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MULTICHANNEL SPECTRAL DECOMPOSITION USING MATCHING PURSUIT STEERED BY A RELATIVE GEOLOGICAL TIME MODEL

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Summary

This paper presents a multichannel spectral decomposition method which uses a Relative Geological Time (RGT) model to steer the lateral propagation of wavelets extracted using the classical matching pursuit method. The proposed workflow is made of several extraction / propagation rounds. A single round consists in the extraction of a wavelet using the classical matching pursuit method following by a multichannel propagation phase. The extracted wavelets are propagated laterally to reconstruct a seismic reflector by following iso-values of the RGT model, where each iso-value corresponds to a relative geological age. Applied to a real dataset, results are less sensitive to noise and enable the extraction of spectral components which are more geologically consistent and with a better lateral continuity. In addition, this multichannel approach avoids to go through the heavy and time consuming process of the classical matching pursuit method.

Multichannel spectral decomposition using matching pursuit steered by a Relative Geological Time model

Introduction

Spectral decomposition, also known as time-frequency analysis, is a largely used method in seismic interpretation. It decomposes the seismic signal into its constituent frequencies and can assist the stratigraphic interpretation and bed thicknesses analysis (Chopra and Marfurt, 2007). The matching pursuit method consists in breaking up each seismic trace independently into a linear combination of wavelets that locally match its time-frequency signature (Mallat and Zhang, 1993). The best matching wavelets are chosen by cross-correlating the seismic trace with a collection of wavelets obtained by varying a set of wavelet parameters: frequency, phase, scale and time delay. To reduce the search domain, a complex trace analysis can be performed to provide a preliminary estimate of the frequency, phase and time delay before proceeding to a local optimization (Liu and al., 2004). Besides, a small perturbation in the seismic trace may result in an entirely different decomposition outcome leading to lateral discontinuities (Castagna and Sun, 2006). To solve this issue, Wang (2010) suggests to use the lateral coherence of seismic traces as a constraint during the seismic trace decomposition. Xu and al. (2020) proposed another multichannel approach by introducing some directionality constraints. Their method assumes that the waveforms along a reflection are continuous to a certain extent by propagating the extracted wavelet to the neighbouring traces. They implemented this solution for the spectral decomposition of 2D seismic profiles. In this paper, an alternative method is proposed which uses a Relative Geological Time (RGT) model obtained from the seismic interpretation to steer the lateral propagation of extracted wavelets for a 3D seismic cube.

Methodology

The proposed method consists of adding a 3D structural constraint into the matching pursuit decomposition by integrating a RGT model. The RGT model is a volume where a relative geological age is assigned to each voxel belonging to the same depositional surface and represented in the seismic domain by one seismic reflector. As a result, a wavelet may be propagated laterally to reconstruct a seismic reflector by following iso-values of the RGT model. In the following case, the RGT model has been obtained from a comprehensive seismic interpretation method described by Pauget et al. (2009).

From a picked seed trace, wavelets are extracted and iteratively propagated along the RGT model geological ages. The decomposition of the seismic volume is performed in several rounds. A round starts by the extraction of a reference wavelet from a seismic trace using the classical matching pursuit method (Figure 1.a), subsequently followed by a propagation step steered by the RGT model relative ages at its centered time position (Figure 1.b and 1.c). The RGT model enables to know at which time the reference wavelet needs to be propagated and then extracted for each neighbour trace. The waveforms along a seismic reflection change progressively as we move away from the trace where the wavelet has been extracted. Consequently, the propagation phase must be stopped when the waveforms on the neighbour traces are too different to the extracted wavelet being propagated. Inspired from Xu and Jin (2020), validation criteria are defined using the amplitude, the instantaneous frequency and the instantaneous phase of the neighbour traces. The propagation of the wavelet to a given neighbour trace is rejected when it does not satisfy the following criteria anymore:

Criterion 1 :

$$\alpha_{Amp}^{low} \leq \frac{Amp_{propa}}{Amp_{ref}} \leq \alpha_{Amp}^{up} \tag{1}$$

Criterion 2 :

$$\alpha_{f}^{low} \leq \frac{f_{inst\,,\,propa}}{f_{ref}} \leq \alpha_{f}^{up} \tag{2}$$

Criterion 3 :

$$\begin{cases} \alpha_{f}^{low} \leq \dfrac{\varphi_{inst\,,\,propa}}{\varphi_{ref}} \leq \alpha_{f}^{up} \;;\; if\,\varphi_{ref} \geq 0 \\[2ex] \alpha_{f}^{low} \leq \dfrac{\varphi_{ref}}{\varphi_{inst\,,\,propa}} \leq \alpha_{f}^{up} \;;\; if\,\varphi_{ref} < 0 \end{cases} \tag{3}$$

with:

- $\boldsymbol{Amp_{ref}}$ and $\boldsymbol{Amp_{propa}}$: the amplitude of the extracted reference wavelet and the amplitude of the wavelet being propagated;
- $\boldsymbol{\alpha_{Amp}^{low}}$ and $\boldsymbol{\alpha_{Amp}^{up}}$: the lower and upper bounds of the search threshold for the amplitude;
- $\boldsymbol{\varphi_{ref}}$and $\boldsymbol{\varphi_{inst\,,\;propa}}$: the phase of the reference wavelet and the instantaneous phase of the neighbour trace at the iso-RGT value of the reference wavelet;
- $\boldsymbol{\alpha_{\varphi}^{low}}$ and $\boldsymbol{\alpha_{\varphi}^{up}}$: the lower and upper bounds of the search threshold for the phase;
- $\boldsymbol{f_{ref}}$ and $\boldsymbol{f_{inst\,,\;propa}}$: the frequency of the reference wavelet and the instantaneous frequency of the neighbour trace at the iso-RGT value of the reference wavelet;
- $\boldsymbol{\alpha_{f}^{low}}$ and $\boldsymbol{\alpha_{f}^{up}}$: the lower and upper bounds of the search threshold for the frequency.

As the propagation process continues in all directions by following the RGT model and by respecting the criteria (1)-(3), this method avoids going through the heavy and time consuming process of the single channel matching pursuit where each trace is processed independently. Once all the traces have been rejected forming a closed loop, and so blocking all possible expending paths, the propagation is stopped (Figure 1.d). A new wavelet is then extracted using the classical matching pursuit algorithm for a new reference trace located in the neighbourhood where the propagation has been stopped (Figure 1.e). The propagation of the newly extracted wavelet is then also performed, and so forth. This process is repeated until at least one wavelet has been extracted for each trace of the survey, ending the current round (Figure 1.f). Finally, this round process is reiterated until all the seismic traces have been decomposed.

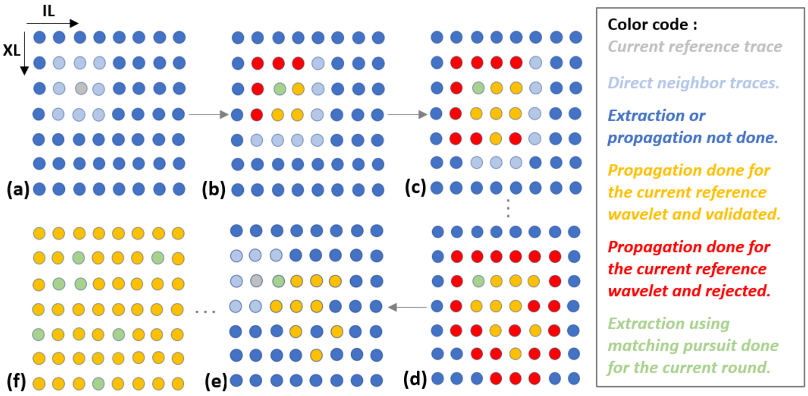

Figure 1 *Extraction/propagation processes for a single round. Each colored dot corresponds to a seismic trace. (a) A reference wavelet is extracted from a seed trace. (b) The reference wavelet is propagated to the direct neighbour traces by following its iso-RGT value. Depending on traces, the propagation is validated or rejected. (c) The process recursively continues for the direct neighbourhood of the traces whose propagation had been validated. (d) The propagation ends when no more path is available. (e) A new reference wavelet is extracted and a new propagation process is launched. (f) The previous steps are repeated until at least one wavelet has been extracted/propagated for all traces, implying the end of the round.*

Results and discussion

The following example showcases the spectral decomposition of Maui field's seismic data located in the Taranaki Basin, offshore New Zealand. The RGT model used in this study was obtained from the comprehensive interpretation of the Maui field's seismic data (Durot et. al., 2017). The 48 Hz spectral component of the seismic data has been extracted using the RGT model-based multichannel matching pursuit (Figure 2.a) and compared with the results from the classical single channel method (Figure 2.b). The results of the proposed method are less sensitive to noise and are more geologically consistent with a better lateral continuity. Ultimately, the 38 Hz - 48 Hz - 58 Hz spectral components extracted from both methods have been mapped into a Red-Green-Blue (RGB) blending viewer. A moderately lower frequency resolution is observed, expressed by a slightly narrower color variability in the RGB blending. This effect is a direct consequence of the propagation process where the same wavelet is extracted for several traces, by comparison with the single trace approach of the classical matching pursuit. It can be controlled and minimized by changing the search threshold values of the validation criteria (1)-(3). In addition, some step patterns can be noted on the results obtained with the RGT model-based approach (Figure 3.a). They can be lessened by incorporating a spatial correlation length parameter into the validation criteria to stop the propagation for traces located to a certain distance, chosen by the user, from the reference trace. A correlation length of 50 traces and 15 traces has been used on the Figure 3.a and on the Figure 3.b respectively. The reduction of the correlation length mitigates the step patterns to a certain extent at the expense of the spatial continuity.

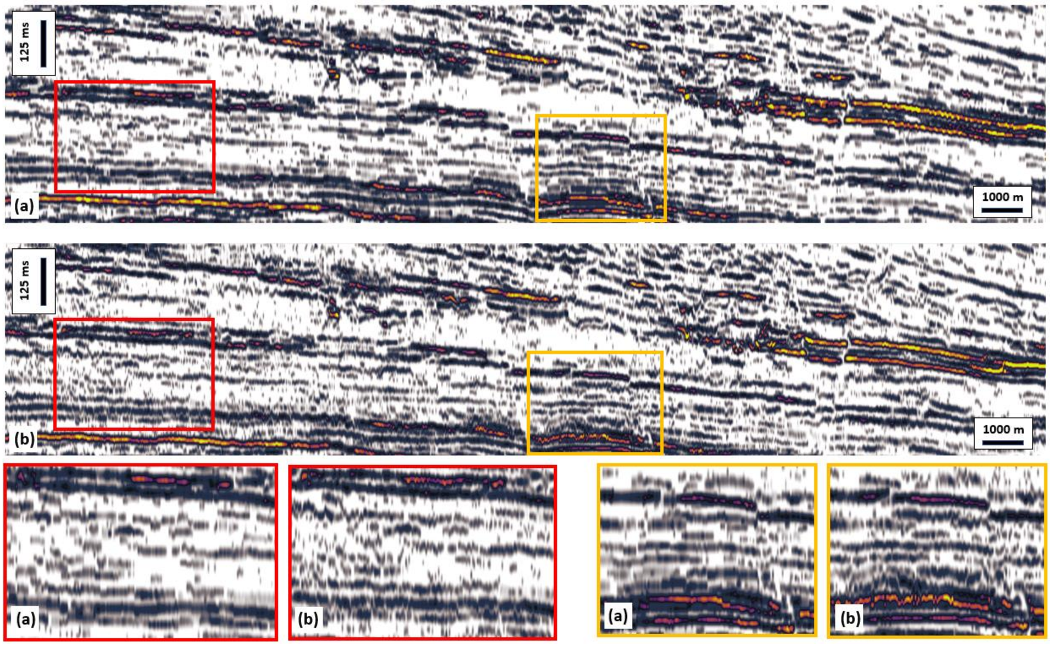

Figure 2 *Comparison between (a) the RGT model-based multichannel matching pursuit and (b) the classical single channel matching pursuit.*

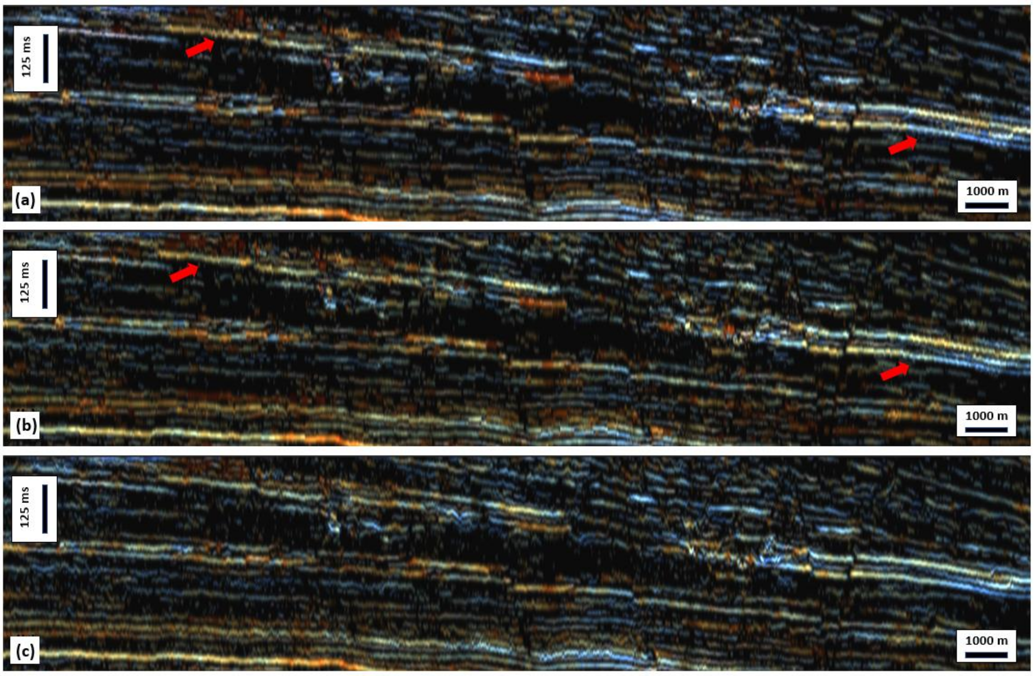

Figure 3 *RGB blending of frequencies 38 Hz - 48 Hz – 58 Hz: (a) using the RGT model-based multichannel matching pursuit with a correlation length of 50 traces, (b) with a correlation length of 15 traces and (c) using the single channel matching pursuit.*

Conclusion

This paper presents an innovative multichannel matching pursuit method to decompose spectral components with increased lateral continuity. The extracted wavelets propagation is guided by the RGT model relative ages. Applied to the Maui seismic dataset, this technique shows good results and avoids going through the heavy and time consuming process of the classical matching pursuit method where each trace is treated independently. The quality of the output decomposed images can be controlled by integrating a validation criteria for extraction, but also be improved by constraining the propagation distance of the reference wavelets.

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