UNIVERSITY
OF TRENTO

DEPARTMENT OF INFORMATION AND COMMUNICATION TECHNOLOGY

38050 Povo – Trento (Italy), Via Sommarive 14
http://www.dit.unitn.it

MULSTICALING RECONSTRUCTION OF METALLIC TARGETS FROM TE AND TM EXPERIMENTAL DATA

R. Azaro, M. Donelli, D. Franceschini, A. Massa,

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Multiscaling Reconstruction of Metallic Targets from TE and TM Experimental Data

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The non invasive imaging of unknown objects is of particular interest in several industrial applications. In this letter, an iterative multi-resolution strategy (IMRS) is applied to the reconstruction of metallic targets from experimental measurements. A representative test case is presented for evaluating the effectiveness of the IMRS in dealing with real data collected in a controlled environment in both TE and TM illuminations.

Introduction: Methodologies for the reconstruction of unknown objects in a non-invasive fashion are appealing in many industrial applications [1], [2]. The methods that exploit microwaves can be used to obtain a quantitative description of dielectric and conductivity profiles by means of a processing of the field data collected away from the scatterers.

Because of the intrinsic ill-posedness, the arising inverse scattering problems are usually reformulated as optimization ones (see [3], [4] and the references therein) by defining a suitable cost function that estimates the fitting with measured scattered field data.

In this context, the IMRS has been recently proposed in order to exploit in an efficient way the limited information [5] collected through the scattering experiments ([6], [7]). Such a methodology demonstrated its effectiveness in terms of spatial resolution in correspondence with a transverse magnetic (TM)

illumination. However, no experiments have been performed in the transverse electric (TE) case.

For completeness, this letter presents the results of the reconstruction of a metallic target from experimental data aimed at validating the robustness of the approach in a real controlled environment comparing two type of polarization (i.e., TM vs. TE). Such a test plays a relevant role in order to further investigate on the range of applicability of the IMRS in practical applications.

Problem formulation and Solution Strategy. An unknown object located in a bounded investigation domain D_I is successively illuminated from V different directions with a monochromatic electric field ($\underline{E}^v_{inc}(\underline{r})$, $v = 1,...,V$) at a fixed angular frequency ω. The total electric field, $\underline{E}^v_{tot}(\underline{r})$, inside and outside the scatterer satisfies the following integral equation

$$\underline{E}^v_{tot}(\underline{r}) = \underline{E}^v_{inc}(\underline{r}) + (k_0^2 + \nabla\nabla\cdot)\int_{D_I} \underline{\underline{G}}(\underline{r}/\underline{r}')\tau(\underline{r}')\underline{E}^v_{tot}(\underline{r}')d\underline{r}' \qquad (1)$$

where k_0^2 is the free space wave number, $\underline{\underline{G}}(\underline{r}/\underline{r}')$ is the dyadic Green's function and $\underline{r}'$ denotes a point inside the investigation area D_I. Moreover, $\tau(\underline{r})$ is the object function to be reconstructed and defined as follows

$$\tau(\underline{r}) = \varepsilon_r(\underline{r}) - 1 - j\frac{\sigma(\underline{r})}{\omega\varepsilon_0} \qquad (2)$$

$\varepsilon_r(\underline{r})$ and $\sigma(\underline{r})$ being the relative dielectric permittivity and the conductivity, respectively.

Under tomographic condition, the solution of Eq. (1) simplifies. Moreover, it reduces to a scalar relationship [4] in dealing with a TM illumination or to a

two-component vectorial equation for the TE case [3]. In general, such relationships are exploited to define a suitable functional to be minimized in order to retrieve the problem unknowns ($\underline{\underline{E}}^{v}_{tot}(\underline{r})$ and $\tau(\underline{r})$).

In a compact form, the cost function for the TE problem can be expressed in the following way (for the TM case the reader may refer to [6])

$$\Phi_{TE} = \frac{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{x,scatt}\right] - \left[\hat{E}^{v}_{x,scatt}\right] \right\|^2}{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{x,scatt}\right] \right\|^2} + \frac{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{y,scatt}\right] - \left[\hat{E}^{v}_{y,scatt}\right] \right\|^2}{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{y,scatt}\right] \right\|^2} + \frac{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{x,inc}\right] - \left[\hat{E}^{v}_{x,inc}\right] \right\|^2}{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{x,inc}\right] \right\|^2} + \frac{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{y,inc}\right] - \left[\hat{E}^{v}_{y,inc}\right] \right\|^2}{\sum_{v=1}^{V} \left\| \left[E^{v,meas}_{y,inc}\right] \right\|^2} \tag{3}$$

where the arrays $\left[E^{v,meas}_{x,scatt}\right]$ and $\left[E^{v,meas}_{y,scatt}\right]$ contain the samples of the two components of the scattered field (computed as $\underline{\underline{E}}^{v}_{scatt}(\underline{r}) = \underline{\underline{E}}^{v}_{tot}(\underline{r}) - \underline{\underline{E}}^{v}_{inc}(\underline{r})$) collected in the observation domain (D_M), while $\left[E^{v,meas}_{x,inc}\right]$ and $\left[E^{v,meas}_{y,inc}\right]$ the values of the incident field available in D_I. Moreover, the symbol "^" denotes the quantities computed through Eq. (1) starting from the estimate of $\underline{\underline{E}}^{v}_{tot}(\underline{r})$ and $\tau(\underline{r})$.

As far as the estimation of $\underline{\underline{E}}^{v}_{tot}(\underline{r})$ and $\tau(\underline{r})$ is concerned, the proposed IMRS aims at fully exploiting the limited number of independent data collectable from measurements by properly defining the achievable spatial resolution of the unknown quantities in D_I. In fact, at each step of the iterative process, the reconstruction obtained minimizing Φ_{TE} allows the definition of the region-of-interest (RoI) [7] inside D_I where the object is supposed to be located.

Successively, according to a sort of zooming process, the resolution level is enhanced in the RoI to improve the accuracy of the reconstruction by performing again the minimization of (3). The process terminates when the stationariness criteria defined in [7] hold true.

Numerical Validation: In order to asses the effectiveness of the IMRS in dealing with TE experimental data, the measurements of the field scattered by a rectangular metallic cylinder have been taken into account. Such data have been collected at the Institute Fresnel, Marseille (France) [8] and they are concerned with a TM illumination, too. Fig. 1 shows the anechoic chamber with the 2D bistatic measurement system able to perform multi-view/multi-illumination imaging experiments at different frequencies. Thanks to such an experimental setup, the effectiveness of the IMRS has been evaluated against real targets. Moreover, since scattered data from the same metallic target are available for a TM illumination too, the database allows a comparative study of the IMRS capabilities when TE or TM are used.

More in detail, the scatterer under test is a rectangular metallic target of dimensions $24.5 \times 12.7\, mm^2$ (sketched in Fig. 2) probed with a TM (dataset "*rectTM_cent.exp*") and a TE (dataset "*rectTE_8f.exp*") incident field. The whole set of measurements ($V = 36$ and $M = 49$ sensors) at the frequency $f = 4GHz$ has been processed. As far as the reconstruction of the imaginary part of the object function is concerned, a thresholding to $\xi_{\max} = -10.5$ has been performed when $\mathrm{Im}\{\tau(x,y)\} < \xi_{\max}$. By comparing the plots shown in Fig. 3 (TM-case) and Fig. 4 (TE-case), the actual profile exploiting TM data turns out to be faithfully estimated. Such a behaviour can be related to the

measurement configuration. As a matter of fact, only the electric field component lying in the xy-plane and perpendicular to the radial direction is collected in the TE experiment, while two electric field components are present.

Conclusions: In this letter, the results of the inversion of experimental scattered field data obtained with the IMRS have been presented both for TE and TM polarization. The experiments concerned with a metallic target have shown that the IMRS-TM achieves a more faithful reconstruction with respect to the TE case. Consequently, it turns out that measuring the field component perpendicular to the radial direction is not sufficient for collecting the amount of information needed to satisfactorily solve the TE inverse scattering problem.

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Authors' affiliations:
R. Azaro, M. Donelli, D. Franceschini, and A. Massa (Department of Information and Communication Technology, University of Trento, Via Sommarive 14, 38050 Trento – ITALY)

Corresponding Author
Prof. Andrea Massa
Department of Information and Communication Technology
University of Trento
Via Sommarive 14
38050 Trento
ITALY
E-mail: andrea.massa@ing.unitn.it

Figure captions:

Fig. 1 The experimental setup and the anechoic chamber where the experimental data have been acquired (by courtesy of K. Belkebir and M. Saillard, Institute Fresnel, France)

Fig. 2 Sketch of the reference metallic target and of the acquisition system

Fig. 3 Reconstruction of the rectangular metallic cylinder under TM illumination (Experimental Dataset "*Marseille*")

Fig. 4 Reconstruction of the rectangular metallic cylinder under TE illumination (Experimental Dataset "*Marseille*")

Figure 1

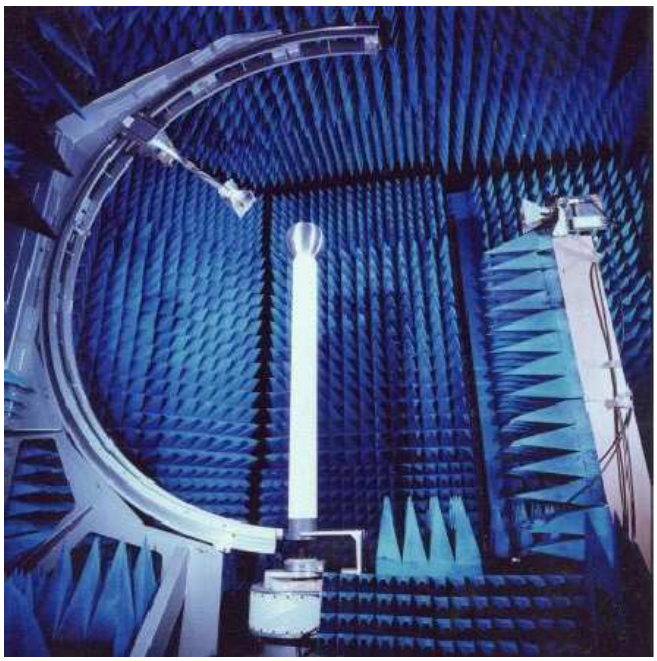


Figure 2

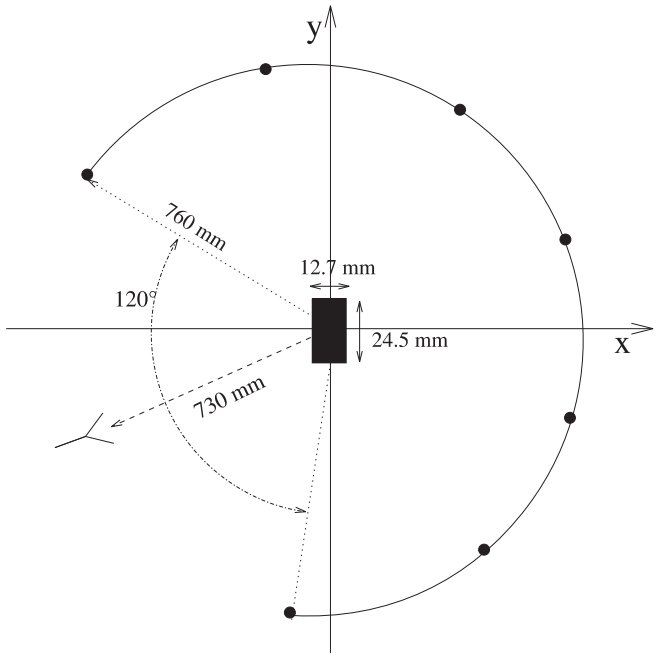
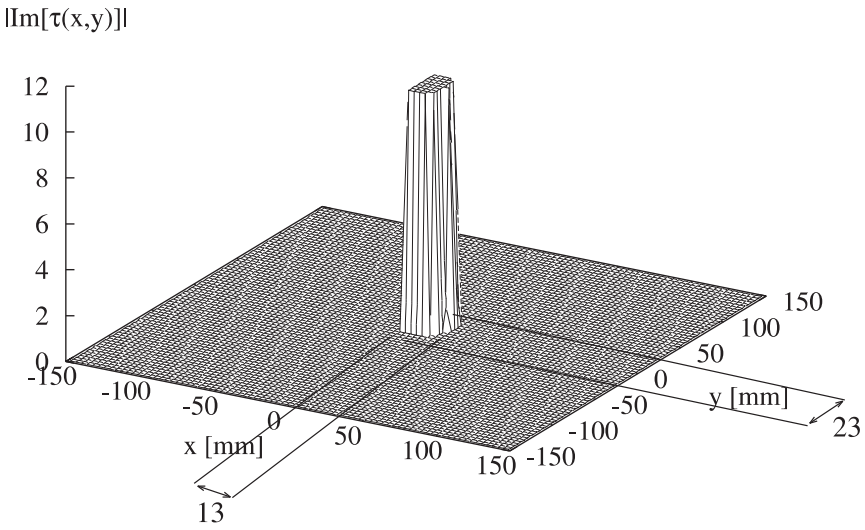


Figure 3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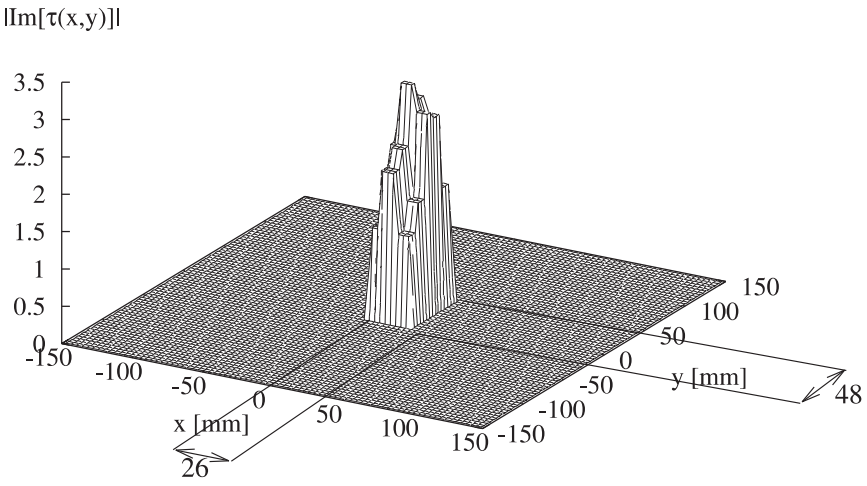
y [mm]
23

Figure 4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