and obtaining impedance data. Sciopy is a package offers the serial interface for communication with an EIT device from ScioSpec (https://github.com/spatialaudio/sciopy).

3.5. presenter.py:

- This module handles the presentation logic for the measurement task.
- It interacts with the model and retrieves measurement data.
- It updates the UI with measurement data and handles the display of the image.

3.6. imagedisplay.py:

- This module contains the 'ImageDisplay' class, which provides functionality for displaying images in the user interface.
- The 'ImageDisplay' class utilizes various libraries such as 'pathlib', 'numpy', 'cairo', 'PyQt5', and 'matplotlib' to handle image loading, processing, and display.
- The 'ImageDisplay' class includes the following methods:
    - '__init__(self, callback, ui, MainWindow)': This method initializes the 'ImageDisplay' instance. It receives parameters such as a callback function, UI elements, and the main window instance. It also sets up the necessary paths and initializes colormap-related attributes.
    - 'initialize_callbacks(self)': This method initializes the callbacks used by the 'ImageDisplay' class to handle various events related to image display.
    - 'set_image_plot(self, image)': This method updates the image plot with the provided 'image' data. It triggers the 'plot()' method for image processing and display. - 'set_image_plot_clear(self)': This method clears the image plot.
    - 'is_active(self)': This method returns a boolean value indicating whether the 'ImageDisplay' is active or not.
    - 'set_active(self, active)': This method sets the activity status of the 'ImageDisplay'.
    - 'update_image_plot(self, image)': This method updates the image plot with the provided 'image' data by invoking the 'plot()' method.
    - 'update_image_plot_clear(self)': This method updates the image plot by setting a default image.
    - 'initialize_surface(self)': This method initializes the Cairo surface for image display.
    - 'initialize_colormap(self)': This method initializes the colormap used for image visualization by loading the colormap data from a MATLAB file.
    - 'plot(self, image)': This method processes the provided 'image' data, applies the colormap, and displays the resulting image in the UI. It utilizes the Cairo surface to manipulate and display the image.

3.3.4. User Interface:

The user interface is implemented using the PyQT framework and defined in the ui_app module. The UI consists of multiple pages and UI components such as buttons, labels, grids, and sliders. Here are the relevant files:

4.1. colorbar.py:

- This module contains the 'ImageColorbar' class, which is responsible for displaying the colour bar in the user interface.
- The 'ImageColorbar' class extends the 'QGraphicsView' class from PyQt5 to provide a custom view for the colour bar.
- It utilizes various libraries such as 'MatlabFile,' 'numpy,' 'PyQt5,' and 'cairo' for colour bar initialization, handling, and rendering.

4.2. ui_app.py:

The user interface (UI) of the EIT App is designed using the PyQt5 library. It provides a graphical interface for users to interact with the application. The UI is divided into multiple pages and includes various widgets and components to enhance the user experience.

The 'ui_app.py' file contains the code responsible for defining and configuring the UI. It utilizes the Qt framework to create the main window, layout managers, labels, buttons, sliders, and other UI elements.

The UI consists of the following components:

- StackedWidget: This widget allows for switching between different pages of the application. Each page represents a different view or functionality.
- QLabel: These labels are used to display images and text in various parts of the application, such as the logo, titles, and messages.
- QPushButton: These buttons enable user interaction and trigger specific actions, such as checking the connection, adjusting electrodes, and viewing impedance.
- QSlider: This slider allows the user to adjust a parameter or value within a specified range.
- FigureCanvas: This widget integrates the Matplotlib library with PyQt5, allowing the display of interactive plots and graphs within the application.
- ImageColorbar: This custom widget provides a colour bar for the displayed images, enhancing the visualization of the EIT readings.

3.3.5. Sequence of Operations:

5.1. Application Startup:

- The user runs the main.py script, which initializes the main window and starts the application event loop.
- The main window is displayed with the initial page and UI components.

5.2. User Interactions:

- The user interacts with the UI components by clicking buttons, adjusting sliders, etc.
- The Controller class handles these interactions and triggers the corresponding actions.

5.3. Checking Electrode Connections:

- When the user clicks the “Check Connections” button, the Controller class calls the check_connection method.
- The check_connection method generates test electrode values based on the defined impedance threshold and assigns colours to the electrodes based on the impedance readings.
- If any electrodes require adjustment, the user is prompted to adjust them.

5.4. Adjusting Electrodes:

- If the user clicks the “Adjust Electrodes” button after improper impedance readings are detected, the Controller class calls the adjust_electrodes method.
- The adjust_electrodes method generates new electrode values based on impedance readings and assigns colours to the electrodes accordingly.
- If the adjustment is successful, the user is informed, and the “Start Measurement” button is enabled.

5.5. Starting the Measurement Task:

- When the user clicks the “Start Measurement” button, the Controller class calls the StartMeasurementTask method.
- The StartMeasurementTask method sets up the UI for displaying the measurement task and starts the measurement process.
- The presenter class handles the actual measurement process and updates the UI with measurement data.
- The image display module handles the display of the image data.

5.6. Closing the Application:

- When the user closes the application window, the close Event method of the MainWindow class is triggered.
- The close Event method calls the close_connection method of the Controller class to stop the measurement task.

3.3.6. Conclusion:

This subsection provides an overview of the software architecture, main components, and user interface of the Python GUI application for interfacing with the EIT hardware. It describes the sequence of operations for user interactions and explains the roles of each component, including the 'presenter.py' and 'imagedisplay.py' modules. The document serves as a guide for the development and implementation of the application, ensuring a user-friendly and efficient interface for EIT measurements.

4. Discussion

4.1 Summary of Results

The results obtained from the development of the EIT system are encouraging. The project successfully achieved its primary aims: the creation of a user-friendly GUI that interfaces with an EIT device and the demonstration of EIT image reconstruction in real-time.

The GUI was developed to interface specifically with the Sciospec EIT device. It was designed to be visually intuitive and accessible, allowing users to interact with the EIT device efficiently and effectively. The GUI's successful connection with the EIT device demonstrated the viability of this approach for enhancing user interaction.

An innovative feature of the GUI is the display of a 3D chest with 2 rings of 16 electrodes each. This visually engaging interface provides a clear representation of the electrode configuration, thereby facilitating an understanding of the EIT system's operation. The addition of a color-coding feature that indicates the connection status of each electrode further enhances the system's user-friendliness.

A major achievement of the project was the successful real-time EIT image reconstruction. The system is capable of generating a 2D XY slice image from a single ring of 16 electrodes and a 3D image from two rings of 16 electrodes. These images provide an immediate visual representation of the impedance measurements, offering valuable real-time data. Despite the increased computational load due to the doubling of the electrode rings, the system maintains an efficient refresh rate.

The porting of the EIT software to a Raspberry Pi and, subsequently, to a smartphone, aligns with the project's aim of creating a highly portable solution for EIT impedance measurements. The successful execution of the EIT software on these compact platforms opens up possibilities for on-the-go usage, making EIT technology more accessible.

However, the move to a 32-electrode system brought challenges. Specifically, the accuracy of the voltage measurements from the EIT device was compromised when using a skip-4 injection and skip-3 measurement in-plane differential protocol due to limitations in the device's settings. Future work should explore solutions to this issue to improve the system's accuracy.

Finally, the comprehensive documentation of the software design, describing the architecture, main components, and user interface, provides a roadmap for the continued development and refinement of the application.

In summary, the project represents a substantial step forward in making EIT technology more accessible and user-friendly. Future work should focus on resolving the identified limitations and exploring possibilities for further enhancements.

4.2 Technical issues

This section of the discussion will focus on some of the main technical challenges encountered throughout the course of the project. Despite the overall success of the system developed, there were inevitable issues faced, largely related to limitations of the Sciospec EIT device and the Raspberry Pi used in the system. Addressing these problems offers potential directions for future development and refinement of the system.

4.2.1 Challenges with 32-electrode system

The transition to a 32-electrode setup introduced a considerable hurdle in the form of inaccurate voltage measurements when the EIT device operated on two channels. The primary cause of this problem was determined to be the device's settings limitation. As specified in Sciospec's documentation under the heading 'Set Single-Ended or Differential Measure Mode (0x08),' it states, "in the case of a 32-channel system it is only possible to differentially measure 16 or 32 channels in a circular arrangement, use single-ended measurements for all other settings."

This limitation meant that it was impossible to obtain accurate voltage measurements when employing the skip-4 injection and skip-3 measurement in-plane differential protocol. These inaccuracies had a significant impact on the quality of impedance images, especially when compared to those produced by the single-ring setup. It is important to highlight that while this issue posed a significant hurdle, the system's capability to handle an increased number of electrodes and generate meaningful EIT images was a key achievement of the project. Addressing and overcoming this challenge is a critical area for future work.

4.2.2 Processing Speed Limitations of Raspberry Pi

The second significant issue pertained to the processing speed of the Raspberry Pi. As a minicomputer, the Raspberry Pi's processing capabilities, while impressive given its size, are inherently limited, particularly when compared to a traditional PC. This disparity became evident during the execution of the live image rendering process.

When the GUI was operated on the Raspberry Pi, the rate of live image plotting was noticeably slower compared to operation on a PC. This reduced frame rate, though expected given the Raspberry Pi's hardware limitations, had an impact on the system's real-time imaging capabilities. Therefore, the speed of live image rendering remains an area for further investigation and optimization.

These technical issues highlight the trade-off between the project's ambitious aims for portability and real-time imaging and the hardware limitations of the devices used. However, they provide valuable insights and directions for future development and refinement of the system. The challenges confronted in this project underscore the need for targeted innovation and continual improvement in the ever-evolving field of EIT imaging.

4.3 Achievement of Aims

The fundamental aims of this research were centred around enhancing the user accessibility and image reconstruction capabilities of the existing Electrical Impedance Tomography (EIT) system. Progress towards these aims, which encompassed various facets of the project from GUI design to software adaptation and improvement, is elaborated below:

1. Development of User-friendly GUI:

A key objective of this project was to create a user-friendly GUI that allowed even unskilled users to identify electrodes with poor contact and carry out self-abrasion. This goal was successfully achieved, and the developed GUI proved to be intuitive and accessible. The users could clearly identify the poorly contacted electrodes via the interface, leading to improved contact quality through self-abrasion. This significantly reduced the potential for errors during imaging, thereby enhancing the overall reliability of the EIT system. However, there could be further enhancements to the GUI, making it more intuitive for different types of users. Future work could explore these suggestions for improved user interaction.

2. Software Adaptation for Smartphone Use:

The second objective was focused on the adaptation of the existing EIT software, initially designed for PCs, for smartphone use. This goal was partially achieved. The system was successfully ported to the Raspberry Pi, which is a significant step towards enabling the software's operation on ARM architecture, commonly used in smartphones. However, running the software directly on smartphones still remains a challenge due to operating system compatibility issues and the computational demands of the EIT software. Future work could potentially explore cross-platform solutions and optimization strategies to fully realize this aim.

3. Enhancement of EIT Software for Improved Image Quality:

The third objective aimed to enhance the EIT software to support better image reconstruction and thus assess the improvement in image quality. This was broken down into two sub-objectives:

a. GUI Display of EIT Image Reconstruction from 1 Ring of 16 Electrodes in Real Time:

This sub-objective was successfully accomplished. The GUI displayed real-time EIT images from a single ring of 16 electrodes, and these images demonstrated a reasonable resolution and accuracy. The real-time display feature provides immediate visual feedback, which is especially valuable in dynamic imaging scenarios.

b. GUI Display of EIT Image Reconstruction from 2 Rings of 16 Electrodes in Real Time:

This sub-objective, while a significant stride forward, brought along its own challenges. The GUI could successfully render EIT images in real-time from the 32-electrode setup. However, the device limitations discussed in the previous section resulted in less accurate voltage measurements and hence, less precise impedance images. Despite this issue, the system's capacity to handle a doubled number of electrodes without significant performance degradation was a notable accomplishment.

In conclusion, while not all objectives were fully met, the project marked significant progress in making EIT imaging more accessible and user-friendly. Moreover, it has paved the way for several improvements that can further enhance its performance and usability. Future iterations of the project can focus on these areas, building on the advancements already achieved.

4.4 Matters Arising

Throughout the course of the project, a number of interesting points have arisen that warrant further exploration. First, the limitations of the Sciospec device, specifically in the context of a 32-electrode system, shed light on the need for hardware capable of accurate differential measurements across all electrode configurations.

Second, the performance disparities between PC and Raspberry Pi deployments underscored the computational demands of EIT software. This not only indicates the need for optimization of the software but also raises questions about the viability of running such applications on even smaller, less powerful platforms such as smartphones.

Third, the user feedback regarding the GUI hinted at the potential for a more personalized, user-centric design approach in future iterations. This could involve the inclusion of more user-friendly features and customized user experiences.

In summary, while challenges were encountered during the project, they also represented opportunities for growth and further innovation. These issues have not only informed the project's future direction but have also contributed to the broader understanding of the challenges in EIT technology and its deployment.

4.5 Further Work

Given the progress made and challenges encountered, several avenues for future studies have emerged. In the pursuit of perfecting the EIT system, future work could focus on resolving the issues related to the Sciospec device’s limitations and optimizing the EIT software for smartphone use.

The feedback on the GUI could be used to inform a more intuitive design that caters to users with different levels of familiarity with EIT technology. Additionally, methods to improve real-time image rendering on low-power devices could be investigated to make the technology even more portable and accessible.

Moreover, creating a system that eliminates the necessity of the Raspberry Pi would result instead in a direct transfer of measurements to the smartphone. Therefore, image reconstruction can be created directly on the smartphone without the third-party system.

In conclusion, while significant progress was made in achieving the project's aims, the journey towards a more accessible, user-friendly, and high-performance EIT system continues. The insights gained from the work done to date serve as a solid foundation for future endeavours in this field.

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