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Experimental study of one step linear Gauss-Newton algorithm for improving the quality of image reconstruction in high-speed Electrical Impedance Tomography (EIT)

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Abstract.

One step linear Gauss-Newton was well known as one of image reconstruction algorithm in Electrical Impedance Tomography (EIT). In the present study, we proposed the mathematical model of one step linear Gauss-Newton for processing the experimental data for achieving the best image reconstruction. Two ways were conducted to solve this study. The first one, we build EIT hardware that mainly controlled by Single Board Computer (SBC) to produce a constant current at 1 mA 20 kHz that will be injected to the 16 electrodes of the practical phantom with speed of 1 ms/data for acquiring the data of voltage boundary from that practical phantom when using aluminium as anomaly.

The second one, we processed the data of voltage boundary using one-step linear Gauss-Newton to achieve the best image reconstruction with modified the exponent (p) of Regularization matrix that varied at 0 ? 1 by the increment of 0.1 and hyperparameter value (?). The result showed that the best image reconstruction obtained at p = 0.7 and ? = 8 for this algorithm.

Introduction Electrical Impedance Tomography (EIT) can reconstruct conductivity data distribution from the measurement process inner of the practical phantom become a biomedical image[1].

This device injects 1mA 20kHz of current to the practical phantom using neighbouring method[2-4]. Then, voltage feedback is measured from electrode pairs in the phantom[5-6]. After that algorithm is needed for image reconstruction process from voltage data[7]. Many kinds of the algorithm in EIT has been proposed for improving image reconstruction quality[8]. One of this algorithm is the Gauss-Newton algorithm. The characteristic of the Gauss-Newton algorithm but the basic of Gauss-Newton is not enough to get the best image reconstruction. Modified Gauss-Newton become an alternative for resolving this problem[9].

The mathematical approach is applied in modifying of Gauss-Newton algorithm. One of the mathematical models is one step linear Gauss-Newton. One step linear Gauss-Newton has a linear solution for conductivity change with boundary voltage data[10]. Circle phantom model is commonly used for this simulation[11]. From the Mathematical model and reconstruction test simulation show that this algorithm gives better performance than the basic one but the performance of this algorithm in high-speed electrical impedance tomography is never verified before.

So, in this study, it will be verified the performance of this algorithm by processing the experimental data and also find the best adjustment of this algorithm to give the best image reconstruction. 1

Researh Method Hardware Design EIT hardware must be assembled to get the boundary voltage data from the practical phantom.

The boundary voltage is needed as the main recipe for achieving the conductivity matrix distribution in the image reconstruction process. In another word, this boundary voltage has an important role in one step linear Gauss-Newton algorithm evaluation and looking for the best adjustment of this algorithm. EIT is mainly divided into unit control (single board computer), current source, a multiplexer as the fast programmable switch, voltage measurement sensor including an analog to digital converter and phantom as shown in figure 1. Figure 1.

EIT Hardware Design with Circle Phantom 16 Electrodes. Basically, the working principle of EIT like Figure 1 diagram. First, Unit Control controls the current source to produce 1mA 20kHz. The frequency source can be adjusted digitally with unit control as user demand. After that, the constant current is injected into the practical phantom using a multiplexer. the anomaly used in this research is aluminum. The multiplexer is a fast programmable switch. In this research, Multiplexer runs in 1ms/data transfer speed and using neighboring method for current injection pattern.

The neighboring method is the condition when the pair of electrodes is injected current and another pair of electrodes is measuring the voltage at this process is repeated in 16 times. So, The total boundary voltage data of this method is 256 data. The speed of EIT for achieving 256 data is clearly fast with 1ms/data speed. So, this system can be high-speed EIT. After the voltage measurement process, the boundary voltage data will be processed by Algorithm to produce reconstructed image. For the next process, the evaluation of the algorithm will be applied using this boundary voltage data.. Alogarithm Evaluation In this section, the boundary voltage data from the measurement will be processed by one step linear Gauss-Newton algorithm.

Before the algorithm computes the matrix conductivity distribution from the boundary voltage data, there is some step that must be passed before. First, circle phantom mesh must be created as shown in figure 2. Then, calculate the nodal and element of mesh. This step needs the Finite Element Method (FEM) to solve this boundary problem. The element of this mesh has the triangle shape. This process uses the Python programming language. In this research, the diameter of circle phantom is 90 mm. So, the area of the circle can be calculated and then used to find the area of each element. One element represents one value of conductivity from the reconstructed image.

So, the area of conductivity can be calculated and compared with the real anomaly. The Output of this step is the area of each element from the circle phantom.

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Figure 2. Circle mesh model _Figure 3. Distance measurement of anomaly from the center anomaly to the center of phantom

Secondly, <mark>Mathematical model of one step linear Gauss-Newton</mark> is proposed. Some variable in this algorithm such as x is matrix conductivity distribution, y is boundary voltage change from homogenous condition (no anomaly) until inhomogenous condition (anomaly), J is Jacobian matrix, W is the model measurement accuracy, ? is a hyperparameter value, R is regularization matrix, and p is an exponent of the regularization matrix as shown in equation (1),(2) and (3).

x ? ?2 ??1,? y? ? ?v2 ? ??v1? _ (1)

i i i x ? ?JTWJ ? ?2 R??1 JTWy ? By _ (2)

?R? ? ??J T J ?? p _(3)

i,i i,i

From this step, there is some modification of p and ? to get the best adjustment of the reconstructed image after boundary voltage has been inputted. The value of p is varied from 0 - 1 by the increment of 0.1 and the value of ? is depended on the best result for each p increment. Each adjustment produces one slice of reconstructed image and also matrix conductivity distribution (x). Conductivity value is equal with colorbar value. The red color is conductive and blue is resistive.

So, it can be concluded that one colorbar value is equal with one element of a triangle then it can be calculated the area of the reconstructed image based on colorbar by counting the total of the element with the same threshold value of colorbar. Then, this result is compared with the real area of anomaly and plot it in the percentage level of similarity area. Last, the distance comparison between the reconstructed image and the real anomaly. The distance is measured from the center of an anomaly until the center of the phantom as shown in figure 3. This process needs image analysis software. In this research, ImageJ is a well-known image analysis software.

ImageJ scale must be calibrated using the real geometry of phantom such as real diameter. So, each pixel of an image will be equal to the real distance of the phantom. After that, all reconstructed images will be analyzed the distance of anomaly in the image and compared with the real distance. The final result of this process will be known as the best adjustment p and ? depend on distance and area similarity. Result and Discussion After EIT hardware had been build and collected all boundary voltage data from condition homogenous and inhomogeneous. Then, boundary voltage data would be processed by one-step linear Gauss-Newton.

Before that, let see the result of the meshing process of circle phantom model. Figure 2 shows that the total of nodal is 2113 and element of the mesh is 4096 and the area of the real phantom is 6361.73 mm2. Therefore, the area of each element is 1.55 mm2. Then, the data of boundary voltage data would be reconstructed by one-step linear Gauss-Newton for each value of p and ? as shown in figure 4. The real aluminum position in phantom is near 3-4 electrode and the diameter is 30 mm with distance from center aluminum to the center of the phantom is 25 mm. Real Image _p = 0, ? =0.0005 _p = 0.1, ? =0.0015 _p = 0.2, ? =0.0075 _ _/ _/ _ / _ / _ _p = 0.3, ? =0.025 _p = 0.4, ? =0.1 _p = 0.5, ? =0.4 _p = 0.6, ? =1.75 _ _/ _/ _/ _/ _ _p = 0.7, ? =8 _p = 0.8, ? =40 _p = 0.9, ? =375 _p = 1, ? =2000 _ _

/ _/ _/ _/ _ _Figure 4.

Reconstructed Image with anomaly of aluminium and processing by one-step linear Gauss Newton with value p and ? variation. Figure 4 shows that the performance of EIT is reliable. It can detect the position and the characteristic of aluminium. The position of anomaly is same as shown by the reconstructed image at near 3-4 electrode and it gives a red color to the reconstruction image which indicates that the anomaly is conductive. Like a Gauss distribution, the color intensity of anomaly is high at the center and faded at the edge. Increasing the value of p and ? causes the color of the anomaly to shift to the center of the phantom.

as explained in the previous method that the matrix conductivity distribution was also calculated to find the area of conductivity based on the element at the threshold of certain value colorbar from reconstructed image. The threshold colorbar value is set at >0.8, >0.7, >0.6 and >0.5. the reason to choose that threshold value because the max colorbar value is set at 0.8 and the minimum value is based on the potential of noise can occur at <0.5. so, Color picker test in ImageJ can help to define the color value of noise. After we got the total of the element at a certain threshold then it would be multiplied by the area of each element triangle that had been calculated before. It is about 1.55 mm2 . after that the area of an anomaly of reconstructed image was compared with the real area of anomaly and plot it in percentage similarity scale as shown in figure 5. / Figure 5.

Similarity of area comparison between the anomaly of reconstructed image with the real area of anomaly. Figure 5 shows that the area of an anomaly in the reconstructed image at >0.8 only has a maximum 45% similarity area. So, it is not enough to represent the real area of the anomaly. So, it must be tested until near 100%. The similarity area is near 100% at >0.5. it is about 94.1% and it happened at p = 0.7

,? =8 but it is slightly different with p = 0.6, ? =1.75. so, it needs another comparison like distance similarity comparison but the important thing of this result is the adjustment of one step linear Gauss- Newton algorithm based on p and ? value. If we add more threshold like <0.4, the noise will appear as shown in figure 4.

It has happened because some corrosion in copper electrode caused by the NaCl solution inside the phantom and some noise distributed by moving electronic circuit contact like a cable jack, switch and some electronic parts have a moving part. From this experimental data evaluation, we got some big information about the behavior of one step linear Gauss-Newton algorithm. One step linear Gauss-Newton has behavior that the reconstructed image moves from the edge of the phantom until center of phantom so the adjustment is needed for each different phantom.

So, the best result of this evaluation cannot be used as fix adjustment but it can be made as the reference guide at certain of p value will give the result like as shown in figure 4. So, this adjustment is not entirely random and can predict the best value range of this algorithm. For the next evaluation is the distance comparison. The distance comparison will answer and add more evidence of behavior algorithm. The distance comparison is between the distance of the center of the anomaly until the center of the phantom from the reconstructed image and the real image. all processes use ImageJ image analysis software.

A known distance of real anomaly to center phantom is used as calibration data of ImageJ scale and we got distance from the reconstructed image and compared it with the real distance Then plotted it in percentage scale of similarity distance. If the comparison distance is below 100 %. it means that the object is far from the center of phantom and vice versa. So, if the comparison distance is near 100% that means the distance is the same. / Figure 6. Similarity of distancce comparison between the anomaly of reconstructed image with the real area of anomaly. Figure 6 shows the best adjustment occurs at p = 0.7, ? =8.

The distance similarity percentage is 101% and the important thing is the distance moves from the edge to the center of phantom. If we add information from the area deformation as shown in figure 4. The anomaly image moves at certain distance and it also make some deformation from unshaped until circle shaped. Conclusion

The result showed that the best image reconstruction obtained at p = 0.7 and ? = 8 for one step linear Gauss Newton. The adjustment of value p and ? makes the anomaly image moves from the edge until center of phantom including shape deformation.

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