ABSTRACT

Seismic activity monitoring represents a fundamental challenge in seismology due to the complex and nonlinear nature of earthquakes. This research develops a Spatio-Temporal Graph Attention Network (ST-GAT) model for forecasting maximum microseismic magnitude using earthquake event data from Amatrice, Italy. Multi-horizon forecasting refers to prediction at various future time steps, while multi-resolution forecasting means performing prediction with temporal aggregation at different time scales (e.g., 1 hour, 2 hours, to 24 hours). The multi-resolution approach is designed to capture temporal dependencies at various time scales simultaneously. The ST-GAT model integrates Graph Attention Network (GAT) to capture spatial relationships among seismic locations and Long Short-Term Memory (LSTM) to model temporal patterns of earthquake activity. The preprocessing pipeline transforms 900,050 raw events into a structured spatio-temporal representation with 133 active nodes through temporal aggregation and spatial gridding. The model architecture consists of 2 GAT layers with 4 attention heads, learnable node embeddings, skip connections, and 2 LSTM layers with a total of 47,185 parameters. Evaluation on the multi-resolution approach demonstrates superior performance with R^2 = 0.706 at 1-hour resolution. Results show that modeling at multiple time resolutions is more stable compared to multi-horizon prediction at a single fixed resolution, achieving an average R^2 = 0.658 across all tested horizons. Uncertainty analysis using Deep Ensemble with 5 independent models per resolution achieves 95% coverage after calibration, with uncertainty levels increasing as the estimation horizon extends. The deep learning model demonstrates significant performance improvement over statistical baselines (Naive, Moving Average, ETAS), with a +0.730 difference between the ST-GAT R^2 value and the average R^2 of the statistical baselines, confirming the effectiveness of spatio-temporal graph-based approaches for seismic activity monitoring with calibrated uncertainty estimation.

Keywords: Seismic Monitoring, Graph Attention Network, LSTM, Deep Ensemble, Uncertainty Estimation