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Regularizing machine seismic traces using Machine Learning – a statistical approach

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Introduction

Seismic acquisition uses sources and receivers that are ideally arranged on a regular grid. However, due to experimental limitations, neither the sources nor the receivers are equally spaced in a grid. Despite this, accurate seismic imaging requires that the positions of these devices be mapped onto a regular grid. The procedure of transforming seismic data acquired on an irregular spatial grid to a regular one is referred to as regularization. Various interpolation techniques, either in the data domain or in the frequency-wavenumber domain, have traditionally been employed for this purpose. More recently, Machine Learning (ML) approaches have been explored to address this task. In this work, we developed a seismic trace regularization technique using ML that makes use of the law of large numbers. Furthermore, our technique does not rely on prior knowledge of the trace positions.

Method

The core principle of the proposed method is to develop a ML model capable of interpolating regularly sampled seismic traces from irregularly sampled data. The methodology leverages the law of large numbers, wherein a Neural Network is trained on irregularly spaced data to estimate the optimal average, which asymptotically converges to the value of the corresponding regularly sampled trace as the size of the training dataset increases. To operationalize this approach, we consider sequences of an odd number of traces—five traces, for illustrative purposes—where the objective is to regularize the central trace. Specifically, the Neural Network receives the four adjacent traces as input and predicts the value of the central trace as output. The seismic datasets used for training and validation were synthetically generated based on a velocity field representative of the Brazilian pre-salt region. The acquisition geometry consists of an array of 400 ocean-bottom nodes spaced at 40-meter intervals, and 30 seismic shots.

Results and Conclusions

We evaluated several ML architectures for seismic trace regularization, including Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), and Fully Connected Networks (FCN), with the first demonstrating the most promising performance. The selected model consists of a four-layer FCN employing the Rectified Linear Unit (ReLU) activation function. The loss function is defined as the mean squared error (MSE) augmented with an L2 norm regularization term, and the initial learning rate was set to 1×10^{-3} with a reduction factor of 0.2 applied on plateaus. The network was trained using a scheme in which four irregularly sampled traces were provided as input to predict a single regularized trace as output. To assess the effectiveness of our approach, we compared its performance against conventional cubic interpolation and frequency-wavenumber (FK) domain regularization. The proposed methodology outperformed cubic interpolation and achieved comparable error levels to the FK regularization technique. A notable advantage of our method is that it does not require prior knowledge of the spatial positions of the irregular traces for the regularization process. Furthermore, the computational time of the proposed approach is either lower or of the same order of magnitude as that of the reference methods.