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Application of Antileakage Fourier Transform for Regularization

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Abstract: *Seismic datasets are generally irregularly sampled in inline midpoint, cross-line midpoints, offset and azimuth.This irregular sampling can cause spectral leakage, which can lead to both poor levels of repeatability between 4-D surveys and artifacts in pre-stack imaging. This work is to eliminate or minimize the impact of missing shots and traces, due to cable feathering in marine acquisition and obstacles such as building and other structures around acquisition sites on land and also to harmonize fold and minimise migration artefacts. Irregular samplings can also limit the effectiveness of high-end 3-D demultiple and imaging algorithms such as 3-D SRME. To overcome these issues in seismic data processing, it is important to apply regularization. In this study, we used the ALFT algorithm tool to regularize and correct for the leakage problem caused by irregularly sampled data, which is an improved approach to yielding better result with respect to some other methods. The results achieved show that regularization is an effective technique that can fill in gaps and remove noise on seismic data to presenting a good and clearer image.The applicability of the findings of this work can help eliminate challenges during processing due to the variations in spatial sampling relating to the acquisition azimuth, bin size, shot and receiver line spacing and establish uniform 3-D coverage and optimum performance of Pre-Stack inversion, AVO, and the application of 3D surface related multiple elimination (3D SRME).*

Key word: *regularization, interpolation, crossline , algorithm, spectral leakage, migration*

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I. Introduction

One of the goals of geophysicists during seismic data acquisition is to sample the subsurface at regular interval in all spatial dimensions such as inline, crossline, offset and azimuth. Such goals are often time impeded during the acquisition phase. This is because missing shots, platforms and other obstacles, editing of bad traces as well as tides and current give rise to cable feathering in marine acquisition which generally results in an irregular sampling of the predefined sampling points (Chopra and Marfurt, 2013, Xu et al. 2005). Missing traces are also experienced on land acquisition. On land, uniform 3-D coverage is rarely achieved due to practical and economic constraints or the presence of buildings around the acquisition site in cities.

Poorly sampled data affects the migrated quality of the processed seismic data, this is because migration is sensitive to irregular and coarse sampling points, the migration of an irregularly sampled data can generate artefacts or acquisition footprint. A poorly sampled data affects both the performance of processing algorithms and interpretation tools. For the optimum performance of Pre-Stack inversion, AVO, and the application of 3D surface related multiple elimination (3D SRME), it is expected that seismic data should be regularly sampled in all spatial dimension. In the interpretation environment, poorly sampled points affect the performance of geometric attributes such as coherence attributes and curvature attributes. When these attributes are used as an interpreting tool in a poorly sampled seismic data, the interpreted data give rise to acquisition footprints (Chopra and Marfurt, 2013). Irregularly sampled data creates gaps or holes on the data as shown in Figure 1a.

When the subsurface is not properly sampled, noise may impede the clarity of the subsurface image as shown in Figure 1a. In Figure 1a we can clearly see that, the data before applying regularization was contaminated with noise as indicated by the orange circular loop. After applying regularization, events are clearly seen as shown in the blue and orange circular loop in Figure 1b; the overall signal-to-noise ratio is significantly improved. The blue loop in Figure 1a shows the data not properly sampled and are filled with holes, the blue loop in Figure 1b, shows the holes are filled after regularizing the data.

When a data is not properly sampled during acquisition, the best way to go about such problem is to go back to the field and reshoot the points that were not properly sampled. But going back to the field to reshoot the irregularly sampled point could be more challenging to know the exact coordinates in order to reshooting the irregular sampled points and it would also be quite expensive to redeploy the equipment for reshooting. The problems of irregularly sampled points are corrected during the processing phase using interpolation. In interpolation adjacent traces are used to populate the irregularly sampled points (Chopra and Marfurt, 2013).

Regularization in seismic data processing requires generating seismic traces at locations where shots were not taken. This can be achieved by interpolating or extrapolating seismic traces from the acquired data on the regular grid to the irregular grid (Xu et al. 2005).

The merging of multi-survey datasets often pose significant challenges during processing due to the variations in spatial sampling relating to the acquisition azimuth, bin size, shot and receiver line spacing. To overcome such challenges, it is important to regularize the sampling of the data in order to harmonize fold and minimise migration artefacts (Rivault and Motagally, 2011).

Interpolation

Interpolation is the process of creating new traces from existing surrounding traces; it is a major part of regularising the data, which can fill holes by creating new traces. While Extrapolation is the process of Creating new traces from adjacent traces beyond existing trace locations.Extrapolated traces are generally less accurate than interpolated traces because they are generated using less information. According to Thevenaz et al. (2000), interpolation can be defined as a model-based recovery of continuous data having a known range of abscissa.

Various techniques of interpolation have been proposed by different researchers to properly regularize irregularly sampled points on seismic data. Liu and Sacchi(2004) proposed MWNI (Minimum Weighted Norm Interpolation) method. Xu et al. (2005), proposed the ALFT (Anti-Leakage Fourier Transform) method. While Abma and Kabir(2006) proposed the POSC (Projection onto Convex Sets) method. Also, Chopra and Marfurt (2013) applied 5D Interpolation of missing data to regularize seismic data set before applying Pre-stack migration.

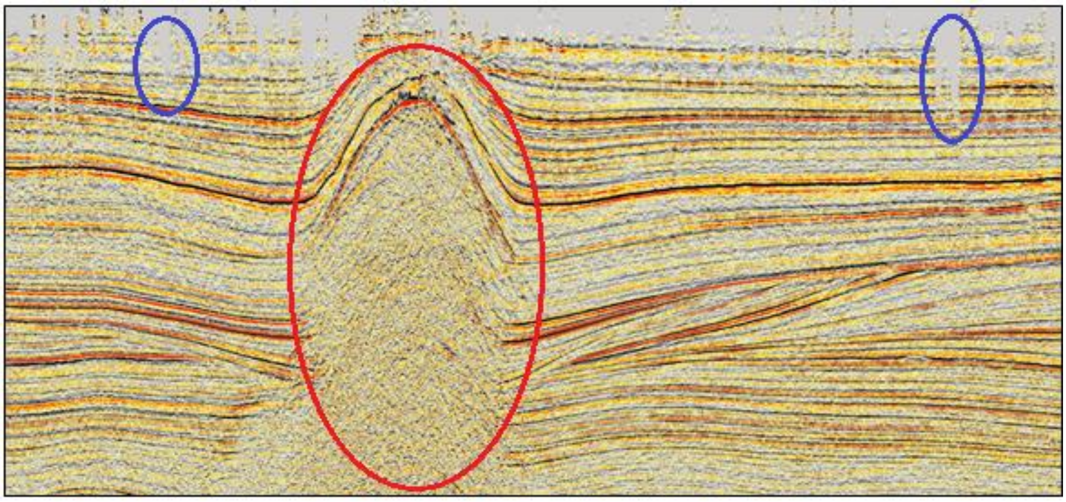


Figure 1a: data showing holes (blue loop) and some noise (orang loop) without regularization.

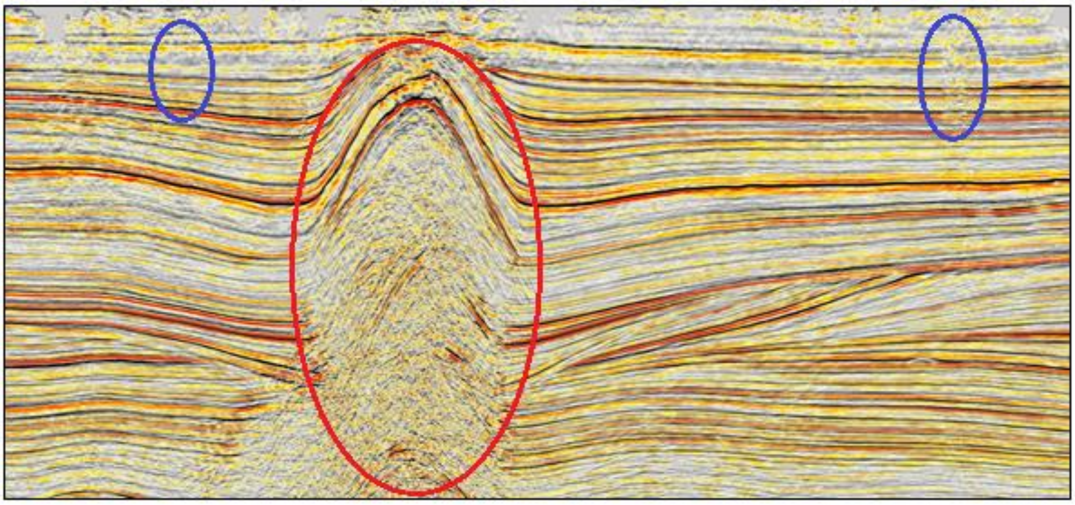


Figure 1b: Holes in data are filled after regularization as shown in the blue loop and the noiseinthe data also removed after regularization as shown in the orange loop.

According to Chopra and Marfurt (2013), 2D and 3D triangular trace interpolation algorithms were initially used to replicate missing traces, such techniques are referred to as local methods of interpolation; this is because they need localized information for their operations. Such techniques are fast and are easy to implement, but the issues with these methods is that they cannot handle large irregularly sampled points, because the local information they need does not exist i.e. there are no data around the trace to interpolate (Trad, 2009).

Global methods for data interpolation have been established that use farther well-sampled data to populate the missing data. These methods are multi-dimensional rather than one dimensional, operating simultaneously in as many as five different spatial dimensions (5D), and are able to predict the missing data more accurately. The disadvantages with these methods are that they are computer intensive and have longer run-times than the local methods (Chopra and Marfurt 2013).

Regularization

Regularization places the seismic data onto a regular grid from an irregular grid, it attempts to mitigate for the finite and poorly sampled data that are recorded during acquisition. Regularization accounts for the irregular spacing of the seismic trace. Regularization is a processing technique that spatially transforms irregularly sampled acquired seismic data to regularly sampled data using sophisticated mathematical algorithm such as Fourier theory that estimates the spatial frequency content on an irregularly sampled grid so that the data can be reconstructed to any desired grid (Xu et al. 2005).

Poole and Herrmann (2007) introduced a versatile 2D Fourier regularization algorithm to simultaneously regularize seismic data along two axes. Their algorithm addresses the data regularization problem for a number of data types where two passes of a 1D algorithm are not sufficient. They demonstrated their algorithm on a synthetic cross-spread gather using recording coordinates from a real dataset.

Their algorithm was compared to synthetics generated at the output recording coordinates thus validating its ability to preserve amplitudes and handle conflicting dips. When they applied their algorithm to a real seismic dataset, it showed an improvement in the continuity of events. Their algorithm makes use of all traces (i.e. pre-binning) and performs regularization as well as missing trace interpolation in one process, thus simplifying the pre-stack processing flow. Their algorithm regularizes the input seismic data and further fills the gaps in the acquired seismic data set.

According to Xu et al. (2005), a quick way of regularizing seismic data is the binning method, this technique bin the data and disregard the true data acquisition locations in the bin. Such techniques often time produce artefacts which can end up contaminating the final migrated image.

II. Materials And Method

The conventional method of regularizing seismic dataset is to apply fast Fourier transform (FFT) on the data, such method is effective on regularly sampled grid; applying such method on an irregular sampled dataset, the transformed dataset often-time is altered by noise due to spectral leakage. The leakage is caused by the irregularities of sampling and boundary effects (Xu et al. 2005). The leakage is called noise; if the data is transformed back into the TX domain it will produce artefacts in the data.

According to Xu et al. 2005, Fourier transformation of irregularly sampled data can be achieved by direct evaluation of trigonometry sums expressed mathematically as

$$\hat{f}(k) = \sum_{l \in N_P} f(x_\ell) e^{-2\pi i k x_\ell}, \; k = 0, \pm 1, \; \ldots, \; \pm N. \qquad (1)$$

The Fourier coefficient in equation 1 is not adequate for data interpolation and regularization (Xu et al. 2005). The theory of Fourier transform on data regularization is to estimate the Fourier coefficient from the input dataset as accurately as possible, but this could not be achieved on an irregularly sampled dataset (Xu and Zhang, 2009).

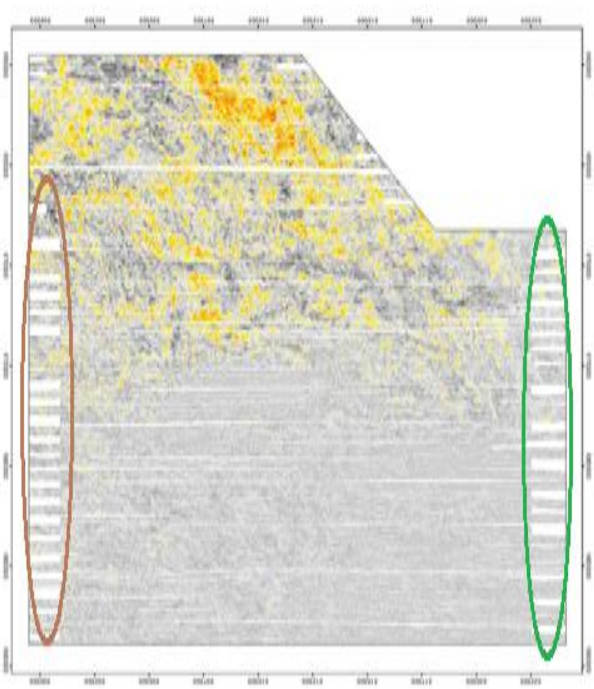
To correct for the leakage problem caused by irregular sampled data, we apply the ALFT algorithm as proposed by Xu et al. (2005) to regularize our data. According to (Xu and Zhang, 2009) the goal of the ALFT is to estimate the Fourier coefficients from the irregularly sampled input seismic traces that were difficult to estimate using FFT. The ALFT algorithm was applied to correct for the spectral leakage problems associated with irregularly sampled data with the following steps:

1. Compute all Fourier coefficients of the irregular signal.
2. Select the Fourier coefficient with maximum energy.
3. Subtract the contribution of this coefficient from the input data.
4. Use this new data as input for step 1, 2 & 3, iteratively, until all coefficients are found.

III. Results And Discussions

The data used for this research is a 3D seismic data set acquired from a marine environment. The data was split into 51 offset classes of 100 m each. We present the time slice map and the stack data at two different crosslines.

Looking at the time slice in Figure 2a, the green loop indicate the presence of holes casued by the irregular sampling of the data during data acquisition, in Figure 2b, the holes have being closed after reguglarizing the data. Figure 3 and Figure 4 show two different stack results at different crosslines. The holes in Figure 3a were closed in Figure 3b after regularizing the data. in Figure 4b, after applying regularization to the dataset in 4a; the holes were closed and the noise reduce as shown in the black square.
The results presented in Figure 2, 3 and 4 show that the ALFT algorithm applied on the data had significantly filled the holes in the data and given a clearer picture of the events.



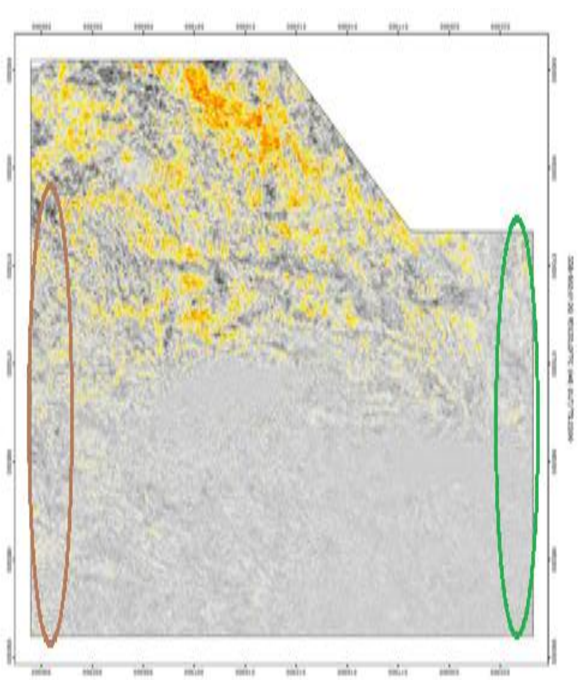
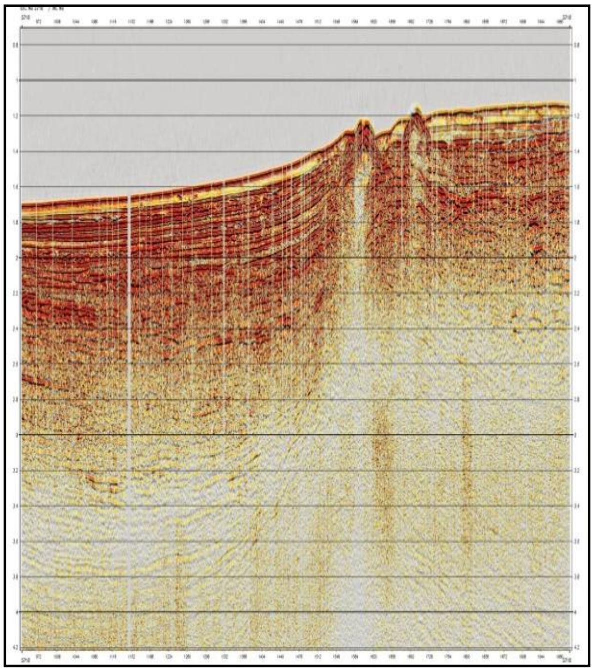


Fig 2a: Times slice without regularization **Fig 2b:** Time slice after regularization



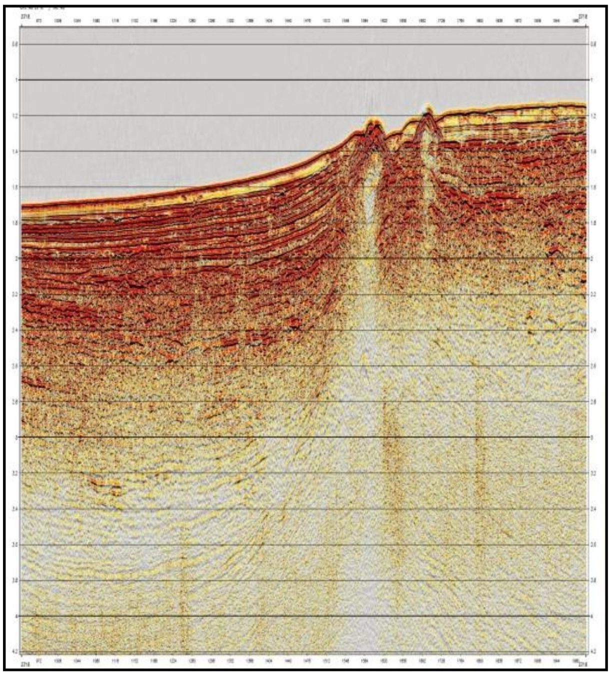
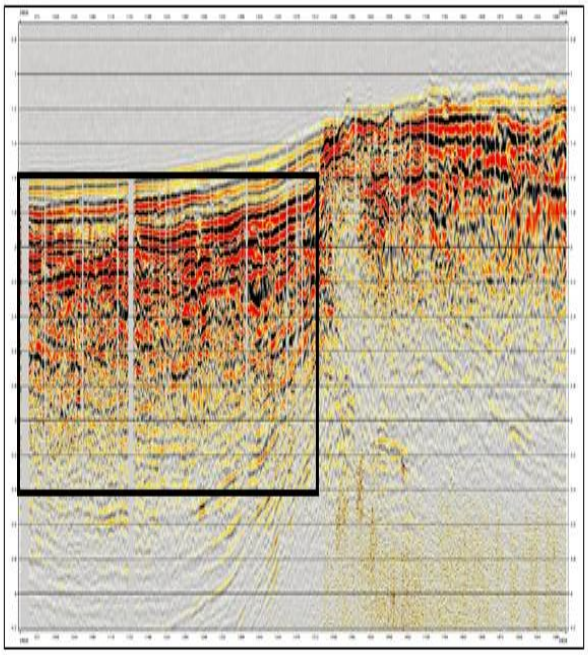


Fig 3a: Stack section before reularization**Fig 3b:** Stack section after reularization



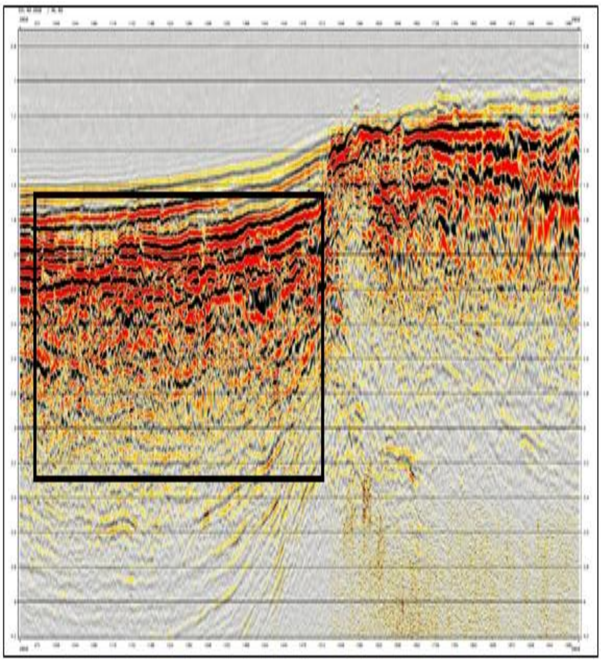


Fig 4a: Stack section before reularization**Fig 4b:** Stack section after reularization

IV. Conclusions

This research has shown that the use of the ALFT algorithm is an effective tool in seismic data processing in correcting for the irregularities in poorly sampling of the subsurface at irregular intervals during acquisition. It is recommended that regularization should be applied on seismic data so as to achieve optimum performance of 3D SRME, AVO and migration. The results achieved have shown that regularization can fill in gaps and remove noise on seismic datato presenting a good and clearer image of horizon and event underground. This approach for regularization indeed eliminates the worriesto knowing the exact coordinates in the presence of obstacles for reshooting such irregularlysampledpoints and avoids the expenses and inconveniences to redeploy equipment for reshooting. It is indeed a reliable approach to establish full and uniform 3-D coverage and produce a clearer image of an acquired seismic data.

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