
Methane Leak Detection & Remediation (LDAR) - Motivation

2nd Most potent GHG.

75% Methane emissions for O&G can be avoided. [1]

84-87 20-year Global Warming Potential (GWP) than the CO₂. [1]

40% With no net cost. [1]

10.2B USD Total Available Market (TAM) for O&G in the US

15.4GT of CO₂e Total emissions abatement opportunity for O&G sector

Methane Leakage across the O&G Value Chain

[1] IPCC Fourth Assessment Report
Natural Gas Leak Detection Technologies

**Satellite**: Surveillance via satellites enables regional & global coverage over a regular period. Analysis of this data can help identify methane hotspots.

**Aerial Survey**: Aircraft systems conduct on-demand surveys of an area/region of interest and collect high spatial resolution measurements.

**Drones**: Automated drone flights along a pre-planned path collect 3D near-ground data at a regular cadence. This can be beneficial for remote locations.

**Optical Gas Imaging Cameras**: EPA uses OGIC evidence for regulatory compliance. Traditionally manual survey to identify leaks & sources.

**Fixed Sensors**: Fixed sensors provide onsite methane sensing to protect facilities through an early warning system to detect gas leaks.

**Ground Sensor Grids**: IoT sensor grids with data streams that can be analyzed in near real-time to accurately detect anomalous emissions, perform source attribution and undertake remediation measures.
Problem formulation

- **Dense placement (ideal) advantages**
  - Captures all possible leakages.
  - Does not require as much environmental information, such as wind direction, as other techniques;

- **Dense placement disadvantages**
  - One of the most prolific Oil and Gas producing regions in the US, the Permian Basin, has over 250,000 km² of area.
  - Ensuring sensor coverage over such a vast area can be cost-prohibitive and unrealistic due to budget constraints

- Objective: Propose a sparse sensor placement strategy to capture methane leaks in an Area Of Interest (AOI) timely and accurately.
Methane Sensor Placement Optimization Workflow

Data Ingestion

Methane Dispersion Modeling

Sensor Placement Optimization

Oil & Gas facility map (well pads, pipelines, processing plants ...)

Meteorology variables (wind speed, direction, solar radiation ...)

Historical Oil and Gas assets leak rates and distribution

Gaussian plume model for methane dispersion

Consolidated gas presence map

Maximum coverage solver

Optimal O&G methane sensor placement
Given the simulated methane emission map, the sensor placement optimization is formulated as a **maximum coverage problem**.

- Given sets $S = \{S_i\}_{i=1}^N$ and number $k$. $S_i$ may contain some entity $e_i \in E$.
- Find subset $S' = \{S_1, ..., S_m\} \subseteq S$.
- Objective: maximize the covered elements $\left| \bigcup_{S_i \in S'} S_i \right|$, such that $|S'| \leq k$.

The objective function is to maximize the sum of the covered elements:

$$\text{maximize } \sum_{e_j \in E} y_j$$

subject to:

$$\sum x_i \leq k$$  (no more than $k$ sets are selected)

$$\sum x_i \geq y_j$$  (if $y_j > 0$ then at least one set $e_j \in S_i$ is selected)

$$y_j \in \{0, 1\}$$  (if $y_j = 1$ then $e_j$ is covered)

$$x_i \in \{0, 1\}$$  (if $x_i = 1$ then $S_i$ is selected for the cover)

Given possible sensor locations, find the subset that maximizes the coverage of possible methane leakage while constrained by the number / budget of sensors.
Current Methodologies

- Compute the dominant/average wind direction and place sensors at a given distance/height near the sources.
- Possible detection height and distance could vary a lot for different leakages under different weather conditions.

- Heavily depending on the initialization of sensor locations.
- The sensors can only be put on the subset of initial positions.

Proposed Methodology

- Given possible sensor locations, find the subset that maximizes the coverage of possible methane leakage while constrained by the number / budget of sensors.

  - Greedily selecting grid points with maximum scenario coverage.
  - Spatially clustering the points with DBSCAN.
  - Get the centroid of the largest cluster, remove the covered scenario from the simulation.
  - Sensor locations

  Clustering-based Greedy selection

- Requires no sensor initialization.
- Always the clustering center of the most likely area.
Results and Conclusion

- **Data ingestion pipeline** incorporating **multi-modal data** (such as organized oil & gas facilities maps, station weather data and historical methane leak rate distributions) has been built for the methane sensor placement optimization problem.

- We model **methane dispersion** with the Gaussian Plume Model.

- A **new clustering-based greedy method** is proposed for sensor placement optimization.
  - It explores **spatial diversity** for sensor locations and **captures variance of methane plume dispersion over days**.
  - In one sensor for every three sources (**1:3** sensor-source number ratio) case, the proposed methodology detected **6.8%** more leaks than the baseline.
  - The proposed methodology achieves **87.9%** detection rate of the CH\textsubscript{4} leaking sources, as apposed to the **82.8%** of the baseline, with **5.8%** improvement over the detection rate.
  - Our proposed method, in its initial iterations alone, **surpasses** or is **at par** with published literature, with potential for far greater upside.
Future Roadmap

- Improvement of **methane dispersion modeling**.
  - A more complex atmospheric dispersion model / DNN, with the inclusion of more variables such as Digital Elevation Model, gridded weather data etc.
  - Include more types of sources: pipelines, processing plants etc.

- Improve methane leak rate sampling algorithm.

- The **clustering-based greedy algorithm** is more flexible and offers potential for further refinement, such as adding constraints to potential sensor locations and optimizing for source attribution.

- **Longer period dataset** is needed to capture the weather of the area for more robust sensor placement.
Thank you!

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