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Minimum-Phase Wavelet Estimation Using Convolutional Neural Network

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Introduction

Minimum-phase wavelet estimation is crucial for seismic processing and interpretation in various applications, including filtering, well-tie, and seismic inversion. In this context, the application of Deep Learning to automate the wavelet estimation stage can offer advantages over traditional estimation methods, such as eliminating the need to know the reflectivity function of the subsurface, as well as the ability of a trained neural network to estimate the wavelet of a seismic trace quickly. For example, convolutional neural networks (CNN's) can learn by adapting cell values of convolutional filters that sweep the input data in order to obtain the lowest possible cost function for the CNN output. Therefore, this research work aims to explore the potential of a CNN in estimating minimum-phase wavelets based on the geometry of the convolutional model of the seismic trace.

Method and/or Theory

By despising the seismic attenuation in the wave propagation, the convolutional model in the time domain describes the seismic trace as the composition of reflectivity convolved with the wavelet. Using this model, we generate synthetic traces by creating synthetic reflectivity functions. We randomly fill a null vector of 256 samples with 100 values ranging from -1 to 1, sorted according to a Gaussian distribution, which represents the reflectivity coefficients of 100 interfaces between earth layers. Once the reflectivity model was determined, this vector was convoluted with various idealized wavelets, such as Ricker, Gabor, and Sinc, with a dominant frequency varying between 5 and 50 Hz. The Ormsby and Klauder wavelets have four and two dominant frequencies, respectively, which were determined in the range between 1 and 125 Hz, with the condition of at least a 20 Hz difference between each frequency. Finally, a noise content was added with a signal-to-noise ratio (SNR) of 10 dB, generating 100,000 synthetic noisy seismic traces. Each trace is pre-processed by normalizing the standard deviation of each trace and then used as input of the convolutional neural network (CNN) to be trained to obtain as output the wavelet closest to the one used to generate the trace itself. The CNN is based on the U-net architecture. Furthermore, this research proposes adapting the traditional cost function, which is the logarithm of the hyperbolic cosine of the residual, by adding a penalty term based on the decrease in the Pearson correlation metric. This modification ensures a high linear correlation between the estimated wavelet and the expected wavelet, as well as a minimum Mean Absolute Error (MAE).

Results and Conclusions

The trained CNN metrics measured excellent Pearson Correlation values of 91% for training and 88% for testing. The mean absolute error for testing and validation varied by approximately 1.1% of the expected values. In conclusion, CNN has demonstrated a good generalization between training and testing for various types of wavelets with one, two, and even four dominant frequencies, as well as for a wide range of frequencies. As such, the objective of this research work was achieved; we aim to explore possible next steps, such as testing the algorithm on real data to perform a deconvolution step of real seismic trace.