ACTA TECHNICA CORVINIENSIS
BULLETIN OF ENGINEERING

[1.] ANJAN KUMAR KUNDU, [2] BIJOY BANDYOPADHYAY

AN IMAGE RECONSTRUCTION AND ENHANCEMENT TECHNIQUE FOR MICROWAVE TOMOGRAPHY

Abstract:
An inverse iterative algorithm for microwave imaging based on moment method solution is presented here. This algorithm is based on Levenberg-Marquardt method. Different mesh size of the model has been used here to overcome the inverse crime. The reconstructed image is then processed through different image enhancement tools.

Keywords:
regularization, microwave tomography, Levenberg-Marquardt method, inverse crime, image processing

INTRODUCTION

Microwave tomography techniques for biomedical applications have been subject to intensive research during the last few decades. The objective of microwave tomography is to reconstruct the dielectric properties of a body illuminated with microwaves from a measurement of the scattered fields. Additional advantages include the fact that the probing radiation is not harmful at the low powers employed. As the human body exhibits large variations in the dielectric properties of its various tissue types, microwave tomography is expected to give information on the distribution of tissue types within the body in image form.

Apart from our first generation algorithms [4, 5], we had proposed several algorithms [1, 2, 3, 6] which reconstructed the image without any misfit under noise-free environment. However, in the above stated algorithms, the mesh size remains the same both in the forward problem and the inverse problem leading to inverse crime. In this paper, an iterative algorithm based on Levenberg-Marquardt regularization technique with necessary considerations to avoid inverse crime has been proposed. The reconstructed image is then undergone through several image enhancement mechanisms to reduce the noise.

FORWARD PROBLEM

The structure of the forward problem is same as that of our previous work [6]. A cylindrical object of arbitrary cross section is considered here which is characterized by a complex permittivity distribution $\varepsilon(x,y)$.

An electromagnetic wave radiated from an open-ended waveguide is used here for the illumination. The incident electric field E^{inc} is parallel to the axis of the cylinder.

The expression for the total electric field E is

$$\vec{E} = \vec{E}^{\,inc} + \vec{E}^{\,s} \qquad (1)$$

where E_s represents the scattered field which is generated by the equivalent electric current radiating in free space.

The total electric field can be calculated with an integral representation

$$\vec{E}(x,y) = \vec{E}^{\,inc}(x,y) + \iint_s \vec{J}_s(x,y)\, G(x,y;x',y')\, dx'dy' \qquad (2)$$

where the Green's function can be given by

$$G(x,y;x',y') = -\frac{j}{4} H_0^2\left(k\sqrt{(x-x')^2+(y-y')^2}\right) \quad (3)$$

Here (x,y) and (x',y') are the observation and source points respectively.
The solution of the forward are carried out by moment method [7] using pulse-basis function and point matching technique.

INVERSE PROBLEM

The aim of the inverse problem is to find a stable solution for permittivity distribution ε^* which minimizes the squared error output at the receivers i.e.

$$\|E(\varepsilon)-e\|_2^2 \quad (4)$$

where $e \in C^n$, the n electric fields we measure at receiver points, $E : C^m \longrightarrow C^n$, a function mapping the complex permittivity distribution with m degrees of freedom into a set of n approximate electric field observations, and also $\varepsilon \in C^m$, the complex permittivity distributions with m degrees of freedom..
The details of the Levenberg-Marquardt regularization technique has already been discussed in our earlier work [6]. The Levenberg-Marquardt regularization technique for the minimization of the (4) leads to an iterative solution

$$\varepsilon_{i+1} = \varepsilon_i + \Delta\varepsilon_i \quad (5)$$

where ε_{k+1} is the permittivity distribution at the $k+1^{th}$ iteration.
$\Delta\varepsilon$ can be written as

$$\Delta\varepsilon = (E'(\varepsilon)^{\dagger}E'(\varepsilon) + \lambda I)^{-1} E'(\varepsilon)^{\dagger}(E(\varepsilon)-e) \quad (6)$$

where E' is the Jacobian matrix, † denotes the conjugate transpose, λ is a monotonically decreasing regularization parameter, I is the identity matrix, $E(\varepsilon)$ is the calculated electric fields at the receivers.

NUMERICAL MODEL

The theoretical model used to test our algorithm is shown in Figure 1.
It is a high contrast square biological object 9.6 cm × 9.6 cm consisting of muscle and bone having complex dielectric constants 50-j23 and 8-j1.2 respectively at a frequency of 1 GHz. The object is kept immersed in saline water having complex dielectric constant 76-j40.

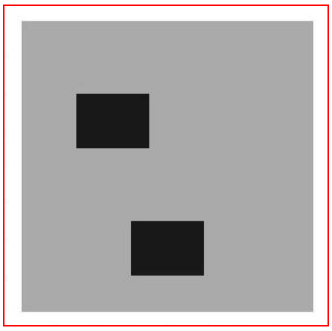
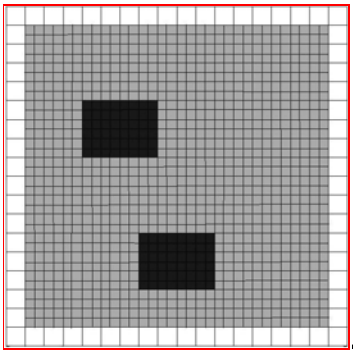
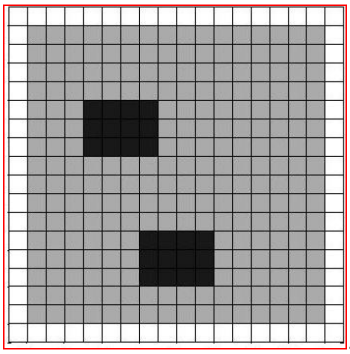


Figure1. Numerical model

The target is illuminated with TE fields radiating from an open ended dielectric filled wave guide having sinusoidal aperture field distribution. The transmitter is moved along four mutually orthogonal directions. For each of the transmitter positions along a particular transmitting plane, the received fields at eighteen locations in the other three orthogonal planes were measured theoretically at a frequency of 1 GHz
If the same meshes are used both in the simulation of the measured data and in the solution of inverse problem, we may commit a so-called inverse crime, where numerical errors may be cancelled out inadvertently. To avoid inverse crime, different meshes are used as shown in figure 2. The finer mesh is used in the forward problem (Figure 2(a)) whereas the inverse solver uses the coarse mesh (Figure 2 (b)).



a)



b)

***Figure 2.** Meshes used to overcome the inverse crime (a). Mesh used in forward problem (b). Mesh used in inverse problem*

In case of forward problem, the rectangular model is divided into 1024 square cells of dimension 0.3cm X 0.3cm and the saline water region is divided into 32 cells of dimension 0.6cm X 0.6cm. During the inverse problem, the rectangular model together with saline water region is divided into 324 equal square cells 0.6 cm× 0.6 cm. The measurement set contains 288 independent data [3].

During the iterative reconstruction, the complex permittivity values of the cells filled up with saline water were assumed to be known, thus rendering the problem of estimating the complex dielectric constants of the remaining 256 cells.

RESULTS AND DISCUSSIONS

To apply the reconstruction algorithm, it was initially assumed that the biological medium is filled up with muscle only. The received fields at different receiver locations were computed for each transmitter position.

In our earlier works, the regularizing parameter was monotonically decreasing by a factor of 10. In this paper when the same decrement factor is used, the reconstructed model was not satisfactory as shown in the figure 3. Instead, when the decrement factor is chosen as 2, the reconstructed model is quite acceptable. So, the decrement factor for the regularizing parameter is chosen as 2 here.

a) b)

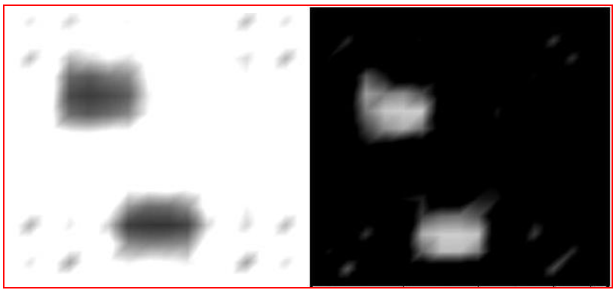
***Figure. 3.** Reconstructed model with λ=10 (a). Real part (b). Imaginary part*

As usual, the only priori information we have used in our algorithm is that the real part of the complex dielectric constant cannot be negative and the imaginary part cannot be positive. Figure 4 (a) and Figure 4(b) shows the real part and imaginary part of the reconstructed model with our present algorithm with λ =2.

a) b)

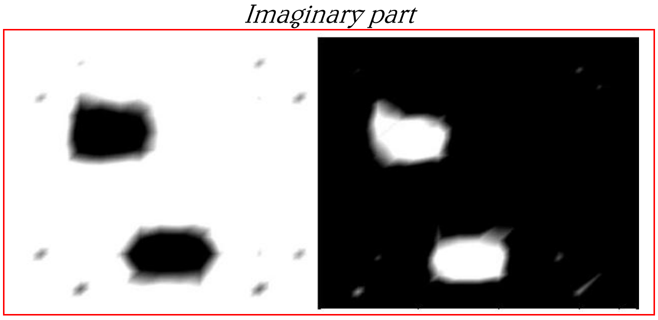
***Figure 4.** Reconstructed model with λ = 02 (a) Real part (b) Imaginary part*

After applying the different image Arithmetic filters and image enhancement filters to the above reconstructed model, the quality of the reconstructed model have been improved in terms of noise as shown in the Figure 5, Figure 6 and Figure 7.



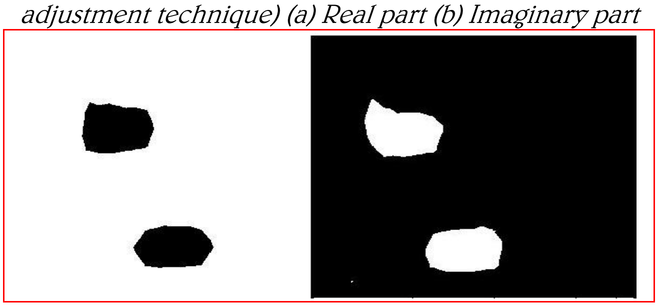
a) b)

***Figure 5.** Reconstructed model after the image arithmetic filter being used (using image addition/subtraction technique) (a) Real part (b) Imaginary part*



a) b)

***Figure 6.** Reconstructed model after the image enhancement filter being used (using image adjustment technique) (a) Real part (b) Imaginary part*



a) b)

***Figure 7.** Reconstructed model after the image enhancement filter being used (using histogram equalization technique). (a) Real part (b) Imaginary part*

The clarity of an image can be highly improved through different image enhancement techniques. Reducing the noise, deblurring the image and/or increasing the contrast can enhance the quality of an image in terms of human viewing. Among the several image enhancement techniques, the image addition/subtraction technique, the image adjustment technique and the histogram equalization technique produced the desired enhanced output in our present problem.

In case of image addition or subtraction technique, the algorithm basically adds or subtracts two images, or add/subtract a constant to image defined by the programmer.

In case of image adjustment technique, the algorithm maps the image intensity values to new intensity values specified by the programmer. This increases the contrast of the output image.

In case of histogram equalization technique, the algorithm enhances the contrast of images by mapping the intensity values of an image, so that the histogram of the output image matches a specified histogram.

Thus applying different image enhancement techniques to our reconstructed model, the clarity of the image has been improved significantly.

REFERENCES

[1] A.K.KUNDU, B.BANDYOPADHYAY "Reconstruction Algorithm for Microwave Tomography Using Iterative Regularized Gauss-Newton Method", International Conference on Computer and devices for Communication (CODEC 06), Kolkata, 2006

[2] A.K.KUNDU, B.BANDYOPADHYAY "Reconstruction Algorithm for Microwave Tomography Using Levenberg-Marquardt Regularization with Multiple Illuminations"-, IEEE Applied Electromagnetic Conference, 978-1-4244-1864-0/07, 2007

[3] A.K. KUNDU, B. BANDYOPADHYAY, S. SANYAL, "An Iterative Algorithm for Microwave Tomography Using Modified Gauss Newton Method", Biomed 2008, Proceedings 21, pp. 511-514, 2008, Springer-Verlag Berlin Heidelberg 2008

[4] A.N. DATTA, B. BANDYOPADHYAY, "An SIRT style reconstruction algorithm for microwave tomography", IEEE Trans. Biomed. Engg., vol 32, pp 719-723, 1985

[5] A.N. DATTA, B. BANDYOPADHYAY, "Non-linear extension of moment method solution for microwave tomography", Proc. IEEE. vol., pp.604 - 605, 1986.

[6] B.BANDYOPADHYAY, A.KUNDU, A.N.DATTA, "An Iterative Algorithm for Microwave Tomography Using Levenberg-Marquardt Regularization Technique", Ind J Pure & Appl Physics, 43, 649 – 653, 2005

[7] J.H. RICHMOND, "Scattering by a dielectric cylinder of arbitrary cross- section shape," IEEE Trans. Antennas and Propagation, vol. 13, No. 3, 334-341, 1965

AUTHORS & AFFILIATION

[1.] ANJAN KUMAR KUNDU,
[2] BIJOY BANDYOPADHYAY

[1.] INSTITUTE OF RADIOPHYSICS & ELECTRONICS, UNIVERSITY OF CALCUTTA, KOLKATA, INDIA
[2.] INSTITUTE OF RADIOPHYSICS & ELECTRONICS, UNIVERSITY OF CALCUTTA, KOLKATA, INDIA.

ACTA TECHNICA CORVINIENSIS – BULLETIN of ENGINEERING
ISSN: 2067-3809 [CD-Rom, online]

http://acta.fih.upt.ro