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Modification in Field Measurement Applied on Exact Algorithm for Biomedical Imaging

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ABSTRACT

A modification has been proposed by the authors to calculate the field strength at the cells of a biological target which is illuminated by a transmitting array antenna with a beam width of 6^0. The biological target is divided into large number of cells so that complex permittivity and electric fields are assumed to be constant in the small area of each cell. The electric fields are calculated at the cells which are under the illuminated zone of a transmitting beam. The electric fields are assumed to be zero in those cells which are outside the coverage zone of the said transmitting beam. Whereas in the previous cases, all the cells of the biological target are considered to be illuminated by the beam. For efficient reconstruction, narrowest possible beam is required. This modified method of field measurement when applied on a semi-human sized biological model consisting of human organs like fat, muscle, kidney and muscle type material improves the reconstructed complex permittivity value of the biological target. A comparative study of reconstructed image obtained by previous field measurement technique and improved field measurement technique are presented in this paper. Reconstruction of complex permittivity of target area is simulated using Force 209 FORTRAN and results are depicted by using colour gradation scale.

Keywords: Complex permittivity, Exact algorithm, Simultaneous iterative reconstruction technique (SIRT), Tomography

1. Introduction

The Greek word 'tomos' means parts or section and 'graph' means representation. Hence tomography is the imaging of unknown cross section of any object. Tomography of a biological body using low microwave frequency range (near about 1 GHz) will be a non invasive technique for medical diagnosis as low microwave signal has no radiation hazard like X-rays in computed tomography. Moreover, interaction of microwaves with dielectric properties of biological tissue is attractive as complex permittivity of the tissue changes with the water content in it and this water content also changes with infection of disease. The reconstruction of complex permittivity of the biological tissue discriminates the healthier tissue from the diseased one. Various iterative reconstruction algorithms based on moment method solution for randomly inhomogeneous biological model had been developed on the assumption that change of characteristic parameter of a cell produces effects on the other and hence, results a coupled effect on the receiver point. Since exact solution of such a large number of non-linear equations containing a large number of unknown variables are impossible, the iteration methods [1]-[4] have been adopted.

Improved first order and second order algorithm [5] considering the first order and second order mutual interaction terms fails to reconstruct larger model as higher order terms greater than second order play the dominant role and perturbation equation becomes non-convergent. It also fails to detect smaller model with large perturbation by the same reason.

Considering the above facts, a new exact algorithm [6] had been developed where the difference of two electric fields which are obtained when the object medium is assumed to be a homogeneous one and when actual experimental model is used, at a particular receiver location is expressed in terms of unknown permittivity, relevant co-factors of co-efficient matrix corresponding to the homogeneous medium and perturbed internal fields.

The exact algorithm is based on the integral equation for the field of harmonic source in presence of a dielectric medium which is assumed to be divided into large number of small cells. The areas of the cells are kept very small so that electric field intensity and complex permittivity in each cell are nearly constant. According to Richmond [7] a system of linear equations are obtained by enforcing the condition that total field at the centre of each cell must be equal to the sum of the incident field and the scattered field in that cell from the neighbouring cells.

Further, the change of characteristic parameter of a cell produces effects on all other cells and hence, results a coupled effect on the receiver point. Previously, it was assumed that all the cells of the biological target are illuminated by the antenna located in each transmitter position. But, in practice each transmitting beam has a finite beam width and incident fields are calculated in those cells which are under the beam contour. Incident fields are assumed to be zero in those cells which are outside the coverage zone. Hence, cells which have incident field strength will produce a coupled effect to a particular cell for the said beam and cause no change to the other cells outside the zone. So, necessary corrections are required in the measurement technique of incident fields [8],[9],[10], perturbed fields in the target cells and finally to the received fields. In this paper, the number and location of the cells in a rectangular region of a biological

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target illuminated by a transmitting antenna beam of width 6^0 are calculated using elemental geometrical approach.

2. Algorithm for perturbed field

As stated by Richmond [7] a system of linear equations can be obtained by equating the total field at the centre of each cell with the sum of incident and scattered fields at that centre for a sufficiently large number of cells.

The field distribution in unperturbed homogeneous medium is expressed by the equation:

$$[C].[E_i] = [E_i^{in}] \quad (1)$$

Where E_i^{in} is the incident field at i-th cell in free space and E_i is the internal field at i-th cell when the medium is assumed to be homogeneous one having known permittivity distribution.[C] is (n x n) coefficient matrix of homogeneous medium.

The permittivity values of the cells are perturbed simultaneously by small amounts of $\Delta\varepsilon_i$ (i = 1, 2 ,…., n) when the homogeneous medium is replaced by a inhomogeneous one and the corresponding changes in the internal fields are ΔE_i's :

$$[C'].[E_i']=[E_i^{in}] \quad (2)$$

where $[C']$ is the coefficient matrix corresponding to the inhomogeneous medium and $E_i'=[E_i+\Delta E_i]$ is the perturbed total field at the i-th cell.

Using necessary correction for incident field measurement, the incremental change in field at i-th cell for the k-th transmitter due to change of permittivity and fields(only illuminated cell's field will take part instead of all the cell's fields) in the other cells of the model is given by the equation as:

$$\Delta E_i(k) = -x_i E_i' + \sum_{j=1}^{m} x_j E_j' \frac{M_{ji}(0)}{\Delta(0)} \quad (3)$$

$\Delta(0)$ and $M_{ji}(0)$ are the determinant and cofactor of (j,i)-th element of unperturbed coefficient matrix [C] respectively. x_i is the exact value of fractional changes in permittivity of the model cells with respect to saline water.

$$x_i = (\varepsilon_{model}-\varepsilon_{homo})/(\varepsilon_{homo}-1)$$

where ε_{homo} and ε_{model} are the complex permittivity of i-th cell of homogeneous medium and experimental model respectively. Here m does not signify total number of cells in the target area rather number of cells illuminated by k-th transmitting beam. So, if i-th cell is outside the coverage area of k-th transmitter, at the starting of iteration in Eqn. 3,$E_i=E_i'=0$, and then incremental field at the i-th cell will depend only upon the fields for cells, those are under the coverage area of transmitter k. This procedure is repeated for rest of the transmitter positions. For each time, iteration is performed with new value of $E'_i=(E_i + \Delta E_i)$ and continued until the difference between two successive values of incremental fields (ΔE_i) for all cells become less than 0.1% of that incremental field. Then the change of fields at the receiver location (for transmitting beam k) is obtained by the equation:

$$\Delta E_R(k)= \sum_{j=1}^{m} x_j E_j' \frac{M_{j,R}(0)}{\Delta(0)} \quad (4)$$

Since x_i =0 for all receiver cells as they are located in saline water region.

Therefore, measured field at the receiving point in presence of the model will be obtained after adding ΔE_R with field at the same receiver location for the same transmitting beam in absence of the model. The same procedure is repeated for 24 transmitter positions to simulate the measured data required for tomographic imaging at a frequency of 1 GHz.

The difference of homogeneous field and perturbed field is the measure of requisite reconstructed complex permittivity value. This can be written as :

$$E_{Rml}(k)-E_{Rol}(k)= \sum_{j=1}^{m} x_j E_j' \frac{M_{j,R}(0)}{\Delta(0)} \quad (5)$$

Where $E_{Rml}(k)$ and $E_{Rol}(k)$ denotes the scattered field intensity at the l-th receiver location for the k-th beam in the inhomogeneous and homogeneous numerical model respectively and x_j is the requisite fractional change of complex permittivity with respect to the homogeneous medium water (76-j40). If there are k=1,2,…q numbers of beam passing through a particular cell, then from a set of q number of equations, the values of (x_j) can be calculated by using Eqn. (5) and SIRT technique. The same procedure is adopted for all the cells one by one in the target region.

Here it is assumed that the beam axis of the k-th beam passes through the j-th cell and all the cells contained within its beam width are equally responsible in producing some change at the l-th receiver location. All other rays passing through that cell are examined one after another and resultant correction is the average of all that obtained from different rays.

The iteration is continued until minimum rms deviation δ of the theoretical output field from the estimated one corresponding to different rays is obtained [6].

3. Comparative study between existing field measurement algorithm and its modified form

3.1. Numerical model

A semi human-sized model of 360 cells, each of 1 sq. cm. in area is chosen for verifying existing field measurement [6] and modified field measurement technique on Exact SIRT algorithm [6]. It is a complex biological model consisting of different internal structures having complex permittivity identical to those observed in different human organs viz. kidney (48-j12), muscle (50-j23), muscle type material (40-j23) and fat (25-j5). The model is surrounded by saline water region having 340 cells, each of same 1 sq. cm. area. The total area of model and saline water region is 28x25 sq. cm.

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The model is illuminated by 15x15 quarter wave dipole array antenna shown in the figure 3 with a beam width of 6^0 operating at 1 GHz [5].20 half wave dipoles are used as receivers and placed at the opposite side of the transmitting antenna. To reduce the antenna length and multipath propagation exterior to the target, the transmitting antenna, receiving antenna and the biological target should be immersed in saline water. Wavelength in this medium is reduced to 3.14 cm due to large dielectric constant of value76 in saline water. This also imposes impedance matching at the water target interface as water is the primary composition of the biological medium.

Due to large attenuation in water the target should be placed in the reactive zone of the array. As a result of which the radiation by elements of the array are not parallel to each other and hence are not in phase at a point on the axis perpendicular to array plane due the path difference. Hence amplitude and phase conjugation is highly required and this is realized by placing the array antenna in a spherical surface with focal length of 50 cm.

3.2 Figures and Tables

Numerical calculations are simulated using Force 209 FORTRAN [11] and depicted using colour gradation scale

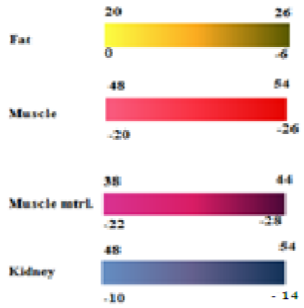

Figure 1: Gradation scale used for the imaging

I. Reconstruction of normal model

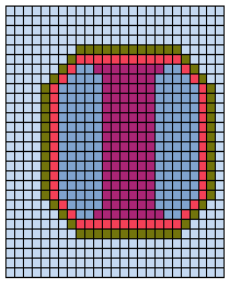

Figure 2.1

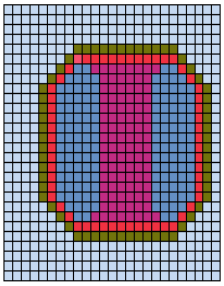

Figure 2.2

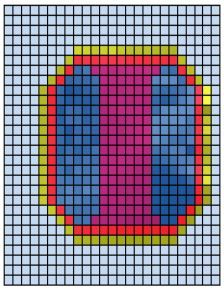

Figure 3.1

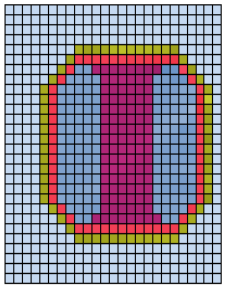

Figure 3.2

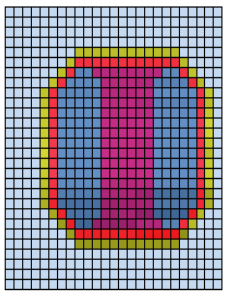

Figure 4.1

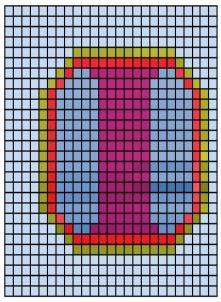

Figure 4.2

Fig. 2.1 & Fig.2.2: Real and imaginary values of complex permittivity for normal Model respectively; Fig.3.1 & Fig.3.2: reconstructed real and imaginary values of complex permittivity for normal model respectively (using previous field measurement technique); Fig.4.1 & Fig.4.2: reconstructed real and imaginary values of complex permittivity for normal model respectively (using modified field measurement technique).

II. Reconstruction of diseased model(Method –I)

The model under study is the same as that considered in earlier case, except its kidney region is affected by some disease and hence characterized by a different value of complex permittivity (52.8-j13.2) [12] where as for normal kidney it is assumed as (48-j12).

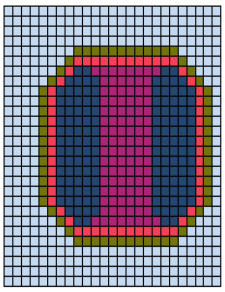

Figure 5.1

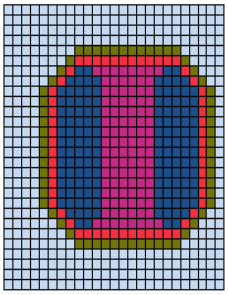

Figure 5.2

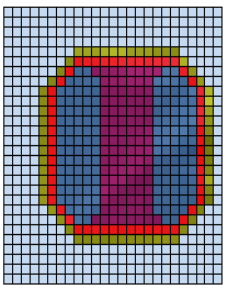

Figure 6.1

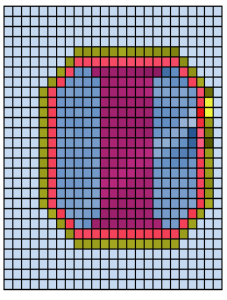

Figure 6.2

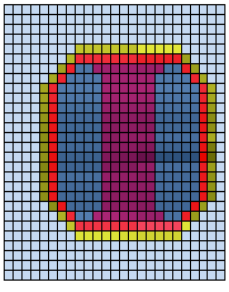

Figure 7.1

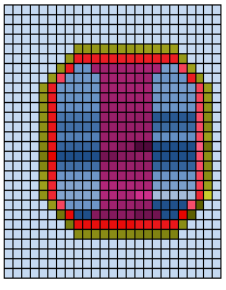

Figure 6.2 Figure 7.2

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Fig.5.1 & Fig.5.2: Real and imaginary values of complex permittivity for diseased Model respectively; Fig.6.1 & Fig.6.2: reconstructed real and imaginary values of complex permittivity for diseased model respectively (using previous field measurement technique and method-I); Fig.7.1 & Fig.7.2: reconstructed real and imaginary values of complex permittivity for normal model respectively (using modified field measurement technique and method-I).

III. Reconstruction of diseased model(Method–II)

Though the reconstructed image obtained by Method-I indicates the location of a diseased organ, a more effective procedure for studying diseased organ will be to perform iteration on this suspected organ only assuming other organs are in their normal state.

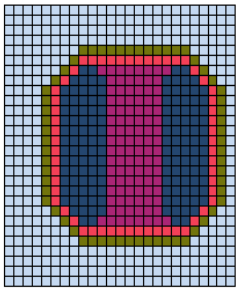

Figure 8.1

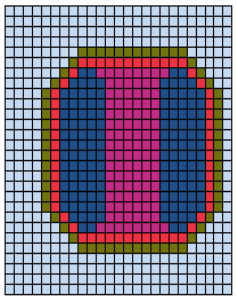

Figure 8.2

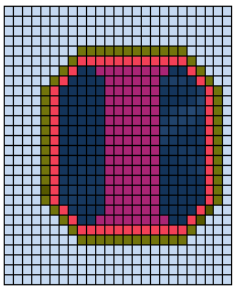

Figure 9.1

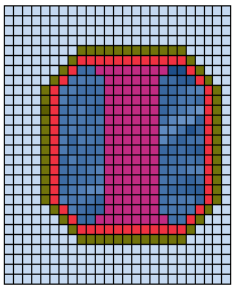

Figure 9.2

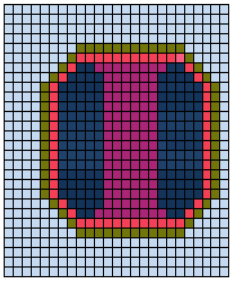

Figure 10.1

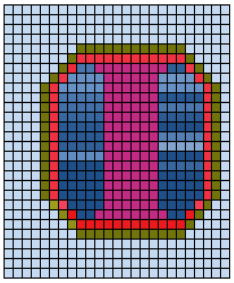

Figure 10.2

Fig.8.1 & Fig.8.2: Real and imaginary values of complex permittivity for diseased model respectively; Fig.9.1 & Fig.9.2: reconstructed real and imaginary values of complex permittivity for diseased model respectively (using previous field measurement technique and method-II); Fig.10.1 & Fig.10.2: reconstructed real and imaginary values of complex permittivity for diseased model respectively (using modified field measurement technique and method -II)

TABLE I
Average values of reconstructed complex permittivity of different organs of normal model

Different Organs of Model	**Average Values of Complex Permittivity of Different Organs**		
	Normal Model	**Reconstructed Normal Model**	
		Using Previous Field Measurement Technique	**Using Modified Field Measurement Technique**
Fat	25-j5	22.43-j3.00	22.57-j3.12
Muscle	50-j23	51.15-j23.82	51.28-j23.87
Muscle material	40-j23	39.60-j23.82	39.49-j23.87
Kidney	48-j12	**48.77-j11.13**	**48.61-j11.16**
Water	76-j40	76-j40	76-j40

TABLE II
Average values of reconstructed complex permittivity of different organs of diseased model (Method-I)

Different Organs of Model	**Average Values of Complex Permittivity of Different Organs**		
	Diseased Model	**Reconstructed Diseased Model(Method-I)**	
		Using Modified Field Measurement Technique	**Using Modified Field Measurement Technique**
Fat	25-j5	23.90-j3.49	22.72-j3.92
Muscle	50-j23	52.63-j24.24	51.90-j24.68
Muscle material	40-j23	41.29-j24.24	41.02-j24.68
Kidney	52.8-j13.2	**50.49-j11.49**	**50.30-j11.99**
Water	76-j40	76-j40	76-j40

TABLE III
Average values of reconstructed complex permittivity of different organs of diseased model (Method-II)

Different Organs of Model	Average Values of Complex Permittivity of Different Organs		
	Diseased Model	Reconstructed Diseased Model(Method-II)	
		Using Previous Field Measurement Technique	Using Modified Field Measurement Technique
Fat	25-j5	25-j5	25-j5
Muscle	50-j23	50-j23	50-j23
Muscle material	40-j23	40-j23	40-j23
Kidney	52.8-j13.2	**53.98-j12.44**	**53.83-j12.44**
Water	76-j40	76-j40	76-j40

4. Conclusion

The reconstructed image of normal model obtained by using modified field measurement technique is slightly better (average accuracy 99.89%) than that obtained by earlier field measurement technique (average accuracy 99.75%).

In case of diseased kidney model the real part of the reconstructed images obtained by using previous field measurement technique and with the proposed one show some deviations of complex permittivity from their normal values which create an erroneous suspense of being attacked by some ailment. But, now, difficult to accurately locate the region from where the disease originates. The reconstructed image for imaginary part of diseased kidney region obtained by using modified field measurement technique is able to indicate the affected portion, but not so accurate because complex permittivity of other region also deviates from their normal values due to the averaging effect of SIRT method itself.

The reconstructed image obtained by using exact algorithm method-II has been improved with modified field measurement technique showing better resemblance with the diseased model and appears to be very promising for detection of diseased portion in its early stage even in larger model with large perturbation (not more than 20%).

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