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A numerical method for earth mover's distance calculation and its application in full waveform inversion

Conventional full waveform inversion (FWI) using least square distance (LSD) suffers from local minima. Recently, earth mover's distance (EMD) has been introduced to FWI to compute the misfit between two seismograms. Instead of comparisons bin by bin, EMD allows to compare signal intensities across different coordinates. This measure has great potential to account for time and space shifts of events within seismograms. However, there are two main challenges: (1) the compared signals need to satisfy non-negativity and mass conservation assumptions; (2) the computation of EMD between two seismograms is expensive. In this work, a strategy is used to satisfy the two assumptions via decomposition and recombination of original seismic data. The computation of EMD based on dynamic formulation is formulated as a convex optimization problem, which is solved by a primal-dual hybrid gradient method with linesearch on GPU device. The new method is efficient and also easy to implement. A 1D time-shift signals case study has indicated that EMD is more effective in capturing time shift. Two applications to synthetic data using transmissive and reflective recording geometries have demonstrated the effectiveness of EMD in mitigating cycle-skipping issues. The new method has been applied to SEG 2014 benchmark data. The result demonstrated that EMD can mitigate local minima and provide reliable velocity estimations without using low frequency information.