

# EA Automatic Seismic-to-Well Tie by Restricted Adjustment of Sonic Logs\*

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## Abstract

The objective of the well-to-seismic tie is to match, as close as possible, information from well logs to the seismic section. Usually, this process involves shifting, stretching and/or squeezing the synthetics until the correlation with the observed traces is high. These operations, which are somewhat arbitrary and prone to human errors, may lead to unrealistic velocity models and wavelet deformations. These issues can be alleviated by automatic methods, such as the one proposed in this work. The strategy allows to obtain high correlation values between the synthetics and the observed data by applying a smooth function that perturbs, in a controlled manner, the original sonic log. Since the trace is not stretched and/or squeezed at any stage, as opposed to other automatic well tying methods, the resulting synthetics preserve the wavelet shape, a feature that certainly contributes to a better interpretation of the seismic data. In addition, the proposed method guarantees that the velocity changes after the perturbations are small to honor the measured borehole observations within a given tolerance.

## Introduction

Integrating well logs and seismic data is crucial to identify geological horizons in the seismic sections and/or estimating the wavelet for seismic inversion (A. Ziolkowski and Johnston, 1998; White and Simm, 2003, e.g.). The process of tying these two signals involves several interpretative steps with a significant margin for human errors (Muñoz and Hale, 2012). Many procedures for tying well logs to seismic data can be found in the literature (Walden and White, 1984; White and Hu, 1997; A. Ziolkowski and Johnston, 1998; White and Simm, 2003; Duchesne and Gaillot, 2011; Edgar and van der Baan, 2011; Herrera R. H., 2014; Muñoz and Hale, 2015, e.g.). Best practices and advises for a confident matching are given by White and Simm (2003) and Newrick (2012). To create a synthetic seismogram, we need to convolve a reflectivity series generated from well logs (density and sonic logs) with a suitable wavelet (Anderson and Newrick, 2008). Also, a time-depth relationship to convert depth to time information is needed (Muñoz and Hale, 2015).

The objective is to match and identify distinctive reflectors in the seismic section with the corresponding events in the synthetic seismogram (Newrick, 2012). The quality of the tie is usually measured by the correlation coefficient between the synthetics and the seismic data (Herrera and van der Baan, 2014; Herrera R. H., 2014; H. Wu and Liu, 2017), which is expected to be maximum. In practice, high correlations between

these two signals are infrequent and the interpreter needs to edit the synthetic to increase the correlation. For this purpose, commercial software allows the users to interactively shift, stretch and/or squeeze the synthetic seismogram until obtaining a satisfactory match, among other adjustments. Since these processes are somewhat arbitrary and susceptible to errors due to subjectivities, it is essential to have an automatic tying algorithm. Few methods have been published for automatic well-to-seismic tying. Herrera R. H. (2014) and Muñoz and Hale (2015) introduced an algorithm known as Dynamic Time Warping (DTW) to compute well ties. This algorithm has been used to compare different speech patterns in automatic speech recognition and to automatically cope with time deformations associated with time-dependent data in the field of data mining (Mueller, 2007). In a well-seismic context, DTW is a powerful algorithm able to modify the synthetic seismogram using the so-called warping path. The warping path, which is obtained by linear programming, is used to stretch and squeeze the synthetic trace until the correlation with the observed data is highest (Herrera R. H., 2014). The warping path needs to be conveniently constrained in order to keep the velocity changes within reasonable values. One limitation of DTW, and of any strategy that "edits" the synthetic trace, is that the seismic wavelet may not preserve its shape.

To overcome this issue, we propose a new automatic strategy that relies on a function that, when applied to the observed sonic-log data, leads to a new synthetic trace that has a higher correlation with the observed data. The function is built using monotonic cubic splines interpolation with a fixed number of nodes. We use Differential Evolution (DE), an iterative global optimization algorithm, to find the optimum node values. The iterative process concludes when the correlation between the synthetic and the observed traces is maximal. One advantage of our method, and in contrast to DTW, is that the seismic wavelet is not altered in the tying process, because the stretching/squeezing process is replaced by a modification of the well-log data before calculating the synthetic trace. In addition, the velocity changes are easily constrained by limiting the nodes of the interpolation function, as we will show later.

## Method

The goal of our method is to tie a synthetic seismogram and a seismic trace while honoring the velocity model within a given tolerance. To this end, we perturb the sonic log interactively by applying a function that leads to an increase in the correlation coefficient between the synthetic and observed traces. At each iteration, the synthetic seismogram is computed using the updated sonic log by following the traditional steps (Newrick, 2012). That is, first we generate the reflectivity series from the new sonic log; then we apply a time-depth relationship; and finally, we convolve with a suitable wavelet. For simplicity, in the examples below we consider a constant density log. As for the time-depth relationship, because we have no VSP or checkshot data, we compute the time-depth function by integrating the sonic log.

We build the aforementioned function by means of monotonic cubic spline interpolation with a fixed number of nodes. The nodes have two coordinates: depth and fractional change. The depth coordinate is fixed and equally spaced along the depth range of interest. The fractional change coordinate can vary within a given percentage range around the sonic log. This allows the interpreter to have control over the resulting velocity changes during the well tying process. The new sonic log can be expressed as follows:

$$DT_{new} = DT_{obs} * [1 + w(z)], \quad (1)$$

where  $w(z)$  is the function that is built using cubic splines with  $n$  nodes, and  $DT_{obs}$  is the observed sonic log. In practice,  $w(z)$  takes values between a minimum and a maximum value (e.g. from -0.05 to 0.05 to allow a change of 5% at most). Since the estimation of the nodes values represents a non-linear and multimodal maximization problem, we use the global optimization algorithm DE (Differential Evolution) (Storn and Price, 1997). In each iteration of DE the nodes are updated, and the sonic log is modified using equation 1. The tying process ends when the correlation coefficient between the synthetic seismogram and the seismic trace is maximum.

## Examples

Figure 1 illustrates the method. The figure depicts the observed sonic log (black curve in panel a), and a representative observed seismic trace (blue curve in panel c) in the nearby well. The red curve in the same panel shows the synthetic trace built as described above using the observed sonic log and a 30-Hz Ricker wavelet. The correlation between the observed and the synthetic trace is 0.64, denoting that the match between the two traces is relatively low. Figure 1b shows the optimized function  $w(z)$  using 10 nodes and a maximum variation of 5%. When applied to the observed sonic log via equation 1, we obtain the new sonic log plotted in green in Figure 1a. This updated sonic log leads to the new synthetic trace plotted in red in Figure 1d. The correlation coefficient increased from 0.64 to 0.84, denoting that the match between the two traces has been improved significantly. It is important to mention that the seismic wavelet is not altered, in contrast with the manual stretch/squeeze or other approaches that modify the synthetic trace directly.

To analyse the behavior of the algorithm when using different number of nodes and allowed fractional changes in the sonic log, we repeated the tying process using various values for these parameters. The results are summarized in Table 1 and the resulting sonic logs, functions  $w(z)$  and synthetic traces, depicted in Figure 2. We observe that we can get correlation values as high as 0.99 if we allow large velocity changes and use a large number of nodes. Of course, these situations are not realistic, and the user is recommended to be conservative and judicious in the selection of the parameters. Usually, correlation values in the range 0.8-0.9 are high enough for an optimal interpretation of the data. These values can be achieved by selecting 5 to 15 nodes and allowing changes below 10%. In the examples summarized in Table 1, we obtained correlations above 0.8 even when using only 5 nodes and a constraint of 5%. The selection of the optimum values will depend, naturally, on the length of the window along which the tying is desired, and on how much the user trusts on the observed sonic log measurements, among other reasons.

## Conclusions

The proposed well-to-seismic tying strategy allowed us to carry out the tying automatically. The results show that one can obtain high correlation values between the synthetics and the observed data by applying a smooth function that perturbs, in a controlled manner, the original sonic log. This strategy guarantees that the velocity changes are kept within reasonable ranges, thus guaranteeing that the measured borehole observations are honored well. On the other hand, since the trace is not stretched and/or squeezed at any stage, the resulting synthetics preserves the wavelet shape, a feature that certainly contributes to a better interpretation of the seismic data.

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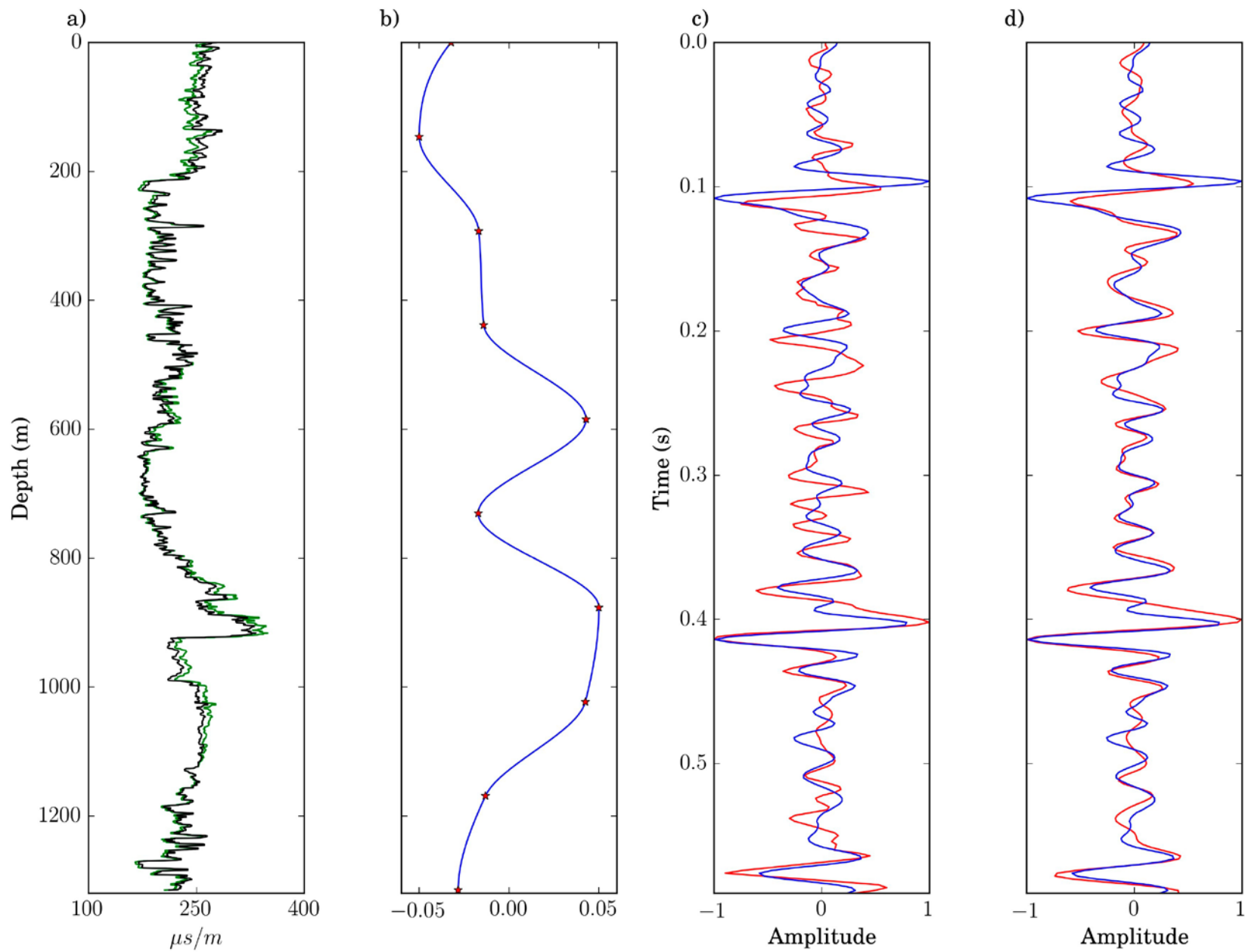


Figure 1. Results with a constraint of 5% and 10 nodes. The correlation coefficient increased from 0.64 before the tying to 0.84 after applying the proposed method. a) Observed (black) and perturbed (green) sonic log, b)  $w(z)$  function, c) and d) synthetic seismogram (red) and seismic trace.

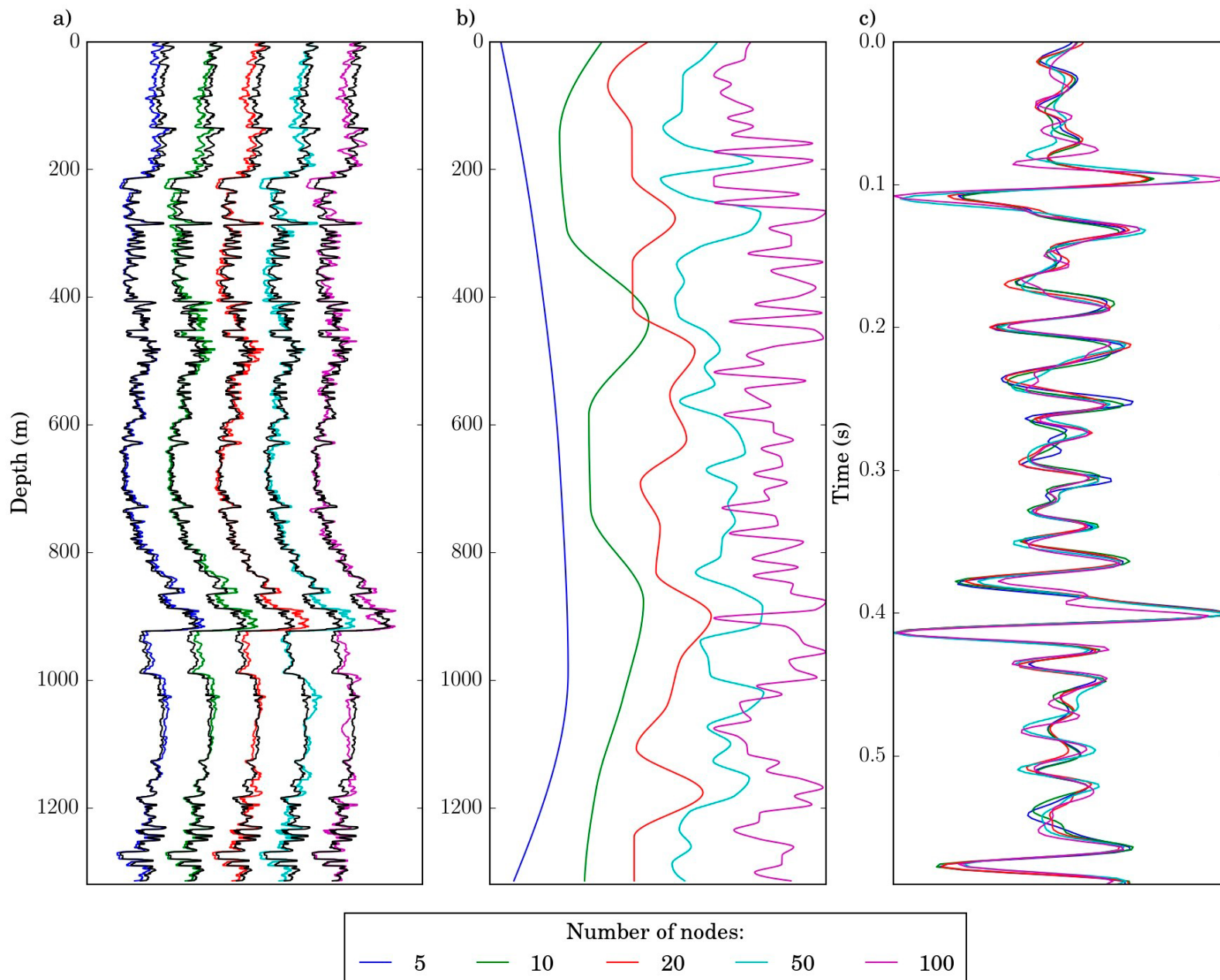


Figure 2. Results with a constraint of 10% for different number of nodes. a) Observed and perturbed sonic logs, b)  $w(z)$  function and c) synthetic traces calculated from the modified sonic logs.

<b>%Changes/#Nodes</b>	<b>5</b>	<b>10</b>	<b>20</b>	<b>50</b>	<b>100</b>
<b>5%</b>	0.83	0.84	0.86	0.90	0.93
<b>10%</b>	0.84	0.86	0.87	0.91	0.99
<b>20%</b>	0.84	0.86	0.88	0.93	0.99

Table 1. Values of the correlation coefficient for different number of nodes and constraints for the function  $w(z)$  after tying the seismogram of [Figure 1](#). The original correlation is 0.64.