

Application of Yu's wavelet filtering and SVI technique in first arrivals picking

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Summary

This paper applies the Super Virtual Interferometry (SVI) method and Yu's wavelet filtering technique to the first arrival picking of seismic data in the Kuche Mountain. The processing results indicate that the comprehensive application of these two optimization measures significantly improves the signal-to-noise ratio and identifiability of the first arrival wavefield. Consequently, it enhances the accuracy and picking rate of first arrivals, effectively addressing near-surface modeling and static correction issues.

Introduction

In recent years, the widespread use of nodal geophones for data acquisition, vibrator sources, and various external interferences have resulted in low signal-to-noise ratios and poor quality of first arrival picking, directly impacting the final processing results. First arrival picking algorithms generally fall into categories such as amplitude-based methods (e.g., energy ratio method) and multi-trace cross-correlation algorithms utilizing waveform similarity between traces (Ziyu Qin et al., 2021). These algorithms require high signal-to-noise ratios, and even artificial intelligence-based techniques struggle to achieve satisfactory results in low signal-to-noise scenarios (Ping Liu et al., 2021). Therefore, improving the signal-to-noise ratio of seismic data in complex regions and enhancing picking rates and accuracy remains a pressing issue.

Professor Yu Shoupeng proposed a broadband Ricker wavelet, also known as Yu's wavelet, which is composed of superimposed Ricker wavelets of different frequencies. It possesses advantages such as a narrow lobe, small side lobe amplitude, simple waveform, high resolution, fidelity, and signal-to-noise ratio (Cai Xiling, 2000; An Shengpei et al., 2015). In order to improve the signal-to-noise ratio of first arrivals, Dong et al. (2006) introduced the refraction wave interference theory, resulting in virtual refraction waves with high signal-to-noise ratios. Mallinson et al. (2011) and Bharadwaj et al. (2012) introduced the Super Virtual Refraction Interference (SVI) theory, extending the refraction wave interference method. Al-Shuhail (2015) and An et al. (2015b) applied SVI to improve first arrival picking.

This paper applies the SVI method and Yu's wavelet filtering technique to the processing of 3D data in a specific exploration area in Kuche. From the processing results, it is evident that the joint application of these two methods significantly improves the quality of first arrival data, enhances the picking rate, and consequently improves the effectiveness of static correction.

Filtering First Arrival Data Using Yu's Wavelet

Professor Yu Shoupeng (1996) synthesized Ricker wavelets of different frequencies to obtain a new type of wavelet, namely Yu's wavelet, with the expression:

$$h(t) = \frac{1}{q-p} \int_p^q [1 - 2(\pi gt)^2] e^{-(\pi gt)^2} dg \quad (1)$$

where p and q are the lower and upper limits of the g variable integration, representing two parameters characterizing the frequency of the Ricker wavelet.

When $p = 10$, $q = 100$, the corresponding Yu's wavelet and its amplitude spectrum are shown in Figure 1. It can be observed that Yu's wavelet has a narrow main lobe with strong energy and small side lobe amplitude, which is advantageous for the processing of first arrival data.

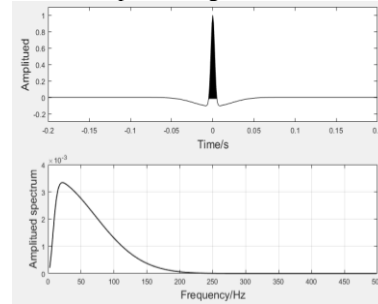


Figure 1: Yu's wavelet (up) and amplitude spectrum (down)

Figure 2 illustrates an application example of Yu's wavelet filtering technique to suppress side lobes in vibrator source records. The upper image shows first arrival data after linear moveout correction, where poor coupling of the baseplate leads to strong side lobe, making it challenging to identify true first arrival events. The lower image presents the results after Yu's wavelet filtering, effectively suppressing side lobes, resulting in a clear jump and improved signal-to-noise ratio. Figure 3 demonstrates an application example of Yu's wavelet filtering to enhance the signal-to-noise ratio of first arrival data. The upper image displays the original first arrival data with strong noise energy, making it difficult to pick first arrivals. The lower image shows the results after Yu's wavelet filtering, where the signal-to-noise ratio is significantly improved, revealing clear first arrival event for picking.

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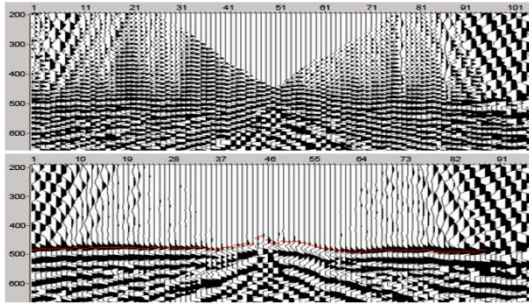


Figure 2: example of Yu's wavelet filtering to suppress vibrator record side lobes

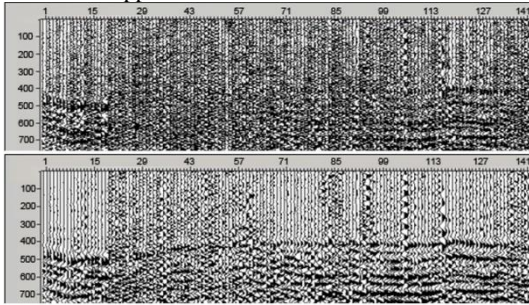


Figure 3: Example of Yu's Wavelet Filtering to improve SNR of first Arrival data

Reconstructing first arrival data using super virtual interferometry method

Yu's wavelet filtering is a single-trace processing method that may struggle when interference wave frequencies overlap with those of first arrival data. The Super Virtual Interferometry (SVI) method, utilizing adjacent shot and receiver pairs to reconstruct the first arrival wavefield, offers a multi-trace processing approach involving two steps: cross-correlation to obtain virtual sources and convolution reconstruction. Figure 4 illustrates the concept of obtaining virtual sources through cross-correlation, where X represents the source, y and Z represent receivers. The correlation of refraction wave records at points Z and y yields the response corresponding to the arrival time difference of refraction waves at points Z and y , symbolizing a virtual source at y' with a propagation time. This time corresponds precisely to the time difference between the refraction waves received at points Z and y . The cross-correlation expression is given by Equation (2), where $A(x_1, z)$, $A(x_1, y)$ represent the amplitudes of the refraction records at points Z and y . To enhance stability, multiple virtual sources can be obtained using different sources, as shown in Figure 4 using at the top, middle, and bottom to obtain virtual sources of y' .

$$\begin{aligned} \varphi(y, z) &= |A(x_1, z)| |A(x_1, y)| e^{i\omega(\tau_{x_1 y'} + \tau_{y' z} - \tau_{x_1 y} - \tau_{y' y})} \\ &\approx |A(x_1, z)|^2 e^{i\omega(\tau_{y' y} + \tau_{y' z} - \tau_{y' y})} = |A(x_1, z)|^2 e^{i\omega\tau_{y' z}} \end{aligned} \quad (2)$$

Figure 5 illustrates a schematic diagram of the reconstruction of first arrival waves (where S represents the seismic source, and R_i represents the receiver). By utilizing the cross-correlation function between the records at point R_4 and point R_1 , as well as convolving the seismic record of refraction waves at point R_1 , it is possible to reconstruct the seismic record of refraction waves at point R_4 . This process can be repeated to reconstruct the seismic records of refraction waves at other points. Similarly, multiple adjacent traces can be used to reconstruct the seismic records of refraction waves at different points. The upper, middle, and lower images in Figure 5 represent the reconstruction of trace R_4 using traces R_1 , R_2 , and R_3 , respectively.

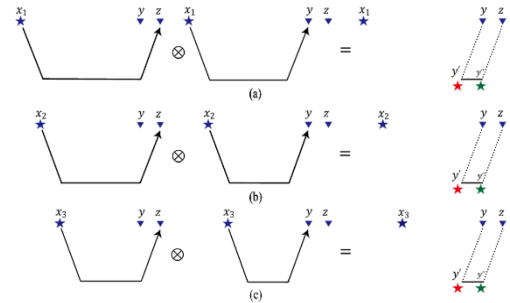


Figure 4: schematic diagram of cross-correlation to obtain virtual sources

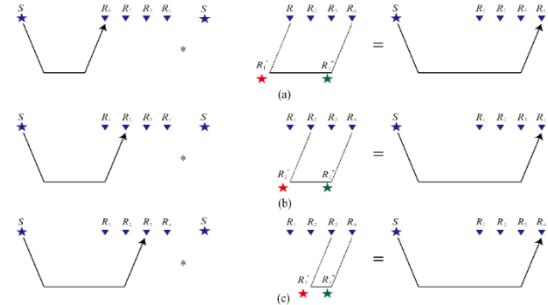


Figure 5: schematic diagram of convolution reconstruction of first arrival wavefield

In practical applications, these two techniques can be used individually or in combination to achieve the best processing results. Figure 6 presents an example of comprehensive application effects: (a) shows the original data, (b) shows the result after Yu's wavelet filtering, (c) shows the result after SVI reconstruction, and (d) shows the result after the combined use of Yu's wavelet filtering and SVI wavefield reconstruction. The combination enhances the signal-to-noise ratio and lateral continuity of the first arrival data.

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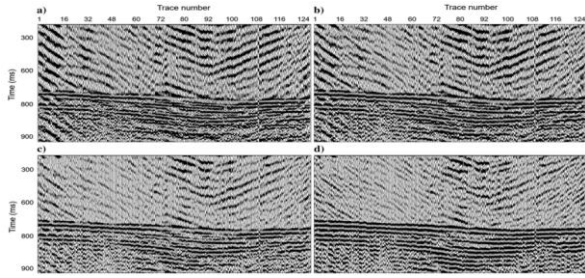


Figure 6 comprehensive application effect of Yu's wavelet filtering and SVI wavefield reconstruction

Case study

In a specific 3D working area in Western China, characterized by complex terrain and strong external interferences, the effectiveness of these measures is demonstrated. Figure 7 shows the original first arrival data (up), the picking result on the original data (middle), and the picking result on the optimized data (down). It is evident that the use of these measures increases the number of picked traces and improves the picking quality. Figure 8 illustrates the distribution of picking rates before and after optimization. The left image shows the picking rate distribution on the original data, with most rates below 50%, and the average picking rate for the entire working area is only 35%. After applying the optimization techniques described in this paper, the right image shows a significantly improved distribution, with the majority of shots achieving a picking rate above 80% and an average picking rate of 86%.

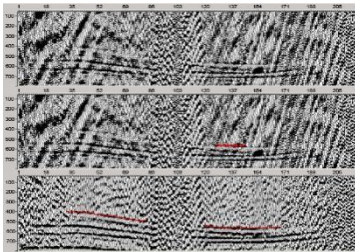


Figure 7 example of improved picks with first arrival optimization

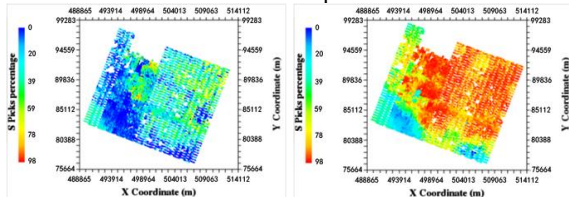


Figure 8 picking rate distribution before (left) and after (right) first arrival optimization

Using the first arrival times picked before and after optimization, first arrival tomography inversion and tomostatics calculations were performed. Figure 9 displays the stack section obtained by tomo-statics based on the first

arrival times before (left) and after (right) optimization. After optimization, with higher first arrival picking rates and accuracy, the stacking quality is significantly improved, as indicated by the red arrows.

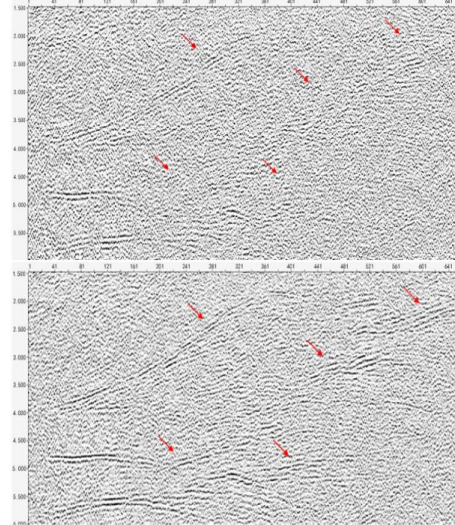


Figure 9: Stack section based on first arrival times before (up) and after (down) optimization

Conclusion

As vibrator sources and nodal geophones become prevalent, relying on high coverage to improve exploration efficiency has become the primary method for seismic exploration in the Kuche mountain region. However, this compromises the quality of first arrival data and increases the difficulty of first arrival picking. In complex exploration areas, where high picking rates and accuracy are crucial for subsequent first arrival tomography inversion and static correction, the techniques presented in this paper have achieved positive results in enhancing the quality of first arrival data in Kuche mountain region seismic data processing.

Keywords Super virtual interferometry (SVI), Yu's wavelet, first arrival picking.

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