Robust traveltime determination of redatuming operators

Leandro Sadala (Petrobras) and Carlos Theodoro (Petrobras)

Abstract

We present a robust automated algorithm for traveltime determination of redatuming operators. This technique is similar to the CFP approach in applying the principle of equal traveltime to validate the operator traveltime. However, it uses only the two-way traveltime extracted from the seismic dataset in the offset domain over an event selected as the new datum in its computation, avoiding a massive human intervention in picking the traveltime residuals in each iteration to update the operator traveltime. Also, It requires a simple parameterisation in comparison with previously published methods and reproduces more accurately the picked two-way traveltime. A simple example demonstrates how the one-way traveltime of the event is generated and shows its equivalence with the operator one. The robustness of the optimisation process is verified by its application on a 2D synthetic dataset through the avaluation of the absolute error and the fitness between the optimised operator traveltime and its corresponding one-way event in the CFP domain in the end of the process.

Introduction

The ability in producing better images of the subsurface to facilitate the interpreter work never was an easy task to accomplish in practice, specially in complex geological areas. Robust techniques have arose and have been improved over the years trying to reveal information still hidden in seismic datasets. FWI, Least-squares Migration and Joint Migration Inversion are some of the recent techniques which have shown promising results. Another well-known methodology is the redatuming of seismic data in which sources and/or receivers are simulated in a datum nearby the geological target. The redatuming is a very attractive process because it transforms the original dataset in another one with lower degree of structural complexities, since the propagation effects that the wavefield takes place above the new datum vanish. However, its success depends on the availability of an accurate propagation velocity model or on the one-way Green's functions defined between the new datum and the surface of the dataset registration.

Berkhout (1997a,b) and Thorbecke (1997) show how to obtain the traveltimes of these Green's functions of an image point with the CFP approach. In short, the method consists in combining the application of an operator to each shot gather simulating the downward propagation of the receivers to a virtual receiver located at the choosed image point, building the so-called CFP gather. The accuracy of the operator is evaluated by the fitness of the superposition of the operator over the selected event in the CFP gather. The presence of a misfit requires the human intervention to pick the time residual between them, repeating the process until it gets to zero. That is the reason why this process becomes cumbersome and unfeasible.

In order to work around this interative procedure, Verschuur and Marhfoul (2005) developed an approach by defining the operator traveltimes by a few parameters which are updated with a genetic algorithm. The optimum operators are obtained by the maximization of the stacking amplitude of the dataset samples that lies under the two-way traveltimes computed from the optimized operators. The main problems with this method is the definition of the variation ranges of the parameters and to get reasonable results in the presence of geological complexities, since the operators have intrinsically hyperbolical shape.

We propose a new algorithm to determine the traveltime of the operators based only on the two-way ones extracted in the offset domain from a selected reflection event in the dataset. This data feeds the iterative process that starts with a hyperbolical initial operator which, in turn, gives origin to the one-way traveltime of the event in the CFP domain and finally computes the residual between them to get the operator traveltime for the next iteration. The process finishes when the error between these curves is lower or equal to a predefined minimum one. This technique is employed in a 2D synthetic dataset and its robustiness is verified by the evaluation of the error and match of the obtained operator and its corresponding one-way event in the CFP domain.

Methodogy

Let's consider a 2D space with propagation velocity v bounded by the surface and a reflector R. Now, let's indicate the reflection traveltime of an arbitrary source and receivers spread all around the surface of the model by $\tau(x_s; x_g)$. Also, let's represent the upward operator traveltime of an arbitrary focal point on the reflector at the same receiver positions by $t(x; x_g)$. The subtraction of these two curves produces one whose stationary point gives the traveltime from the source x_s to a virtual receiver at x or, by reciprocity, from a virtual source at x to a receiver at x_s (Thorbecke, 1997).

This procedure give us the one-way traveltime of that reflection in a trace at the source coordinate. If we repeat this process for every source and combine the resulting upward one-way traveltimes at their own positions, we get the one-way traveltime curve of that reflection in CFP domain. Similarly if we change the focal points along the reflector, keeping the same source location, and then, combine the one-way reflection traveltimes gotten from the stationary points of the difference between the reflection traveltime and the operators traveltimes, we get the downward one-way traveltime for that source.

Taking this into acount, we can establish a scheme to estimate the optimal operator traveltime based on the minimization of the residual between the correspondent one-way traveltime of the reflection and the operator one. First, we define hyperbolical initial operator curves. Then, in each iteration, the one-way traveltime curve in the CFP domain is created following the same steps decribed previously by positioning the times of the stationary points at the source coordinates. And finally, the operator traveltime is updated by subtracting half of the residual between itself and the generated curve. This process has high level of convergence and, consequently, of accuracy, as will be seen in the following.

Numerical Examples

Our first example is a demonstration of the construction process of the one-way traveltime related to the reflection selected as the new datum and the verification of its equivalence with the correct operator traveltime. To do

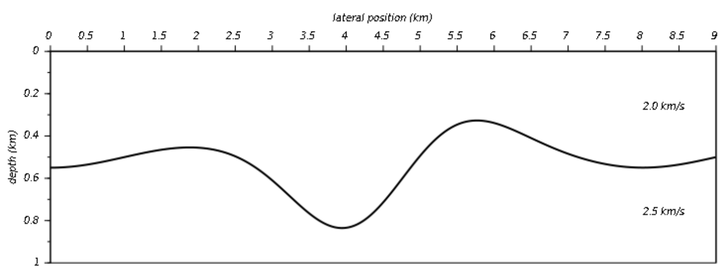

Figure 1: Simple model representing a reflector between two layers with propagation velocity of 2.0 km/s above and 2.5 km/s below it.

this, we created a very simple model with a single reflector separating two homogeneous layers with propagation velocities of 2.0 km/s above and 2.5 km/s below it (Figure 1).

The one-way traveltime of a single trace in the CFP domain linked to the reflection which is originated by an intermediate step in the process is depicted in Figure 1. It shows the traveltime of a reflection whose energy was generated at the source position 4.5 km and registered on the surface, the upward traveltime of an operator of a focal point located at 4.2 km on the reflector and the difference between them. The stationary point of the last one provides the traveltime from the source to the focal point and vice-versa.

In sequence, Figure 3 shows the complete downward one-way traveltime curve referred to the reflection after the combination of traveltimes gotten from the stationary points of the difference between the reflection traveltime of the same source and several operators which is indicated by the line with circles superimposed over the calculated downward operator traveltime indicated by the

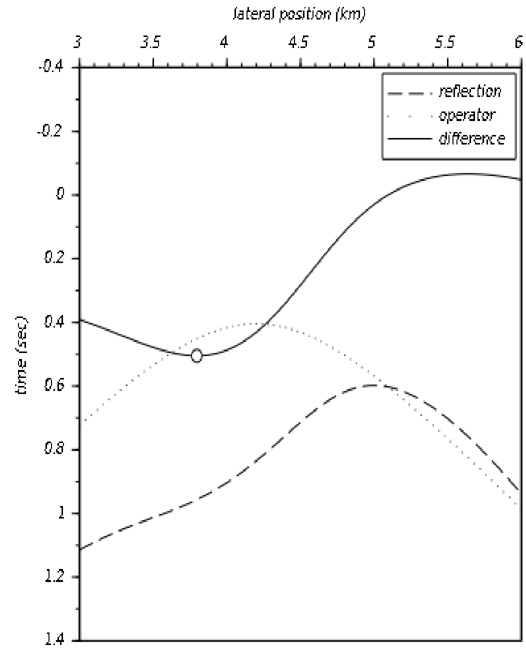

Figure 3: Reflection traveltime curve for a source at 4.5 km, operator traveltime for a focal point at 4.2 km and the difference between them. The stationary point (circle) indicates the traveltime from the source to a virtual receiver at the focal point.

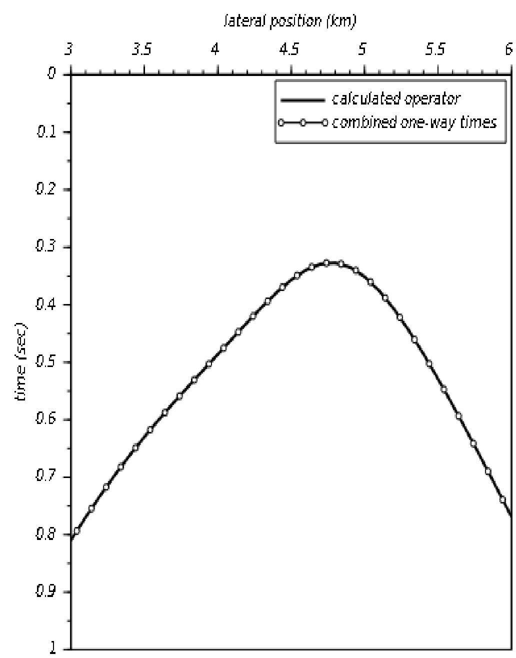

Figure 2: Superposition of the combination of all one-way traveltimes over the calculated operator.

solid line. The preference for the downward traveltimes was intentionally choosed to see their assymmetric shapes since for the upward ones we would not detect it, since the propagation velocity is constant.

Now, let's see the application of the method in practice. First of all, we need to set the input data which are the reflection traveltimes and the initial operator curves. The input data is obtained by sorting of the picked traveltimes done in offset domain by their source-receiver positions. And the initial operator is simply defined by the NMO expression with two parameters, the zero offset time and the NMO velocity.

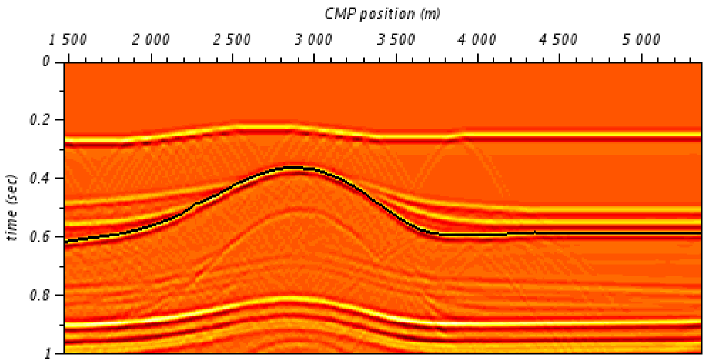

Figure 4: Reflection traveltime curve extracted from the common offset section (black line) for an offset of -60 m.

So, let's consider the synthetic dataset, borrowed from Delphi examples, represented in Figure 4 by the offset section of -60 m with the traveltime picked of the choosed event that will be the new datum. To construct the input data we have picked the traveltimes for the 60-720 m offset range incremented by 60 m. Additionally, the initial operators were created using zero-offset time and NMO velocity equal to 0.2 s and 2000 m/s, respectively.

To analyse the results, we selected two focal points horizontally positioned at 2700 and 3300 m. Figures 5 shows the estimated operator at 2700 m compared with its initial one used in the optimisation process. The convergency is rached after 4 iterations with an error below 1 ms as shown in Table 1. Similarly, in Figure 6, the final operator is obtained after 5 iterations with an error around 0.7 ms for the second focal point located at 3300 m which can also be seen in Table 2.

Aditionally, we generated the CFP gathers based on the optimised operators for both focal positions and make the superposition of themselves which can be appreciated in Figures 7 and 8, respectively. These results clearly demonstrates the robustness of the scheme.

Conclusions

A robust scheme to automatically determine optimised traveltime of redatuming operators was described. Its employment needs the reflection traveltimes of a selected event in the dataset and intial operators in order to create the traveltime curve related to the reflection choosed in the CFP domain which, in turn, is used in the update process of the operator.

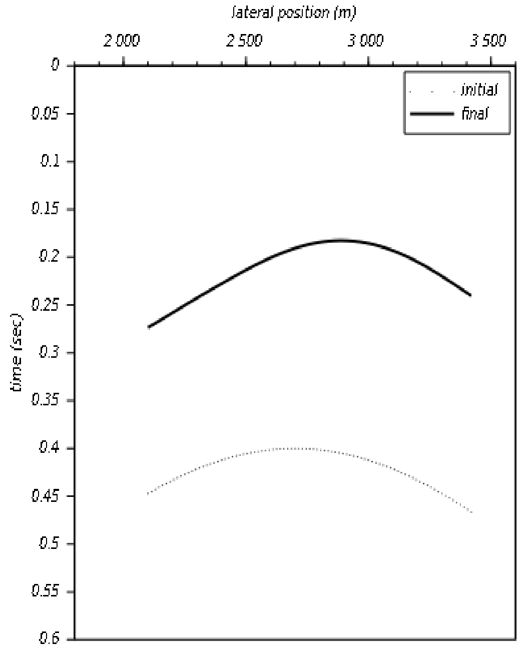

Figure 6: Optimisation of the initial operator at 2700 m. The dotted and solid lines represent the initial and optimised operators, repectively.

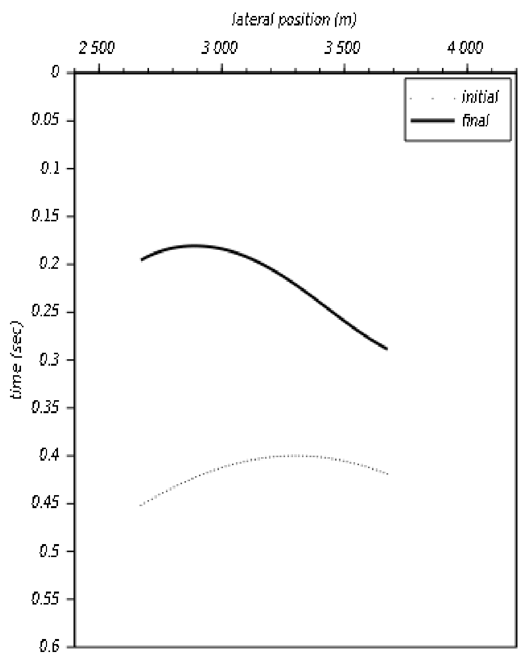

Figure 5: Optimisation of the initial operator at 3300 m. The dotted and solid lines express the intial and optimised operators, repectively.

We numerically demonstrated the accuracy of the technique by measuring the error of the optimised operators and visually by the match of the operator traveltime and its related event in CFP domain.

Iteration	Error (sec)
1	0.418211
2	0.008280
3	0.002315
4	0.000976

Table 1: Error of each iteration in the optimisation of the operator at 2700 m.

Iteration	Error (sec)
1	0.405743
2	0.022546
3	0.007105
4	0.002270
5	0.000760

Table 2: Error of each iteration in the optimisation of the operator at 3300 m.

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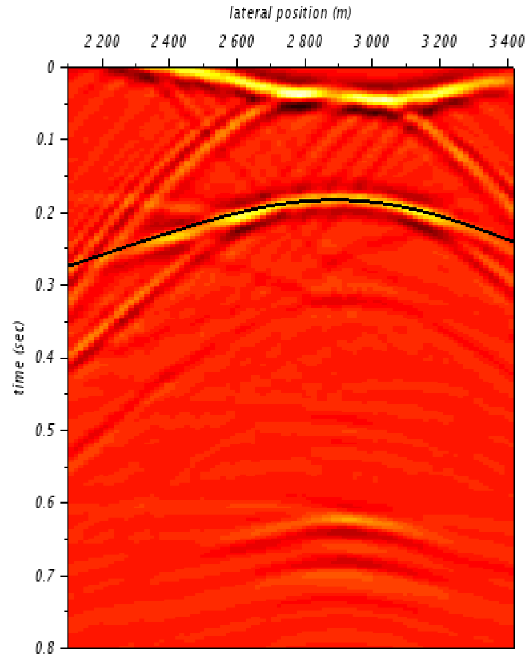

Figure 7: Superposition of the optimised operator over the CFP gather for a focal point positioned at 2700 m.

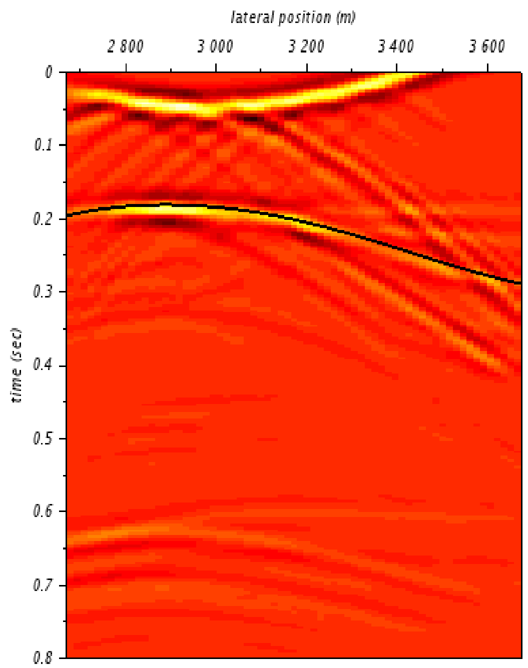

Figure 8: Superposition of the optimised operator over the CFP gather for a focal point positioned at 3300 m.

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