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A knowledge based ANN approach for geophysical monitoring of sub-surface layers by means of GPR data

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In this work we consider the problem of determining the dielectric and geometric characteristics of subsurface layers by means of GPR systems. In particular, suitable features, strictly related to the geophysical parameters of the scenario, are first extracted from the GPR electromagnetic signal and then fed to an artificial neural network (ANN) in order to derive the dielectric permittivity and the thickness of the sub-surface layer.

In our past research, this issue was addressed focusing on the analysis of a numerical simulation of the electromagnetic field scattered by the buried layer, obtained as the difference between the whole signal at the receiver (RX) and the field emitted by transmitter (TX) in freespace. Unfortunately, this kind of approach - although providing good and encouraging results - is too dependent on the source properties (for example, current/voltage pulse that feeds the antenna) and a few drawbacks arise when facing practical applications. The main inconvenience is just the lack of knowledge about the transmitted signal, but, of course, it must always be taken into account the huge effect of background noise.

For these reasons, in order to reduce as much as possible the a priori information about the electromagnetic source and to pursue a strong generalization, we present a new approach which manages only the amplitude of the received waveforms and exploits the fix time scale, forced by scenario and GPR system's geometrical configuration, to determine the signal time dynamics. The required preliminary knowledge is then very limited (only signal duration and system geometry are needed) and above all it is low-cost, since it is generally available from GPR producers' specifications or, in any case,

it is easy to be inferred by ad hoc initial acquisitions.
In this way, from signal amplitudes and time lags, it is possible to extract, from a general point of view, convenient features that are almost univocally bound to the parameters of interest, namely the electric permittivity of the layer and its thickness.
The inverse process that relates the extracted information to the geophysical characteristics of sub-surface is here realized through a back propagation ANN, that, after an initial training phase (requiring a small amount of samples), is able to efficiently and rapidly associate features to parameters.

Within the described framework, the study was first developed on simulated scenarios, differing in waveforms' shapes (e.g., modulated pulses, square waves) and GPR system and scenario's properties (TX/RX and TX/ground distances, layer's permittivity and thickness), in order to broadly assess the capabilities of the method and to evaluate possible drawbacks.
Since the algorithm was originally devoted to rail-track substructure monitoring, it has been therefore tested on real data acquired from different railroad tracts in diverse locations by means of a GPR antenna mounted on a probe vehicle. Although the typical noise affecting such systems (DC shift, jitter, non uniform sub-grade, sleepers, etc.), results are still promising and confirm the high accuracy achieved in the numerically simulated analysis. At the end of the processing chain is therefore possible to provide useful information about subsurface conditions, from soil composition to presence of anomalies, for instance faults in ballast or trapped water on railroads.

It is straightforward the relevance of the supplied information, above all considering the fact that this topic has become, in its general scope of improvement and maintenance of Transport Networks, one of the key actions for today's sustainable development. Moreover, it is important to stress that, thanks to the high degree of generalization of the proposed approach, its use is expected to be easily and successfully widened to many other infrastructure applications, such as pipe and cable detection or pavement profiling.