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Unified Environmental Sensing and Monitoring Framework Based on Graphical Neural Networks

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Abstract

Climate-induced stressors heighten the need for reliable environmental monitoring in vulnerable ecosystems, yet Wireless Sensor Networks deployed in such settings face persistent node failures and data loss from harsh conditions, communication breakdowns, and sensor degradation that compromise downstream decision-making. Existing imputation approaches rely on static spatial assumptions or temporal interpolation evaluated under idealized single-failure conditions, leaving a critical gap in how learned methods perform under realistic simultaneous multi-node failure stress. This paper presents a dual-pathway spatio-temporal Graph Neural Network for resilient WSN data imputation, jointly exploiting spatial correlations through a Graph Convolutional Network and per-node Gated Recurrent Unit pathway, and temporal self-memory through an independent Long Short-Term Memory pathway operating on raw pre-failure sensor history, unified through a learnable daptive adjacency matrix that discovers latent spatial relationships beyond geographic proximity and a gated shortcut mechanism that blends observed and neighbor-derived estimates dynamically. Evaluated on eleven Ugandan weather stations against Linear Interpolation, Ordinary Kriging, and a single-pathway T-GCN baseline under a deployment-honest protocol with pre-generated identical trial masks across one to eight simultaneous station failures, the proposed model achieves the lowest
mean RMSE on both temperature and humidity across the full failure spectrum, with win rates of 40–53% on temperature and 31–52% on humidity through seven simultaneous failures, while the learned adjacency reveals geographically interpretable non-distance correlations consistent with synoptic climate patterns. The framework is domain-agnostic and directly transferable to traffic, air quality, and industrial WSN deployments, with relevance for resource-constrained monitoring infrastructure in East Africa and similar climate-vulnerable regions.

Keywords: **Sensor Resilience, Environmental Monitoring, Graphical Neural Network**