Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

Int. J. Electron. Commun. (AEÜ) 64 (2010) 142 – 151

International Journal of Electronics and Communications AEÜ

www.elsevier.de/aeue

Shape reconstruction of 3D metallic objects via a physical optics distributional approach

Raffaele Solimene[a], Aniello Buonanno[a], Rocco Pierri[a], Francesco Soldovieri[b,*]

[a]*Dipartimento di Ingegneria dell'Informazione, Seconda Università di Napoli, Via Roma 29, I-81031 Aversa, Italy*
[b]*Istituto per il Rilevamento Elettromagnetico dell'Ambente, Consiglio Nazionale delle Ricerche, Via Diocleziano 328, I-80124 Napoli, Italy*

Received 30 June 2008; accepted 19 November 2008

Abstract

The problem of determining the shape of 3D perfect electric conducting (PEC) objects starting from the scattered far field under the incidence of plane waves with a fixed angle of incidence, varying frequency and two orthogonal polarizations is dealt with.

Two strategies of reconstruction are presented and compared. In particular, in the first solution strategy the data acquired at the two polarizations are singularly exploited to achieve two different reconstructions and the object surface is then obtained as their "union". In the second one, all the data (i.e., for both the adopted polarizations) are simultaneously exploited to obtain the reconstruction.

In all the cases, by adopting a distributional formulation for the unknown of the problem and thanks to the exploitation of the Kirchhoff approximation, the problem is cast as a linear inverse one and the solution is made stable by adopting a regularization scheme based on the truncated singular value decomposition (TSVD).

The reliability of the inversion approach is tested with synthetic data against model error and noise on data.

Keywords: Inverse scattering problems; Shape reconstruction; Kirchhoff approximation

1. Introduction

In this contribution we consider the electromagnetic inverse scattering problem of localizing and reconstructing the shape of unknown perfect electric conducting (PEC) objects from scattered field observations in a three-dimensional (3D) geometry. Such a problem is of relevant interest for different applications; for example, ground penetrating radar [1], nondestructive testing or evaluation of materials [2], medical imaging [3], just to mention a few.

Imaging PEC objects is a typical electromagnetic inverse scattering problem and several reconstruction approaches have been developed, which can be coarsely classified into two groups according to whether the nonlinearity of the formulation is preserved or not.

Methods accounting for the nonlinearity generally cast the reconstruction as an optimization problem where a suitable cost functional has to be globally minimized [4–7]. These methods have a relatively high computational cost, suffer from the false solutions problem when a deterministic gradient-like minimization scheme is employed [4,6], and in some cases require the a priori information about the number of scatterers embedded within the spatial region under test [4,5]. Another class of reconstruction algorithms is based on contour deformation and level set method [7]. Such methods still require to run an iterative minimization algorithm and to solve a forward problem for each iteration

* Corresponding author. Tel.: +39 81 5707999; fax: +39 81 5705734.
E-mail address: soldovieri.f@irea.cnr.it (F. Soldovieri).

1434-8411/$ - see front matter © 2009 Elsevier GmbH. All rights reserved.
doi:10.1016/j.aeue.2008.11.011

step but are more flexible as they do not require the a priori information on the number of scattering objects.

Finally, among the methods which do exploit the exact model of the scattering phenomenon the so-called qualitative methods are worth mentioning [8]. These methods build up an indicator function computed for each point within the investigated spatial region; then the scatterers' supports are identified because the indicator function assumes very different value (in norm) depending whether it is evaluated for points lying inside the scatterers' supports or not. Even though they are computational effective, they work only when data are collected under different incident field impinging directions and thus the necessity of a multi-view/multistatic measurement configuration arises.

The problem at hand can be drastically simplified if the Kirchhoff approximation is adopted to describe the electromagnetic scattering. In fact, in this case the Kirchhoff approximation along with a suitable representation of the unknown objects' contours allows to cast the problem as a linear inverse scattering one [9,10]. In this way, a reliable inversion algorithm, which is not affected by the false solutions problem, and which is computationally effective, can be devised. Moreover, when the aim is to obtain "only" a "qualitative" reconstruction of the scatterers (in terms of their geometrical features) it has been shown that linear inversion schemes work well beyond the limits of the forward models upon which they are based [11].

It is worth remarking that, differently from the 2D case, when a 3D geometry is considered, computationally effective inversion schemes are particularly appealing. Accordingly, here we exploit a linear inversion algorithm based on the Kirchhoff [9–11] approximation while the objects' surfaces are represented as the support of delta-distributions [10,11]. This allows to cast the problem as the inversion of a linear integral relationship that is performed by means of the truncated singular value decomposition (TSVD) scheme [12].

Accordingly, the present contribution can be considered as the extension to the 3D case of the approach presented in [10,11] for the 2D and scalar case. It is worth noting that, for the 3D inverse scattering problem at hand, the unknown to be reconstructed has a vector nature since the current over the scatterers' surfaces, induced by the impinging fields, is a vector. This situation is different from the problem of reconstructing dielectric objects where the unknown is given in terms of the so-called contrast function which is a scalar function that accounts for the relative difference between the electromagnetic properties of the targets and the ones of the host medium [13]. However, by analyzing the mathematical nature of the inverse problem at hand it is possible to properly select the components of the scattered field so that the problem can be still cast as a scalar linear inverse one. This will lead to clear advantages in terms of the computationally effectiveness of the overall inversion procedure.

In particular, the paper is concerned with the problem of the shape reconstruction of 3D objects starting from the knowledge of the scattered field over a bounded domain in far zone. The incident field is provided by plane waves having fixed direction of incidence, varying frequency and two orthogonal polarization; therefore, here we consider a multi-frequency/single-view measurement configuration.

Two strategies of reconstruction will be presented and compared. In particular, in the first solution strategy the data acquired at the two polarizations will be singularly exploited to achieve two different reconstructions and the object surface will be then obtained as their "union". In the second one, all the data (i.e., for both the adopted polarizations) will be simultaneously exploited to obtain the reconstruction.

The inversion approaches will be checked against synthetic data that are generated independently from the model used to develop the inversion algorithm by means of a finite element method (FEM) based forward solver. Also the effect of noise on data will be considered.

The paper is organized as follows. Section 2 is devoted to show the formulation of the problem by reporting the linear integral equations upon which the inverse problem is based. In Section 3, the inverse problem is formulated under simplified assumptions and two solution strategies are described. In Section 4, the two solution strategies are tested with synthetic data and also the effect of the noise on data is investigated. Finally, conclusions follow.

2. Formulation of the problem

The geometry of the problem is depicted in Fig. 1. 3D PEC scatterers are located in the free space within the investigation domain D and we denote by S the union of the surfaces of N_C scattering objects.

The investigation domain D is assumed to be centered at the origin of the reference frame and equal to $D = [-x_M, x_M] \times [-y_M, y_M] \times [-z_M, z_M]$.

The investigation domain is illuminated by y-polarized or x-polarized multi-frequency plane waves having common incidence direction along the z-axis, i.e., the incident field is

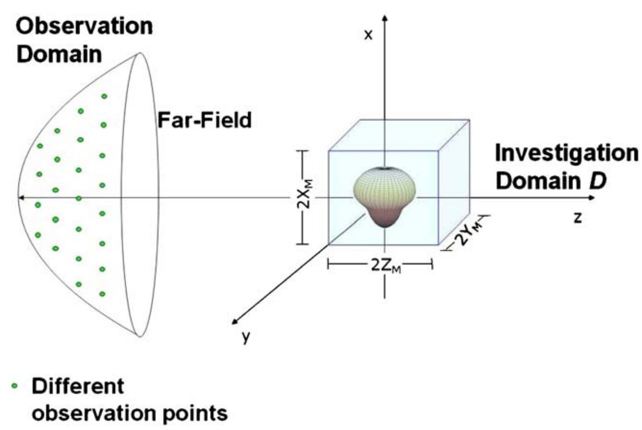

Fig. 1. Geometry of the problem.