Design of electrical impedance tomography for biomedicine

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Abstract. Electrical Impedance Tomography (EIT) has an advantage than another imaging systems in the medical field, they are safe, fast, and simple. The role of EIT is promising, so that it is necessary to develop electrical impedance tomography devices, especially in the biomedical field. we have successfully constructed a multi-frequency EIT system for biomedicine consisting of an oscillator, buffer, VCCS (voltage controlled current source), mux-demux, differential amplifiers based on Arduino Mega. The system successfully has been tested to produce an image of conductors, insulators, and animal organs so that suitable for biomedical field.

1. Introduction

The electrical properties are interesting objects properties in the medical field because each tissue has a different one [1]. In the 1990s, electric tomography known as Electrical Impedance Tomography (EIT) was developed. EIT is a technique for imaging the resistivity or conductivity distribution based on the injection of current and the potential difference measurement in the boundary.

The limitation of this system is the low spatial resolution of the image reconstructed. The second disadvantage is that the injected current diffuses in all directions so that the potential data obtained in the boundary plane is less sensitive or known as ill-pose conditions. The third weakness is the high noise of the measured data caused the signal cable, electrodes, and object movement [2]. Although the EIT system has many limitations, this system has several advantages compared to another systems, namely, it is safer because it does not use ionizing or electromagnetic radiation so that it can be used in real-time for monitoring. Another advantage is cheap because the device is very simple.

EIT can be applied in the medical field, including the monitoring of intracranial hemorrhages or hematomas [3], cancer detection [4], study of pelvic fluid accumulation [5], pulmonary ventilation analysis [6], blood pressure measurement [7], lung imaging [8], Hyperthermia Treatment [9], Pediatric Lung Disease [10], Breast Imaging [11, 12], Brain Imaging [13]. Several researchers developed EIT devices including a telemedicine system based on the fast and portable EIT [14]. Alzbeta Elizabeth Hartinger et.al developed EIT based system with a handheld probe comprising 16 disposable semi-invasive electrodes for the early diagnosis of skin cancer [15], and Tushar Kanti Bera et.al designed a
multifrequency EIT system for biomedical imaging [16]. The variety and importance of the EIT for biomedicine, that it is necessary to develop EIT, especially in the biomedical field.

2. Method
This study develops an EIT for biomedicine. The research begins the design and performance test of modules. The modules are integrated and synchronized into the EIT system. The test is carried out per module and the whole. Synchronization and integration are conducted to hardware and software into a single system. Data collection is an experimental step to test the performance of the EIT system.

Figure 1 shows a diagram of an EIT data acquisition system. This system consists of an oscillator, buffer, and voltage-controlled current source (VCCS), multiplexer-demultiplexer, differential amplifier, and microcontroller. The oscillator (AD 8950 module) generates a signal with an adjustable frequency. The signal is input to VCCS as the current source in the EIT system.

![Figure 1. Diagram of electrical impedance tomography developed System.](image)

The position of the voltage electrode measured is adjusted by a multiplexer, while the current injection is adjusted by demultiplexer. This research develops VCCS, electric current injection mechanism, and voltage measurement and uses linear methods from EIDORS to reconstruct it.

2.1. **VCCS (Voltage Controlled Current Source)**
The signal generated by the oscillator is passed through the buffer and VCCS to produce a current. Figure 2 is a schematic of the AD 8950 module, high passed filter, amplifier, and buffer. The function of the amplifier is to amplify the signal generated by the AD 8950 module. The gain will affect the current that will be generated by VCCS. The VCCS was tested by loads $R_L = 1, 2,$ and $3 \, \text{k}\Omega$. Characterization of VCCS is related to the stability of the current against frequency and load.

![Figure 2. Schematic of voltage controlled current source.](image)
2.2. **Mechanism of Current Injection and Voltage Measurement**

This study used 16 electrodes, namely electrodes E1, E2, ..., E16. This process starts from the injection of the current through the adjacent electrodes, namely E1 (signal) and E2 (ground) while measuring the voltage at the adjacent electrode pairs, namely (E2 – E3, E3 – E4, ..., E16 – E1), and so on.

### 2.2.1. **Mechanism of Current Injection**

The process of current injection is conducted by an electric mechanism. The mechanism of electrode selection for injecting current uses an IC4052 demultiplexer and two IC 4051 multiplexers. The same mechanism is also used for electrode selection for measuring the potential difference with two IC 4051 demultiplexers. The schematic of the designed electrical mechanism is shown in Figure 3.

**Figure 3.** The selection mechanism of the current injection electrode and voltage measuring electrode selection.

For technical reasons, the process of the current injection and voltage measurement is divided into two mechanisms. The first mechanism is the odd electrode as a signal and the even electrode is the ground and the second mechanism is the odd electrode as ground and the odd electrode is the signal.

The mechanism is the injection of an adjacent current, namely E1 (signal) and E2 (ground), the voltage measurement is carried out on the adjacent electrode pairs, namely (E2 – E3, E3 – E4, ..., E16 – E1) and so on. The electric current starts from the signal generator connected to 4052 via x1 and exits through Z1. The mechanism of x1 and Z1 relationship is controlled by CS (INH = 0 B0 = 0 and A0 = 1). Z1 is connected to the Y input by IC I 4051 and through the outputs (X1, ..., X8). It is connected to the electrodes of current injections into the object alternately and sequentially (E1, E3, ..., E15) and pair with electrodes (E2, E4, ..., E14, E16) to ground via demultiplexer IC 4051 (X1, ..., X8) as input and Y as output. The setting mechanism on IC 4051 through CS (A1, B1 C1) while IC 4051 through CS (A2, B2 C2). The Y pin of IC II 4051 connected to Z2 IC 4052 as an input connected to the y1 output, then this current through the resistor is connected to the ground.

### 2.2.2. **Mechanism of Voltage Measurement**

The process of measuring the voltage is conducted using an electrical mechanism on the side voltage section. The electrode of voltage measurements are connected to the buffer before connecting to the multiplexer. The odd electrodes (E1, E3, ..., E13, E15) are connected to the buffer before connecting the multiplexer IC III 4051 in a row at the input (X1, ..., X8). The even electrodes (E2, E4, ..., E14, E16) are connected to the buffer before connecting the multiplexer IC IV 4051 in a row at the input (X1, ..., X8).

Voltage measurement is performed after current injection. The selection of odd electrode is controlled by IC III 4051 through CS (A3, B3, C3), while the selection of even electrode is controlled by IC IV 4051 through CS (A4, B4, C4). The output pin Y IC III 4051 and Y IC IV 4051 connected to a differential amplifier. The output of differential amplifier will produce a voltage between the two
electrodes. The voltage signal from the differential amplifier cannot be read directly by the microcontroller. Therefore we need an RMS to DC, namely AD 536A.

2.3. Reconstruction

The linearization method assumes that the change in boundary potential is a linear function of changes in conductivity, it can be written in matrix form in equation (1).

\[ \delta V = [S][\delta \rho] \] (1)

Where \( \delta V \) is the change in boundary potential, \( [S] \) is the sensitivity matrix, and \( [\delta \rho] \) is the change in resistivity. Equation (1) can be solved after the matrix \( [S] \) is found. However, the matrix \( [S] \) is not square, \( [\delta \rho] \) cannot be obtained directly so that equation (1) must be multiplied by the transpose \( [S] \). Generally \( [S]^T[S] \) is singular matrix so that it don't have invers. To solve this problem, the Tikonov regulation can be used so that the matrix has an inverse as shown in equation (2). where \( \alpha \) is regularisation parameter and \( I \) is identity matrix.

\[ [\delta \rho] = ([S]^T[S] + \alpha I)^{-1}[S]^T[\delta V] \] (2)

3. Result and Discussion

The important parameters in this study are the stability of the VCCS and the accuracy of the measured voltage between the electrodes. The result of the EIT system as a whole is greatly influenced by the performance of all the equipment.

3.1. VCCS (Voltage Controlled Current Source)

The VCCS performance can be seen from the current stability. This VCCS can produce a constant electric current of 1 mA. VCCS can produce stable currents up to a frequency of 150 kHz at 1 kΩ loads, up to 100 kHz for 2 kΩ loads, and up to 80 kHz for 3 kΩ loads. The effect of 1-3 kΩ loads on the stability of the frequency current from 10 to 100 kHz. Frequencies of 10 to 100 kHz are used for medical applications. For example, suppose for the detection of the breast cancer. This is based on electrical conductivity tissue characteristics. The conductivity or impedance of normal tissue and breast tumours significantly changes at a frequency of 10 kHz against 100 kHz, while the normal tissue conductivity is constant at these frequencies [17].

3.2. Measurement of voltage

Potential measurement is done by AD536A which can convert Vrms to DC. The test of linearity Vrms to DC to ensure the accuracy of the voltage measurement. Linearity is observed at input voltages of 10, 20, 50, 100 mV, and output at frequencies of 10 Hz to 100 kHz.

3.3. Scanning and image reconstruction

The process of scanning an electric potential carried out on adjacent electrode pairs is known as the neighboring method. The scanning process is carried out on all electrodes attached to the surface of the object. The object used is a phantom consisting of Metal - Aluminum (conductor), Metal - Aluminum (conductor) + Rubber (insulator), Kidneys - Goats, and Lungs - Goats + goat's heart as shown in Figure 4.

![Figure 4](a) (b) (c) (d)

Figure 4. A circular phantom is made of PVC material filled distilled water and (a) placed metal, (b) metal-rubber, (c) goat’s kidneys, and (d) goat's heart-lungs.
This scanning uses an electrical current of 50 kHz. The data obtained from the EIT system is electrical potential. The relationship between the potential data and the position of the electrode is shown in Figure 5.

![Figure 5. An electrical potential data from scanning by the neighbouring method.](image)

The reconstruction image is obtained by reconstructing the four data. This reconstruction process uses a linear or filtered back-projection method. The four reconstructed images are the impedance images shown in Figure 6.

![Figure 6. Image reconstruction (a) metal conductor (b) metal conductor-rubber isolator (c) goat kidney (d) goat lung – heart.](image)

4. Conclusion
The EIT for biomedicine has been successfully developed consisting of an oscillator, buffer, and VCCS, multiplexer, phantom, buffer, demultiplexer, Arduino Mega-based differential amplifier. The scanning process data is then reconstructed using the linear method so that it produces a reconstruction image from the phantom of the distilled water from the objects of the conductor (metal), isolators (rubber), and animal organs (kidneys, lungs, and heart).

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References
[1] Cheney M and Isaacson D and Newell J C 1999 Electrical Impedance Tomography *SIAM*, *41* 85–101
[2] Dai T and Adler A 2008 Electrical Impedance Tomography Reconstruction Using l1 Norms for Data and Image Terms *30th Annual International IEEE EMBS Conference*
[3] Ayati S B Bouzaazza-Marouf K and Kerr D 2015 In vitro localisation of intracranial haematoma using electrical impedance tomography semi-array Medical engineering & physics 37(1) 34–41
[4] Gao J, Yue S, Chen J and Wang H 2014 Classification of normal and cancerous lung tissues by electrical impedance tomography Bio-medical materials and engineering 24(6) 2229–2241
[5] Li R, Gao J, Li Y, Wu J, Zhao Z and Liu Y 2016 Preliminary study of assessing bladder urinary volume using electrical impedance tomography Journal of Medical and Biological Engineering 36(1) 71–79
[6] Bordes J, Goutorbe P, Cungi P J, Boghossian M C and Kaiser E 2016 Noninvasive ventilation during spontaneous breathing anesthesia: an observational study using electrical impedance tomography Journal of Clinical Anesthesia 34 420–426
[7] Proenca M, Braun F, Sola J, Thiran J P and Lemay M 2016 Noninvasive pulmonary artery pressure monitoring by EIT: a model-based feasibility study Medical & Biological Engineering & Computing 1–15
[8] Adler A, Berthiaume Y, Guardo R and Amyot R 1995 Imaging of pulmonary edema with electrical impedance tomography In Engineering in Medicine and Biology Society IEEE 17th Annual Conference 1 557-558
[9] Conway J 1987 Electrical impedance tomography for thermal monitoring of hyperthermia treatment: an assessment using in vitro and in vivo measurements Clin. Phys, Physiol. Meas., 8, Suppl. A 141-6
[10] Pham T M T, Yuill M, Dakin C and Schibler A 2011 Regional ventilation distribution in the first 6 months of life European Respiratory Journal (ERJ) 1(37) 919-924
[11] Zain N M and Chelliah K K 2014 Breast imaging using electrical impedance tomography: correlation of quantitative assessment with visual interpretation Asian Pacific Journal of Cancer Prevention 15 (3) 1327-1331
[12] Ain K, Kurniadi D, Suprijanto, Santos O 2020 Dual Modality Tran-Admittance Mammography and Ultrasound Reflection to Improve Accuracy of Breast Cancer Detection Jurnal Teknologi 82(4) 117-124
[13] Holder D S, Rao A and Hanquan Y 1996 Imaging of physiologically evoked responses by electrical impedance tomography with cortical electrodes in the anaesthetized rabbit Physiol. Meas. 17 pp A179–A186
[14] Zhou Z, Nan L, Hui X, Jin G, Zhaolin S, Haijun L and Hongqi Y 2012 The Design and Implementation of a Portable EIT Telemedicine System International Conference on Intelligent System Design and Engineering Application IEEE 571-575
[15] Hartinger A E and Gagnon H 2012 EIT System and Reconstruction algorithm adapted for Skin Cancer Imaging The 11th International Conference on Information Sciences, Signal Processing and their Applications 798-803
[16] Bera T K and Nagaraju J 2012 Multifrequency Electrical Impedance Tomography (EIT) System for Biomedical Imaging IEEE
[17] Qiao G, Wang W, Wang L, He Y, Bramer B and Al-Akaidi M 2007 Investigation of biological Phantom for 2D and 3D Breast EIT images IMBE proceding 17 328-331