Gas Source Localization Under Realistic Environmental Conditions with Gas Sensing Robots

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The Problem

Gas Source Localization (GSL) is the process of identifying the location of a gas leak by detecting and analyzing the plume of gas that it emits. Mobile robots equipped with chemical sensors are well-suited for this task due to their maneuverability, that could mitigate the potential danger to human and animals. This can be important for a variety of applications, including environmental monitoring, industrial safety, and emergency response.

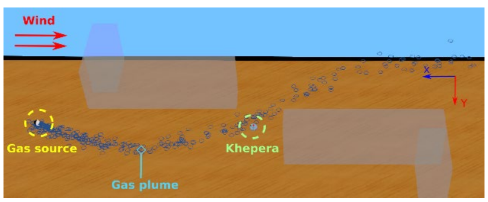

Figure 1. Gas Source Localization Problem

State of the Art

In order to tackle this problem, we leverage a probabilistic state of the art algorithm, Source Term Estimation (STE). This algorithm requires an underlying gas dispersion model, which is very difficult to build in a realistic environment due to the unpredictable nature of the gas dispersion. To further advance the field, a Data-Driven Plume Model (DDPM), generated using a deep Convolutional Neural Network (CNN) is introduced in [1]. However, although this preliminary works has some promising results, the dataset is gathered under fixed wind speed and release rate. In this project, we extended the current DDPM-based STE framework under different wind speeds and release rates, which represent a more realistic scenario in real applications.

Dataset Generation

The pipeline to generate new dataset for DDPM with the following steps:

- Built environment maps with obstacles of random shapes in random locations.
- Simulated wind flow in the environment maps using OpenFOAM simulation**.**
- Loaded the wind maps into Webots and placed the gas source at random locations to get the gas dispersion results.

	Before	Now
Wind speed (m/s)	0.75	0.25, 0.5, 0.75, 1, 1.25
Release rate level	High	Low, Medium, High
Training maps	4000	30'000
Validation maps	8	2'400

Table 1. Dataset Extension

DDPM Extension

To extend the current Neural Network Architecture to different wind speeds and release rates, we explored several feature engineering methods. After evaluation, we chose to extend the current DDPM model based on a U-Net architecture to take as input 5 different maps: Flow def, SDF, Inverse distance to source, constant wind speed and constant inverse release rate. The new model is then trained and validated to predict gas concentration maps under varying environmental conditions.

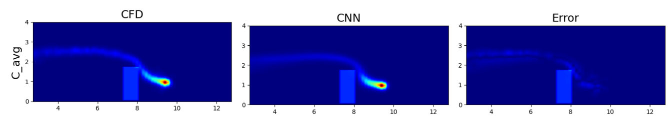

Figure 2. Gas Concentration Map Prediction

DDPM-based STE Extension

This new trained model was then integrated into the Source Term Estimation algorithm. The estimation parameters, that we seek are extended to include the source position (Sx, Sy), the wind speed (Ws), and the release rate (Rr), to be Θ= {Sx, Sy, Ws, Rr}.

Performance Evaluation

We evaluated the performance of the DDPM-based STE framework on Webots in different validation maps under various wind speeds and release rates. The robot navigates until the entropy drops to zero or the number of iterations exceeds 50. The GSL was successful for more than 85% of all our trials.

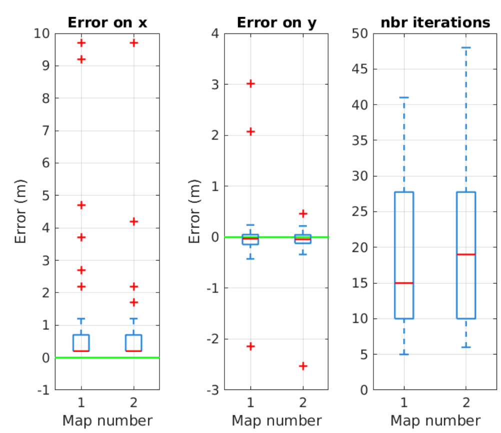

Figure 3. DDPM-based STE Performance

Future Work

It's now time to validate with real world experiments in the wind tunnel. However, we'll have to face the potential gap between reality and simulation.

[1] W. Jin, F. Rahber and A. Martinoli, "Towards efficient gas leak detection in cluttered environments: Data-driven plume modeling for gas sensing robots," in IEEE International Conference on Robots and Automation, 2023