Duke | Wireless Intelligent Sensor Networks
IGERT WISeNet

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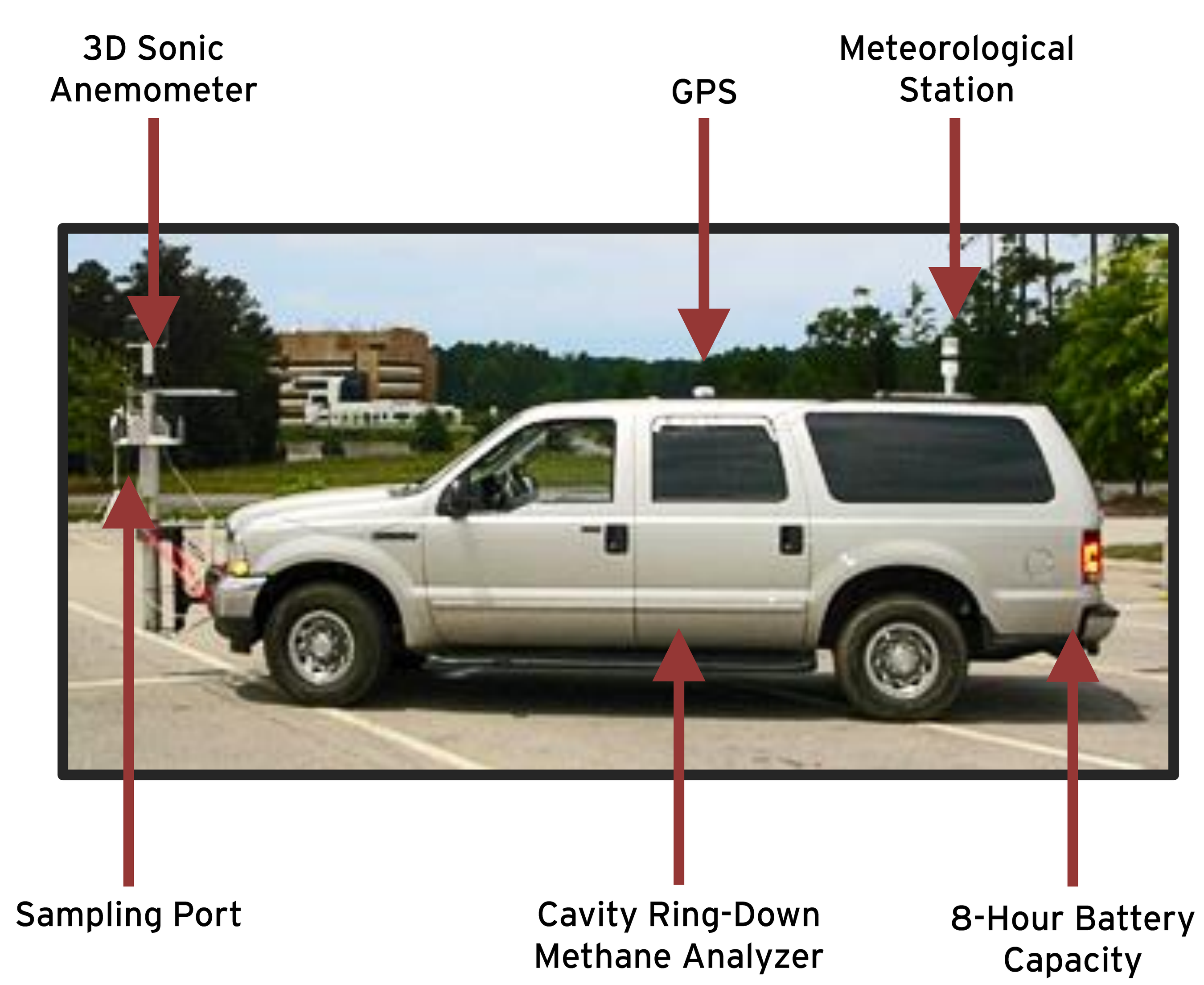
Optimal Sensor Path Planning for the Detection and Quantification of Fugitive Gas Emissions

Introduction

In the United States, natural gas systems are the largest anthropogenic source of methane emissions into the atmosphere. Approximately 37% of the methane released by these systems occurs during field production, and is primarily attributed to **fugitive** – uncontrolled or unintended – emissions [1]. Methane, CH_4, is a powerful greenhouse gas twenty times more effective than carbon dioxide in trapping heat in the atmosphere over a 100 year period [2]. Accordingly, recent scientific efforts have focused on the prevention and detection of methane emissions. Determining the sources of fugitive emissions is critical in reducing the impact of natural gas systems on the environment.

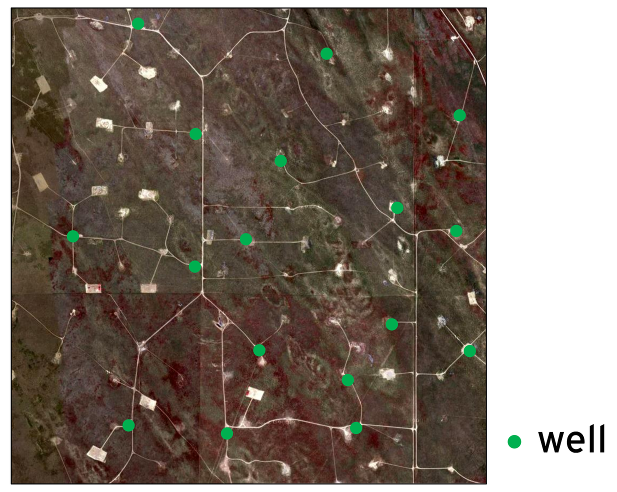
This project addresses the problem of detecting fugitive methane emissions from distributed natural gas and oil field production sites by way of a direct assessment approach. By use of a mobile sampling vehicle, remote emissions measurements (REM) of methane concentrations along public roadways and measurements of atmospheric conditions can be acquired. Through a partnership with the Environmental Protection Agency (EPA) and the IGERT on Wireless Intelligent Sensor Networks at Duke University, this research will propose an **inverse dispersion** technique for identifying sources of fugitive emissions from REM collected by the EPA's mobile sampling vehicles. Furthermore, the proposed project will develop a methodology for planning **optimal paths** for the REM vehicle, which will maximize the confidence in source strength estimates while minimizing the operational costs of the mobile sensing agent. This novel approach will integrate environmental forecasts and predictions, dispersion models, and mobile sensor navigation strategies.

Mobile Sampling Vehicle



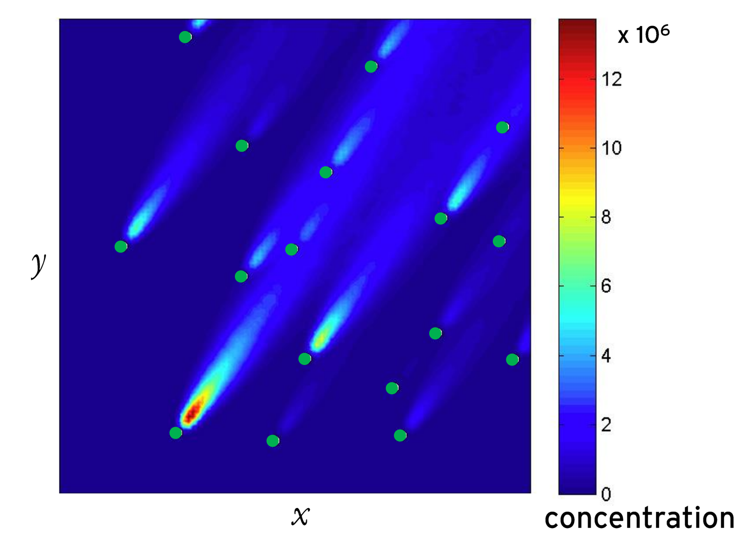
Mobile Sampling

Given concentration data obtained along public roadways and atmospheric measurements, this project aims to identify the sources of fugitive methane emissions in distributed natural gas field production operations. For the purpose of initial investigation, this research is limited to the field production sites located in Greeley, CO, an example of which can be found below.



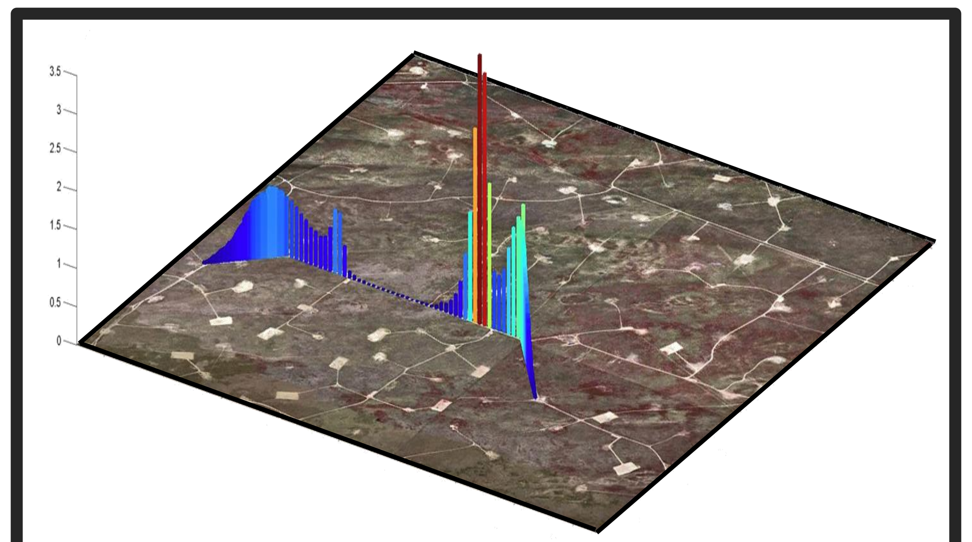
Example of Field Production Sites: Greeley, CO

The stochastic modeling of environmental processes is a fundamental component of the development of data processing algorithms and environmental sensor management. Using the Gaussian plume model for methane dispersion, an artificial concentration field was created for the sample domain above.



Concentration Field

In reality, the concentration field is unknown. The sensing agent must infer the strengths of the fugitive emissions from concentration data collected along public roadways. This paradigm is referred to as inverse-dispersion. For the field site and concentration field above, the mobile sampling vehicle would obtain concentration measurements, such as those found below.

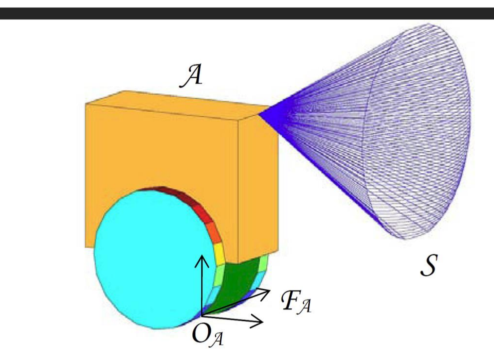


Concentration Measurements

This project will develop a methodology for determining the source strengths of the wells that best utilizes the concentration data collected by the REM vehicle.

Optimal Sensor Path Planning

Recently, mobile sensing agents have emerged as effective, inexpensive solutions to a variety of dynamic measurement problems, including military reconnaissance missions, mine detection, and the monitoring of urban environments. Sensor path planning is concerned with determining the optimal trajectory of a mobile sensor that maximizes the information profit and minimizes the operational costs of the system.



A Robotic Sensor with Geometry $\mathcal{A}$ and Sensor Field of View $\mathcal{S}$

A primary concern in determining the sources of fugitive emissions from concentration data, by means of the inverse-dispersion approach previously discussed, is the quality and completeness of the measurements. The goal of this project is to define an optimal path for the REM vehicle that returns the lowest uncertainty in source estimates, while minimizing the operation cost of the system, such as the distance traveled and time in the field. The methodology developed will integrate previous work by the authors in sensor and robot path planning with the stochastic modeling of environmental processes. By utilizing atmospheric forecasts and predictions, and real time data collected from the sonic anemometer, meteorological stations, and methane analyzer, the researchers will develop a path planning algorithm for the REM vehicle, which will return the concentration data required to accurately locate fugitive emissions sources using the inverse-dispersion approach discussed in the previous section.

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