IMAGE RECONSTRUCTION ALGORITHMS OR SUT-1 EIT SYSTEM

Amir Movafeghi[1a], Ali R. Nateghi[a], Manouchehr Soleimani[b], Mohammad H. Kargarnovin[a] and Hamid Soltanianzadeh[c]

[a]Sharif University of Technology, School of Mechanical Engineering, Azadi Ave., P.O. Box: 11365-9567, Tehran, Iran;
[b]UMIST, Department of Mathematics, PO Box 88, Manchester M60 1QD, UK
[c]Henry Ford Health System, Radiology Research Lab., Michigan, USA

ABSTRACT: SUT-1 is a 2-D system for EIT. The system is developed in Sharif University of Technology and consists of a PC computer in which an I/O card is installed with an external current generator, a multiplexer, a power supply and a phantom with an array of normal ECG electrodes. In the area of data acquisition, the developed software (system control software) is written using C++ environment. In the field of image reconstruction a series of software are developed using MATLAB environment. Moreover, a simple program is developed which is capable of generating different meshes for Finite Element Modelling (FEM). In this F.E. model, triangular elements are used for image reconstruction. Then, for the image reconstruction in the 32-electrode mode of operation, a modified Newton–Raphson method is implemented. During APT mode of operation, image reconstruction is performed with 16 electrodes using Back Projection algorithm and iso-potential lines. Basically this was the "Sheffield Algorithm" with some changes and modifications corresponding to the SUT-1 specification. In this paper, mostly reconstruction algorithm for APT mode of operation is discussed.

Keywords: Image reconstruction, applied potential tomography, back projection, EIT

1. INTRODUCTION

The Electrical Impedance Tomography is a new modality for medical imaging. The image is the electric conductivity contrast. The image reconstruction process is a kind of ill-posed inverse problem. The data needed for image reconstruction are the voltage on the attached electrodes generated by injected current via the electrodes. Normally, the array of electrodes is attached to the peripheral boundary of image plane. SUT-1 is a multi-electrodes electrical impedance tomograph (EIT) that was designed and fabricated in Sharif University of Technology. Information about hardware and main specification of system and some results and also software for solving forward problem by FEM was introduced before [1-3]. The main objective of this paper is discussion about some image reconstruction methods for EIT; especifically in APT(applied potential tomography) mode; presenting some results from image reconstruction software based on such methods and verification of software with simulation and actual test data from SUT-1.

2. METHODOLOGY

Image in EIT is mapping of conductivity distribution, by means of observation of electric potential (measurement of voltage) in the finite number of points in the surface of object that such potentials made by injection current to media[4]. The sensors for injection current and sensing voltages are electrodes. In the image reconstruction one needs to have a simulation of the measurement process, the modeling of this observation is so called forward problem and the algorithms for image reconstruction are using the results from forward solution and by iteration method like N-R trying to fit the voltage measurement by simulation. The point is if there are some mismatch information in the forward modeling this goes to the wrong calculated image. According to uniqueness of Neumann to Dirichleh map we expected that with the wrong information data from forward solver we will not be able to reconstruct the image and for example the image reconstruction is failing. But the point is that there is no analytical solution for inverse and forward problem so one has to use the numerical method and according to the numerical modeling we converge to wrong results. The mathematical model of forward model Poisson's equation with Neumann (injected current) such as:

[1] amov@mehr.sharif.edu; phone +98 912 1021918; fax +98 21 800-8376; http://mehr.sharif.edu/~amov

$$\nabla.\left[\tilde{\delta}(P).\nabla\tilde{U}(P)\right] = 0 \quad \text{at B (B is the object)} \tag{1}$$

$$\tilde{\delta}(P)\frac{\partial\tilde{U}(P)}{\partial n} = J \qquad P \in S \text{ (Surface)} \tag{2}$$

$$\int_S \tilde{U}(P)ds = 0 \qquad P \in S \tag{3}$$

where $\tilde{U}(P)$ is voltage and $\tilde{\delta}(P)$ is specific admittance of B; in which $\tilde{\delta}(P) = \delta(P) + j\omega\varepsilon(P)$
S is surface boundary of B. The finite element is well known method to solve this model.[4,5]

3. IMAGE RECONSTRUCTION METODS

As described in previous section, in EIT we deal with an ill-posed boundary problem. If b and f stand for boundary measurement vector and conductance distrubution inside the object, respectivly, equation 4 shows their relation:

$$b = T.f \tag{4}$$

T is a matrix which has to be determined for image reconstruction.
There are different alghorithm for image reconstruction fir EIT. Descriptive equation in a single step alghorithm are as following:

$$\sigma_k = \sigma_{k-1} + \Delta\sigma_{k-1} \tag{5}$$

$$g_p = \frac{g_c - g_u}{g_u} \tag{6}$$

$$g_p = F.c_p \tag{7}$$

$$c_p = F^T(F\,F^T)^{-1}g_p \tag{8}$$

where σ is conductivity in each step (here k=1), g is the differences in each measuremnet and F is the sensitivity matrix. g_p describes relative differnce in the boundary measurments so $\Delta\sigma$ is esual to c_p in the first iteration step. For calculating of c_p the equation 7 ought to be inversed and the results will be equation 8.

3.1. Static imaging

Image reconstruction in EIT is an ill-posed inverse problem. From the time of advent EIT in 1983 very much works were made in EIT image reconstruction and this kind of effort is continued up to now. For reconstruction in mode of static imaging a modified Newton–Raphson Method with 32 electrodes was implemented. In this approach we interested in minimizing the function ϕ with respect to σ defined as follows:

$$\phi = \frac{1}{2}(f - V)^T(f - V) \tag{9}$$

V is measured voltages and f is forwad problem results.
The minimization of ϕ turns out to be the Newton iteration which is shown in this equation, This is simply an update for σ:

$$\Delta\sigma_k = -[f'(\sigma_k)^T f'(\sigma_K)]^{-1} f'(\sigma_k)^T[f(\sigma_K) - V] \tag{10}$$

A very fast image reconstruction method with using one step of Newton-Raphson and solving forward problem by analytical method is implemented this method is named by NOSER [6]. We developed a mixed image reconstruction based on Broyden and modified Newton methods that in first step of image reconstruction modified Newton – Rophson algorithm is used and the near of solution Broyden method. Figure 1. shows an image reconstructed by this method.

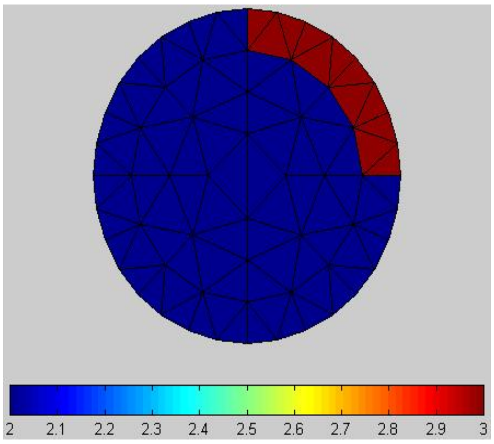

Fig.1. Newton-Raphson method, simulated.

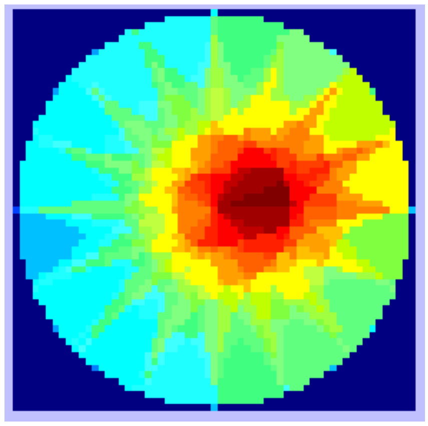

Fig.2. A simulated image with BP method.

3.2. Dynamic Imaging

For dynamic imaging mode of operation, image reconstruction was performed with 16 electrodes using Back Projection algorithm and iso-potential lines. Basically it was a *Sheffield Algorithm* with some improvement and modification for matching with SUT-1 system characteristics. Here we have a deeper look to this algorithm. In back projection (BP) method, F^T in equation 8 is replaced with BP operator (B) and the results is:

$$c_p = B(FB)^{-1}g_p \tag{11}$$

B is pseudo inverse matrix of *T*. In this condition data vector operation has two steps: at the first $(FB)^{-1}$ shows filtration in boundary data and in the next step $B.(FB)^{-1}$ back project this data into an image. In our process BP process is carried out between the iso-potential lines. This method is suggested first by Barber et al [7] and then developed by other researcher. Image reconstruction can be described in 4 steps:

1- calculating of voltage of each node in generated mesh by Finite Element Method
2- determination of iso-potential area
3- calculating of correction by

$$\sigma = \sigma_0 \times abs\left(\frac{v_{ih} - v_{jh}}{(v_{inh} - v_{jnh}) - (v_{ih} - v_{jh})}\right) \tag{12}$$

where ΔV is the voltage difference between the electrodes, h is homogeneous and nh is non-homogeneous medium

4- reconstruction implementation

Finally BP can be summarized by equation 12.

$$f(x,y) = 1/M.\sum_{i=1}^{M}\sum_{k=1}^{N} T_{ik}(x,y).\left|(Z_m I_{ik} - Z_m H_{ik})/Z_m H_{ik}\right| \tag{13}$$

where f is reconstructed image, k is voltage sensing electrodes No., i is the current electrode No., Z.H is measred impedance in homogeneous medium and Z.I is impedance for non- homogeneous medium.
If the point lies between the iso-potential lines T is 1 and in the other case T is zero. Figures 2-6 show some of our results.

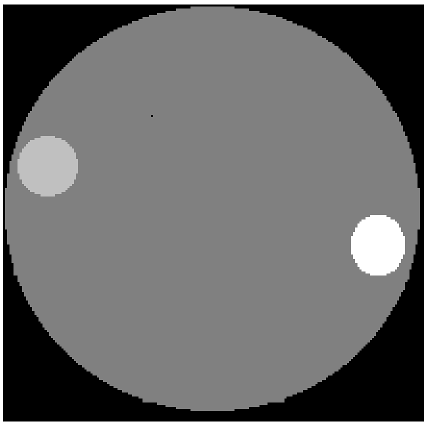

Fig.3. An object with 3 different zones.

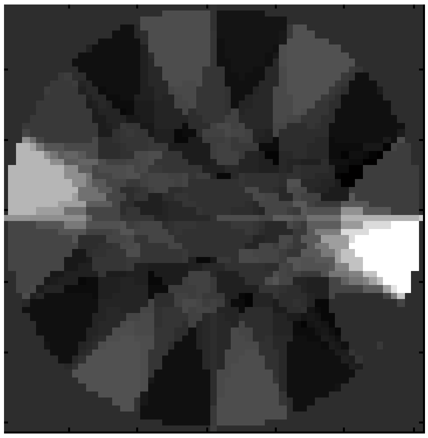

Fig.4. Reconstructed image by APT.

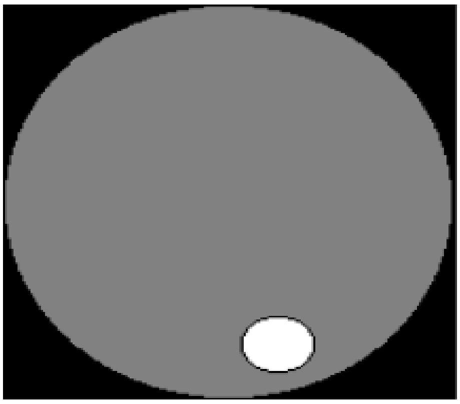

Fig.5. An object with 2 different zones.
by APT measurement

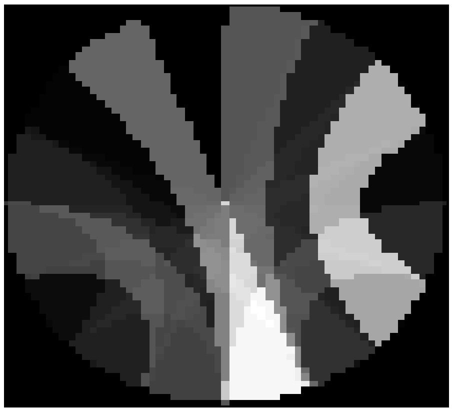

Fig.6. Reconstructed image

CONCLUSION

Image construction algorithms for SUT-1 EIT system is described briefly and some of the results expressed. The results show better results in APT mode of operation.

REFERENCES

1. M. Soleimani, Design and fabrication of an electrical impedance tomography system, M.Sc. thesis under supervising Dr. S. A. Mireshghi , Dept of Mech. Eng. Sharif Univ. of Tech. Tehran Iran , 1999, in Farsi.
2. A. Movafeghi, M. Soleimani , A.R. Nateghi and S. A. Mireshghi, Introducing SUT-1: a simple and efficient EIT system , XI International Conference on Bioimpedance, Oslo University, Norway , 17-21 June 2001.
3. M. Soleimani , A. Movafeghi and S. A. Mireshghi, Consideration of some reasons for creating artifact in EIT image, 4th Iranian Conference on Medical Physics , 1999, In Farsi.
4. M. Cheney , Isaacson D. and Newell J. C., ‘Electrical Impedance Tomography’, SIAM Review, 1999.Vol. 41, pp. 85-101
5. W.R.B. Lionheart W.R.B., ‘EIT reconstruction algorithms: pitfalls, challenges and recent developments’, Physiological Measurement, 2004 Vol.25, pp.125-142
6. M. Cheney , D. Isaacson D. , J. C. Newell , S. Simske and J. Goble , NOSER; An Algorithm for solving the inverse conductivity problem, Int. J. of Imaging sys. And tech., Vol.2 , 66-75, 1990.
7. C.C. Barber and B.H. Brown B. H., ‘Single step Algorithms for Image reconstruction’, IEEE Transactions on Biomedical Engineering, 1985 Vol.32, pp.100-105