Two-dimensional electrical impedance tomography (EIT) for characterization of body tissue using a gauss-newton algorithm

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Abstract. The gauss-newton algorithm is applied to reconstruct a two-dimensional image of Electrical Impedance Tomography (EIT) using python program. The study aimed to determine the characteristics of body tissues either conductive or resistive properties through the tissue structure which is displayed in the form of images so we can distinguish between one tissue and another. In this study, it was a fabricated hardware system, phantom, and software system. The EIT technique is performed by injecting a low constant electric current of 1 mA at 50 kHz frequency on a pair of electrodes on 16 copper electrodes (Cu) surrounding a phantom filled with ground meat as conductor of electricity, flat bone, and cord bone of chicken as anomalies. The principle of the neighboring method achieved voltage measurements from the other electrode pair. The measurement data is processed with the python program using gauss-newton algorithm to obtain a reconstructed image of the tissue structure. The characteristics of body tissue can be identified from the color distribution, position, shape, and size of the object in the reconstructed image so it can distinguish between one tissue and another. The original analysis of body tissue either conductive or resistive properties could be reconstructed by two-dimensional electrical impedance tomography conjunction with the gauss-newton algorithm.

1. Introduction

The technique of disease diagnosis is one of the technologies being developed in the health field recently. One of these is the technique of imaging or also called tomography. Tomography is a technique done by studying the network structure of living things in the form of images. There is a wide variety of tomography including CT Scan and MRI (Magnetic Resonance Imaging). Both of these techniques have weaknesses that are expensive cost, especially CT Scan has side effect of damaging the tissue due to radiation exposure is given, so it is necessary to develop a method that does not destroy objects that are imaged, not painful (non-invasive), rapid response, and low cost in manufacturing, one of which is Electrical Impedance Tomography (EIT) [1-5].

Electrical Impedance Tomography (EIT) is imaging techniques that can detect the existence of an object/material by measuring the electrical value of the material. Measurements are made using electrodes that have been connected onto the surface of the imaged material [2]. The basic principle of EIT is to see the difference in the electrical characteristics of each material. Differences in the value of these characteristics can be used to distinguish or detect the presence of abnormalities in a medium [3-5]. EIT was performed by injecting a low electrical current into an object that has been surrounded by surrounding electrodes. Measured voltage can be determined from the pair electrodes in the position
that defined before so that can be used to determine distributions of the conductivity and resistivity on the material object then displayed in the reconstructed image using inverse method [4-5]. In the present study, we used the gauss-newton algorithm to produce smooth images with good conductivity patterns regarding shape, size, and position of objects [5].

The human body may be analogous as a resistive, piecewise homogeneous, and linear volume conductor. Some components of the human body have a different tissue resistivity value. Blood has a resistivity value 1.6 $\Omega \cdot m$, the heart has 2.5 $\Omega \cdot m$, lungs have 20 $\Omega \cdot m$, fat has 25 $\Omega \cdot m$, and bone has a resistivity value 177 $\Omega \cdot m$. The resistivity of blood depends strongly on hematocrit (Hct) which denotes the percent volume of the red blood cells in whole blood [6].

In the present study, the conductivity and resistivity distributions on the tissue will be investigated using two-dimensional electrical impedance tomography to distinguish between one another.

2. Method

The hardware system that consists of a current generator circuit, a voltage measuring circuit, and the measured data display as shown in Figure 1.

![Figure 1. Hardware system fabrication and the process of EIT.](image)

The EIT technique is performed by injecting a low constant electrical current of 1 mA at 50 kHz frequency on a pair of electrodes on 16 copper electrodes (Cu) of the phantom. Phantom is an object container that used to determine the distribution of resistivity and conductivity during this study. We made a phantom from PVC pipe surrounded by 16 copper electrodes (Cu). There are two states when data collection that is a homogeneous and inhomogeneous state (Figure 2). Homogeneous state when
phantom is filled with ground meat or minced meat of chicken. The process describes the normal state of an object without anomalies. Minced meat was chosen because of its reasonable ability to conduct electricity. Inhomogeneous state when phantom is filled with minced meat, flat bone, and cord bone of chicken as an anomaly. The process describes the unnormal state of an object with anomalies. Voltage measurements from the other electrode pair were achieved by the principle of the neighboring method [7].

The current is injected into a pair of electrodes using the neighboring method that produced 13 pieces of voltage data measured between pairs of other electrodes. However, no voltage is measured between the electrodes where the current is injected. This step is repeated up to 16 times until data of 208 voltage data is obtained [7].

The current is injected into pairs of electrodes number 1 and 2. Subsequently, the voltage is measured between the electrode pairs 3 and 4, 4 and 5, 5 and 6, and so on until the electrode pairs 15 and 16 as shown in Figure 3. The voltage is not measured between pairs of electrodes 16 and 1, 1 and 2, and 2 and 3 because the electrodes number 1 and 2 are places where the current is injected. The same step is repeated where the current is injected into the pair of electrodes next to them, number 2 and 3. Subsequently, the voltage is measured between electrode pairs 4 and 5, 5 and 6, 6 and 7, and so on until the electrode pairs 16 and 1 Exceptions are pairs of electrodes 1 and 2, 2 and 3, 3 and 4. This process is repeated 16 times so that it got $13 \times 16 = 208$ voltage data. Furthermore, all data used as input for image reconstruction in determining object inside the phantom based on a distribution of their conductivity.

All voltage data that measured from phantom is called the forward Process whereas to calculate the conductivity distribution of the medium displayed in the form of image based on the voltage data obtained. It is called Inverse Process. By using voltage data, the tomogram or image of the impedance tomography which is a vector from all pixels can be calculated using equation as follows [8]:

$$Z_n = B \cdot v_n$$  \hspace{1cm} (1)

Where $B$ is the reconstruction matrix or algorithm to convert voltage data into conductivity distribution. The voltage data resulting from a homogeneous state is called the reference voltage ($v_{ref}$) while the voltage data resulting from the inhomogeneous state is called relative voltage ($v_n$). The calculation of the difference in two state data is:

$$\Delta v_n(i) = \frac{v_n(i) - v_{ref}(i)}{v_{ref}(i)}$$  \hspace{1cm} (2)

So that the relative impedance of is generated [8]:

$$\Delta Z_n = B \cdot \Delta v_n$$  \hspace{1cm} (3)

Gauss-Newton linear one-step reconstruction matrix is defined [9]:

$$B = (J^T W J + \lambda^2 R)^{-1} J^T W$$  \hspace{1cm} (4)
Where $J$ is a Jacobian matrix, $J^T$ is the transpose of Jacobian matrix, $W$ is the weight of matrix, $\lambda$ is hyperparameter value, and $R$ is regularization matrix [9]. After that, we get the impedance tomography which describes conductivity and resistivity distribution that displayed in the form of a reconstructed image.

### 3. Results and discussion

The reconstructed images display the conductivity and resistivity distribution of the tissue structure. The conductivity value of flat bone is lower than cord bone because the flat bone resistivity value is high, respectively. The conductivity value of cord bone is high which the bone is still attached muscle, fat, and blood. Ground meat or minced meat consists of fat, muscle, and body fluids has a high conductivity value so that it can conduct electricity well.

The conductivity and resistivity distribution of the tissue structure can be identified from the color of the reconstructed image as summarised in Table 1.

**Table 1.** The results of image reconstruction

| No | Object | Reconstructed image |
|----|--------|---------------------|
| 1- | ![Object 1](image1.png) | ![Reconstructed Image 1](image2.png) |
| 2- | ![Object 2](image1.png) | ![Reconstructed Image 2](image2.png) |
| 3- | ![Object 3](image1.png) | ![Reconstructed Image 3](image2.png) |
The color of the flat bone image (number 1 and 2) is light blue on the bottom position of the color bar scale, while the color of the cord bone image (number 3 and 4) is light red until dark red on the top position of the color bar scale. Color in the top position of the color bar scale indicates the conductivity distribution of the tissue. Instead, color in the bottom position of the color bar scale indicates the resistivity distribution of the tissue. The anomaly size of light blue color spread on the image number 2 is longer than the image number 1 because the flat bone shape on number 2 is longer than number 1. The anomaly size of red color spread on the image number 4 (dark red) is more significant than the image number 3 (light red) even though the object is the only one because the longer the experiment time the meat gets rotten causing noise on the edge of the phantom. However, the position of an anomaly on the all of reconstructed images is almost the same.

Although there is a little noise on the edge of the phantom in the reconstructed image, we can still find out the characteristics of each tissue from the color distribution of a reconstructed image such as flat bones has resistive properties while the cord bone has conductive properties. Gauss-Newton algorithm is quite helpful in producing smooth reconstructed images regarding shape, size, and position of tissues.

4. Conclusion
The original analysis of body tissue either conductive or resistive properties could be reconstructed by two-dimensional electrical impedance tomography conjunction with the gauss-newton algorithm. The characteristics of body tissue can be identified from the color distribution, position, shape, and size of the object in the reconstructed image so it can distinguish between one tissue and another.

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