Analysis of Electrode Materials for Medical Images by Electrical Impedance Tomography

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Abstract
Electrode material plays an important role in the Electrical Impedance Tomography (EIT) applications. In this study Copper and Aluminium materials were tested for their capabilities as the electrode material for the EIT studies. The analysis of the mono-polar voltages show that the Copper has better electrical conductivity compared to Aluminium. Also, the dispersion or variation in the voltage values of copper was found to be low in comparison with Aluminium hence making it as an alternate electrode material for the EIT studies next to silver/silver chloride material.

Keywords: Medical Imaging, Electrical Impedance Tomography, Electrode Material, Copper, Aluminium, Conductivity, Voltage, Standard Deviation.

Introduction

Electrical Impedance Tomography (EIT) is a non-invasive medical imaging technique. It reconstructs two dimensional (2D) images based on variation of resistance or conductance within the test object through an array of electrodes using Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software (EIDORS) [1]. Electrodes are the sensors used for measuring 2D electrical field within the test object in EIT applications. Earlier studies showed that a wet, non-polarizable, circular, silver electrode was suitable for the EIT studies. However, the cost of the silver electrodes would limit its wide usage for EIT applications. Hence, this paper analyzes other possible electrode materials like Copper and Aluminium for their suitability as electrode materials.

Literature Review

The spatial resolution of the reconstructed EIT images also depends on the electrode material. The EIT electrodes must have minimum contact impedance and maximum contact stability. The five performance parameters to be considered for the EIT electrodes are discussed in the following paragraphs:

Electrode material

Electrode material can be of two types. Wet type that uses the conductive gel between the electrode and the testing area. This helps the electrodes to conduct better current flow. The other type is the dry type without any conductive gel. EIT measurements often involve wet type electrodes than dry type electrodes [2]. These act as polarized electrodes reducing the capacitive effects. Material examples include, Platinum and Gold. On the other hand, the non-polarizable electrodes are characterized by their free flow of current when a voltage is applied across them. For example, Aluminum/Aluminum Chloride wet type electrode is mostly used as EIT electrode material. The non-polarized electrodes are extremely stable and has less noise compared to the polarized electrodes. Carbon electrodes were introduced for users comfort as compared to a wet electrode but caused artefacts [3]. Likewise, a flexible belt using nano-fiber electrodes was designed to provide lower contact impedance during the measurement process. However, the prototype had unwieldy wires and hence the system was large and inconvenient [1].

Electrode configuration
There are two types of electrode configurations, mono-polar and bi-polar. The mono-polar electrode configuration measures the voltages from individual electrodes with respect to ground. However, the bi-polar electrode configuration measures the differential voltage considering a pair of electrodes.

Electrode dimensions
Mostly circular and rectangular shaped electrodes are used in EIT systems. Larger electrode area is considered for the current injection and smaller electrode area is considered for the voltage measurements [4]. It was observed that the circular electrodes assist to minimize the contact impedances but not at the peripherals. This does not improve the resolution of the image and further deteriorates with the decrease in the current supply [1].

Electrode number
It is a myth that increasing the electrode number in EIT increases the image resolution. However, there is a limit in increasing the electrode number beyond which the resolution of the image does not improve further. In fact, as the electrode numbers increase, the EIT hardware becomes more complicated in terms of connections and would also increase the processing time. Usually, the number of electrodes in EIT system are multiples of 8 (8, 16, 32, … so on). The effect of number of electrodes on the quality of the reconstructed image was evaluated by considering the differences in several aspects for instance, conductivity, conductivity distribution, measurement strategies and meshes. Different numbers of electrodes, i.e. 8, 12, 16, 20, 24, 32, 36, 40 and 48 were used for evaluation. Results of comparative studies were explained by application of Singular Value Decomposition (SVD) in the spectral analysis. This was carried out by comparing the magnitudes of singular values for the models with different number of electrodes for different measurement strategies. From the simulation results and SVD analysis, it was deduced that the best image reconstruction for the models with fine meshes (60 x 60 grids) in the inverse problem solver was obtained with 32 electrodes [5].

Inter electrode distance
The distance between the mid points of any consecutive electrodes is called as inter electrode distance (IED) and should not be more than 20 mm for EIT studies [2]. Also, an electrode belt was designed with two bands, viz inner band and outer band with elastic sponges placed between the electrodes. The inner band contained 16 uniformly spaced embossed electrodes with an IED of 30 mm [3].

Methodology
A circular tank made of non-conductive plastic material having a diameter of 55 mm was chosen for the intended study. Copper and Aluminium were selected as the electrode materials. Each of them was cut to round shape of 5 mm diameter. An IED of 20 mm was followed during their assembly on the test tank and were at 45 degrees from one to another.
A voltage-controlled oscillator (VCO) generating an alternating voltage of 1 V_{PP} at 100 kHz was designed using IC AD9850. A voltage controlled current source (VCCS) converted this signal into a current of 1 mA considering a load of 1 KΩ. This current was then injected to a pair of electrodes using adjacent, opposite and cross methods [6] as shown in Plate 1. The adjacent method also known as the neighboring method was proposed as the best excitation method for circular test objects [7], for a single current source [8], for static images [9] and for the boundary measurements [10].

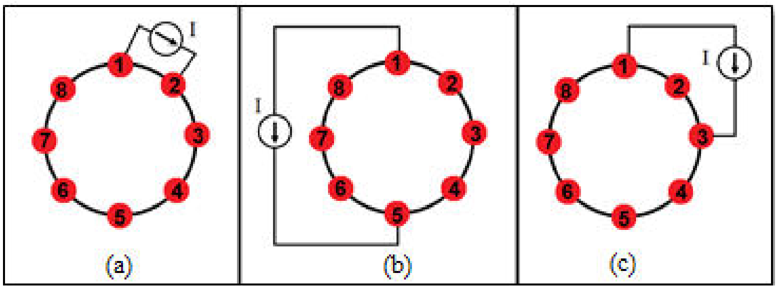

Plate 1: (a) Neighboring (b) Opposite (c) Cross methods of Current Injection

The mono-polar voltages were finally measured from the remaining non-current carrying electrodes. The voltages of the current carrying electrodes are not measured due to a large voltage drop across them. Later all the measured voltages are summed up for better readings [11]. A LabVIEW program was developed for shifting the currents according to a sequence using multiplexer circuit. The entire experimental set up is shown in Plate 2.

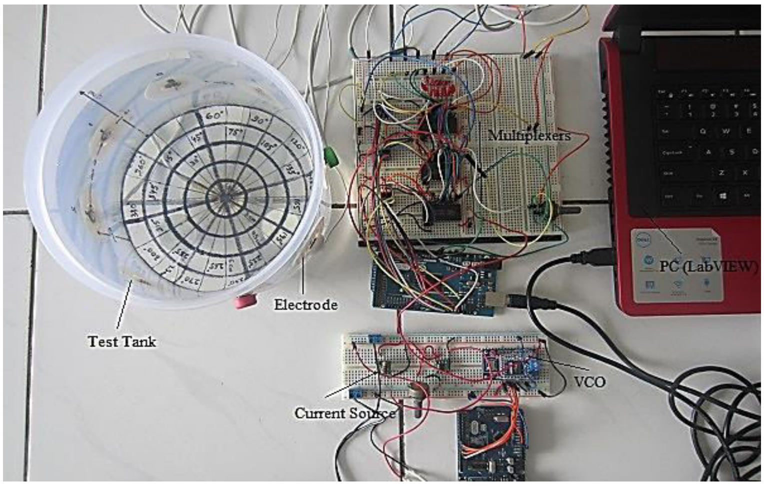

Plate 2: Complete experimental set up

The switching order of the multiplexers for the three different methods is according to [12]. Each electrode would get eight analog voltage readings for each cycle. However, two of these readings were zero, because each electrode injects current once, and once will be grounded. A VI was developed to get the sum of the eight readings from each electrode.

Results and discussion

The mono-polar voltages are tabulated for the three different methods of current injection. The measurements were carried out three times for each excitation pattern. The mono-polar voltages acquired by the neighboring, opposite and cross methods for copper electrode are shown in Table 1, Table 2 and Table 3 respectively.

Table 1: Measured voltages by the neighboring method for Copper Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	0.7	1.5	1.5	0.4	0.4	0.7	0.7	0.6
2	0.6	1.0	1.5	0.4	0.4	0.6	0.6	0.6
3	0.7	1.4	1.5	0.4	0.4	0.7	0.7	0.7
Avg	0.7	1.3	1.5	0.4	0.4	0.7	0.7	0.6

Table 2: Measured voltages by the opposite method for Copper Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5
2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
3	0.7	1.5	1.6	0.4	0.5	0.7	0.7	0.7
Avg	0.6	0.9	0.9	0.5	0.6	0.6	0.6	0.6

Table 3: Measured voltages by the cross method for Copper Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	1.75	1.79	1.64	1.52	1.46	1.33	1.09	1.72
2	0.85	1.47	1.41	1.16	1.48	1.15	1.6	1.68
3	0.77	0.73	0.72	0.71	0.74	0.76	0.74	0.74
Avg	1.12	1.33	1.26	1.13	1.23	1.08	1.14	1.38

The mono-polar voltages acquired by the neighboring, opposite and cross methods for Aluminium electrode are shown in

Table 4, Table 5 and Table 6 respectively

Table 4: Measured voltages by the neighboring method for Aluminium Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	0.7	0.46	0.74	0.36	1.84	0.3	0.28	1.04
2	0.71	0.45	0.83	0.63	1.45	0.55	0.64	0.27
3	0.76	0.46	1.3	0.63	1.78	0.46	0.33	0.74
Avg	0.72	0.46	0.96	0.54	1.69	0.44	0.42	0.68

Table 5: Measured voltages by the opposite method for Aluminium Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	4.07	4.33	4.04	4.24	2.42	0.73	4.47	4.14
2	0.92	2.1	0.24	2.31	4.01	4.06	4.2	0.4
3	4.43	2.68	0.66	1.74	2.25	4.32	4.32	0.96
Avg	3.14	3.04	1.65	2.76	2.89	3.04	4.33	1.83

Table 6: Measured voltages by the cross method for Aluminium Electrode

Test No	Mono-Polar Measured Voltage (V)							
	1	2	3	4	5	6	7	8
1	4.39	0.72	0.04	1.11	0.52	0.39	0.5	0.63
2	4.44	0.58	1.07	4	0.54	0.65	0.57	0.64
3	3.31	1.09	0.34	0.8	4.28	3.48	0.5	1.58
Avg	4.05	0.8	0.48	1.97	1.78	1.51	0.52	0.95

The amount of variation or dispersion of a set of data values was calculated by the standard deviation (σ) for the three methods. The standard deviation for copper electrode for the neighboring, opposite and cross methods was 0.399, 0.157 and 0.109 respectively. On the other hand, the standard deviation for Aluminium electrode for the neighboring, opposite and cross methods was 0.425, 0.831 and 1.170 respectively.
The average output voltages of Copper and Aluminium electrode are plotted for the three different methods of current injection i.e. the neighboring, opposite and cross methods as shown in Plate 3 and Plate 4 respectively.

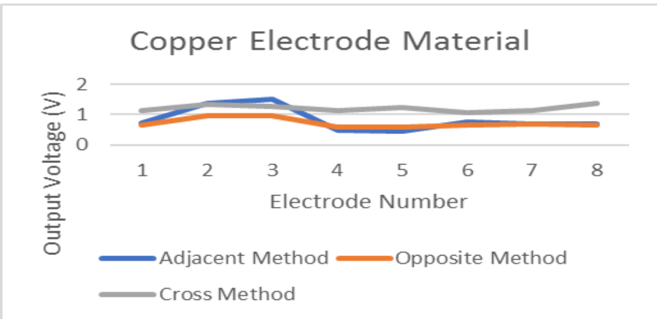

Plate 3: Output Voltage Graphs for the Copper Electrode

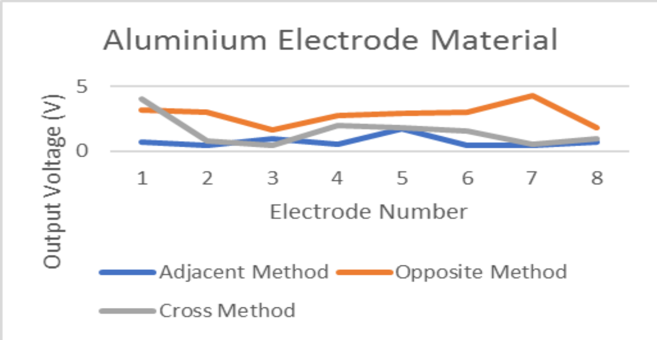

Plate 4: Output Voltage Graphs for the Aluminium Electrode

The calculated standard deviation values are summarized in Table 7.

Table 7: Standard deviation of the three excitation methods

Method	**Copper**	**Aluminium**
Neighboring	0.399	0.425
Opposite	0.157	0.831
Cross	0.109	1.170

In case of copper electrode, the Cross method has the lowest dispersion or variation in the mono-polar voltage values and is suggested as the most suitable excitation method for the EIT applications. Whereas, in case of Aluminium electrodes, the neighboring method has the lowest dispersion or variation in the mono-polar voltage values and is still suggested as the most suitable excitation method for the EIT applications.

Conclusion

Overall, Copper electrode has the lowest dispersion or variation in the mono-polar voltage values in comparison with Aluminium electrode for the EIT studies. The cross method of excitation shows more stabilized mono polar voltage readings, compared with the neighboring and opposite methods, as the standard deviation of the adjacent method is less than that of the opposite and cross methods. Hence, Copper could be a good alternative as the electrode material for the EIT applications and because it is economical and easily available.

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