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Design 2-Dimensional Digital Filter In Reconstruction Of EIT

Dong-Hoon Kang, Byung-Chae Kang, Ji-Hoon Kim, Sang-Pil Hwang
Jin Yeop Kim, Jae-Duck Jang, Seung-Ha Lee, and Bong-Yeol Choi
Department of Electrical Engineering, KyungPook National University, Daegu, Korea
(Tel : +82-53-940-8853; E-mail : rookee07@hotmail.com)

Abstract: Electrical impedance tomography (EIT) has been suffered from the severe ill-posedness which is caused by the inherent low sensitivity of boundary measurements to any changes of internal resistivity values. So, small noise occur unexpected reconstruction image. Generally in EIT system, if measured voltage includes noise, we can't find object location and resistivity values. In this paper, we propose digital filter for measured voltage in EIT. Newton-Raphson is the most popular algorithm in EIT, but noise cause to blur image. We use Fourier transform (FT) in order to minimize the noise and design the filter. After filtering, result of reconstruction image is improved better than before filtering.

Keywords: EIT, FFT ,filtering, mask

1. INTRODUCTION

Electrical impedance tomography (EIT) is internal resistivity distribution estimation that is earned by current injection into attached small electrodes around object and measured voltage on electrodes. EIT has cheaper hardware expenses, worse spatial resolution of reconstructed image but better temporary resolution, more securities about human body than computed tomography (CT). It is used monitoring tools in chemical engineering, geotechnology, and material engineering. And that is used assistant equipments in medical engineering [1, 2].

EIT system consists of two parts, one is hardware part, current is injected into object and voltage is measured. The other is software part, which estimates internal resistivity distribution using measured voltage. Image reconstruction process earn from iterative solution of forward problem and inverse problem based on mathematical model of electromagnetic equation where, forward problem is processes that inject current into electrodes and then measure voltage, inverse problem is process that estimate resistivity distribution using injected current and measured voltage, then reconstruct image. We assume internal initial resistivity distribution, and then improve internal resistivity from iterative operation forward problem and inverse problem, when computed voltage lie in permissible voltage error range, earn final image. EIT has problems those are ill-posedness from low sensitivity of external measured voltage complied with change of internal resistivity. Because of ill-posedness, included noise estimate an unexpected reconstruction image. In the other filtering method introduced, C.J. Kotre "EIT image reconstruction using sensitivity weighted filtered backprojection" and W. Wang "Noise equalization", these paper are applied to improve the image quality at the center of the image, a method of noise equalization using longer collecting times on the smaller potentials than larger potential had been suggested [3, 4]. Equalization is hardware part, so differ from this propose. N. kerrouche is applied Fourier transform in EIT. An alternative method is to treat each pixel of an image as independent and to analyse the conductivity of the pixel sequence using the fast Fourier transform (FFT). It's not a filter design, FT is used to interpret in vivo EIT data.

As like Wang's propose, filter is designed hardware part, the other is software part. In this paper, we propose a filtering method of software. No-noise voltage data is compared with noise voltage data. We design proper filter, through voltage data analyse. Using this low pass filter, we earn improved reconstruction image. There is comparatively one anomaly or multi-object for various locations. We reconstruct the image using 1 frame information from equation. In simulation part, we can show some reconstruction image [5, 6].

2. MODIFIED NEWTON-RAPHSON

We would like to find conductivity ρ whose voltage patterns $U^1(\rho), U^2(\rho), ..., U^L(\rho)$ are equal to the measured ones. To do this, we attempt to minimize the functional.

$$E(\rho) = \sum_{k=1}^{L} \left\| U^k(\rho) - V^k \right\|^2 \quad (1)$$

Generally, modified Newton-Raphson (mNR) is used in EIT reconstruction algorithm. Yorkey is proposed mNR algorithm that is better than any other algorithm compared with convergence rate and residual error. mNR cost function is as follow [7],

$$\Phi(\rho) = \frac{1}{2}[U - V(\rho)]^T [U - V(\rho)] + \frac{1}{2}\alpha\rho R^T R\rho \quad (2)$$

where $U \in \Re^{L \times L}$ is the measured voltage on each electrode about current pattern, $V(\rho) \in \Re^{L \times L}$ is the computed voltage about current pattern, $R^T R = diag(J^T J)$ and α is regularization parameter. Solution of minimized resistivity is as follows,

$$\rho_{i+1} = \rho_i + \left(J_i^T J_i + \alpha R^T R\right)^{-1} J_i^T \left(U - V(\rho_i)\right) \quad (3)$$

where J is Jacobian at $\rho = \rho_i$ form as,
Jacobian has ill-posedness, so we need regularization.

$$J \equiv \frac{\partial V(\rho_i)}{\partial \rho} \quad (4)$$

In this paper, we propose to reduce noise of measured voltage $U \in \Re^{L \times L}$, then we earn improved image [8].

3. DIGITAL FILTER

3.1 The Fourier Transform

EIT system has ill-posedness problem from low change of measured voltage comply with change of internal resistivity, so reconstruction image is affected by small noise. Such problem, we need some filtering method, which is used before image reconstruction algorithm. Measured voltage has a noise that was mentioned above, but we can eliminate this noise using digital filter based on FFT. Generally, voltage data has more high level than noise, however noise have high frequency. We need distribution of voltage data in frequency domain. And we refer to the distribution. Filter is applied to difference data between homogenous data and inhomogeneous data. We don't know how much noise is mixing in EIT data if we don't use difference data. In EIT homogenous data and inhomogeneous data are very similar, but the difference data has clearly distribution.

$$V_d = V_{ho} - V_{inh} \tag{5}$$

In image reconstruction procedure of EIT, voltage data need to analyse frequency domain. In this paper, using 2-Dimensional FFT analyse power spectral density (PSD), and design digital filter. Generally, Fourier transform is as follow,

$$F(p,q) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} f(m,n) e^{-j(2\pi/M)pm} e^{-j(2\pi/N)qn} \tag{6}$$

where $p = 0,1,\ldots, M-1 \qquad q = 0,1,\ldots, N-1$

$$f(m,n) = \frac{1}{MN}\sum_{p=0}^{M-1}\sum_{q=0}^{N-1} F(p,q) e^{j(2\pi/M)pm} e^{j(2\pi/N)qn} \tag{7}$$

where $m = 0,1,\ldots, M-1 \qquad n = 0,1,\ldots, N-1$

In the frequency domain, low frequency data is distributing edge of region. To design digital filter, we compared noise data with no-noise data, and then relocate the frequency from edge to center region using FFTSHIFT. There is comparatively one anomaly or multi-object of various locations. We observe various voltage data. Through each object data, we can know prior information for general filter design.

3.2 Filter Design

Flow chart of digital filter system is as follow

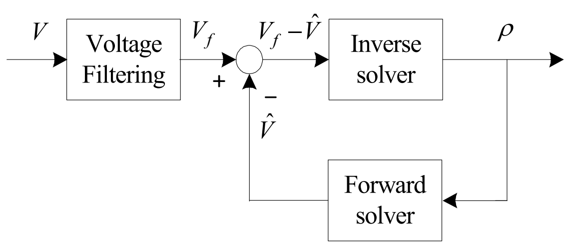


Fig. 1 System block diagram.

In filter design, filtering frequency is calculated many experimental result of PSD data. The threshold value is mean of PSD. Equation is as follow,

$$PSD_{th} = PSD_{avg} \tag{8}$$

$$\text{if } PSD_{ij} < PSD_{th} \qquad PSD_{ij} = 0 \tag{9}$$

where $i = 1,2,\ldots,32 \qquad j = 1,2,\ldots,32$

equation (8) examines PSD data. Using this PSD data design effective filtering mask. Totally filtering procedure is as follow,

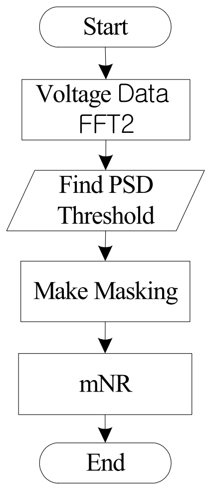
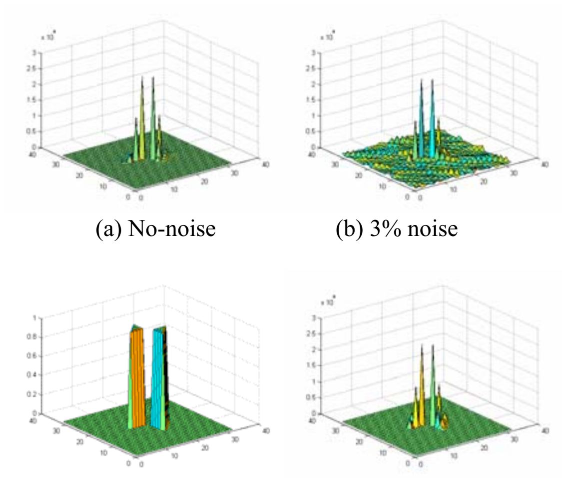


Fig. 2 Filtering procedure.

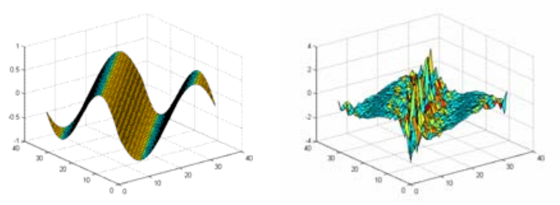
Mask is designed dominant region of PSD. To make the mask does a low pass filter. PSD data comparison is as follow,


(a) No-noise (b) 3% noise

(c) Mask (d) Filtering PSD

Fig. 3 PSD distribution.

We refer to the low frequency area which is easily to know through Fig.3. To get the part to be the dominant most, we cut off less than average value and design filtering mask as like Fig.3 (c). Figure. 3, we apply to mask in voltage data to earn as like PSD distribution of no-noise data (Fig.3 (d)). Figure. 4 is the result of filtering in voltage data.



(a) No-noise (b) 3% noise

Fig. 4 Different voltage data_1.

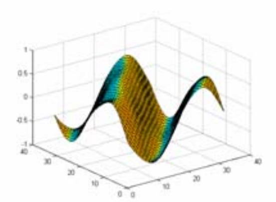


Fig. 5 Different voltage data_2.

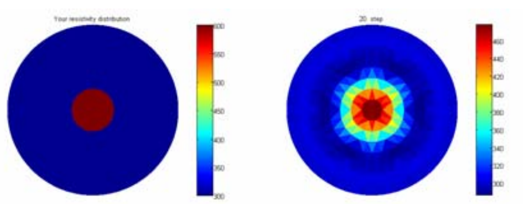
The object of Fig.4 is locating center of phantom, the shape is circle. Through the comparison of Fig.4 (a) and (b), we can know that noise is generated distortion in voltage data. In this paper, change Fig.4 (b) into Fig.5 using by proposed filter. Filtered voltage estimate improved reconstruction image.

4. SIMULATION

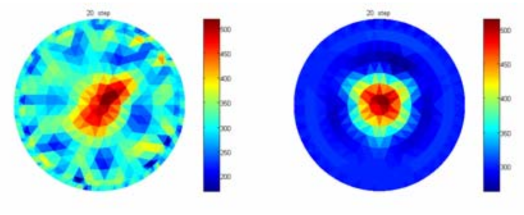
Simulation condition is as follow, mashes of forward problem are FEM meshes having 3104 elements and 1681 nodes. We must decide proper element of mesh because of increase of operation. So mashes of inverse problem are 1/4 smaller than forward problem that have 776 elements and 453 nodes. The number of electrode is 32, radius of phantom is $8cm$, impedance of background is $300\Omega cm$, and impedance of object is $600\Omega cm$. Applied current pattern is adjacent (ADJ) current pattern. In EIT, there are various current patterns: trigonometric, adjacent, opposite, and etc. In this paper apply to filter for ADJ current pattern. Each current pattern data size is different, in ADJ current pattern, current and voltage data size is $\Re^{L\times L}$. For comparison and evaluation, we define root mean square error (RMSE) as follow. Reconstruction iteration is 20 th.

$$RMSE \equiv \sqrt{\frac{[U_k - V_k(\rho_k)]^T [U_k - V_k(\rho_k)]}{U_k^T U_k}} \qquad (10)$$

We compare static EIT image reconstruction algorithm mNR with proposed algorithm and analyzed performance. Using proposed algorithm, three type of object are used for simulation, there is a circle in center (case_1-1 and case_1-2), multi-object (case_2) and shield shape object between boundary and center (case_3).



(a) Original image (b) Reconstruction image



(c) No-filtering image (d) Filtering image

Fig.6 Simulation case_1-1.

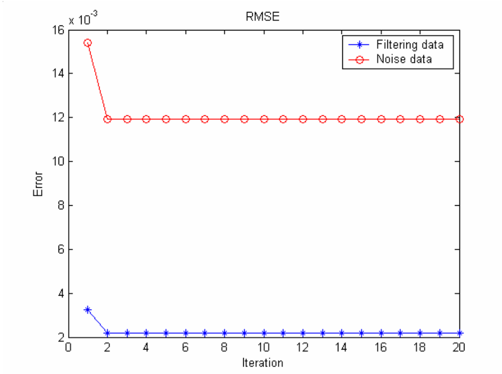
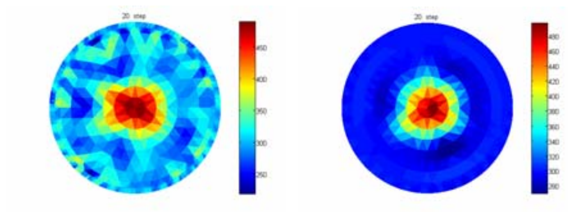


Fig. 7 RMSE.

There is a circle in center. Although mNR is robust in noise, the result of reconstruction is very blurring (Fig. 6 (c)). Through voltage filtering can earn better improved image than no-filtering image (Fig. 6 (d)). Figure. 7 is RMSE for mNR and proposed method.



(a) No-filtering image (b) Filtering image

Fig. 8 Simulation case_1-2.

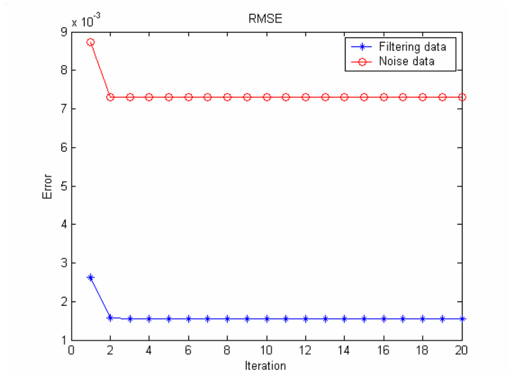
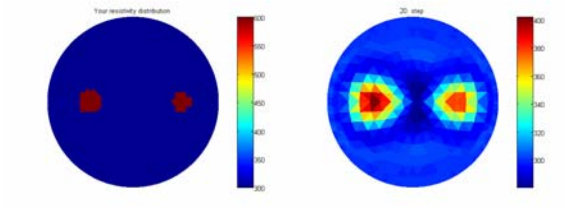
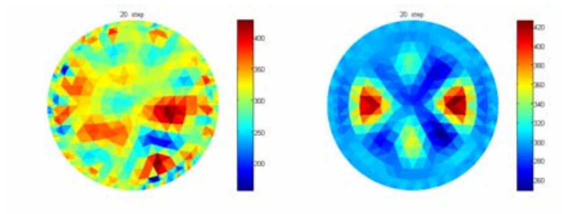


Fig. 9 RMSE.

2% noise reconstruction image, where object locate a circle in center. Image resolution and RMSE are better than simulation case_1-1. The result is rather superior 2% noise in the simulation result of different case in 3% noise naturally.



(a) Original image (b) Reconstruction image



(c) No-filtering image (d) Filtering image

Fig. 10 Simulation case_2.

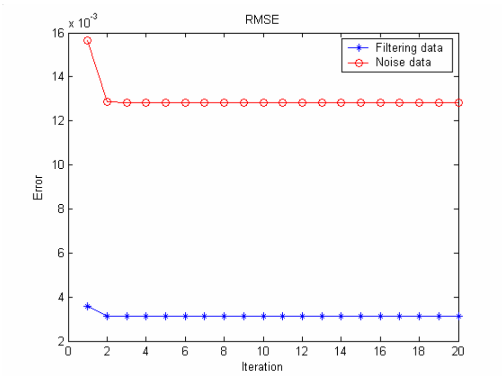
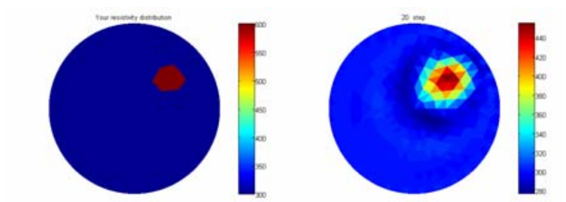
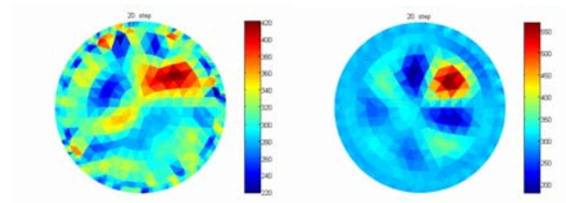


Fig. 11 RMSE.

In case of multi-object, we have the result to be improved too. Figure. 11 is RMSE for before and after. Though no-filtering image never know object location, but filtering result can know the collect location of object.



(a) Original image (b) Reconstruction image



(c) No-filtering image (d) Filtering image

Fig. 12 Simulation case_3.

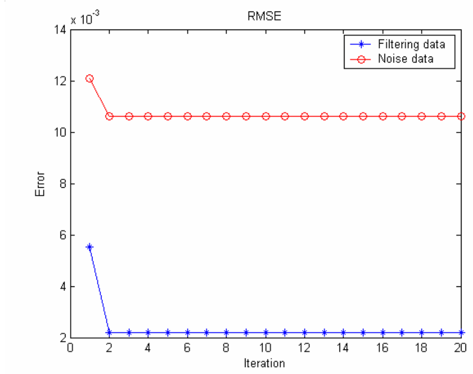


Fig. 13 RMSE.

There is a shield shape object between boundary and center. As same former simulation result, reconstruction image is better than no-filtering. By these results, we can verify that proposed method has better performance than conventional mNR's.

5. CONCLUSION

In this paper, we introduced a noise filtering for conventional EIT, and we earned improved image better than no-filtering. Cause of ill-posedness, mixing some noise in data, we shouldn't find anomaly location and resistivity value. We used the FFT and drew a plan to improve the advantage the filter. In the maximum 3% noise is added, we can has a distinct image the improvement of result. Simulation compared the after filtering with before filtering. In this point, this paper can show improved reconstruction result. The reconstruction image is advanced resolution, also by result of RMSE, we proposed method has the more increase its frame the smaller error than mNR.

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