APPLICATION OF ATTRIBUTE-BASED AUTOMATED PICKING TO GPR AND SEISMIC SURVEYS

M. Dossi, E. Forte, M. Pipan
Department of Mathematics and Geosciences (DMG), University of Trieste, Italy

Introduction. An accurate reflection picking, as independent as possible from the subjectivity of the interpreter, is of paramount importance when performing both qualitative (e.g. stratigraphic interpretation) and quantitative (e.g. amplitude inversion) analyses of several wave-field geophysical surveys. Automated picking processes can be used to facilitate interpretation and to recover several parameters and attributes (Chopra and Marfurt, 2005) from the recorded profile, most importantly the reflected amplitudes and the two-way traveltimes, which can then be used to estimate the main impedance contrasts in the subsurface. In ground penetrating radar (GPR) surveys, examples of application include the identification of contaminants in near-surface hydrogeological settings (Backer, 1998; Babcock and Bradford, 2013); the inspection and maintenance of roads through the identification of damaged sections (Saarenketo and Scullion, 2000); and the monitoring of glaciers in terms of their temporal variations in stratigraphy and water content (Forte et al., 2014a, 2014b; Colucci et al., 2015). In seismic surveys, an accurate picking can be used for first-breaks detection and data processing (Sabbione and Velis, 2010); amplitude-versus-offset analysis (AVO; Castagna and Backus, 2007); and the identification of faults in a profile, which are characterized by discontinuities in the picked events (Hoyes and Cheret, 2011).

Several picking techniques exist (Dorn, 1998), and they differ in terms of 1) their adopted picking criteria, like for example manual picking, amplitude cross-correlation, or interpolation between control points (seeds); 2) the assumptions made with regards to the analyzed data set, for example that the recorded events are locally smooth; 3) the accuracy of the picked results and their dependence on the interpreter’s subjectivity and experience. We developed an automated process designed to accurately detect, and mark as a horizon, any event that shows lateral phase continuity, and to select specific reflection phases for subsequent analysis and interpretation. In this paper, we give a short description of the main features of the implemented algorithm (more details in Dossi et al., 2015a, b; Forte et al., 2015), and show a few examples of its application to both GPR and seismic data sets.

Automated picking. The algorithm starts by performing attribute analysis on the recorded data set, also known as complex trace analysis (Taner et al., 1979; Barnes, 1996, 2007), separating the signal into its reflection strength (also referred to as instantaneous amplitude, or trace envelope) and the cosine of its instantaneous phase (also referred to as cosine phase). The cosine phase profile allows to follow reflections more accurately with respect to the
original amplitude section. The algorithm uses this feature to track any event with lateral phase continuity, connecting signal phases with the same polarities and close arrival times. Given its independence from the reflection strength, the system can even track events characterized by lateral amplitude variations or changes in the shape of the reflected wavelet. The picking procedure is nevertheless sensitive to the presence of noise and interference in the recorded profile. For example, a hyperbolic diffraction can intersect an unrelated reflection and deform horizons originating from such reflection, while noise-related distortions of the signal phases can interrupt the tracking of an event. Therefore, the analyzed profiles may require a certain degree of processing before picking. The algorithm itself can reduce such effects by automatically connecting horizons which belong to the same coherent event but were separated by a few distorted phases. This is done by using close parallel horizons as patches across the gaps, and it has the effect of reducing the total number of horizons, while increasing their average length. Once all possible horizons have been constructed, they are superimposed on the recorded profile for visual interpretation. Optional constraints on the reflection strength can be set, in case the interpreter wants to selectively display events that reach specific energy thresholds.

After picking, the algorithm automatically analyzes each horizon, searching for close sub-parallel events that can be considered part of the same reflection. The aim is to obtain single horizons representing each reflection, using either phase or energy-based constraints, in order to reduce the total number of displayed picked events, and therefore improve the interpretation. The phase-based method groups together sub-parallel horizons by reconstructing the reflected wavelet in each of them and then confronting their shapes. The wavelets are reconstructed by averaging the cosine phase along each horizon, which preserves the reflected signal while removing other unrelated events. If the two shapes are similar by means of cross-correlation, the two sub-parallel horizons are considered to be part of the same reflection. Under favorable conditions of high signal-to-noise ratio and absence of interfering events, this process (also called phase assessment) can be used to identify the initial phase (as well as later ones) in each reflection, and therefore its polarity, which allows to reconstruct the subsurface reflectivity. Specific phases can then be selected for further analysis and interpretation. The energy-based method is instead used when lateral signal variations, caused by either dispersion, noise, or interference, do not allow the accurate reconstruction and comparison of the reflected wavelets. In this case the recorded profile is separated into energy packages by defining the main peaks of the reflection strength. Sub-parallel horizons from the same package are then grouped into the same event using statistical analyses of their arrival times. Specific horizons can then be selected by using either energy or time-related constraints with respect to the peak reflection strength in each energy package.

**Examples of application.** *Stratigraphic interpretation (reflection seismics).* In this section, we apply the automated picking to a seismic profile acquired in 2010 in the west Mediterranean Sea by the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS), as part of the WS10 exploration project (Geletti *et al.*, 2014). Attribute analysis allows to clearly define the subsurface structures by disregarding the amplitude information, as it can be noticed from the cosine phase profile in Fig. 1A. In the analyzed pre-stack time migrated profile, three different domains can be identified, namely a sedimentary basin (S), the seismic basement (B) and a salt dome (D), all showing slightly different seismic signatures. As previously discussed, we applied the energy-based grouping method, due to the inherent variation of the reflected wavelet caused by seismic processing (e.g. stacking), which prevents its accurate reconstruction through cosine phase averaging. The horizon grouping results are shown in Fig. 1B, superimposed on the amplitude section. The algorithm divided the profile into energy packages and selected from each reflection those horizons with an average energy equal to at least 50% of the peak reflection strength in the respective package. This selection method can be sensitive to vertical resolution, which can cause close parallel reflections to be grouped into the same energy package so that, although accurately picked, the weaker one is not automatically displayed after grouping (e.g.
white arrow in Fig. 1B). Nevertheless, the results are consistent in all the domains, and allow to correctly mark the sedimentary sequence, its lateral boundaries, and even the salt dome intrusion. Such area is indeed a complex target for all the existing picking procedures, due to the high velocity contrast between the salt and the intruded sediments, as well as the abrupt lateral changes in the horizon continuity.

**Fig. 1 – Application of the picking procedure to a reflection seismic profile.** The figure shows: A) the cosine phase section, and B) the resulting picked reflections, superimposed on the amplitude profile, after applying on the horizons energy thresholds equal to 50% of the peak reflection strength in each energy package. Positive amplitudes are marked in green, negative amplitudes in red. The profile images a sedimentary basin (S), the seismic basement (B) and a salt dome (D). The white arrow indicates an example of distinct parallel reflections automatically grouped within the same energy package, preventing the weaker one from being displayed. Refer to the text for further details.

**Road inspection (GPR).** In this section, we analyze a common offset (CO) GPR data set acquired over an airport runway. The recording system was a Malå Geoscience ProEx GPR, connected to 500 MHz ground-coupled bistatic shielded antennas. An exemplary profile, acquired using a 0.185 ns sampling interval and an average 0.19 m trace spacing, is shown in Fig. 2A. The applied processing sequence consists of DC removal, drift correction, background removal, and band-pass filtering. Amplitude recovery algorithms were not used, and so the signal shows a steady decrease of amplitude with depth (Fig. 2A). Nevertheless, as previously discussed, the cosine phase allows to correctly track laterally continuous events (Fig. 2B), even without any applied gain function. More chaotic results can be noticed in the deeper part of Fig. 2B, where the signal-to-noise ratio is lower, preventing the identification of clear coherent structures. However, most of these artificial horizons are automatically disregarded during the described phase-based horizon grouping process, whose results are displayed in Fig. 2C. In fact,
the figure shows those horizons which were automatically identified as part of the first three phases of reflections with at least two identified phases, which means that each horizon must have at least one recognized sub-parallel event in order to be displayed. These requirements remove noise-related horizons, but they can also affect areas characterized by interference or overlapping. For example, some recognizable structures in the shallow region (0-15 ns), clearly marked by the algorithm in Fig. 2B, are not automatically displayed in Fig. 2C, because the local quality of the recorded signal prevents such horizons from meeting the thresholds set for the phase-based grouping method. The horizons shown in Fig. 2C are the result of a totally automated procedure, with only a few required control parameters and thresholds being set by the interpreter. However, the algorithm is able to identify the base of the runway pavement (H1), made by concrete plates, as well as other features interpreted as natural sedimentary contacts, with the two most apparent layer interfaces marked as H2 and H3.

**Glacier monitoring (GPR).** In this section, the picking algorithm is applied to a CO GPR data set acquired over the Prevala glacieret (Forte et al., 2014a), which is located at an elevation of 1830-1960 m a.s.l. in the Julian Alps, near the border with Slovenia. The recording system was a ProEx Malà Geoscience GPR equipped with 250 MHz shielded antennas, with a 0.4 ns sampling interval and an average 0.2 m trace spacing. The latter parameter was measured with an odometer that was also used as a triggering device. The recorded profile is shown in Fig. 3A, and contains several features, including a well stratified surface layer (L), a central debris layer (D) producing several hyperbolic diffractions, and older deeper ice reaching the glacieret base.
(B). The applied processing sequence consists of DC removal, drift removal, spectral analysis and band-pass filtering, spatial filtering to remove ringing and late arrivals of the ground wave, spherical divergence correction, and time migration. In the last two steps, a constant velocity equal to 20 cm·ns⁻¹ was used: this value was estimated by integrating the analysis of dedicated common mid-point (CMP) gathers with direct measurements obtained in a nearby snow pit dug concurrently with the GPR survey. The results of the picking and phase-based grouping method are shown in Fig. 3B, and include those horizons automatically identified as part of the first three phases of reflections with at least three identified phases, which means that each horizon must have at least two recognized sub-parallel events in order to be displayed. The complex nature of the analyzed data set offers an interesting test for the picking procedure, since the profile contains not only laterally continuous sub-horizontal reflectors, but also discontinuous reflections and interfering diffractions caused by the debris layer, some of which are not fully corrected by the applied migration algorithm. Moreover, in the deepest part of the profile there are low amplitude discontinuous reflectors, which were interpreted as the internal ice layering and the glacieret base. Although with different levels of accuracy in different parts of the profile, all the main features have been properly detected by the applied procedure.

![Fig. 3](image)

**Fig. 3** – Application of the picking procedure to a glaciological 250 MHz CO GPR profile. The figure shows: A) the processed GPR profile; and B) those horizons automatically identified as one of the first three phases of reflections with at least three recognized phases. Positive amplitudes are marked in green, negative amplitudes in red. The applied labels highlight the layered firn (L); a mixed ice and debris layer (D); and the glacieret base (B), respectively.

**Discussion.** The proposed picking method presents two main advantages with respect to other commonly used techniques: 1) it is mostly independent from the interpreter, not needing any initial manually picked seed for horizon tracking, and with just a few required control parameters and thresholds; 2) the interpreter can check the results at each step in order to evaluate the performance, manually intervene in complex areas where the algorithm might fail,
and change parameters or even the used approach (e.g. by switching between the energy-based and the phase-based grouping methods). Indeed, the entire procedure (i.e. picking, grouping, and even the phase assessment) is implemented as an interactive process rather than a “black box”.

We showed the versatility of the algorithm, which can be successfully applied to both reflection seismic and GPR data sets, as well as to both CO and CMP gathers. Furthermore, the process can equally perform at different levels of complexity in terms of structural domains and subsurface material variations. We demonstrated that data processing is not a critical issue for the procedure, although both picking and grouping performances are improved with higher signal-to-noise ratios. Nevertheless, the algorithm can be applied to data sets with just basic processing and without (or with limited) amplitude recovery, which allows it to pick amplitudes free from possible subjective distortions caused by the interpreter’s assumptions regarding the propagation velocity and signal dissipation in the subsurface materials. This is very important in case the picking results are to be used for further analysis (e.g. AVO) or inversion processes (e.g. amplitude inversion).

**Conclusion.** We presented a few examples of application of an automated process designed to detect and track, in an accurate and objective way, reflections inside a recorded data set by exploiting their lateral phase continuity. The results, obtained in different profiles from both reflection seismic and GPR surveys, are quite accurate, since they are able to mark most of the recorded reflections and their different phases, with only a few exceptions in more complex areas characterized by noise or interference. Although the presented examples were limited to just 2D sections, the procedure can be easily extended to 3D data sets. A few input parameters must be selected and carefully evaluated by the interpreter, nevertheless the degree of subjectivity is greatly reduced with respect to other commonly used picking algorithms, leading to a faster and more objective process. Further improvements can be achieved by using integrated attributes as additional thresholds, or by evaluating the behavior of other physical parameters, such as changes in the spectral distribution.

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**References**


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