A semi-supervised learning framework for seismic acoustic impedance estimation

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Summary

For compensating the limited bandwidth in seismic data, one reliable approach for robust acoustic impedance estimation is to integrate 3D seismic data with 1D well logs by building an optimal non-linear mapping function between them. However, most of the existing mapping methods, including these by machine learning, are performed in 1D that utilizes only the single seismic trace corresponding to a well. Therefore, their performance is restricted within a small zone around the wells, while consistent prediction cannot be obtained throughout the entire seismic survey. In addition is the down-sampling of high-resolution well logs to the seismic scale, which fails to fully utilize the information available in the wells. For resolving both limitations, this work presents a semi-supervised learning framework of two components: (1) seismic feature self-learning and (2) seismic-well integration, each of which is formulated as a deep convolutional neural network. The performance of the proposed framework is evaluated through an application to the synthetic SEAM dataset. The good match between the machine prediction and the earth model demonstrates the capability of the proposed semi-supervised learning in reliable seismic and well integration, particularly in the zones of poor seismic signals due to the presence of geologic complexities.
Introduction

Estimating seismic acoustic impedance is an important but challenging task in subsurface interpretation, into which geoscientists have devoted numerous efforts. To compensate limited bandwidth of seismic data, one robust approach is to integrate 3D seismic data with 1D well logs by building an optimal non-linear mapping function between the two types of data (Carron, 1989). Most of the existing mapping methods, including these by machine learning (e.g., Alfarraj and AlRegib, 2019; Wang et al., 2019), are performed in 1D that utilizes only the single seismic trace corresponding to a well. Therefore, their performance is restricted within a small zone around the wells, while consistent prediction cannot be obtained throughout the entire seismic survey. In addition is the down-sampling of high-resolution well logs to the seismic scale, which fails to fully utilize the information available in the wells. For resolving these limitations, this work proposes a semi-supervised workflow for efficient acoustic impedance estimation through deep convolutional neural networks (CNNs).

Workflow

Figure 1 illustrates the proposed workflow for 3D seismic and 1D well integration, and its training procedure consists of two steps: (a) seismic feature self-supervised learning (SFSL) and (b) seismic-well integration (SWI) (Di et al., 2020a). Each is formulated as a deep CNN. Both CNNs are connected by initializing part of the SWI CNN using the pre-trained SFSL CNN, instead of from scratch in most of the existing CNN implementations in seismic. The benefits of such integration are twofold as reported in (Di et al., 2020b).

Examples

For performance evaluation, we use a subset of the synthetic 3D SEG-SEAM dataset, which has the corresponding earth models as ground truth. The cropped survey consists with 101 inlines, 422 crosslines, and 751 samples per trace, with 20 ft as the sampling interval. 8 wells are used for training. Figure 2 shows two sections of inline 1793 and 1919, through each of which only 1 well penetrates. Compared to the ground truth, the machine prediction,
• captures the variations of acoustic impedance from shallow to deep
• reveals the subtle events indicative of thin beds particularly in the deep areas of poor seismic quality
• has high lateral continuity, indicating the capability of the proposed workflow in generalizing what it learns from the 8 training wells to the entire seismic survey.
Conclusions

For robust seismic acoustic impedance estimation, we have presented a semi-supervised learning framework capable of efficiently integrating the 3D seismic data and a few sparsely-distributed wells. As tested by the synthetic SEAM dataset, the proposed method successfully provides highly consistent and accurate acoustic impedance estimation for the entire seismic survey.

References


