Multi-Trace Coherence Mapping and Data Fusion for Improved GPR Imaging

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Highlights:

• Usually only GPR reflection amplitudes are imaged, while GPR data contain far more information.
• Multi-trace GPR coherency visualisations offer new insights into structures otherwise hardly visible.
• Image fusing permits the combined display of different GPR data attributes (amplitude and coherency).

Keywords: GPR, coherence, amplitudes, imaging, high-resolution, data fusion.

Amongst all geophysical near-surface prospection techniques, the GPR method (Conyers, 2013) permits under suitable ground conditions the highest imaging resolution and greatest data density, as well as the application of the most advanced data processing and visualisation algorithms. Conventionally, GPR data are visualised by plotting the GPR reflection amplitudes for a certain time- or depth-range in form of 2D sections, aka GPR profiles, or horizontal amplitude maps, so called GPR time- or depth-slices. When the time- or depth-range of the slices to be generated exceeds one recording sample, commonly thick slices are computed by averaging the amplitude of the Hilbert transformed traces over the corresponding time or depth-range. This process inevitably reduces the vertical imaging resolution. In contrast, the imaging of single-sample full amplitude slices offers highest vertical imaging resolution, but involves a much larger number of slices to be analysed (Trinks \textit{et al.}, 2010). The visual appearance of thick, Hilbert transformed slices with only positive amplitude values differs greatly from that of single-sample slices with both positive and negative amplitude ranges.

Any imaging approach that only takes the GPR reflection amplitudes into account, neglects the fact that GPR data contain much more valuable information, such as frequency content and frequency variations, phase and phase shift, as well as relative changes between neighbouring GPR traces. All this information could and should be extracted and analysed for improved GPR subsurface imaging. Currently, the GPR methodology employed for near-surface geophysical prospection is still rather primitive compared to the state-of-the-art in exploration seismology, which likewise deals with the recording, processing and visualisation of time series that are comprised of wavelets representing subsurface reflections of a transmitted wave.
source impulse. Modern GPR technology in all but very few exceptions is reduced to single-channel, single-offset data acquisition, preventing the adaptation and use of any sophisticated, albeit laborious, seismic pre-stack data processing routines. A particularly successful approach to advanced exploration seismic imaging has been the analysis of seismic attributes (Chopra & Marfurt, 2005, 2006a, 2006b; Randen & Sønneland, 2005). Seismic attributes can be divided into pre-stack as well as post-stack attributes. Of interest for GPR data analysis are post-stack single- as well as multi-trace attributes. So far, only few have attempted to utilize seismic attributes for the analysis of GPR data (e.g. Tronicke & Böninger, 2013; Böninger, 2010; Böninger & Tronicke, 2010, 2012).

Recent advances in GPR technology regarding the development of dense multi-channel antenna arrays and their integration with automated, accurate positioning solutions in motorised prospection systems permit the efficient acquisition of large 3D GPR data volumes with very dense trace spacing (Trinks et al., 2018). The generated high-resolution GPR data sets with 8 × 4 cm horizontal trace spacing are ideally suited for multi-trace attribute analysis, such as coherence or similarity. Not relying on the reflection amplitudes, coherence attribute imaging offers insights into structural changes in the subsurface that not necessarily generate strong reflections or pulse absorption (Trinks & Hinterleitner, 2020).

Image fusion (Verhoeven, 2015; Verhoeven et al., 2016) permits the combined visualisation of different information contained in the GPR data, such as reflectivity and coherence. To demonstrate the potential of the proposed approach, we present examples from sites in Denmark and Norway where extensive high-resolution GPR surveys conducted for archaeological prospection have revealed the buried remains of pits, postholes and trenches embedded in layered sediments.
Figure 2. Fusion image of coherence and reflection amplitude, showing the circular ring structures that surrounded Iron Age burial mounds, as well as larger and smaller pits, several of which are likely to have been burials. This data was collected in the framework of the Vestfold Monitoring Project (VEMOP) conducted by Vestfold and Telemark County Council in collaboration with the Norwegian Institute for Cultural Heritage Research and the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology.

References


