Gas Leak Detection with Sensor Network by Using Graph Neural Networks

Jin Kilidjian

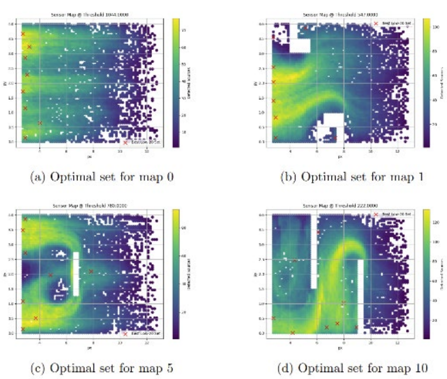
Professor : Alcherio Martinoli
Assistant(s) : Wanting Jin

Gas leaks pose significant risks across various environments, from large-scale industrial facilities and chemical plants to urban distribution networks and even residential buildings. In this project we aim to leverage Graph Neural Networks (GNNs) to achieve systems that detect leaks reliably and at early stage using fixed sensor networks using only 8 nodes.

The project is separated in two main components: optimal sensor placement and the GNNs implementation.

Optimal sensor placement

First, we focus on determining the optimal placement of sensors to maximize leak detection coverage. Out of 4096 possible cell locations, we seek the combination of 8 that detects the greatest number of potential leak sources. We evaluated two approaches: a Greedy algorithm and Integer Linear Programming (ILP). The ILP method consistently provided better source coverage. Therefore, we applied it once per map to derive the optimal sensor configuration for each configuration.



(a) Optimal set for map 0 (b) Optimal set for map 1 (c) Optimal set for map 5 (d) Optimal set for map 10

Optimal sensor sets for each map

GNNs implementation

Now that we have the optimal sensor placements, based on the input that we get from the sensors at these placement, we seek to implement two different GNNs: Graph Deviation Network (GDN) and Spatio-Temporal Graph Attention Network (ST-GAT).

GDN is an autoencoder style GNN that learns to predict each sensor's next reading based on its current window of measurements and positional information. This is done by using an encoder, followed by a decoder and we try to minimize the reconstruction loss. This reconstruction loss can then give us a measure of the anomaly of the window.

ST-GAT is a spatio-temporal GNN that models both the spatial relationships between sensors and the temporal dynamics of their readings. It uses attention mechanisms to weigh the importance of different neighboring nodes and past time steps when making predictions. By capturing how sensor readings evolve over space and time, we can effectively detect unusual patterns that may indicate a gas leak.

We trained and tested both networks on simulated scenarios with and without noise across multiple map configurations to compare their performance.

Model	Precision	Recall	Average delay
GDN (without noise)	1.00	0.866	80.11
ST-GAT (without noise)	1.00	0.6202	174.07
GDN (with noise)	0.998	0.220	179.45
ST-GAT (with noise)	0.997	0.5138	208.35

Results for GDN and ST-GAT on simulated scenarios

GDN achieved perfect precision and faster detection in clean data but its performance degraded under noise. In contrast, ST-GAT maintained a better balance of precision and recall when noise was present, but with higher average detection delay. We also tested our models on real world data, but we got poor results.

Conclusion

In this project, we managed to established the foundation for GNN based gas leak detection using ST-GAT and GDN. Despite promising results in simulations, practical deployment will require further tuning of certain hyperparameters or retraining of the models to account for real-world noise characteristics, which may differ from those in the simulated environments.