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Application of Image-guided Interpolation to Build Low Frequency Background Model Prior to Inversion

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SUMMARY

Accurate low frequency background models are essential for pre-stack inversions. We compare horizon based to image-guided interpolations' ability to build low frequency background models. We show that image-guided interpolation produces either comparable or improved low frequency models compared with horizon based interpolation while saving a significant cost. This is demonstrated through a few examples which show horizon based interpolation depends heavily upon having accurately picked horizons. If all the necessary horizons are not picked, horizon based interpolation will produce a non-geological background model which will impact the absolute inversion results.
Introduction

Pre-stack seismic inversions has been the focus of much research due to their ability to obtain estimates of P-wave velocity, S-wave velocity and density (or alternative elastic parameters) from which one predicts the fluid and lithological properties of the subsurface of the earth. These inversion processes require a starting model, which is commonly obtained from well log data. The starting model is created using a low frequency filtered version of the well log data, often called a low frequency background model or LFBM. The LFBM is used to regularize the inversion and fill the low frequency gap of seismic data, which results in absolute impedance volumes (Ma, 2002; Mallick and Fu, 2007; Pillet et al., 2007).

Common practice is to pick horizons corresponding to coherent reflections in the seismic image. These horizons are then used to facilitate interpolation of properties measured in boreholes by means of kriging algorithms. However, horizon picking can be both tedious and time consuming. Hale (Hale, 2010; Hale, 2009) introduced a method for image-guided interpolation of borehole data, which enables one to resample the borehole data onto a uniform 3D sampling grid without the use of horizons but instead using the seismic image. The outcome of this method is a 3D volume of a subsurface property interpolated from a borehole log. The volume will conform to geological layers and faults because their respective features in the seismic data are guiding the interpolation.

In this abstract, we use image-guided interpolation to create LFBM and present case studies from North Sea and Anadarko basin. We will demonstrate the benefits of using image-guided interpolation to build our initial low frequency model prior to inversion.

Method

In order to build an initial model for our pre-stack inversion, the higher frequency content must be filtered out of the logs (these frequencies must only be recovered from seismic data). We applied a Butterworth filter with corner frequencies of 0-0-8-16 to our logs in order to retain the low frequency content we desire while removing the higher frequency information. One rather hopes to add the higher frequency information from the seismic to our final inversion product.

The frequency filtered logs are then used to build our initial models using horizon based interpolation and image-guided interpolation. The image-guided interpolation is designed to calculate a metric tensor field from the seismic image which will depend on a structure tensor and semblance attributes calculated from seismic data. This metric tensor is then used to create a non-Euclidian distance image, which is referred to by Hale as \( \text{time} \). The value of \( \text{time} \) will be smallest near known samples and largest in the corners of the image. \( \text{Time} \) will increase rapidly across incoherent features or strong reflections. Therefore, two points within the same geological formation are “near” while two points in different formations are “far” away in \( \text{time} \).

![Seismic image used to pick horizons and guide the interpolation.](image)

The algorithm goes through every point in the seismic image and finds the nearest known well-log sample, then stores the \( \text{time} \) to that nearest sample and the log sample’s value. Once this is complete, the 2D image of the logs’ values is then smoothed using the \( \text{time} \) image. Similarly this can be extended to 3D.

Example: Scenario 1

We begin our inversion process by first creating our initial model which will be based on three wells shown in Figure 1. After having frequency filtered the Acoustic Impedance (AI) logs, we use horizon-based and image-guided interpolation. The results are shown in Figure 2. Figure 2(a) shows the low frequency model build using image-guided interpolation. One can note how it isn’t able to perfectly follow all the picked horizons. This is due to the complex nature of our seismic image. Figure 2(b) shows the low frequency model build using horizon based interpolation. The image demonstrates that
horizon based interpolation performs slightly better in following the horizons with the interpolation. This comes to no surprise due to the interpolation being constrained by horizons while the image-guide interpolation is only constrained by the seismic image.

Displayed in Figure 3 are the results of running a simultaneous inversion using the initial models shown in Figure 2. Figure 3(a) shows the inversion result when using the image-guided interpolation to build initial model. When comparing the (a) to (b) of Figure 3, which shows the inversion result when using horizon based interpolation to build the initial model, there is not a lot of difference, at least in zones of interest, between the two inversion results. Even though image-guided interpolation used no information about the horizons when building its low frequency background model, it was able to create an inversion result fairly similar to the inversion result shown on the right, which did use horizons’ information to build an initial model.

Example: Scenario 2
This example excludes one of the horizons. This will have no effect on the image-guided interpolation method because it depends purely on the seismic image to drive its interpolation. However, it will have a dramatic effect on the horizon based interpolation. This is clearly visible in Figure 4 which shows the initial models build using image-guided and horizon based interpolation. The horizon based interpolation, shown in Figure 4(b), fails in creating an accurate initial model for the formation for which there is no horizon information, whereas the image-guided interpolation has no problem in creating a good initial model as before, Figure 4(a). The image-guided interpolation method lets values be interpolated along geological formations. When a horizon is removed, the horizon based interpolation will not interpolate values correctly within a formation because it doesn’t know the boundaries of the formation anymore. Therefore, image-guided interpolation will produce a more geologically accurate initial model.

Figure 4 AI low frequency models used for Pre-stack inversion for Scenario 2. A) The initial model build using image-guided interpolation. B) The initial model build using horizon based interpolation.

Figure 5 shows the simultaneous inversion results using the initial models from Figure 4. Figure 5(a) shows the inversion result using the image-guide interpolation to build an initial model. Its inversion result has not changed from Figure 3 because no information, necessary for the image-guided method, has been changed. However, Figure 5(b) shows a dramatic change in the inversion result compared
with its predecessor shown in Figure 3. The horizon based method clearly breaks apart when one removes a horizon.

Image-guided interpolation is an excellent tool to build an initial model for a pre-stack inversion. Even though it was not able to build the exact same initial model as the one shown in Figure 2(b), the final inversion results were fairly comparable. Image-guided interpolation gains its advantage by using only the seismic image to influence its result. Thus, image-guided interpolation can be a great way to create geologically accurate inversions results quickly. Additionally, we have demonstrated with our second example, if one does not pick enough of the horizons, the horizon-based interpolation will not create a geologically correct initial model of the subsurface.

**Figure 5** Simultaneous inversion result using initial models shown in Figure 4 where one horizon was removed. A) The AI inversion result using image-guided interpolation to build initial model. B) The inversion result using horizon based interpolation to build initial model.

**Example: Scenario 3**

This example uses onshore seismic data provided by Cimarex Energy to invert for the elastic properties of an unconventional play. Unlike the previous example, this was done for a 3D volume with surface area of 320 square kilometres using 5 wells and only 2 available horizons to build the low frequency models. Thus, very few wells and horizons were used to build the low frequency models which are shown in Figure 6. The reason so few wells were used is due to the fact that, for many unconventional plays, it is rare to have a lot of sonic scanner logs.

The inline shown in Figure 6 goes through a well which was not used to build the low frequency model. Figure 6 shows that there are clear differences between the two interpolation methods for this inline which does not contain a control well. The horizon based interpolation continues to interpolate the log characteristic of the nearest known well while the image-guided interpolation smooths out the general trend as we move away from a control point while keeping the main low frequency characteristic present. Additionally, due to only two horizons being applied for the horizon based interpolation, as we decrease in time and move up shallower, the horizon based interpolation is creating a nongeological model of the subsurface. Thus, image guided interpolation appears to be a better method to interpolate the low frequency logs throughout a large 3D volume when there are not a lot of wells and horizons present.

**Figure 6** Low frequency models of AI used for Pre-stack inversion for Scenario 3. A) The initial model build using image-guided interpolation and B) using horizon based interpolation.

**Figure 7** Simultaneous inversion result using initial models shown in Figure 6. A) The AI inversion result using image-guided interpolation to build initial model. B) The inversion result using horizon based interpolation to build initial model.
Figure 7 shows the simultaneous inversion results using the initial models from Figure 6. Figure 7(a) shows the inversion result using the image-guide interpolation to build an initial model while Figure 7(b) shows the inversion result using the horizon based interpolation. Within the area/play of interest, there is a clear difference between the two inversion results. In Figure 7(b), there seem to be some red zones of higher impedance (indicated by arrows) while Figure 7(a) does not highlight them as much. These higher impedance zones seem to have arisen due to the fact that the horizon based interpolation continued to interpolate the nearest known well logs characteristic through the layer whereas the image-guided interpolation took into account all the nearby wells and created a smoother characteristic for the layer far away from the well. Figure 8 shows the blind well test results where we compare our inversion results using image guided to build our LFBM in figure 8(a) to horizon based interpolation for LFBM in Figure 8(b). One can note that the improvements achieved in generating a more accurate LFBM using image-guided interpolation, as shown in the previous figures, for our impedance volume allowed us to generate a dramatically improved VpVs ratio result. The horizon based method is not able to generate a final inversion result (red curve) that accurately follows the true log curve for VpVs (blue curve). This improvement is significant because our VpVs inversion result generates our other desired rock properties such as Poissón’s Ratio. Thus, getting an accurate VpVs ratio inversion is crucial.

Conclusions
In conclusion, we have shown a case study where we compared the inversion results when using image-guided versus horizon based interpolations to build the initial model. Horizon based interpolation is a better method to create an initial model if one has accurately picked all the horizons. However, if the horizons are not picked accurately, or one hasn’t picked all the necessary horizons, the horizon based interpolation fails in creating a geologically correct initial model for inversion. This may lead to incorrect inversion results. It was also shown with the 3D land data that, if one is creating a low frequency model using only a few wells, horizon based interpolation might generate nongeological low frequency models. Additionally, there is a significant cost/time in picking horizons. Therefore, image-guided interpolation can be used as a good alternative in creating an initial model.

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References


