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Editorial

Editorial for the Special Issue "Review of Application Areas of GPR"

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Ground-penetrating radar (GPR) started as a radio echo sounding technology during the second half of the last century, but it is now a well-established and widely adopted technology for producing high-resolution images of subsurface. The application domain spans many orders of magnitude in size, from glaciology to detecting cracks in pavement. Such continuous expansion in accuracy, as well as in application areas, is a consequence of the increase in computational resources, novel hardware architecture, and algorithm improvements to facilitate interpretation.

This Special Issue (SI), entitled "Review of Application Areas of GPR", includes a collection of literature reviews and case studies on the use of GPR in different fields of application, covering not only well-established fields but also opening new avenues of research in emerging fields and technological developments.

A total of 12 papers are published addressing the evolution of GPR techniques, mainly including the following aspects: (i) emerging fields of applications like precision farming and detection of geothermal resources; (ii) technical developments such as airborne GPR systems; and (iii) novel methodological approaches based on machine learning and full-wave inversion techniques. Below is a brief description highlighting the main contribution and novelty of each of the published papers:

- Lombardi et al. [1] provide an up-to-date overview of the main research areas of GPR, as well as associated challenges and opportunities. From geology to forensics, this paper draws a comprehensive landscape of the application areas in which GPR has proven to be a game-changing methodology. As a high-level contribution, this paper provides insights into the near-to-far future trends and current barriers that must be overcome in terms of system design, system performance, and operational approaches.
- The work by Elseicy et al. [2] describes the current state of GPR and a wide range of alternative NDT methodologies for pavement diagnosis, highlighting sensor and data fusion approaches to overcome current challenges in specific fields of application. In particular, this review suggests how improvements in data collection, joint georeferencing of multiple-source data, and intelligent data analysis could enable the development of a digital twin of road infrastructure, thus permitting advanced monitoring and maintenance.
- The paper by Hou et al. [3] describes the principal processing techniques for GPR data enhancement within four main domains, i.e., bridges, road pavements, underground utilities, and urban subsurface risks. This paper exploits the complexity of GPR signals, provides some structural categories for feature extraction schemes, and highlights promising directions for future research, including dependency on large datasets, NDT integration, and advanced data analysis.

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- Targeting the advantages that early detection of rebar corrosion could offer, the work by Miwa and Nakazawa [4] presents an overview of the use of vibro-Doppler GPR equipment to determine the spatially distributed vibration displacements associated with a rebar corrosion phenomenon. This contribution highlights how exploiting the Doppler-modulated component of a GPR reading enables new NDT applications with a high level of accuracy and efficiency.
- Peng et al. [5] summarise current research achievements in the application of GPR and other NDT techniques for detecting grouting defects behind tunnel shield segments and present a forward-looking aspect regarding research on NDT methods in grouting defect detection. Novel processing schemes, including full waveform inversion and machine learning, advanced GPR transmission, and elastic wave methods, are among the research topics regarded as fundamental for the future.
- The paper by Edemsky et al. [6] provides an interesting review of the status of GPR surveys carried out using helicopters for environmental applications, hydrogeology, and exploration geology. The results demonstrate how overcoming the challenges of radiation divergence in the air and strong reflection from rugged and heterogeneous surfaces could significantly expand the areas of application of airborne GPR.
- Opportunities for the application of GPR to study and better characterize geothermal resources, in particular hydrothermal reservoir, are the highlight of the contribution by Solla et al. [7], which suggests that combining GPR with alternative NDT techniques could allow informed decision making on potential site evolution or reconditioning based on accurate geological, geophysical, and mineralogical details.
- Zhang et al. [8] review existing studies and recent developments in the use of GPR to characterize soil water dynamics, including soil water content and soil hydraulic properties, as well as acquisition and processing approaches. These aspects could facilitate the determination of an optimal method to estimate soil hydraulic properties based on the employed GPR system, leading to the delineation of several research directions that should be considered in the future.
- The currently available balun technologies for GPR instrumentation design and the associated architectural implementations are critically reviewed and assessed in the contribution by van Verre et al. [9]. By taking into account the UWB nature of GPR methodology, as well as the experienced inefficiencies in traditional design solutions, this paper provides a robust ground for evaluating the optimal choice for GPR system design.
- Lombardi et al. [10] analyse the current use of GPR for precision irrigation, specifically its capacity to describe the main soil properties, by exploiting the most widely adopted operational methodologies and data processing approaches. Their review highlights how the natural heterogeneity of soils still hampers the potential of GPR methodology, and suggests that the domain of quantitative analysis, as well as the integration of GPR and other techniques, holds the promise of improving current understanding of soil relationships and the accuracy of soil property estimation.
- The work by Wu et al. [11] addresses the challenges of measuring soil moisture in trench-hill potato fields through the use of full-wave inversion GPR technique. The results of the presented case studies, including numerical and experimental analyses, not only demonstrate the potential for automated irrigation approaches, but also suggest novel research topics associated with the modeling of electromagnetic scattering by structured surfaces.
- Alonso-Díaz et al. [12] present a complementary study of Interferometric Synthetic Aperture Radar (InSAR) and GPR for the early detection of subsidence and sinkhole phenomena. Once again, this paper demonstrates how GPR represents a valuable tool for improving the understanding of subsurface phenomena by highlighting information, such as sinkhole and settlements, that are hardly inferable from InSAR techniques only. InSAR provides information at the network level, while GPR allows

subsurface exploration and monitoring at the project level, thus revealing the probable causes of the subsidence detected by InSAR.

To conclude, this Special Issue shows how and in which ways recent developments in GPR have enabled it to be used in new application areas. The published papers in this SI cover a wide range of topics involving several characteristics and aspects of GPR methodology. These papers represent a large and extensive source of references and background information, and will update readers on emerging GPR research patterns.

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