Application of Automatic Gain Control prior to migration for improved structural interpretation

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Automatic Gain Control, Migration, Impulse Response

Abstract

Seismic data processing aims at generating interpretable subsurface images which mimic the geology of the study area. These subsurface images are an aggregate of the quality of the raw data acquired in the field and the algorithms used to process them. The quality of the raw data depends on the acquisition constraints as well as the geology of the area. In areas with severe energy penetration issues due to the presence of boulder beds or loose formation in the near surface, reflections are either masked by high amplitude energy blasts in the near offsets and are very feeble in the deeper portion. Thus, segregation of signal from noise is very difficult even after several attempts of noise attenuation and surface consistent amplitude balancing. In this type of scenario, methodologies which will help in delineating the subsurface structures by balancing these high amplitudes and improving the stacking power of the signal become a necessity in seismic data processing.

The drastic differences in amplitudes of the near and far offset traces in areas having severe energy penetration issues result in improper Kirchhoff summation which ultimately leads to poor illumination of the subsurface. Even surface consistent processes are insufficient to balance the amplitude difference. After testing of different algorithms, it has been observed that Automatic Gain Control (AGC) tool can effectively balance these high amplitudes and enable to visualize the background signal trend. Migration of these balanced AGC applied gathers aides in better Kirchhoff summation and improves final image of the subsurface reflector for better structural interpretation. It also prevents the migration algorithm from distorting the events due to the presence of such amplitude differences. It has been also observed that similar improvement could not be achieved if AGC was applied either on gathers or stacks after migration instead of applying it before.

This paper is demonstrating the improvement of seismic imaging on a real seismic data by balancing the amplitudes in gathers before migration.

Introduction

In this era, where we are in continuous search of new hydrocarbon prospects, reliable structural interpretation plays a crucial role in defining the exploration and development strategies. Geological complexity, be it related to topographical challenges or energy penetration issues, complicate the seismic data acquisition resulting in poor data quality. It has been noticed that in areas where there are significant energy penetration issues, the signal and noise patterns are quite complex and, in most scenarios, this is the only data that can be acquired.

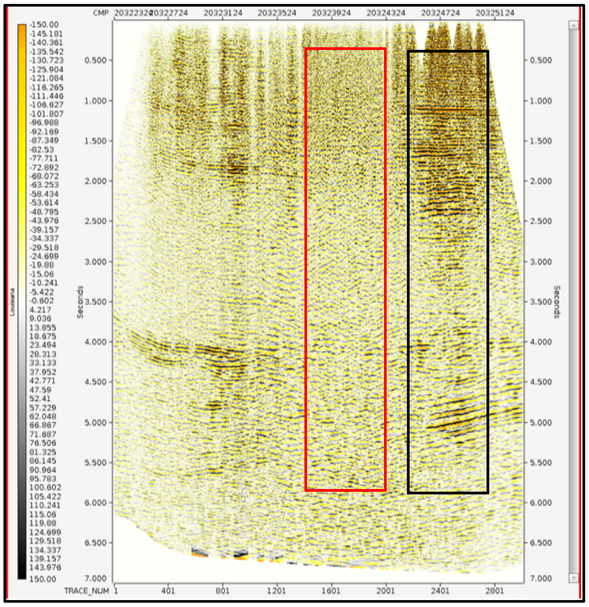

Figure 1: Stack section showing region with good energy penetration (black rectangular box) versus severe energy penetration (red rectangular region) issues.

The dataset shown here have mixed energy penetration responses as shown in **Figure 1**. The region of good energy penetration is shown in a black rectangular box, whereas that with poor energy penetration is shown in the red rectangular box.

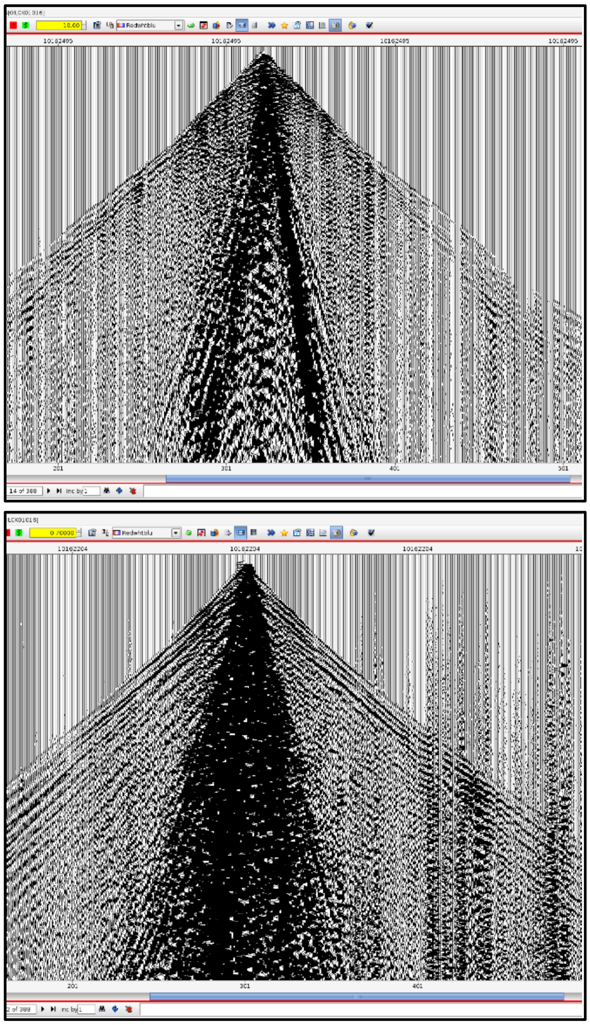

Figure 2: Shot record from an area with no energy penetration issues (top) Shot record from an area with severe energy penetration issues (bottom).

Examples of shot records in areas without and with energy penetration issues are shown in **Figure 2** (top & bottom respectively).

In regions with such issues, any number of noise attenuation or surface consistent amplitude compensation techniques cannot balance the anomalously high amplitudes in the data and any attempts to remove these high amplitudes will also risk the loss of signal. The presence of these high amplitudes in the gathers masks the signal and deteriorate the stacking response. With this type of seismic data, it is also very challenging to pick accurate velocities due to the absence of reliable semblance or Multi Velocity Function Stacks.

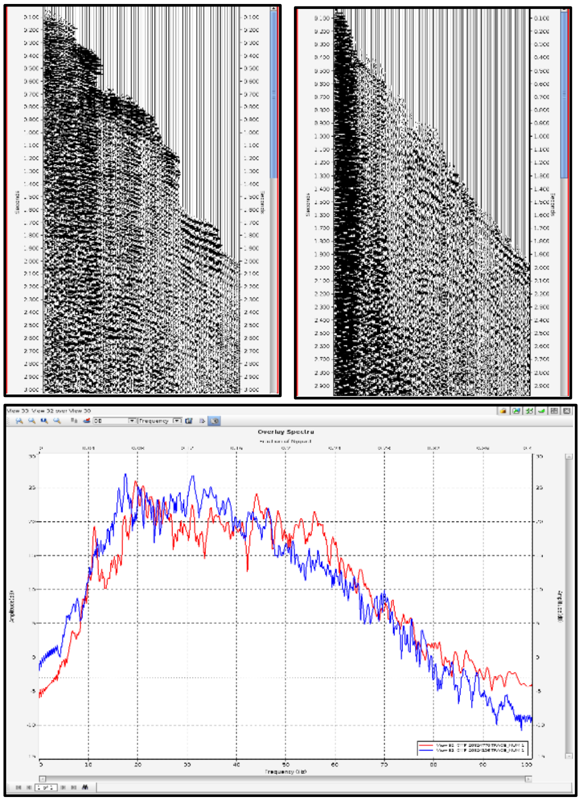

Figure 3: Top Left – Conventional pre-processed CMP Gather, with surface consistent processes applied, in the region with good energy penetration.

Top Right – Conventional pre-processed CMP Gather, with surface consistent processes applied, in the region with poor energy penetration.

Bottom – Amplitude spectra of near offset of CMP Gathers as shown in the top left (in red) and top right (in blue).

In **Figure 3**, example of conventional pre-processed CMP gathers, just before migration from two regions, i.e., regions with and without energy penetration issues are shown, wherein all possible noise attenuation and surface consistent amplitude compensation schemes have been applied. It has been observed that source & receiver components of surface consistent processes are not effective in balancing the amplitude. The bottom section of the same figure shows the amplitude spectra of the near offset of the same gathers, red being that in the good region and blue in the region with energy penetration issues. It can be seen from the amplitude spectra that the frequency range of the high amplitudes events from the bad gathers are falling within the signal range of the good gathers thus differentiating signal from noise based on frequency is very difficult.

Under these constraints, without balancing the amplitude any attempt at migration will not give a satisfactory result. Hence, to obtain the best possible results, alongwith the conventional method of modern-day seismic data processing techniques, we have followed an approach wherein we have performed Pre-Stack Kirchhoff Migration on AGC applied CMP gathers. AGC helps in balancing out the shallower near offset amplitudes which was not achievable with any surface consistent processes.

These migrated gathers when stacked, provided better reflection events even in areas where imaging was not possible in the conventional amplitude preserved processing workflow. Hence, it can be deduced that even though the events have been recorded in the seismic data but due to the presence of this amplitude contrast between the near and far offsets, the migration algorithm is not able to image the subsurface. In order to understand the reason for this, we need to look into the working of the migration algorithm which is done in the next section.

Theory of Kirchhoff Migration

As described by Jones (2014), migration is a process which brings the reflection events from their apparent positions to their true subsurface locations and increases spatial resolution. Migration moves dipping events in the up-dip direction, shortens them and collapses diffractions resulting in a more accurate image of the subsurface.

Figure 4 depicts the utility of migration wherein an event CD, when recorded between receivers A & B will be mapped at location C'D' in a non-migrated section, which moves to its actual position post migration.

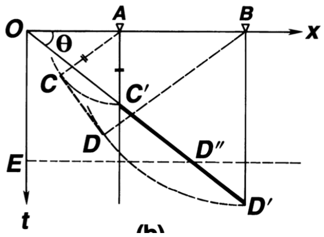

Figure 4: An event CD when recorded between two receivers A & B is mapped at location C'D'. Migration moves this event in the updip direction and shortens it bringing it to its true subsurface location (Yilmaz, 2001).

Kirchhoff migration works on the principle of diffraction summation with the inclusion of the obliquity factor, spherical spreading and wavelet shaping, described by Yilmaz (2001). The amplitudes along hyperbolic paths are summed up to give the final image point in the migrated section. This migration technique searches for an energy in the x – t plane which would have generated due to the presence of a diffracting source in the x – z plane. Understanding from Claerbout's harbor example (as mentioned in Yilmaz, 2001), a Huygen's secondary source (**Figure 5(a)** top) generates a plane wave which results in a diffraction hyperbola on the zero-offset time section (x-t plane) (**Figure 5(a)** bottom). If the number of Huygen's secondary sources increases, we get a superposition of zero offset time responses which results in the regeneration of the reflecting surface (**Figure 5(b).**

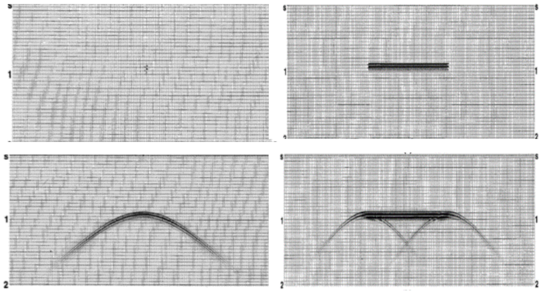
(a) (b)

Figure 5: Principle of diffraction summation – working of migration algorithm (Yilmaz, 2001).

However, in reality the amplitudes in consecutive traces are not of the same order, the superposition of the diffraction hyperbolas may not be constructive in nature and hence the Kirchhoff summation and subsequent migration fails to image the subsurface. Even though it is recommended to remove all gains prior to migration because the algorithm itself applies suitable amplitude compensation, but it also has a limitation in handling anomalously high amplitudes. The application of Automatic Gain Control (AGC) on the gathers input to migration improve constructive summation of diffraction hyperbola and results better stacking power of coherent events in the migrated stack section. This helps in imaging the subsurface reliably for structural interpretation.

Workflow

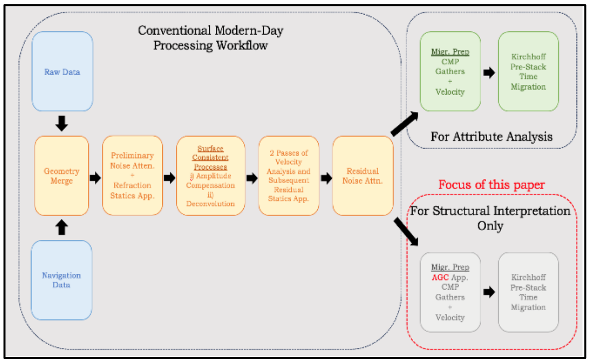

Figure 6: Workflow followed in the processing of the dataset shown in this study.

Figure 6 shows the workflow followed in the processing of the dataset depicted in this study. The pre-processing of the dataset is at par with the conventional modern-day workflow followed in the industry with surface consistent processes applied. For attribute analysis and other amplitude-based studies, a conventional migration output has been generated. For structural interpretation, which is the focus of this study (red dotted box), AGC has been applied on gathers in the migration preparation phase which are then migrated subsequently.

Methodology

Gathers which are input to the migration algorithm have been subjected to the conventional processing workflow with several passes of noise attenuation, surface consistent amplitude compensation, refraction statics application, surface consistent deconvolution and multiple passes of velocity analysis followed by residual statics application. In addition to this, AGC has been applied on these gathers prior to migration to balance out the remnant amplitude variations.

Figure 7 (top) shows the conventional pre-processed CMP gathers prior to migration, with all the surface consistent processes applied, have very high amplitudes in the near offset shallower regions owing to energy penetration issues. The reflection trends are not visible. After the application of AGC as in **Figure 7**(bottom), these gathers become balanced in amplitude, increasing the coherency of the events, due to which some reflection patterns are now visible (encircled).

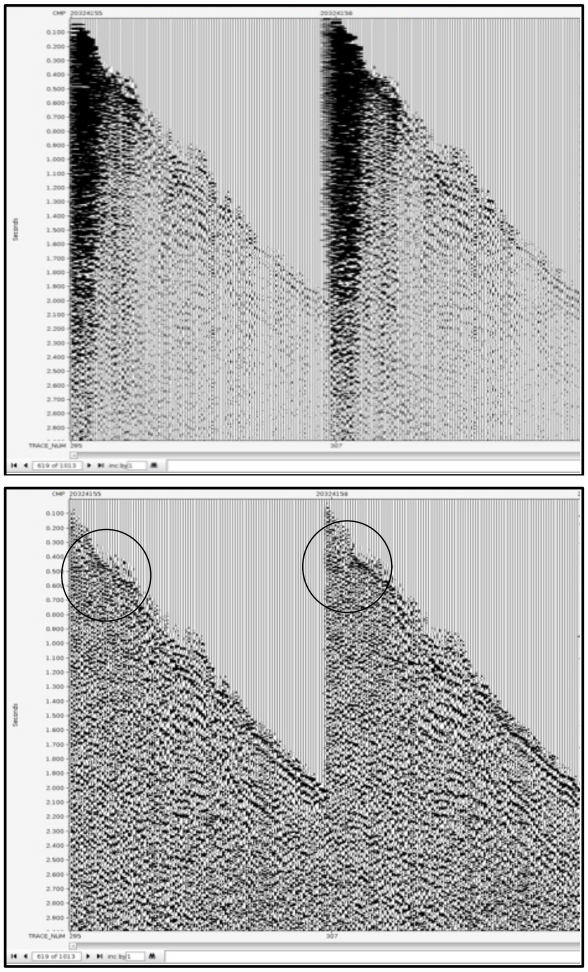

Figure 7: Conventional Pre-processed Common Mid-point Gathers before (top) and after (bottom) the application of AGC. The initial gathers have very high amplitudes in the near offset owing to energy penetration issues in the subsurface.

For better clarity on the working of the migration algorithm, differences in impulse responses from a near offset trace are compared to that of a far offset traces, both before the application of AGC on CMP gathers and after it (**Figure 8)**. Also, this is performed at two locations on the stack section, one in the good data region and the other in the poor data quality region.

In the good data region, the amplitude of the impulse response in the near offset (**Figure 8** top-left) and far offset (**Figure 8** top-right) traces are of the same order, which helps for proper summation and subsequent migration giving good continuity of reflection events.

On the other hand, in the region of poor data quality, the amplitude of impulse responses of the near (**Figure 8** middle-left) and far (**Figure 8** middle-right) offset traces are drastically different which results in poor quality of migrated seismic image, i.e., the amplitudes of the impulse response in the near offset are much higher than in the far offset resulting in improper summation, and hence migration algorithm is not able to map the reflector event properly. The near (**Figure 8** bottom-left) and far (**Figure 8** bottom-right) offset traces of this same location when migrated after the application of AGC give a more balanced impulse response with amplitudes of the same order helping the migration algorithm to perform summation properly and generate a better structural image.

Results and Discussion

An example has been depicted here where the application of AGC on conventional pre-processed CMP gathers, with all the surface consistent processes applied, prior to migration and the subsequent Pre-Stack Kirchhoff Migration on these gathers have helped in improving the structural continuity of the dataset. The reflection events where continuity was not apparent have gained amplitude and can now be marked for reliable interpretation. It is to be noted that there is no effect of AGC on illumination of other subsurface features viz. faults & structures which remain unaltered. It should also be noted that this significant improvement in subsurface imaging cannot be replicated by applying AGC on gathers or stack sections after migration. This signifies that the balancing of amplitudes in AGC applied gathers have helped the migration algorithm in imaging the subsurface reliably.

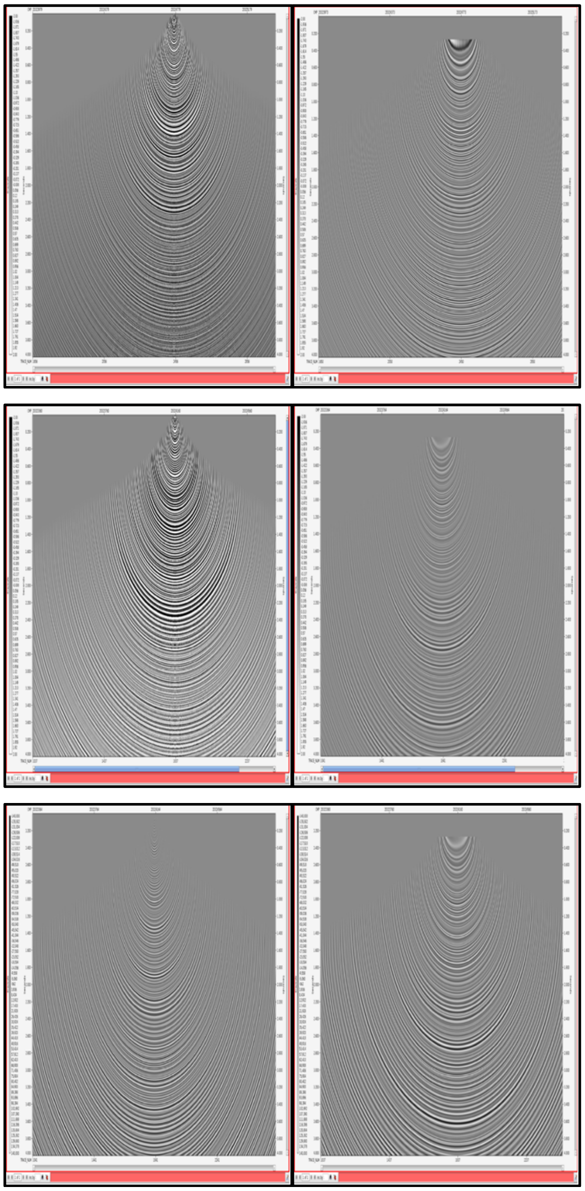

Figure 8: Impulse response of near offset (left) and far offset traces (right). Top – In a region with good seismic imaging. It can be seen that both impulse responses have amplitudes of the same order.

Middle – In a region with high amplitudes in the near offset.The difference in amplitude response can be easily seen.

Bottom – Same as the middle, but AGC is applied on the gathers to balance out the amplitude differences in the near and far offsets.

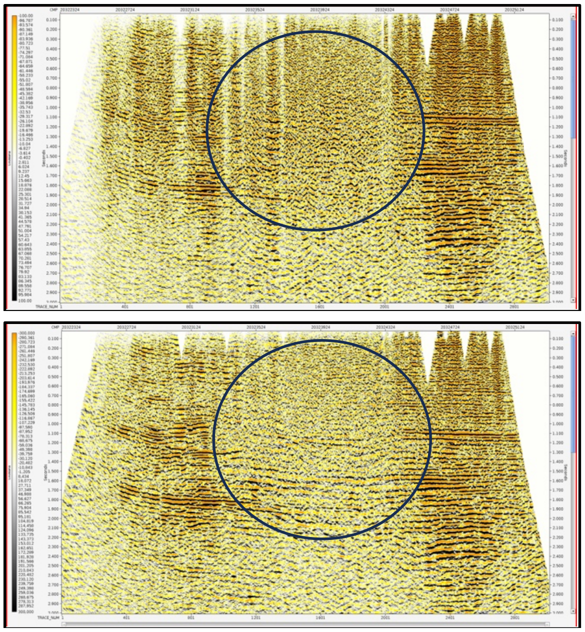

Figure 9: Stack examples. Top - Migrated Stacks with normal gather input with no amplitude correction applied. Bottom– The same stacks with migration on AGC applied gathers.

Figure 9 shows the stacked image sections where migration was performed on gathers without AGC (top) and when migration was performed on gathers with AGC (bottom). It is to be noted that both the sections are raw migrated stack sections, and no post processing has been applied on either. It can be seen that the reflectors in the shallower part of the stack section of AGC applied migrated gathers, with energy penetration issues, have improved in continuity which was absent in the section when migration was carried out without AGC applied Gathers (encircled).

Conclusion

In areas with severe energy penetration issues, where seismic imaging is a challenge, reliable structural interpretation plays a vital role in devising the hydrocarbon exploration and production strategy. Datasets which have complicated noise patterns, where conventional amplitude preserved processing cannot help in delineating the subsurface structures reliably, different methodology needs to be applied. Application of AGC on conventional pre-processed gathers prior to migration helps in proper summation and subsequent migration of the dataset providing better imaging of the subsurface.

It can be seen in the migrated sections in **Figure 9** that the structures present in both the cases are the same in the region where there was good energy penetration. This signifies that the application of AGC on gathers before migration and their subsequent migration does not tamper with the geological structures present. Hence the improvement caused in the central part (region with poor energy penetration) can be attributed to the fact that even though they were present in the dataset, migration algorithm was not able to perform proper Kirchhoff summation to map the subsurface reflectors unless the amplitudes were balanced by the application of AGC. The use of this dataset, which has mixed energy penetration characteristics throughout the line, has helped to ascertain the utility of this methodology to image the subsurface without generation of any artefacts and hence this method can be used in more challenging areas where the conditions are worse.

However, it is prudent to mention here that this methodology only helps in reliable structural interpretation by illuminating the subsurface with poor signal to noise ratio and will in no way suffice the need of robust noise attenuation.

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