ELECTROMAGNETIC INFRASTRUCTURE MONITORING: THE EXPLOITATION OF GPR DATA AND NEURAL NETWORKS FOR MULTI-LAYERED GEOMETRIES

Salvatore Caorsi and Mattia Stasolla

Department of Electronics
University of Pavia
via Ferrata 1, 27100 Pavia, Italy

1. INTRODUCTION

Public infrastructure monitoring is currently one of the main areas of interest for national governments' policies. The problems related to infrastructures and the impact they have on society and economy are straightforward, so that a number of US and EU projects has been funded for the development of advanced sensing techniques for the detailed inspection and analysis of the structural health of bridges, railways, roadways and water systems [1],[2].
There is a major concern among experts regarding the poor ability in suitably monitoring, maintaining and repairing such networks, so that the main challenge is to provide an adequate (accurate, low-cost) technology, along with a competing methodology (as more automated as possible), able to go beyond these limits.

In literature, a variety of methods have been proposed, but the most common approaches are based on Ground Penetrating Radar (GPR), which is a probing system designed primarily for the detection of objects and/or interfaces below the earth's surface [3]. Due to its non-destructive nature and proven diagnostic effectiveness, GPR-based solutions have been developed in many application fields, from infrastructure analysis to pavement profiling, from railroad deterioration assessment to environmental monitoring. In particular, a very challenging issue is the exploitation of GPR as a remote sensing tool for detecting buried objects or characterizing the subsurface structure and properties [4].
To this end, two approaches have been basically studied: inversion techniques, mostly based on approximated solutions of the scattering integral equation [5], and 'machine-learning' algorithms, which, for instance, can use artificial neural networks (ANNs) to find a regression model that relates the GPR data to the desired output [6].

2. METHODOLOGY

The purpose of this paper is to provide a new effective automatic algorithm for the estimation of the geophysical properties (i.e. thickness and permittivity) of subsurface layers in stratified geometries.
The starting point is a preliminary study recently carried out by the authors [7], dealing with the reconstruction of a homogeneous layer placed over a uniform indefinite background by means of Multi-Layer Perceptrons (MLPs).
This technique is based on the extraction from the GPR trace of two suitable parameters – R_k and Δ_k (see Eq. 1) – able to give a measure of the energy backscattered by discontinuities within the medium and of the distance covered by the e.m. signal between two interfaces, respectively.

$$R_k = \frac{\int_{t_k}^{t_{k+1}} s_k^2(t-t_k)\,\mathrm{d}t}{\int_{t_0}^{t_0+\Delta_k} s_0^2(t-t_0)\,\mathrm{d}t} = \frac{\int_{t_k}^{t_{k+1}} \alpha_k^2 s_0^2(t-t_k)\,\mathrm{d}t}{\int_{t_0}^{t_0+\Delta_k} s_0^2(t-t_0)\,\mathrm{d}t} = \frac{\alpha_k^2 \int_{t_k}^{t_k+\Delta_k} s_0^2(t-t_k)\,\mathrm{d}t}{\int_{t_0}^{t_0+\Delta_k} s_0^2(t-t_0)\,\mathrm{d}t} = \alpha_k^2 \quad (1)$$

where $\Delta_k = t_{k+1} - t_k$ and s_0 is a known reference signal

It must be noticed that Eq. 1 holds true in case of non-dispersive media, as the propagating signals do not experience spectral distortion and reach the GPR receiver as scaled replicas of the emitted pulse (see Fig. 2b).
The reconstruction of the actual permittivity and thickness of the layer is addressed by feeding R_k and Δ_k into an ANN architecture made up of 2 MLPs, devoted to the mapping of input data onto the desired output.

In order to extend the solution of a single layer to multi-layered geometries, the above-mentioned processing block can be inserted in a general framework where each stratum is singly analyzed. The flowchart is depicted in Fig. 1.

The radargram is first scanned to detect the echo generated at the first interface ($ground/layer_1$), then this signal is compared to the reference echo s_0 (preliminarily acquired) and fluctuations in the energy profile are evaluated in order to establish the amplitude scaling factor and the arrival time of the subsequent echo ($layer_1/layer_2$ interface). When the reconstruction of the permittivity and the thickess of the first layer (ε_1 and x_1) are accomplished, it is possible to suitably employ this information for the processing of the subsequent layers, within a general framework where the procedure is applied from the beginning and iteratively repeated until sensible backscattered radiation can be revealed.

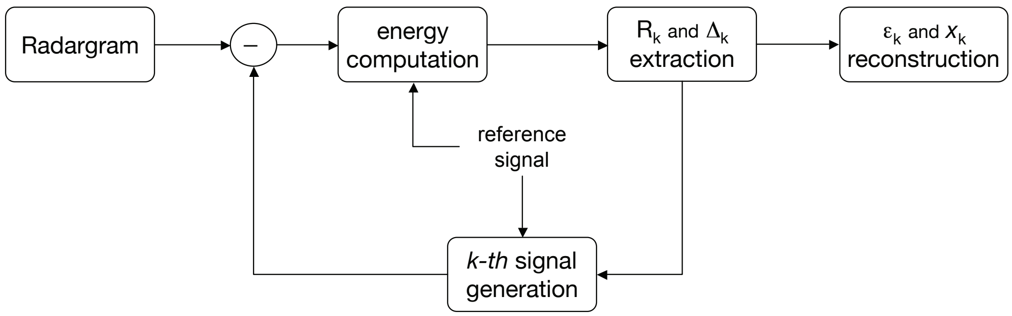
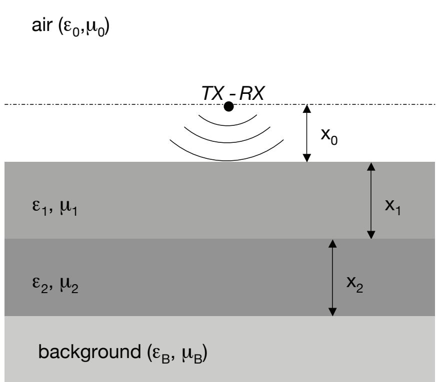


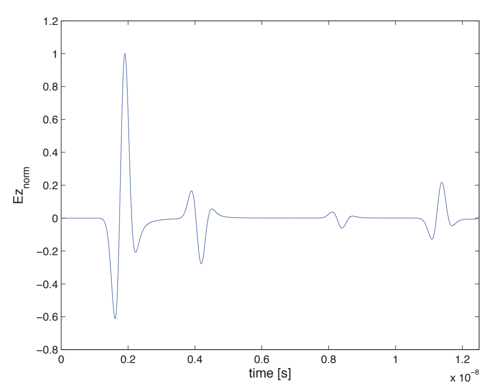
Fig. 1. Workflow.

3. RESULTS

The dataset used for testing the procedure has been created by means of GPRMax [8], a software based on FDTD numerical method, and consists of a number of radargram traces which simulate the e.m. field sensed at the receiver of a typical monostatic GPR which illuminates a multi-layered geometry. It should be noticed that for our purposes – the operational description of the algorithm and the evaluation of its effectiveness – it is sufficient to analyze the scenario depicted in Fig. 2a, as the processing of any other deeper layers follows the same rationale and is straightforward.
Besides providing a quantitative performance assessment in terms of permittivity and thickness' reconstruction errors, results will also explore method's generalization capabilities, e.g. showing its behavior when different GPR models and configurations are used.



(a) Multi-layered scenario.



(b) An example of a GPR trace for the proposed scenario.

4. REFERENCES

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