Analysis of Inverse Source Algorithms for Different Propagation Mechanism

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***Abstract*—. The main aim of the study is to analyze the effect of the inhomogeneous medium to the inverse algorithm and compensation of the results via the inclusion of numerically obtained Green's function of the propagation medium. Here, MUSIC based inverse algorithms are applied for the localization of objects in two-dimensional complex propagation region. The propagation medium is locally modeled using FDTD method. The scattered fields due to the object are obtained for multiple observation points in the required frequency band through two FDTD runs for each single source.**

Keywords—Inverse source problem, MUSIC, FDTD

I. INTRODUCTION

The radiowave propagation in inhomogeneous medium is important for many physical applications such as navigation, communication systems, radar systems as well as military applications. There are both frequency domain and time domain methods for the electromagnetic wave propagation in complex medium such as FDTD (Finite Difference Time Domain), Mom (Method of Moments), FEM (Finite Element Method) [1-3]. Although these methods can also be applied for radiowave propagation analysis for long range applications with some suitable modifications, parabolic equation (PE) solution based techniques are more generally preferred for the sake of reduction of the computation complexity in such problems.

Electromagnetic inverse source problem deals with detecting source from measured scattered field. The detection of the unknown dielectric/conducting object from scattered field is considered as an inverse source problem and has a wide range of applications, such as radar imaging, microwave tomography etc. High resolutioned subspace methods, such as Time Reversal MUSIC (TR-MUSIC)[4,5] and ESPRIT algorithm [6] have been proposed to solve inverse source problems. These algorithms require the knowledge of the background Green's function. For inhomegeneous media, since analytical form of Green's function does not exist, it has to be calculated numerically. Due to complexity of the calculation, the inhomegeneity is usually ignored in the inverse source algorithms which may cause false detection. In the practical applications the effect of the complex propagation medium should be considered rigorously.

In this study, the analysis of MUSIC-based inverse source algorithm for different propagation scenarios is considered. Here, the main aim is to show the deterioration of the reconstructions in the vicinity of irregular terrain as well as to improve the localizations by the inclusion of the numerically calculated Green function values in the inverse algorithm. Here, first the TR-MUSIC algorithm is briefly explained in Section II and then the analysis procedure of the inverse algorithm for different propagation scenarios with irregular terrain is outlined for the scattered field and Green's function values obtained through FDTD in Section III.

II. TIME-REVERSAL MUSIC ALGORITHM

In time-reversal imaging, the unknown object is illuminated with N transmitters and the backscattered fields measured at N receivers yield a N by N multistatic response matrix E, see Fig. 1. The multistatic response matrix is then used to compute the time-reversal matrix $A = E^{\dagger}E$. It is known that the eigenvectors of A are related with the location of the object in a manner that point source response of the object location span the signal subspace of A [4,5]. Since the time-reversal matrix is self-adjoint, its noise subspace is orthogonal to the signal subspace. TR-MUSIC exploits this property to determine the support of the object. To this aim, the point source response of each point in the search domain at the measurement line, that is to say, the Green function of the background medium G_z, is considered as a steering vector. If the steering vector is in the noise subspace then the corresponding location does not belong to the support of object. To visualize the object location, the indicator function is defined as a projection of the steering vector on the noise subspace of A, i.e. P_{noise} as:

$$I(z) = \frac{1}{\|P_{noise}G_z\|}$$

The indicator function takes relatively high values for points which belong to the object compared to the points which does not belong to the object. By plotting the indicator function for whole search domain, the support of the object can be visualized. Notice that the success of the method mainly depends on the accuracy of the background Green function. Therefore, the effect of inhomogeneity of the background medium should be included in Green's function calculation. Otherwise, the object may not be detected.

III. TR-MUSIC AND FDTD

In this study, the two-dimensional propagation medium, which in general can include perfectly conducting or lossy dielectric irregular terrain with inhomogeneous atmosphere, is locally modeled using 2D-FDTD method. First, the time domain scattered fields due to the object and propagation medium are accumulated for multiple observation points in the required frequency band through two FDTD runs for each single source (Fig. 1). Then the frequency response of the scattered field at each observation point is obtained via off-line Fourier transform and the data are used in TR-MUSIC algorithm.

The main problem in such a scenario is the Green's function values required at measurement line for the discrete points (line sources) in reconstruction region, D, where the object is assumed to be located. Since the number of discrete observation points is usually less than the number of discrete points in the reconstruction region, the symmetry condition of the Green's function is used and the location of the source points and measurement points are reversed.

The time domain Green's function values for the propagation medium are accumulated in the reconstruction region without the object for reversed sources on the measurement line and off-line Fourier transform is applied. The required frequency domain Green's function values for inhomogeneous medium are then supplied in the inverse algorithm.

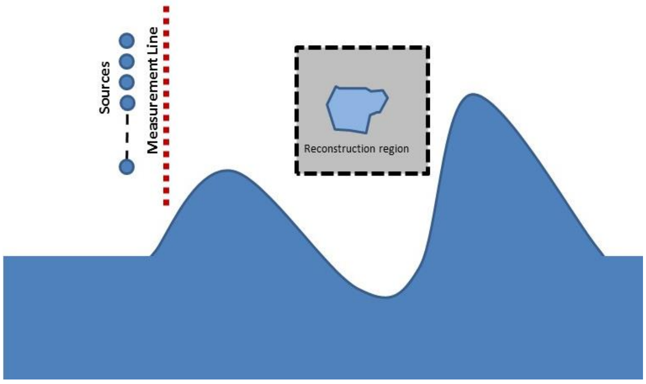

Figure 1. Proplem configuration

IV. NUMERICAL APPLICATIONS

In order to test the procedure outlined in Section III, a simple two-dimensional PEC terrain profile is considered as the propagation background, where the required Green's function is analytically calculated. The FDTD computation space is bounded by 16-layers PML (perfectly matched layer) and the scattered field at the desired frequency is computed. The Green's function values are also numerically calculated as explained in Section III.

As shown in Fig. 2, The PEC object and reconstruction region are taken to be equi-center squares with $0.1m$ and $1m$ side lengths, respectively. The horizontal distance between the measurement line and the center of the square is 3m, while the line of sources which illuminate the object is located with 4m and 1m horizontal distances between center of the square and measurement line, respectively.

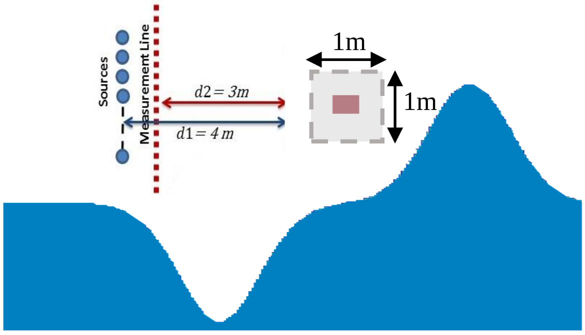

Figure 2. Simulation parameters and terrain profile with scattering object. Reconstruction region: 1m x1m. Source-Object distance: 4m. Measurement-Object distance: 3m.

In the following implementations a first order differentiated Gaussian time-domain pulse is applied to each source with a 350 MHz frequency band. In the simulations, the number of discrete sources and measurement points are set to $N_{sources}$=40 and N_{obs}=58. The FDTD mesh is square with a side-length of $0.025m$. The reconstruction frequency is taken as 300MHz for the analysis. TR-MUSIC is first applied by using the free space Green's function, where the result in Fig. 3 shows that the inverse algorithm fails to reconstruct the object in this case. Nevertheless, applying the background Green's function to the algorithm permits the identification of the object which appears at the center of the reconstruction region as shown in Fig. 4. Hence, the choice of the Green's function as the background Green's function of the propagation space is the key element in the reconstruction process of the inverse algorithm.

The tests were extended to include two objects in the reconstruction region. The geometry of the problem is shown in Fig. 5, where the two objects are positioned such that the distance separating them is equal to λ (1m), at (centered at: x_1: 4.5 m, y_1: 5 m) and (centered at: x_2:5 m, y_2: 5.5 m) respectively. The reconstruction region is chosen in a way to center and include both objects. The reconstruction results are shown in Fig. 6.

It is observed throughout this set of simulations that the results obtained by reconstruction using the TR-MUSIC are satisfactory with background Green function. This procedure can be tested for more complex models with multiple objects and different irregular terrain profiles to show the effect of propagation mechanisms in the inversion algorithm.

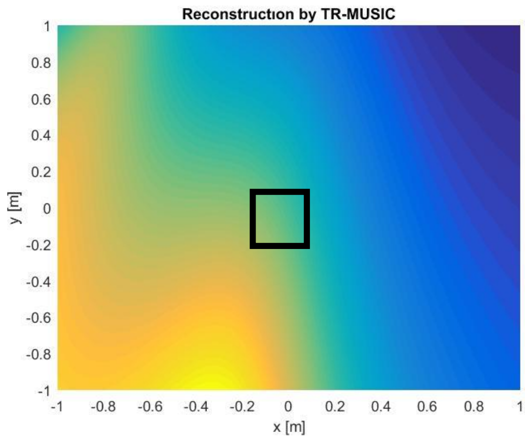

Figure 3. Reconstructed object by using free space Green's Function; 40 sources, 58 observation points, a freequency of 300MHz. Solid line: exact boundary of the object.

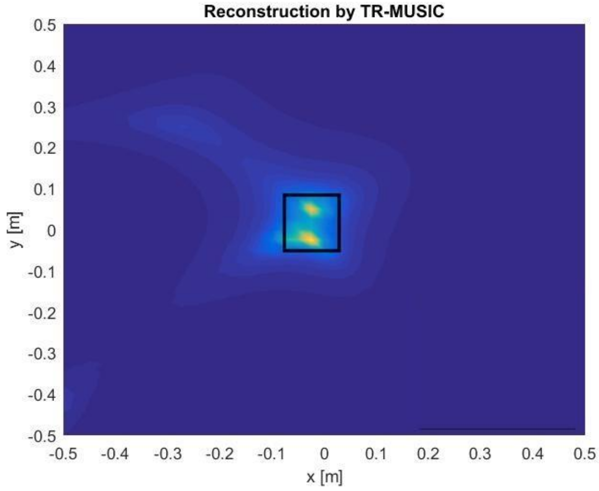

Figure 4. Reconstructed object by using by using the background Green's function; 40 sources, 58 observation points, a freequency of 300MHz and by using the background Green's Function. Solid line: exact boundary of the object

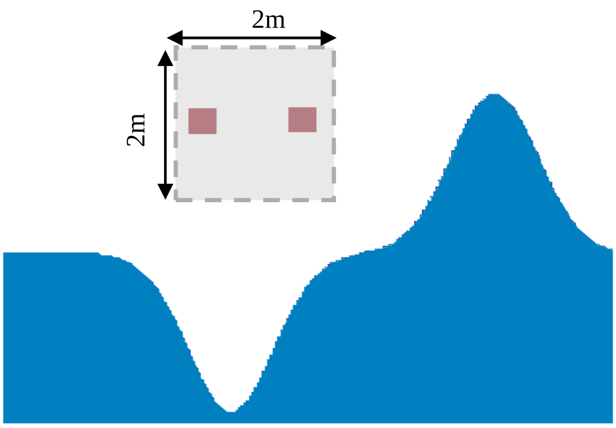

Figure 5. Simulation parameters and terrain profile with double scattering objects. Reconstruction region: 2m x 2m. Source-Object distance: 4m. Measurement-Object distance: 3m.

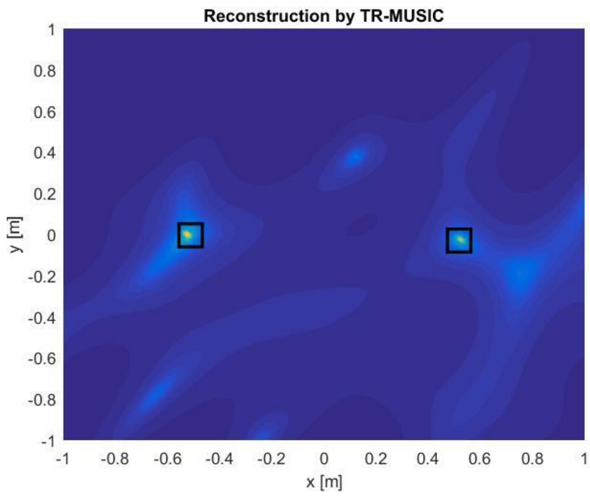

Figure 6. Reconstruction region; 40 sources, 58 observation points, a freequency of 300MHz and by using the background Green's Function. Solid lines: exact boundaries of the objects

V. CONCLUSIONS

In this study, the direct problem related to the electromagnetic scattering from objects located in a complex medium is solved via 2D-FDTD to mimic real measurements required for the inverse algorithm, together with numerical computation of Green's function values of the inhomogeneous environment. TR-MUSIC is applied to reconstruct the unknown object. It is also shown that the use of the homogeneous medium Green's for the inhomogeneous medium leads to the failure of reconstruction. The proposed approach can be used more complicated medium configuration and also be generalized for vectorial three dimensional problems.

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