Median filtering in Kirchhoff migration for noisy data
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Summary

Although non-Gaussian noise may be suppressed by signal processing prior to seismic migration, in many cases its remnant still presents difficulties by spreading its energy into the migration aperture. Non-Gaussian noise reduction can be performed in seismic migration. Median filtering is often effective in removing non-Gaussian noise in a series of values, and it is often applied in the spatial direction to reduce spatial inconsistency. It is very easy to incorporate median filter noise reduction with standard Kirchhoff time migration, in which data is weighted and summed along a T-X curve, as defined by the local RMS velocity. We tested a simple median filter and a n-point median filter before Kirchhoff summation and the results are compared with standard Kirchhoff migration. This method showed an advantage over standard Kirchhoff migration when noise bursts are present. It also shows some potential in reducing spatial aliasing effect in Kirchhoff time migration.

Introduction

Kirchhoff time migration is implemented by weighted summation along diffraction curves defined by local RMS velocity. Often it is assumed that the random noise can be reduced by a factor of $\sqrt{n}$ relative to signal by multitrace stacking, where $n$ is the number of traces being stacked. However, this assumption is only valid in a statistical sense when $n$ is very large. In a limited stacking aperture, noise, such as strong noise burst, is not necessarily random and may not cancel out by summation along a diffraction curve.

A median is the middle point of an ascending-value sequence. For example, $(5, 1000, 6, -1, -2, 7, 10)$, when ordered, becomes $(-1, -2, 5, 6, 7, 10, 1000)$. The median is 6.

The most significant property of a median is that wild values (such as 1000 in the above example) do not affect the median at all. A mean, however, will be dominated by such wild values. A median is the value in a sequence that has a minimal ‘distance’ from all other points, which means that the median value minimizes the absolute value of the sum of differences between it and other points of the sequence (Stewart, 1985). A schematic diagram (figure 1) shows the median filtering operation (after Stewart, 1985).

Figure 1. A schematic diagram of median filtering operation (after Stewart, 1985). Wild values can be easily removed, while the step function is untouched.

A n-point median filter, where $n$ is a number less than the length of a number sequence, can remove wild values without disturbing the dominant variation trend in a number sequence. For example, a 3-point median filter applied on the example sequence gives $(6, 6, -1, -1, 7)$. It roughly follows the variation trend of the original sequence.

Besides outlier removal, median filtering is also used in the F-K domain for random noise reduction. This has been well demonstrated by several authors. Stewart (1985) showed that F-K domain median filters can tremendously reduce noise in VSP data. Duncan and Beresford (1995) applied F-K median filtering to surface seismic data and obtained very good results.

Methods and examples

Two median-filter Kirchhoff time migration methods were tested and compared with the standard Kirchhoff migration. Simple median-filter migration is performed by taking the simple median value instead of the Kirchhoff summation, while an n-point median filter is applied before Kirchhoff summation in the other median-filter migration scheme.

Figure 2 shows a simple reflection model (a) and its zero-offset synthetic data (b) used in the comparison of different migration methods. The model has five diffractors, a horizontal reflector and a gapped 15º dipping reflector. The CDP spacing is 12.5 m and the data are bandpassed to 100 Hz. Four strong noise bursts are inserted to test the effect of median filtering before Kirchhoff summation. A spatially aliased synthetic section with a CDP spacing of 100 m and the same bandwidth is also shown (c).
The standard Kirchhoff migration has produced a good image, but the section is contaminated by the wavefronts from the four spikes. Both median-filter migration techniques suppressed the wavefronts from the noise spikes. The best migration result is produced by the 10-point median filter before summation while the simple median-filter migration produced the worst. The simple median filter has destroyed the images of the two coherent reflectors but has imaged their terminating diffractors. The simple median-filter migration also resolves the diffractors to a size that is below that expected from simple linear resolution theory (compare figure 3a and 3b). The 10-point median-filter migration has produced a good compromise image with the best features of the other two.

Figure 3. Median filter before summation removes the noise spikes. However, the result is degraded if only a simple median value is taken instead of a median filter smoothing.

Figure 4 compares the results from the three migration methods when 100% random noise is present. The four noise spikes in figure 1b were not included in the test. The 10-point median-filter migration and standard Kirchhoff migration have generated similar results, while that of the simple median-filter migration is dramatically different. It generated a high-resolution result and the random noise level is reduced.
Median-filter Kirchhoff migration

Both the standard Kirchhoff migration and 10-point median-filter Kirchhoff migration smeared the image when strong non-Gaussian noise window is present (figure 5a,b,c). The simple median filter removed major part of the non-Gaussian noise and a relatively clear image is recovered (figure 5d). The simple median-filter migration actually produced a better image of the coherent reflectors when they were contaminated by noise than they were noise free (compare figure 3b, 4d and 5d).

The median-filter Kirchhoff migration also shows some potential in reducing the spatial aliasing effect in migration when the data are spatially aliased. Note the strong aliasing noise in standard Kirchhoff migration (figure 6a) compared to that in the 10-point median-filter Kirchhoff migration (figure 6b) and that in the simple median-filter migration (figure 6c). Even in this severely aliased case, the simple median-filter migration still produces sharply focused diffractors and the spatial aliasing noise is the lowest.

The application of the median-filter Kirchhoff migration on a real stacked section was tested. The data is the vertical component of a 3C survey carried out in Alberta, Canada (figure 7a). The a CDP spacing of 12.4 m and only a single \( V(z) \) function is used to migrate the section. Migration noise in the upper-left corner has been successfully suppressed by the 10-point median filter (figure 7c). Simple median-filter Kirchhoff migration can not generate a comparable image.
Median-filter Kirchhoff migration

(a) Stack section of the vertical component data from a 3C survey in Alberta, Canada.

(b) Standard Kirchhoff migration. Note the anti-dipping migration noise in the upper left region.

(c) 10-point median-filter Kirchhoff migration. Note the migration noise in the upper left corner has been removed.

(d) Simple median-filter Kirchhoff migration.

Figure 7. A real data example from a 3C survey in Alberta, Canada. Migration noise has been reduced by the 10-point median-filter migration.

Conclusions and future work

Non-Gaussian noise reduction can be done in Kirchhoff migration by median filtering before summation. N-point median-filter migration is successful when non-Gaussian noise is present and its application on real data is promising. Simple median-filter Kirchhoff migration, although not yet satisfactory when applied to the real data, also shows promising enhancement of image resolution. The median-filter Kirchhoff technique is effective in suppressing wavefronts from noise bursts. It also shows higher resolution of point diffractors and is less affected by spatial aliasing than standard Kirchhoff migration. Unfortunately, the simple median filter also tends to de-emphasize coherent reflectors. A compromise, the 10-point median filter before Kirchhoff summation, produces an image with the best features of both techniques.

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Reference
