PIERS 2004 Summary - Report on papers related to electromagnetic methods and applications for Humanitarian Demining (Conference

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Report on papers related to electromagnetic methods and applications for Humanitarian Demining (sessions 3, 6, 15, 21)

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Conference Overview and Summary

PIERS 2004 took place in Pisa, Italy, under the chairmanship of Prof. Marco Raugi. This marked the event's return to Europe for the first time in 6 years and was the first time it had ever been held in Italy. The conference provided a great opportunity for reporting advances in the development of electromagnetic theory, methods and applications. Scientists, researchers and engineers from all over the world attended the conference in large numbers. About 850 abstracts were received and 250 extended abstracts were submitted before the conference for publication in the volume Extended Papers. Detailed information is available at www.piers.org .

The PIERS international conference is organized every year throughout world locations and covers many aspects of theoretical and applied research in electromagnetism. PIERS features quite a few interesting presentations related to the scattering properties of objects immersed in different type of media, while other presentations are concerned with field inversion methods in the frequency or time domain. In most cases scientific contributions are not directly related to demining problems and have a more general validity; they do however definitely contribute to make useful progress in solving typical problems encountered when electromagnetic methods are applied to landmine detection.

The opening session saw contributions from three invited speakers from Philips, Nokia and Boeing Space. The talks were about the practical problems of computational electromagnetism which industry faces every day when designing new products. The conference's attention to industrial applications in various fields (electronics, medicine, aerospace, telecommunications and computational codes) was demonstrated by the many papers (oral and poster) presented jointly by research institutions and companies. Several industrial patrons (IDS, ANSOFT, GEO Studi Astier, Spin and Magnetek) sponsored the conference and also exhibited their products during the conference.

The PIERS conference is very broad, covering many aspect of electromagnetism ranging from purely theoretical ones to applications. Although humanitarian demining was not an official topic of the conference, several papers on this subject were presented in four sessions:

- Session 3: Electromagnetic Subsurface Sensing: Theoretical, Algorithmic and Technological Advances
- Session 6: Shallow Subsurface Electromagnetic Imaging and Inversion
- Session 15: Detection and Classification Techniques of Buried Objects by Radar
- Session 21: Rough Surface Scattering and Related Problems

Finally I would like to report on a few papers dealing with non-contact methods for the detection of vital signs of human life with pulsed Radar, useful during rescue operations and in intensive-care units.

***Disclaimer**:* These notes represent the author's personal impressions only, based for the most part on notes taken during the talks and later discussions with participants; as such they do not pretend to be complete and engage only himself. *Author's comments are in italics.*

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Introduction

The PIERS conference is very broad, covering many aspect of electromagnetism ranging from purely theoretical ones to applications. Although no specific sessions devoted to humanitarian demining were organized, there were several interesting papers with original contributions to this subject. A description of these selected papers is reported below.

Theoretical aspects for the solution of the inverse field problem were tackled in Session 3: Electromagnetic Subsurface Sensing: Theoretical, Algorithmic and Technological Advances, chaired by A. Massa, S. Caorsi and C. Pichot. This was a very large session with many papers related to numerical methods applied to object reconstruction from Radar acquisition. The particular aspect of field inversion in presence of perturbation due to soil roughness was tackled in Session 21: Rough Surface Scattering and Related Problems, chaired by Alexei Maradudin.
More related to the mine detection application were Session 6: Shallow Subsurface Electromagnetic Imaging and Inversion, chaired by D. Lesselier, and Session 15: Detection and Classification Techniques of Buried Objects by Radar, chaired by L. Capineri. In these two sessions several papers related to the problem of the detection and classification of shallow mines were presented. Some portable systems and the corresponding signal-processing schemes were also described.
I have decided to organize this report by extracting an abstract from selected presentations, for which I reported only on the aspects that I considered more relevant for the mine detection problem.

1 SESSION 3: Electromagnetic Subsurface Sensing: Theoretical, Algorithmic and Technological Advances

On the Effectiveness of Kernel-based Learning-by-Examples Techniques for Electromagnetic Subsurface Sensing

S. Caorsi (University of Pavia, Italy); E. Bermani, A. Boni, M. Donelli, A. Massa (University of Trento, Italy)

A new way to solve the inverse problem for buried targets has been presented. The method considers the Learning-by-Examples (LBE) techniques that have been recently proposed for the solution of sub-surface imaging problems. The target can be described by only a few parameters (such as position and dielectric properties) and the inverse scattering problem can be reformulated as a regression one, where an approximation of the unknown function relating object characteristics and measurement data is obtained on the basis of a set of examples.
This approach is also useful for the "definition of risk maps" (such as in demining or in the identification of "dangerous areas" with unexploded ordnance), and LBE techniques still provide an interesting solution to the arising classification problem.
The effectiveness of the Support-Vector-Machines-based techniques (SVMs) lies in the possibility to reformulate the original non-linear problem in an optimization one by defining a (convex) quadratic functional to be minimized.
In this work, two different SVM kernels (namely, Gaussian and polynomial function) are taken into account and their performances in dealing with subsurface imaging problems compared. Several numerical test cases are carried out, by considering both regression and classification problems. The robustness of kernels to "corrupted measurement data" is also investigated. Finally, some guidelines for the selection of SVM kernels in electromagnetic subsurface imaging are given.

The solution of the inverse scattering problem for the mine detection application is very challenging, considering experiments with "corrupted measurement data". Another problem – the large spread of parameters for soil, target materials, dimensions and shape – is also taken into account in this work. In this case the inverse problem solution is not trivial. The simplified approach to solve this inversion problem described in the paper can lead to useful applications to the detection of mines in large investigated areas, giving an important contribution to the task of area reduction.

Forward-Backward Time-Stepping Method Combined with Genetic Algorithm for Imaging Shallow Subsurface Objects

Z.Q. Meng (Fukuoka University, Japan); H. Jia (Kyusyu University, Japan); T. Takenaka (Nagasaki University, Japan)

The paper describes a tomographic method intended to solve the detection problem of shallow low metal content mines that are likely missed also by metal detectors, unless set to the highest sensitivity. The paper considers tomographic imaging of dielectric objects buried near the ground surface in a two-dimensional geometry. The dielectric profile of the subsurface is reconstructed from the knowledge of the incident pulses and the received pulses. A combination of a Forward-Backward Time-Stepping (FBTS) method and a Genetic Algorithm (GA) is introduced as a time-domain inversion method for the nonlinear inverse scattering problem. First, GA is used to obtain a first approximation of geometrical data about the sizes and locations of the targets by approximating all targets as homogeneous cylinders with a circular or square cross-section. The resulting image is then used as an initial estimate for the FBTS method to get a more accurate image of the subsurface.

A two-step tomographic method described in this paper has been introduced to solve a non-linear scattering problem. The unique solution of this problem in presence of irregular data and irregular shape should also be addressed, as well as numerical complexity issues compared to other tomographic algorithms.

Experimental Detection and Theoretical Reconstruction of Cylindrical Cross Section Objects using TM, TE and Cascaded TM-TE Polarization: Application to Pipes

E. Le Brusq, J. Y. Dauvignac, I. Aliféris, Ch. Pichot (University of Nice-Sophia Antipolis, France); X. Dérobert (Laboratoire Central des Ponts et Chaussées, France)

The general comment about this session, co-chaired by Prof Pichot, is that recent research work dealing with 2D and 3D inverse problems for buried objects, covering both theoretical and experimental aspects, has been detailed. Buried objects like antitank and antipersonnel mines were also considered.
The theoretical development deals with the study of bidimensional tomographic algorithms in 2D TM and TE polarization. For the inverse problem, a Bi-Conjugated Gradient method is used in a multifrequency-multiposition configuration. This method allows to reconstruct the permittivity and conductivity of the objets from the scattered field measured on the measurement line, and from the incident field. In order to enhance the resulting images, a regularization technique which preserves the edges of the objects can be introduced into the inversion algorithm. The most important parameters, such as the length of the measurement line, the incident field (plane waves with limited coverage, antenna field), the polarization (TM, TE or cascaded TM-TE), and the signal-to-noise ratio level, are discussed in detail.
Concerning the experimental aspects, the authors have developed an ultra wideband antenna of the ETSA type (Exponential Tapered Slot Antenna), based on the Vivaldi antenna concept. A very wide frequency band can be covered, from 150 MHz to 20 GHz

and more, by using only three antennas. These antennas have been integrated as electromagnetic sensors in a synthetic-pulse GPR system.

The important results of this research activity lie, on the theoretical side, in the development of a tomographic algorithm, which includes data regularization. Results of a complete numerical study for the reconstruction of cylindrical cross section objects show the good performances of this type of algorithms. Another significant achievement is represented by the antenna design, resulting in a very broadband Radar equipment that covers a frequency range (150 MHz to 20 GHz) *usually not available in commercial equipment. The information collected in laboratory conditions on various types of buried objects is interesting for an analysis of the advantages of this sophisticated type of Radar system for humanitarian demining applications.*

Buried landmine detection using microwave radiometry

M. Peichl, S. Dill, H. Süß (German Aerospace Center, Germany)

A broadband microwave radiometer operating in the frequency range of about 1-7 GHz has been developed and integrated with two other sensors: a metal detector and a ground penetrating radar. Using a common search head, the system is intended to be hand-held and operated like a conventional metal detector, but allowing the application of imaging to all three sensors, in conjunction with an optical-camera-based position monitoring system. In addition, the capability of measuring at multiple low-bandwidth channels by sweeping the radiometer's central frequency allows the examination of the soil considered as a layered structure, where a hidden object lies in a layer. Taking this signature as a fingerprint of the specific depth profile, this information can help to discriminate landmines from other objects.

The paper follows the general strategy for improving the performances of a mine detection system by using sensors based on different physical phenomena. The system has been developed within the HOPE European project. The presented results compare measured and theoretically simulated signatures in typical experimental conditions. The three-sensor system is certainly a powerful detector, but data fusion and the man-machine interface have to be developed so as to make it easy to use, with the high reliability level requested by humanitarian demining applications.

2 Session 6: Shallow Subsurface Electromagnetic Imaging and Inversion

Reduction of surface clutter for detection of buried objects

O. Cmielewski, M. Saillard, H. Tortel (Institut Fresnel, CNRS, France)

The paper addresses a problem that is important for the shallow mine detection with ultra wideband Radar. The finite length of the radar pulse interferes with the response of the shallow object, and these are not separable by simply time windowing.
The work is theoretical and presents numerical results. First a rigorous solution of two-dimensional scattering problems is found by subsoil description with a set of (2D) electric dipoles, playing the role of transmitters and receivers, lying along a line above the rough air-ground interface. Numerical results are obtained in the low frequency range, by using the small perturbation theory.
The authors observed that the SAR imaging technique is not robust against surface clutter in a monostatic configuration, and a multistatic data and multiple frequencies acquisition system has therefore been proposed. With this system the simple isotropic

scattering model reveals deficiencies in discriminating between the direct Radar pulse and the buried object response.
Basically, the proposed approach consists in correlating the scattered fields associated with two incident fields, which coincide at a given point. If a target is located at this point, its contribution is the same for both incident fields, up to the perturbation induced by surface roughness. If there is no target, averaging over transmitter/receiver positions and frequencies cancels out the fluctuations around the expected contribution of a flat interface. In addition, if the target is not deeply buried, it appears that the cross-terms combining the target contribution with that of the mean plane interfere constructively, leading to an enhancement of the signature of the target, as compared to SAR imaging.

The work addresses an important problem in shallow mine detection, especially when Radar frequencies around 1 GHz are employed. The suggested multistatic approach requires the use of SAR with an antenna array mounted on a vehicle. Finally, Radar signal deconvolution techniques should be compared with the proposed method.

3 Session 15: Detection and Classification Techniques of Buried Objects by Radar

Application of Passive and Active Radars for Detection and Classification of Land Mines

S. I. Ivashov, V. V. Razevig, A. P. Sheyko, I. A. Vasilyev (Bauman Moscow State Technical University, Russia)

This paper presented an overview of technologies developed in Russia to locate

1. landmine fields with antitank (AT) mines.
2. antipersonnel (AP) mines.

In the first application radiometric sensors were used to measure the different reflection of millimeter waves from mines instead of surrounding soil. The novelty of this system is the combination of passive and active radiometer sensors. A passive radiometer mounted on a vehicle carrier covers an area on the ground. This area is continuously illuminated by the sky radiation, and at different time intervals it is also illuminated by a noise generator (active sensor) mounted on the same carrier. The sensor systems scan an area by an azimuth and elevation angular movement, and high frequency signals (8mm wavelength radiometer) are collected by the system that it is synchronized with the on-off activation signal of the noise generator. After having acquired the images under both conditions, data processing is applied to use both sources of information in order to detect and locate AT mines. An experimental demonstrator has been built and tested on a field with buried mines. A TV camera was also used during acquisition.
The images presented after preprocessing of experimental data confirm that mines have different contrast, with respect to the background, in the passive and active mode and their spatial location is quite consistent in both images. This should be exploited to improve the false alarm rate.

For the second application a holographic Radar technique has been proposed. The demonstrator is called MiRascan and is based on a radar with five operational frequencies in the range of 1.5-2.0 GHz, transmitting non-modulated signals at each frequency. Signals reflected by a buried object are received in two polarizations.
The radar probe is mounted on a remote controlled cart that scans the surface with continuos lateral and longitudinal movements. For each frequency the received signal is demodulated with the reference signal derived from the transmitter. For each frequency the phase change modulates the amplitude and this information is displayed with gray scale images. In general the reflected signal from a mine is strongly changed in phase only at certain frequencies, while at the other frequencies the variation is negligible.

In the first part of the presentation an exhaustive state of the art of experimental systems for minefield detection developed in Russia has been presented. A radiometer mounted on a vehicle is capable of operating in real time, and the novelty lies in the use of two operational modes (i.e., as passive and active detector). This allows an image enhancement of the buried mines with respect to the background. The presented black and white images should be correlated with the real target shapes, and compared also with non-target shapes (e.g. stones, shrapnel, metal/plastic boxes like cans, etc.).

In the second part of the presentation about a Radar system, the novelty is a live presentation of holographic Radar images in sequence. This is a useful operational mode for this type of instrument because it represents an easy interface with the user. The contrast information of the phase change due to a buried object eases mine detection by looking at the sequences of images. It is less obvious how this method can be used to classify different types of mines and clutter. The small dimensions and weight of the RASCAN instrument are an advantage for a portable system, especially in applications like landmine detection.

GPR for hand-held mine detection

D. Daniels (ERA Technology, UK)

In the first part of this presentation a summary of the design issues was reported. The design issues were defined according to the experience acquired on the field by using ground penetrating Radar for the detection of shallow mines. This detection problem was analysed by simulated curves relative to the Probability of Detection (PD) vs range, for various diameters (5-50 cm) of cylindrical objects buried in the soil. Two important parameters were also considered in this analysis: antenna footprint variation with the distance from the ground surface, and the Radar operating frequency. In a portable system the height of the antenna from the ground can vary from 10 to 50 cm during a manual scan over the surface, and this affects the dimension of the footprint. It has been shown that at greater heights the objects with small Radar Cross Section (RCS) become blurred and difficult to detect due to a convolution effect between the footprint and the mine size. A criterion for the choice of the optimum operating frequency has been presented by analysing simulated PD vs range curves for three different frequencies (0.5, 1 and 2 GHz). Of course the solution is a compromise for the considered range and soil attenuation (30 dB/m in this case). The parametric (cylinder radius) PD curves are plotted for a frequency of 1 GHz; a PD value of 0.9 is obtained from small to large diameters with a range from about 22 cm to 75 cm. A list of critical issues for the GPR response to clutter has also been reported.
In the second part of the presentation a prototype detector, MINETECT, was described. This hand-held device for mine detection combines Metal Detector and GPR techniques in a low weight instrument. A novel method for alerting the user to the presence of a mine is the use of a modulated sound for both GPR and MD. The GPR information about range is converted into an audio signal with higher frequency for small range. The manual sweep across the surface generates a characteristic sound for a buried mine.
The operator starts the investigation with the MD, listening to the corresponding audio output channel, and can then use the GPR with frequency modulated audio to confirm the presence of a mine. Several tests on simulated and real mine sites were presented, resulting in 100% detection rate and at 90% confidence level.

The new concept for detection and classification of shallow mines introduced with MINETECT represents an important step towards easy to use hand-held instruments. The audio signal information is a simple and natural way of interfacing the human operator with the instrument in real-time. The technology requirements for its implementation don't increase much the cost of the instrument. We can observe that there are other fields where the audio output has been successfully used for real-time scanning, like *vascular ultrasonic Doppler. The integrated solution of a MD and a GPR not only provides a high confidence level, but leaves the operator free to use the MD as a well known standardized method for mine detection. The learning time for discriminating clutter responses from mines by listening to the audio output should also be shorter, compared to other outputs based only on displays. The method should also be calibrated (automatically?) to adapt to changes of distance from the ground during a manual scan.*

Classification of buried objects from series of aligned hyperbolic arcs or "pendants" in Radar Scans

C. G. Windsor; P. Falorni, L. Capineri (University of Florence, Italy)

The paper presented a simple technique to classify buried objects according to the different oscillatory response to a Radar probing signal. The method is general and can be applied both for mine detection and for buried utility surveys.
The main idea relies on the consideration that scans across long parallel objects, such as pipes, buried in one metre or so of soil, show complex reflection patterns consisting of a series of inverted hyperbolic arcs characteristic of the object. A classification of the objects has been achieved by an analysis of the arcs, which gives rise to a series of "apex" points defining the lateral position, depth and amplitude of each arc. For objects of size larger or comparable with the wavelength (typically 20cm), several points with alternating positive and negative phases are obtained. Code has been written to associate series of apexes which may all arise from the same object. For example these apexes should all lie within a specified vertical area, and should have appropriately spaced depths, with each ripple having the correct alternating phase. The relative intensities of these apexes provide the necessary features for classification by, for example, a neural net. The method is simulated using two-dimensional examples provided by pipes buried under a road. Different pipes can be identified and readily separated from small objects giving background-scattered signals.

This method has a great potential for devising a classification scheme in a post-processing step. There are several detection techniques based on signal and image processing that can be applied to detect buried objects from their hyperbolic diffraction pattern template. This method is therefore suitable for analyses carried out on B-scan images acquired with ground penetrating Radar equipped with antenna arrays having good lateral resolution. In this case series of hyperbolic templates can be defined rather well with alternate positive and negative phase. The false alarm rate can be significantly reduced when the pendants concept can be applied to discriminate targets from clutter. Apart from the promising results obtained with the classification of buried pipes with different diameters and material, this new concept should be tested on real mine data acquired in laboratory conditions as well as during real measurement campaigns. According to previous work on mine detection by the same authors, the method is likely to be most effective if extended to three dimensions.

4 Session 21: Rough Surface Scattering and Related Problems

Reconstructing of Two-Dimensional Rough Surface Profile Using Optimization technique

Magda El-Shenawee and Eric Miller

In GPR humanitarian demining applications the roughness of the ground surface is considered a major clutter source. In addition, the ground roughness parameters are unknown and it is difficult to measure the roughness with on-site measurements. The paper attempts to solve this problem by reconstructing the rough ground profile from collected radar data, to then remove the ground response as part of the signal processing technique.

A fast algorithm for reconstructing the roughness parameters of two-dimensional (2-D) ground surfaces has been presented. This algorithm uses the electromagnetic waves scattered from the rough ground surface to obtain information about the scatterer (i.e. the rough ground). The basic idea is to combine a fast forward solver and an optimization technique to search for the ground roughness parameters by minimizing a cost function. The proposed reconstruction algorithm is based on the combination of two sophisticated fast algorithms which are: (i) the fast multipole method (FMM) for the forward solver, and (ii) the rapidly convergent descent method for the minimization of a cost function (by Fletcher and Powell 1964 and 1970). Several types of cost functions have been investigated in this work in order to achieve the most accurate reconstruction of the rough surface.

The perturbation of the ground surface on the Radar response from a shallow mine can represent in some cases a strong limit to the confidence of the detection process. The new method proposed in this work should be investigated with real experiments and compared with standard methods. Its computational complexity should also be considered when aiming at a fast response in real-time scanning systems.

5 Remote Sensing of Live Human Activity by Radar

Detection of Human Breathing and Heartbeat by Remote Radar

S. I. Ivashov, V. V. Razevig, A. P. Sheyko, I. A. Vasilyev (Bauman Moscow State Technical University, Russia)

Radars can be conveniently used to monitor the state of a human being in real-time without direct contact with the skin and in a non-invasive way. They present some advantages with respect to other well-known techniques like acoustic sensors for heart and respiratory monitoring and adhesive electrodes for ECG equipment.
In this paper a Radar system is used to record signals in the time domain and their frequency spectrums relative to the heartbeat and respiration.
Radars that operate in the wavelength range of 3–30 cm could solve this task (corresponding frequency range: 1–10 GHz). By subtraction of signals reflected from motionless objects it is possible to achieve high sensitivity for the detection of moving objects.
Organs inside a man's body are subjected to periodic fluctuations induced by the cardiac muscle and the lungs, and typically have frequencies in the range of 0.8–2.5 Hz for the heart and 0.2–0.5 Hz for the lungs.
Two problems for completing this task have been addressed: radar sensitivity and clever algorithms for rejection of background (static and dynamic). Background signals can be originated by other objects/persons around the patient. This requires the design of a directional antenna. Other problems addressed by this research work are the interference of the heartbeat and lung respiratory movement with the speech of the patient. A preliminary analysis of the spectrum has been carried out with a 1.6 GHz radar (model RASCAN) with the signal acquisition on a 30 s time interval, frequency range of recorded signals 0.03 – 3.0 Hz, dynamic range 60 dB and sampling frequency 20 Hz.

This work presented preliminary experimental results that are not conclusive but are certainly of interest for future research works. This Radar application is fairly new and has a strong motivation for diagnostic instruments, for example to monitor a person burned by a blast due to a mine or a bomb. In the case of burned people it is indeed sometimes difficult to find places on the body where acoustic probes or ECG electrodes could be permanently attached with medical adhesive tape. Moreover in emergency situations the Radar monitoring system mounted on a stretcher is immediately working *without need of connection cables. The same system can also be employed in a hospital for patient tracking in intensive care rooms.*

Ultra-Wideband Radar for Remote Measuring of Main Parameters of Patient's Vital Activity

I. Y. Immoreev, S. V. Samkov (Moscow Aviation Institute¸ Russia)

This paper presents the application of ultra wideband radar (UWB) as a non-contact method for monitoring respiration and heart activity of a person.
UWB signals with duration in the range 0.2-1 ns are chosen to transmit electromagnetic energy.
The basic physical principles exploited by this method is the reflection of electromagnetic waves at the boundary between different media and the penetration capability through hard (bones) and soft (internal organ) materials.
The presented system operates with pulse sequences transmitted through a body by an antenna and received by the same device. The received signals are digitized and processed to extract characteristic parameters of the investigated organs. A radar prototype has been developed and tested in accordance with the following specifications: central frequency: 1 GHz, average radiated power: 0.04 mW, receiver gate duration: 250 ps, detection range: 0.06–2 m, motion band-pass filter: 0.16–40 Hz.

The presented hardware prototype has a modular design and is ready to be used on the field for experiment. The separation of the heart beat from the respiratory movement seems to be done efficiently with a band-pass filter. Effects of patient speech and moving objects in the region of interest are under investigation.

Final Remarks

Some general personal observations can be made from the contributions analysed in this report:

- *Light, affordable instruments are necessary for humanitarian demining operations.*
- *The integration of different investigation technologies is a viable way to increase performance (Probability of Correct detection vs Probability of False Alarms).*
- *Radar is a good candidate to be integrated with Metal Detectors.*
- *Robust classification techniques are necessary to obtain object discrimination considering perturbation factors during field experiments: irregular/missing data, different type of soil and surface roughness, radar frequency and antenna coupling condition to the ground.*
- *New operator interfaces exploiting a multimedia approach can substantially simplify the training and the use of such instruments. Range modulated audio and contrast image sequences are good examples of this new approach.*

Finally I would like to report on the organisation of a session on "Biomedical Applications of Microwave Imaging, Spectroscopy and UWB Applications in Medicine", by S. Semenov and E. Staderini. The session reviewed the state of the art of radar applications for real-time contactless monitoring of human vital signs. I believe that this field of research is also correlated with humanitarian demining projects, because new medical monitoring instruments can mitigate the effects of mine explosions on humans during emergency situations.