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Full-waveform inversion of GPR data for civil engineering applications

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Conventional GPR ray-based techniques are often limited in their capability to image complex structures due to the pertaining approximations. Due to the increased computational power, it is becoming more easy to use modeling and inversion tools that explicitly take into account the detailed electromagnetic wave propagation characteristics. In this way, new civil engineering application avenues are opening up that enable an improved high resolution imaging of quantitative medium properties. In this contribution, we show recent developments that enable the full-waveform inversion of off-ground, on-ground and crosshole GPR data. For a successful inversion, a proper start model must be used that generates synthetic data that overlaps the measured data with at least half a wavelength. In addition, the GPR system must be calibrated such that an effective wavelet is obtained that encompasses the complexity of the GPR source and receiver antennas. Simple geometries such as horizontal layers can be described with a limited number of model parameters, which enable the use of a combined global and local search using the Simplex search algorithm. This approach has been implemented for the full-waveform inversion of off-ground and on-ground GPR data measured over horizontally layered media. In this way, an accurate 3D frequency domain forward model of Maxwell's equation can be used where the integral representation of the electric field is numerically evaluated. The full-waveform inversion (FWI) for a large number of unknowns uses gradient-based optimization methods where a 3D to 2D conversion is used to apply this method to experimental data. Off-ground GPR data, measured over homogeneous concrete specimens, were inverted using the full-waveform inversion. In contrast to traditional ray-based techniques we were able to obtain quantitative values for the permittivity and conductivity and in this way distinguish between moisture and chloride effects. For increasing chloride content increasing frequency-dependent conductivity values were obtained. The off-ground full-waveform inversion was extended to invert for positive and negative gradients in conductivity and the conductivity gradient direction could be correctly identified. Experimental specimen containing gradients were generated by exposing a concrete slab to controlled wetting-drying cycles using a saline solution. Full-waveform inversion of the measured data correctly identified the conductivity gradient direction which was confirmed by destructive analysis. On-ground CMP GPR data measured over a concrete layer overlying a metal plate show interfering multiple reflections, which indicates that the structure acts as a waveguide. Calculation of the phase-velocity spectrum shows the presence of several higher order modes. Whereas the dispersion inversion returns the thickness and layer height, the full-waveform inversion was also able to estimate quantitative conductivity values. This abstract is a contribution to COST Action TU1208