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Research on Multi-Station Phase Picking, Association and Location Based on Graph Neural Networks

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INTRODUCTION AND MAIN RESULTS

Seismic monitoring relies on three tightly coupled tasks—phase picking, association, and location—yet conventional methods process them separately, often using single-station waveform analysis. This fragmented approach limits efficiency and accuracy, as the interdependencies between these tasks are not fully exploited.

We propose a Graph Neural Network-based framework that models seismic stations as graph nodes, waveform data as node attributes, and inter-station relationships as edges. This unified approach enables end-to-end learning, integrating waveform feature extraction, physics-informed phase picking, phase association, and event location into an unified workflow. This method enhances automation, scalability, and real-time monitoring capabilities, offering a robust solution for modern seismic networks.

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CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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Highlights

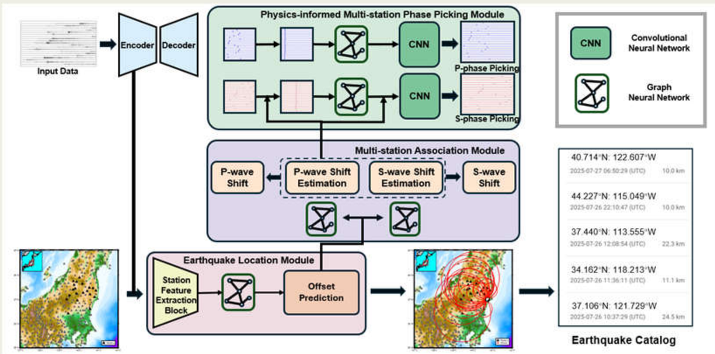
- ◆ Proposed a GNN-based unified intelligent workflow for earthquake monitoring.
- ◆ Utilized multi-station constraints to refine earthquake monitoring results.
- ◆ Enhanced algorithm interpretability and stability through multi-task collaboration and physical constraints.

Introduction

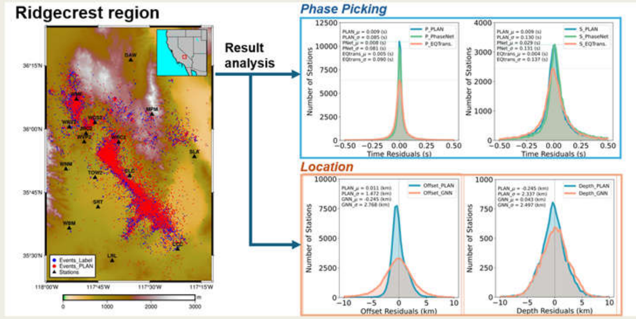
Earthquake monitoring traditionally processes phase picking, association, and location separately, ignoring inter-task dependencies and multi-station constraints. To address this, we propose PLAN, the first unified graph neural network (GNN) that simultaneously performs all three tasks (phase picking, association, and location) by integrating multi-station seismic data and physics-informed inter-task relationships. PLAN employs a GNN to adaptively learn irregular station layouts and enforces consistency through waveform alignment and shared features. Tests in Ridgecrest region show superior performance over PhaseNet and EQTransformer, demonstrating its potential for next-generation automated earthqauke monitoring

Methods

The model takes as input both multi-station seismic waveforms and their corresponding geographic coordinates. PLAN's architecture integrates four interconnected sub-modules: (1) a waveform feature extraction network with encoder-decoder structure, (2) an earthquake location module, (3) a multi-station association module, and (4) a physics-constrained phase picking module. These components are jointly optimized during training through mutual physical constraints, enabling simultaneous enhancement of earthquake detection sensitivity, event association accuracy, and location precision.



Results



We tested the proposed PLAN in Ridgecrest region. The performance of PLAN in phase picking was superior to that of the other two deep learning-based methods (PhaseNet and EQTransformer).

Method	P Picking Metrics			S Picking Metrics		
	mPrecision	mRecall	mF1	mPrecision	mRecall	mF1
PhaseNet	94.83	92.78	93.79	84.50	80.65	82.53
EQtransformer	95.43	91.17	93.25	86.77	78.21	82.27
PLAN-GATv2	95.05	93.02	94.03	85.55	80.49	82.95
PLAN-SAGE	94.99	93.07	94.02	85.65	81.48	83.51
PLAN-Trans	94.65	94.90	94.77	86.88	84.94	85.90

In five of the six metric scores for the P-wave and S-wave picking results, our attention mechanism-based GNN method outperformed the other methods (marked in red).