Session 3A4
Microwave Imaging for NDE/NDT Applications

Issues and Problems in 3D Microwave Tomography (and Possible Answers)

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A large number of papers have been published in the last years concerning 2D inverse scattering problems, while contributions to solution of 3D problems are more recent and relatevely few. Needless to say, accurate and numerically efficient solution procedures of 3D vectorial problems is an extremely relavant topic in applied electromagnetics as it would open the way to new exciting applications. On the other hand, well known difficulties arising in inverse scattering problems (ill-posedness, non-linearity) become an even more serious challenge in this context.

In particular, non linearity of the relationship amongst dielectric (and conductive) characteristics and the scattered fields deserves particular attention in setting solution procedures. As a matter of fact, the so called *false solutions* may occur in case gradient based optimization procedures are used. On the other hand, as their computational complexity grows very rapidly with the number of unknowns, global optimization procedures appear not to be viable in 3D problems herein at hand, due to the possibly very large number of unknowns involved.

All the above considerations claim for methods capable of dealing with 3D problems in a reliable and accurate way, while reducing as much as possible the computational costs and storage requirements. Of course, this is not just a matter of optimizing existing tools, but stimulates development of suitable models and inversion tools.

A first interesting result related to these questions has been recently obtained in the 2D scalar problem, by showing the possibility to achieve quite accurate estimation of the support of the unknown targets from the data themselves before actual inversion. Such a circumstance allow to reduce the number of unknowns in the subsequent quantitative inversion, thus allowing increased robustness against false solutions and ill conditioning problems, as well as faster solution procedures.

A second interesting result, again concerning 2D problems, has been recently obtained by means of a simple rewriting of the scattering equations named Contrast Source-Extended Born (CS-EB) model. This latter has been proved to exhibit a reduction of the degree of non-linearity of the relationship amongst parameters embedding dielectric characteristics and scattered fields as compared to the traditional model, thus furtherly increasing robustness against false solutions in the inversion process and computational efficiency.

The good results obtained in these contexts suggest the extension of these tools to the more demanding 3D vectorial case, which is the subject of the present contribution. As it will be shown during the Conference, the extension of the above tools to the 3D case allows to outperform previous inversion schemes, thus providing useful steps towards quantitatively accurate 3D inverse scattering based imaging techniques.

On the Retrieval of Small Electromagnetic 3-D Scatterers via MUSIC

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The contribution focuses onto the identification of a collection of small volumetric scatterers of unknown number and location embedded within a free or half-space medium. Each scatterer has constant yet arbitrary permittivity, conductivity and permeability (perfectly conducting cases follow from infinite conductivity and null permeability). Time-harmonic receivers and sources are used, typically made of planar arrays of electric or magnetic dipole sources and receivers with prescribed polarization(s) set at some distance (not necessarily in the far field) from the collection. This yields the MultiStatic Response (MSR) matrix that is characteristic of the collection for a set of illuminations and observations — times its conjugate-transpose, it is the time-reversal matrix.

The approach aims at fast numbering, accurate localization, and in best case (well-separated in- clusions) at estimates of the electromagnetic and geometric parameters of the scatterers. It is based on MUSIC (MUltiple SIgnal Classification) methodology, enabling us to profit from the eigenvalue structure of the MSR matrix, and it is an involved extension of previous works in 2-D scalar scattering situations, e.g., [1]. Refer also to [2] for original work in the same direction.

The approach is worked out from rigorous asymptotic formulations, vs. average size of the scatter- ers, of the electric and/or magnetic fields (refer to [3] for related material). The expressions are derived from field integral formulations using the Green dyads of the embedding environment. Notice that one is limiting ourselves thereafter to the leading-order terms of the asymptotic expressions which only involve the (static) electric and magnetic polarization dyads associated to the scatterers.

The asymptotic machinery and the MUSIC-based eigenvalue analysis will be summarized, in line with [4] and a forthcoming SIAM paper.

Main emphasis however will be on the numerical study, to illustrate main features for asymptoti- cally exact, severely noisy data, and/or for data calculated from brute-force numerical codes with no embedded asymptotics. Various configurations of the collection and (ellipsoidal) scatterers thereof, and of source and receiver arrays, will be tackled. Particular attention will be on the case of two close-by scatterers for which electromagnetic coupling matters — the asymptotic formulation provides for this coupling via equivalent scatterers. In addition to displaying MUSIC functionals peaked at the locations of the scatterers and pertinent distributions of eigenvalues, fields due to back-propagation of singular vectors onto the embedding space will be exhibited.

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A Bayesian Approach to Microwave Imaging of Hybrid Targets

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We deal with an electromagnetic inverse scattering problem where the goal is to characterize unknown objects from measurements of the scattered fields that result from their interaction with a known interrogating wave in the microwave frequency range. This nonlinear and ill-posed inverse problem is tackled from experimental data collected in a laboratory-controlled experiment led at the Institut Fresnel (Marseille, France), which consist of the values of the time harmonic scattered electric fields measured at several discrete frequencies.

The modelling of the wave — object interaction is led through a domain integral representation of the fields in a 2D configuration, where the fields appear to be radiated by the fictitious Huygens-type sources (or contrast sources) induced within the target by the incident wave and equal to the product of the total field by a contrast function representative of the target physical parameters.

The inverse scattering problem, which consists in retrieving this contrast function from the measured scattered fields, is solved by means of an iterative algorithm tailored to the case of objects made of a known finite number of different homogeneous dielectric and/or conductive materials. The latter a priori information is introduced via a Gauss-Markov field for the distribution of the contrast with a hidden Potts-Markov field for the class of materials in the Bayesian estimation framework. In this framework, we first derive the posterior distributions of all the unknowns and, then, an appropriate Gibbs sampling algorithm is used to generate samples and estimate them.

This algorithm is applied to the inversion of two coupled integral equations formulated in terms of the contrast sources in a way similar to that of the contrast source inversion method [1]. However, let us notice a fundamental difference between the CSI method and the one adopted herein: the former is developed in a deterministic framework and consists in minimizing a two-term cost functional by alternately updating the contrast sources and the contrast with a gradient-based method, whereas the latter is developed in a statistical framework, the contrast being then sought as a Gaussian mixture [2] by means of a hidden Markov model.

We have already obtained good results of reconstruction in the TM configuration case. Work is going on to improve the Gibbs sampling algorithm by using the bilinear property of the model and to apply the latter to the TE polarization case.

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A Non-destructive Microwave Approach for the Detection of Multiple Defects in Industrial Products

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The non-destructive inspection is a key-problem in many industrial processes since the detection of defects or cracks in the products is mandatory. Many tomographic approaches that have been proposed are based on the use of interrogating microwaves and their effectiveness in inspecting dielectric or conductive materials has been demonstrated. A general NDT/NDE problem solved through an inverse scattering technique is still ill-conditioned and non-linear. Unlike standard microwave imaging problems, a lot of *a-priori* information on the scenario under test (the industrial product) is available. In this framework, *Caorsi et al.*, proposed an optimization technique (FGA) [1], where the problem unknowns reduction was achieved by exploiting such an *a-priori* information. A non-destructive inspection is aimed at detecting a single unknown defect inside a known unperturbed host medium lying on a known background. Starting from this assumption, the a-priori information on the unperturbed structure was exploited by means of a suitable Genetic Algorithm (GA). The inverse scattering problem was significantly simplified since the unknowns was reduced to an array of geometric parameters of the defect: its position, size, orientation, and the electromagnetic properties.

Successively, a further improvement was achieved employing the inhomogeneous Green's function [2], which allows a reduction of the region of interest to the area occupied by the crack without increasing the computational burden of the detection process. Such approach (called Inhomogeneous Green's Approach—IGA) obtained a further improvement of the computational burden as well as more accurate reconstructions.

In order to address more realistic problems, this paper presents a new methodology based on the original IGA and able to deal with problems characterized by more complex geometries in comparison to the singlecrack configurations so far considered. Towards this end, two different strategies have been developed both based on the inhomogeneous Green's function [2]. The former is characterized by a set of parallel GA subprocesses, each of them concerned with trial solutions encoding the same number of crack. The best solution is selected among the different crack-length optimal solutions given by each of the GA sub-processes. The second strategy is based on a single GA process where multiple-length chromosomes are defined in order to code contemporarily different solutions characterized by a different number of defects. This approach allows a considerable computational saving, but requires the definition of a new complete class of genetic operators. As far as the numerical validation is concerned, several realistic test cases have been taken into account and the obtained results demonstrate the feasibility as well as the effectiveness of the proposed approaches both in terms of reconstruction accuracy and computational costs.

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Improving Inverse Scattering Solution Procedures by Means of a Preliminary Support Estimation: Rationale and Test on Real Data

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Due to the large number of underlying applications ranging from biomedical imaging to near surface geophysical explorations, inverse scattering problems are an important research topic. However, in applying these techniques, one has to solve a non-linear ill-posed inverse problem. This introduces many conceptual and computational complications which affect their actual applicability and effectiveness. As a matter of fact, when dealing with monitoring of regions of large extent, the computational burden becomes often unaffordable. On the other hand, in presence of multiple scattering effects, the inversion cannot be dealt within the framework of linearized models so that non-linearity of the problem becomes a critical point.

In order to devise effective strategies, it is extremely important that some features of the unknown targets can be determined from data without solving the inverse scattering problem. Amongst the other features, geometrical characterization of targets seems to be suitable information.

As matter of fact, this kind of information allows to reduce the computational domain and consequently the number of unknown parameters in the inverse problem, thus increasing the ratio between independent data and unknowns of the inverse problems. This ratio has an important rule in defeating ill-conditioning as well as possible occurrence of false solutions in the inversion process. For all the above, it is clear that a preliminary knowledge of the support of the unknown system of targets may improve the reliability of inversion procedures.

In this contribution, we show the possibility to improve the performances of some inverse scattering solution procedures by means of preliminary support information. To this aim, a two-steps approach aimed at characterizing homogeneous dielectric objects embedded in a homogeneous medium is introduced and discussed. The first step amounts to qualitatively reconstruct the geometrical features throughout the solution of a simple auxiliary problem. In particular, the Linear Sampling Method (LSM) introduced by Colton is applied. Such a method allows to estimate the support of the targets without explicitly solving the inverse scattering problem, but observing the behaviour of an indicator given by the norm of the solution of a linear auxiliary problem. It has to be noted that this information is achbieved in a very fast fashion. Exploiting this information as a constraint, the permittivity profile is then retrieved in the second step by means of a non-linear inversion strategy. To this end, both the Contrast Source Inversion (CSI) method and the recently introduced Contrast Source - Extended Born (CS-EB) one have been tested.

Numerical experiments performed on experimental data collected at the Institute Fresnel of Marseille confirm the usefulness and effectiveness of the proposed two-steps approach. As a matter of fact, independently from the fact one is using CS or CS-EB for the quantitative reconstruction of permittivity, the two-steps approach is capable to achieve accurate reconstructions in many cases wherein the usual approaches get stuck in a false solution.

A Neural Network Approach for Electromagnetic Diagnostic Applications

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Abstract—In this paper, a neural network approach is applied to a typical electromagnetic diagnostic problem consisting in the prediction of the electromagnetic field absorption inside a dielectric phantom. The approach has been tested by considering, at the input of the neural network, the values of the incident electric field at a fixed number of locations. Also phaseless measures have been taken into account. The outputs are some features describing the electromagnetic absorption, such as the peak amplitude of the induced field, the location of the absorption peak and a measure of the extension of the induced spot inside the phantom.

Preliminary results show that the approach shows a satisfactory accuracy in reconstructing the selected absorption features, and that it is able to estimate these characteristics very quickly.

1. Introduction

The purpose of this paper is to investigate the potentialities of the application of neural networks to an electromagnetic diagnostic problem.

Electromagnetic non-destructive diagnostics is usually referred to the investigation and the reconstruction of not accessible scenarios by the exploitation of measurable data coming from the interactions between electromagnetic waves and the unknown scatterers. Recent years have experienced a relevant interest in developing electromagnetic inverse scattering approaches for NDE/NDT applications (subsurface mapping of underground utilities, detection of mines or unexploded ordnances, archaeological surveys, inspection of industrial products, monitoring of buildings' deterioration and so on). Among other techniques, new approaches based on neural networks have been recently proposed in order to reconstruct the position, the dimension and the dielectric properties of a subsurface object [1–3].

Nonetheless, electromagnetic non-destructive diagnostics also refers to the prediction of the electromagnetic field distribution inside not accessible scenarios. In this case, also, research areas are manifold. In particular, the scientific community is largely interested in developing electromagnetic non-invasive techniques to achieve the prediction of the absorption of the electromagnetic field inside biological bodies exposed to wireless communication systems. A large amount of research efforts have been spent in order to develop accurate solution approaches, mainly based on the solution of the direct scattering problem and thus requiring the exact knowledge of the electromagnetic source and of the dielectric properties of the investigated biological body, which had to be replicated in a reference phantom. Nowadays, some researchers turned to inverse scattering approaches to predict the electromagnetic field distribution inside the human head [4, 5]. The idea which is behind the inverse scattering approach is that it allows, in principle, to recover the electric field and the dielectric properties of the investigated scenario though the exploitation of the measurements of the scattered field in an observation domain external to the investigation area, and the values of the exposure inside the investigation area. This way, it is indeed possible to avoid the numerical modelling of the electromagnetic source, which is often a very difficult task to be achieved. Also, the approach is completely non-destructive and it could be suitable for in-vivo evaluations.

Since in general this kind of approach is characterized by large computational costs, an alternative approach can be taken into account which is based on neural networks. The fundamental difference with respect to the microwave imaging technique already investigated in [4, 5] is that the new approach is based on a "learning-by-examples" technique able to estimate the function relating the inputs and outputs of the problem provided that a training set of examples is available. It turns out that, as we have already experienced when we applied neural networks to reconstruct buried objects [2, 3], the solution of the problem is very fast, thus making it very appealing for applications requiring a fast and accurate monitoring of in-vivo biological tissues.

The input data for the proposed approach are the complex values of the incident field at few locations inside the investigation domain. However, in real application, near-field phase measurements often require the use of sophisticated equipments and they can be quite inaccurate due to a number of different factors. Thus, accordingly to what has been done for the validation of the microwave imaging approach in [4, 5], in the present paper also the exploitation of amplitude-only information has been considered. This has been done to simulate real conditions measurements but also in order to fully investigate the potentialities of the proposed technique and to underline its limits.

The paper is organized as follows: in section 2 the investigated electromagnetic problem will be described and the neural network approach will be introduced; in section 3, some numerical results, concerning the prediction of the absorption features inside the cross-section of a simplified biological phantom, will be reported.

2. Problem Definition and Neural Network Approach

The neural network is a learning machine whose architecture was inspired by a biological analogy with the human brain. It is well known that a neural network is a very general tool that can be used to solve both classification (pattern recognition) problems and regression ones [6, 7]. Indeed, different models of neural networks have been proposed in the literature. However, as stated by the so-called Universal Approximation Theorem [1], [6], a two-layer feed-forward perceptron with a non-constant, bounded and monotone increasing continuous activation function can approximate any non-linear function relating two sets of variables.

Let us describe the problem we have considered. We have modelled a simple dielectric phantom by means of a homogeneous cylindrical biological scatterer Ω of rectangular cross section. The phantom is characterized by known relative permittivity $\varepsilon_r = 47.76$, relative permeability $\mu_r = 1.0$ and conductivity $\sigma = 1.0\,\mathrm{S/m}$ while the external medium is free-space ($\varepsilon = \varepsilon_0, \mu = \mu_0$). These values are the mean values of the dielectric characteristics of human tissues inside a cross-section of a human head at the operating frequency $f = 900\,\mathrm{MHz}$ [5]. The object is illuminated by an electric current line which radiates a TM polarized wave, in the near field of the phantom.

It is well known that the electromagnetic scattering can be described trough the two well-known integral equations

$$\bar{E}(\bar{r}) = \bar{E}_{inc}(\bar{r}) + \int_\Omega \chi(\bar{r}')\bar{E}(\bar{r}') \cdot \bar{\bar{G}}(\bar{r}/\bar{r}')d\bar{r}' \quad \text{for } \bar{r} \in \Omega \tag{1}$$

$$\bar{E}(\bar{r}) - \bar{E}_{inc}(\bar{r}) = \int_\Omega \chi(\bar{r}')\bar{E}(\bar{r}') \cdot \bar{\bar{G}}(\bar{r}/\bar{r}')d\bar{r}' \quad \text{for } \bar{r} \notin \Omega \tag{2}$$

where $\bar{E}_{inc}$ is the incident electric field, $\bar{\bar{G}}$ is the Green's dyadic and $\chi(\bar{r}) = \varepsilon_r(\bar{r}) - 1 - j\frac{\sigma(\bar{r})}{2\pi f \varepsilon_0}$ is the object function.

Generally speaking, the application of an inverse scattering technique to predict the electric field absorption in the dielectric phantom results in the exploitation of both the incident field measurements in the investigation domain Ω and the scattered field measurements in an observation domain external to Ω. Thus, in [4, 5] a cost functional has been constructed by computing the errors between the measurements and the reconstructed field distribution obtained by the discretization of the integral equations. If we consider Eq. (1), data quantities are thus the measurements of the incident field in the investigation domain, while the unknowns are the values of the electric field inside Ω. It is possible then to define an operator ϕ such that

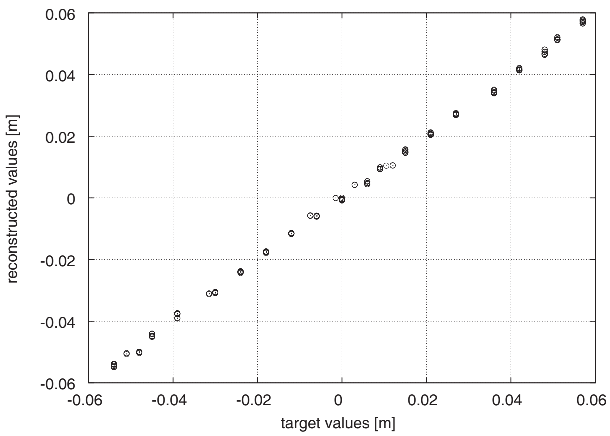
$$\bar{E}(\bar{r}) = \phi(\bar{E}_{inc}(\bar{r})) \quad \text{for } \bar{r} \in \Omega \quad . \tag{3}$$

Equation (3) states that the inverse problem can be recast into a regression problem in which the function ϕ can be estimated through the knowledge of a finite set of input/output pairs. In this work, the estimation is performed by implementing a single-layer feed-forward perceptron neural network with sigmoid activation [6]. Thanks to the flexibility of the prediction tool, it is indeed possible to simplify the problem. Instead of estimating the field values inside Ω, we can focus on the relevant features of the absorption. To this aim, we have identified three output variables: the absorption peak, the location of the absorption peak and the area of the spot around the peak inside which the ratio between the peak value and the amplitude of the fields remains over 6 dB. Thus, the problem can be rewritten as
to find an approximation of ϕ such that

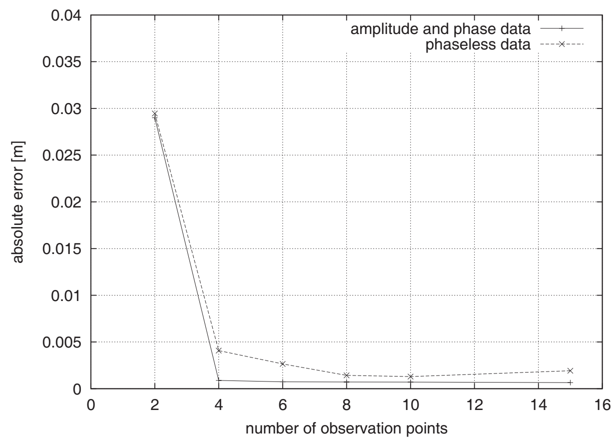
$$\bar{\Psi} = \phi(\bar{E}_{inc}(\bar{r}_i)) \quad \text{for } i = 1, \ldots, N, \bar{r}_i \in \Omega \tag{4}$$

being $\bar{\Psi}$ the array of the output variables, provided a training set of examples $\{\bar{\Psi}, \bar{E}_{inc}(\bar{r}_i)_{i=1,\ldots,N}\}_j, j = 1, \ldots, M$ (input/output pairs).

The neural network here considered is a two-layer feed-forward perceptron neural network. The training of the network has been achieved through implementation of a back-propagation algorithm [6]. During this phase, the neural network is presented with all the examples (input/output patterns) of a suitably defined training set and an iterative procedure, based on a gradient descent, attemps to minimize the error between the outputs of the network and the actual ones, provided that the initial weights of the network are randomly chosen (batch mode of back-propagation learning). For all the computations reported in this paper we cosidered



(a)



(b)

Figure 1: Peak position prediction: (a) reconstructed values vs actual values at the output of the neural network exploiting 15 amplitude and phase measurements; (b) absolute error as a function of the number of receivers.

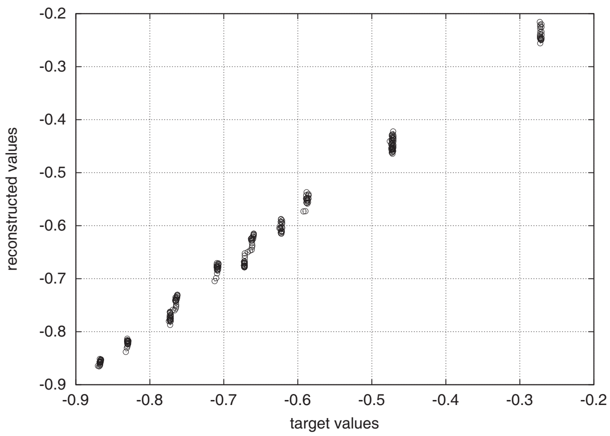
a single training cycle. After the training phase, we have tested the generalization capabilities of the neural network (i. e., we tested the accuracy of the input-output relationship computed by the neural network for input/output patterns never used in training it [6]). Both for the training and testing of the neural network we used synthetic data that have been obtained through the finite element modelling of the problem at hand. The numerical domain has thus been discretized into triangular elements 0.003 m in size. In order to construct a set of input/output patterns for the validation of the approach, we have simulated 1848 different exposure conditions for the training set and 240 for the test set. Thus, 2088 different sets of incident field (input data) distributions have been generated by considering different positions of the electromagnetic source and different amplitudes of the current flowing through the line. For each of them, we also computed the associated features describing the electric field absorption inside the phantom (output variables).

3. Numerical Results

In this section, we are reporting some preliminary numerical results in order to investigate the capabilities of the approach described above. The input data come from the measurements of the electric field exposure while the output data are the identified features describing the electric field absorption inside the dielectric phantom. The measurements of the incident field have been collected at a finite number of points inside the investigation domain.

In the first set of simulations, we tested the capability of the neural network in predicting the electric field absorption for different numbers of observation points. We started from a configuration employing fifteen measurement points equally spaced inside the investigation domain. Input data are represented by the complete information (amplitude and phase) on the incident field at the observation points. Thus, a neural network with 30 neurons in the input layer, 30 neurons in the hidden layer and three nodes in the output layer has been implemented. Results of the neural network processing of the test set patterns are showed in Figs. 1(a), 2(a) and 3(a). The dispersion curves in the graphs represent the reconstructed values of the position of the absorption peak, the amplitude of the absorption peak and the 6 dB area, respectively, as compared to the actual features. In this case, the position of the absorption peak is reconstructed with an average absolute error equal to 0.00065 m and a maximum error of 0.00232 m. It is remarkable to notice that the error doesn't exceed the characteristic dimension of the finite element mesh. It is thus always possible to discriminate between two adjacent positions of the absorption peak corresponding to two different illuminating conditions. As far as the prediction of the amplitude of the absorption peak, also this variable seems to be correctly evaluated since the average error is 5.0% while the maximum error is 10.8%. The extension of the absorption spot inside the phantom is predicted with an average error equal to 8.4% while the maximum error is 21.8%.

The number of measurement points has then been reduced in order to investigate the influence of the field sampling on the performances of the approach. Results are quite interesting, as the reader can infer from the plots in Figs. 1(b), 2(b) and 3(b). In addition, on the same graphs, we reported the results of the neural network processing of phaseless data as compared to the performances achieved when the complete information



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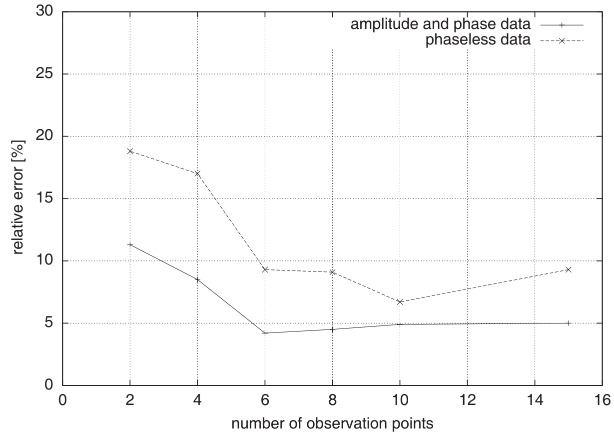
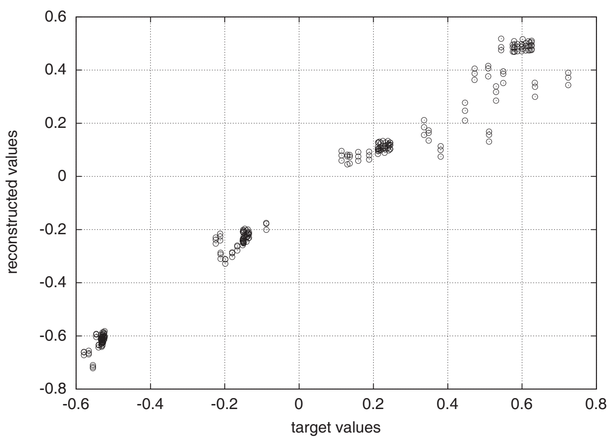


(b)

Figure 2: Peak amplitude prediction: (a) reconstructed values vs actual values at the output of the neural network exploiting 15 amplitude and phase measurements; (b) relative error as a function of the number of receivers.



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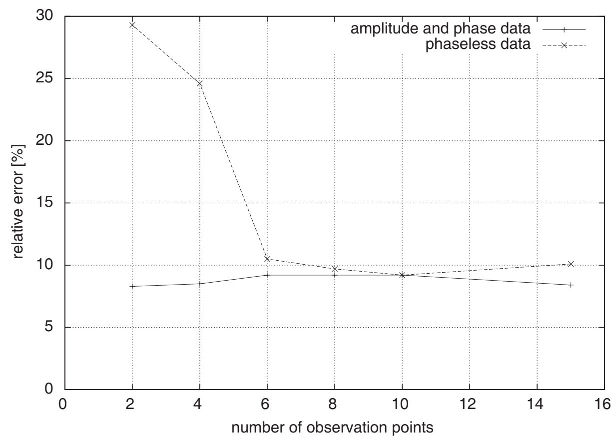

(b)

Figure 3: 6 dB area prediction: (a) reconstructed values vs actual values at the output of the neural network exploiting 15 amplitude and phase measurements; (b) relative error as a function of the number of receivers.

on the field measurements is available. It is immediately evident that the performances of the neural network undergo a significant deterioration only when very few measurement points are considered. When we consider both the information on the amplitude and phase of the incident field at the input, performances seem not to worsen if the number of measurement points remains over four. This seems to be a relevant feature in the considered neural network application since it it proved that satisfactory results can be achieved even when the information on the exposure condition are limited to a very restricted number of measurements. When phaseless data are considered, performances are in general worse with respect to consider full information on the field measurements. As an example, let's consider the neural network exploiting fifteen phaseless measurements of the incident field. In this case, we implemented a neural network with 15 nodes in the input layer, 15 neurons in the hidden layer and three nodes in the output layer. The prediction of the absorption peak location is achieved with an average absolute error equal to 0.00192 m; the average error on the estimated absorption peak is around 9.3%; the average error on the predicted 6 dB area is equal to 10.1%. Moreover, as we have already observed when full data were considered, as the number of measurement points reduces, a significant worsening of the performances is seen to apply only when that number reduces to four or less.

The second set of simulations concerned the investigation of the robustness of the proposed approach. To this aim we have considered the performances of the technique when noisy measurement data are taken into account at six measurement points. We have simulated the presence of a Gaussian noise over the test data by adding to the incident field values a complex quantity whose real and imaginary parts are Gaussian variables characterized by zero mean and variance depending on the considered signal-to-noise ratio (SNR). Table 1 reports the average errors achieved in predicting the electric field absorption features for different values of the signal-to-noise ratio. As can be expected, performances deteriorate when considering lower values for the SNR. In particular, it seems that the prediction of the amplitude of the absorption peak and the extension of the spot is significantly worse when SNR<30 dB.

As far as computational costs are concerned, the training phase of the neural network is usually an intensive task often requiring tens of minutes or few hours, depending on the number of input data, to be ended. However, after the training phase, the processing of the entire test set of data requires less than one second.

Table 1: Mean errors in the prediction for different signal-to-noise ratios.

	no noise	SNR=50 dB	SNR=40 dB	SNR=30 dB	SNR=20 dB
absolute error on peak position	0.00074	0.000752	0.000821	0.00110	0.00245
relative error on peak amplitude	0.042	0.044	0.057	0.084	0.331
relative error on 6 dB area	0.092	0.099	0.110	0.116	0.292

4. Conclusion

In this paper a neural network approach has been investigated for the prediction of relevant features of the electric field absorption inside an exposed dielectric phantom. The input data are the exposure measurements at few locations inside the investigation domain. Moreover, also phaseless data have been considered in the analysis. Preliminary results confirm that the approach seems to provide satisfactory performances in locating the absorption peak and in predicting its amplitude and extension. The robustness of the approach has been tested by considering the effect of noise on measurement data and good results have been obtained for SNRs greater than or equal to 30 dB. These results are encouraging as they show the potentialities of the technique in predicting the absorption with few measurement data and in real-time. Further investigations must be carried out in order to improve the robustness of the approach.

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Faithfull Phaseless Microwave Tomography

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In inverse scattering problems, one looks for a quantitatively accurate description of the electrical and geometrical characteristics of an investigated region from the knowledge of a set of incident fields and measures of the corresponding total or scattered fields (both in amplitude and in phase) on a generic surface lying outside the region under test. The development of accurate and reliable techniques for solving this kind of problems is an important challenge because of their potential applications in biomedical imaging, applied geophysics, non invasive subsurface monitoring and non destructive testing and diagnostics.

By leaving aside peculiar characteristics of the different solution approaches existing in the literature, it is important to note the one of the main drawbacks of commonly suggested procedures resides in the need of measuring both amplitude and phase of the scattered fields. In fact, in several areas of applied science it can be very difficult or very expensive (or not possible at all) to measure the phase of a field. In particular, an accurate knowledge of the field phase involves sophisticated measurement equipments, which are more and more expensive as the working frequency increases, so that phaseless measurements are indeed mandatory at optical frequencies. In addition to that, the existence of minimally invasive (only amplitude) probes strongly suggest the adoption of phaseless techniques also at microwave frequencies. In fact, these probes considerably simplify the electromagnetic scenario with respect to classical (amplitude and phase) probes, thus avoiding multiple interactions and the need for probe compensation.

In this contribution a recently introduced approach to inverse scattering from only amplitude measurements of the total field is introduced and tested against experimental measurements taken at the Institute Fresnel of Marseille (corresponding to inhomogeneous scatterers). The basic idea of the adopted inversion technique is to reconstruct the complex scattered field from only amplitude measurements of the total field in a first step and then to solve a standard inverse scattering problem.

The proposed procedure is therefore organized in two different steps. In the first one, the complex scattered field is estimated by minimizing a functional that is the norm of the discrepancy between the measured pattern amplitude distribution and the calculated one. In such a step, a very important point arises in exploiting or, possibly, developing efficient (i.e. with the minimal possible redundancy) representations of the unknown scattered field. The second step, dealing with a standard inverse scattering problem, allows us to obtain an estimate of the dielectric and geometric properties of the system of targets eventually located in the investigated area.

As the proposed inversion technique needs to know both amplitude and phase of the incident field on the measurement curve, a second contribution amounts to demonstrate the possibility of achieving this information from the amplitude distribution of the incident field. The huge amount of knowledge about phase retrieval problems is exploited in such a 'pre-processing' step.

Numerical examples using the above quoted real data fully confirm the possibility to achieve accurate reconstructions in microwave tomography without performing phase measurements.

It is worth to note that this work, opposite to recent contributions, demonstrates the possibility of achieving faithful phaseless microwave tomography without any loss of accuracy as compared to the case wherein amplitude and phase data are available.

A Point Source Method for Reconstructing of Conducting Bodies Buried under a Rough Surface

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Due to large domain of applications such as non-destructive probing, geophysical prospecting, detection of personnel mines, determination of underground tunnels and pipelines etc. the inverse scattering problems related to buried bodies in a known half-space has a particular importance in the inverse scattering theory. As far as we know almost all of the publications related to these kind of problems concern with the bodies buried beneath a planar surface [1, 2]. Whereas in most of the real applications the bodies are buried in layered media having rough interfaces and the roughness have a strong effect on the scattering phenomena as well as reconstruction algorithms. For instance, in the case of bodies buried underground the roughness of the earth surface can potentially modify object scattering returns from those with a flat surface and this affects the reconstruction procedures in a serious way. For that reason the problem has to be considered in its actual conditions. In other words one has to take into consideration the roughness of the interfaces between the layers where the body is located.

The aim of this paper is to address an inverse scattering problem for the perfectly conducting bodies buried in a half-space with rough interface. The body is illuminated by a fixed point source located in the other half-space not containing the body and the scattered field is measured in the some domain in the same region. Through the Green's function of the background medium with rough interface we establish a point-source method for the reconstruction of the location and shape of the obstacle [3]. The method is based on the determination of the total field in the half-space where the body is buried through the measured scattered data. This is done by establishing a reciprocity relation between the incident and scattered fields. Then one reconstructs the object by observing the points where the total field vanishes. The problem is severely ill-posed and Tikhonov regularization is applied. On the other hand the determination of the Green's function constitutes a separate and difficult problem. Here we give a new and general method based on the assumption that the perturbations of the rough surface from the flat one are assumed to be buried objects in a two-part space with planar interface. Modeling the roughness in such a way yields us to formulate the problem as scattering of cylindrical waves from buried homogeneous cylindrical bodies, which is solved through a method based on MoM. Such an approach is very effective for surfaces having a localized roughness, arbitrary rms height and slobe. An illustrative example is given in order to test the accuracy and the applicability of the method.

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Broadband Spatiotemporal Differential-operator Representations for Velocity-dependent Scattering

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Novel approach, based on spatiotemporal differential-operators, is developed here for broadband, velocity-dependent scattering. Unlike the spectral-domain representations, the new method facilitates a compact formulation for scattering by arbitrary excitation signals, in the presence of moving objects. In free space (vacuum), relativistically exact formulas are developed. After developing the general theory, analysis of relativistically exact free-space scattering by cylinders, and a half-plane, are examined. For cylinders the analysis shows that in the far field pulses are located on circles in the co-moving reference-frame where the object is at-rest. In other reference frames this feature is valid only as an approximation. These results apply also to the diffractive part of the half-plane scattered field. The geometrical-optics contribution is associated with plane-waves and obeys the appropriate transformations. The various zones for these fields in an arbitrary reference-frame are analyzed.