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Physics-informed neural networks for 3D seismic travel time tomography

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Seismic travel time tomography is a widely used technique to image the Earth's interior. Recently, there have been growing interests in employing deep learning for seismic tomography, and physics-informed neural networks (PINNs) are attractive for their integration of physical information into the networks and their greater stability compared to conventional neural networks. PINNs have been successfully used in 2D tomography, including cross-hole tomography (Waheed et al., 2021) and surface wave phase velocity tomography (Chen et al., 2022). However, 3D seismic tomography based on PINNs has not been developed. Here we propose a novel method for 3D travel time tomography based on PINNs and show its effectiveness using both synthetic and real data. The network consists of two branches, one taking in the 3D coordinates of a pair of source and receiver for fitting observed travel times and another taking in the receiver location for predicting velocities. The loss function also consists of two terms, the data fitting residual term and the Eikonal equation residual term. In this way, the two branches are connected using the Eikonal equation loss function term. After training, the network can simultaneously reconstruct the travel time fields and estimate the subsurface velocities. Our method is tested using synthetic and real travel time data for seismic network in Parkfield, California. Compared to traditional travel time tomography methods, this approach offers many advantages, including meshless modeling, no need for regularization and independent on the initial velocity models.