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Extraction of orientation-and-scale-dependent information from GPR B-scans with tunable two-dimensional wavelet filters

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GPR is an invaluable tool for civil and geotechnical engineering applications. One of the most significant objectives of such applications is the detection of fractures, inclined interfaces, empty or filled cavities frequently associated with jointing/faulting and a host of other oriented features. These types of target, especially fractures, are usually not good reflectors and are spatially localized. Their scale is therefore a factor significantly affecting their detectability. Quite frequently, systemic or extraneous noise, or other significant structural characteristics swamp the data with information which blurs, or even masks reflections from such targets, rendering their recognition difficult. This paper reports a method of extracting information (isolating) oriented and scale-dependent structural characteristics, based on oriented two-dimensional B-spline wavelet filters and Gabor wavelet filters.
In addition to their advantageous properties (e.g. compact support, orthogonality etc), B-spline wavelets comprise a family with a broad spectrum of frequency localization properties and frequency responses that mimic, more or less, the shape of the radar source wavelet. For instance, the Ricker wavelet is also approximated by derivatives of Cardinal B-splines. An oriented two-dimensional B-spline filter is built by sidewise arranging a number of identical one-dimensional wavelets to create a matrix, tapering the edge-parallel direction with an orthogonal window function and rotating the resulting matrix to the desired orientation. The length of the one-dimensional wavelet (edge-normal direction) determines the width of the topographic features to be isolated. The number of parallel wavelets (edge-parallel direction) determines the feature length over which to smooth. The Gabor wavelets were produced by a Gabor kernel that is a product of an elliptical Gaussian and a complex plane wave: it is two-dimensional by definition. Their applications have hitherto focused on image classification and texture analysis. Both types of filter exhibit similar F-K characteristics and may be locked on a central (peak) frequency or spatial wavenumber by varying the length of the edge-normal direction.
The filters can be applied directly to B-scan data, in which case they abstract information about given scales at given orientations. Alternatively, they can be rotated to different orientations and applied under adaptive control, so that they remain locked on a given frequency or wavenumber. The resulting images can be stacked in the LS sense, so as to obtain a complete representation of the input data at a given temporal or spatial scale (frequency or wavenumber).
The method is shown to be effective in extracting fine to coarse scale information from noisy data. It is demonstrated with applications to common photographic images and noisy GPR data from geotechnical surveys.