CHAPTER 7

Conclusion and future directions

7.1 Introduction

The attempt to find out the internal structure of objects using electromagnetic waves is an important aim of scientists in many disciplines ranging from medical diagnostics to non destructive testing. These problems involve the estimation of certain quantities such as dielectric permittivity, conductivity etc based on measurement of the scattered fields. The inverse problem of electromagnetic imaging is highly non linear and the nonlinearity increases with the dielectric contrast and size of the scatterer, as well as the frequency of illumination. These inverse problems are ill-posed and the ill-posedness increases when only a limited angle measurement of the scattered data is possible, as in the case of imaging buried objects. Therefore the electromagnetic inverse scattering problem is characterized by multiple minima. Thus any procedure to solve the inverse problem of electromagnetic imaging is liable to get trapped in local minima. The computation per iteration for finding the solution of the inverse scattering process is of the order of $N^3$ where $N$ is the number of unknowns of the inverse scattering process. Thus algorithms designed for computing the solution of the inverse
scattering problem of electromagnetic imaging are beset with convergence and computational issues.

The thesis focused on methods for improving the computational and convergence issues of inverse scattering algorithms employed for electromagnetic imaging.

A multi-scale frequency hopping technique was proposed for the purpose of obtaining globally convergent solutions using any deterministic iterative procedure. Since the deterministic procedures employ linearized search methods to minimize a cost functional, they are liable to get trapped in local minima. The Distorted Born Iterative method and the Newton Kantarovich method were employed for the deterministic iterations in this work. The strategy is independent of the exact deterministic search technique employed. The multi-scaled frequency hopping technique employed a multi-resolution search at a frequency hop for the solution of the inverse scattering problem of electromagnetic imaging. The stability of the solution is larger at a coarser sampling rate. Hence its non uniqueness is less prominent at a lower sampling rate. This solution was taken as the starting point for iterations at increasing sampling rates. Thus the multi-resolution strategy will be less prone to local minima problems than fixed grid methods. However the employment of the cost functional may again introduce local minima. Therefore the multi-scaling strategy was combined with the frequency hopping method suggested by W C Chew et al. The combined strategy was tested on synthetic data as well as experimental data provided by the Centre Commun de Ressources Micro-ondes (CCRM) of Marseille France. The results were compared against those obtained using frequency hopping alone. The proposed strategy yielded results that were closer to the ground truth and were
found to be better localized in the imaging domain. It was also observed that the total computations per iteration were also significantly reduced. This is attributed to the fact that the multiscaling strategy at the lower frequencies succeeded in providing a better initial estimate for the iterations at the higher frequencies for this object, than when the solution was computed at the finest scales alone.

The Degree of symmetry formulation was introduced in Chapter 5. The investigation domain where the scatterer is searched for has to be sufficiently large to include all possible locations of the scatterer. However when the investigation domain is large, the number of unknowns of the inverse scattering problem of electromagnetic imaging increases and a deterministic search to image the scatterer may fail to reach a convergent solution. The total computation time also increases when the number of elements to be reconstructed increases. It was observed that the symmetry of the measured scattered field vector could be used to localize the scatterer in the investigation domain when the scatterer was symmetric, leading to the D.O.S formulations. Synthetic scattered field data was generated to verify the applicability of the formulations. A Probabilistic neural network, trained with the D.O.S vectors, classified the scatterer as belonging to a significantly reduced investigation domain. The entire measured scattered field data was therefore available for the reconstruction of fewer number of investigation domain elements. Thus the degrees of freedom of the inverse scattering problem were reduced, which aided the global convergence of the iterations. The D.O.S formulations also resulted in more robust reconstructions of the scatterer. The formulations were also applied to the problem of
encouraging results.

An experimental setup was designed for performing the verification of the D.O.S formulations. The experimental results confirmed the applicability of the formulations.

7.2 Shortcomings and Sources of Error

The sources of error and accuracy conditions encountered in the work are detailed below.

- The Degree of Symmetry formulation is strictly a two dimensional formulation. The two dimensional model where a 2-D scatterer is illuminated by a TM polarized source, which reduces the scattering equations to scalar ones, has to be applicable. Therefore the D.O.S formulations cannot be applied for the reduction of imaging domain when the scatterer is 3 dimensional.
- Modeling the incident field with a line source: The experimental verification employed a dipole antenna for generating the incident field. More accurate representations should use the field expressions of dipoles, which however, would make the computations more involved.
- Reflections from the measurement setup: Ideally the measured scattered field should be contributed by the scattering from the dielectric object whose cross section is to be profiled. To minimize the scattering from the experimental setup, it is built exclusively using PERSPEX, which is nearly lossless.
Less than ideal performance of the anechoic chamber: The non-ideal performance of the anechoic chamber would mean that reflections from the chamber walls also have to be factored in.

7.3 Possible Directions

Some of the possible extensions that maybe pursued are listed below

- Stochastic search algorithms are extremely slow compared to deterministic search algorithms even though they converge globally and hence were not used in this work. It is suggested that stochastic methods such as Genetic algorithms or Simulated annealing be employed, at least at coarse resolutions, to yield more convergent solutions.

- Variable grid methods such as non-linear multi-grid relaxation based methods maybe tried out for multi-resolution search of the solution of the inverse scattering problem of electromagnetic imaging.

- Proper selection of the regularization parameter is critical for the quality of the electromagnetic inverse scattering solution. Zeroth order regularization was employed in this work, with an empirical formula used for computing the value of the regularization parameter. More sophisticated methods based on the stochastic model of the reconstruction process maybe tried.
Reference

1. Agilent 8714 ET Network Analyzer operating and programming manual