MAE 6790: Final Project

- **For full credit, please describe all steps, and include all figures and discussion of numerical results in a technical report. Include your MATLAB/Other code in an Appendix of the report.**
- **Download the MATLAB code for the concentration fields from Blackboard.**

Introduction and Motivation

Methane, CH_4, is a greenhouse gas twenty times more effective than carbon dioxide in trapping heat in the atmosphere over a 100 year period. As a result of its global warming potential, recent efforts have focused on the prevention and detection of methane emissions. In 2010, the largest anthropogenic source of methane emissions in the United States was the natural gas and oil industry. Approximately 35% of the methane released by these systems occurs during the field exploration and production stages of the natural gas and oil extraction processes. In this stage, the release of methane is primarily attributed to fugitive emissions, which are uncontrolled and/or unintended gas releases. Determining the sources of fugitive methane emissions is integral in reducing the impact of the natural gas industry on the environment, and, as the distance between sources and populations decrease, reducing the risks to human health. The monitoring of oil fields, like the one illustrated in Fig. 1, by a mobile sensor is the motivation for this project.

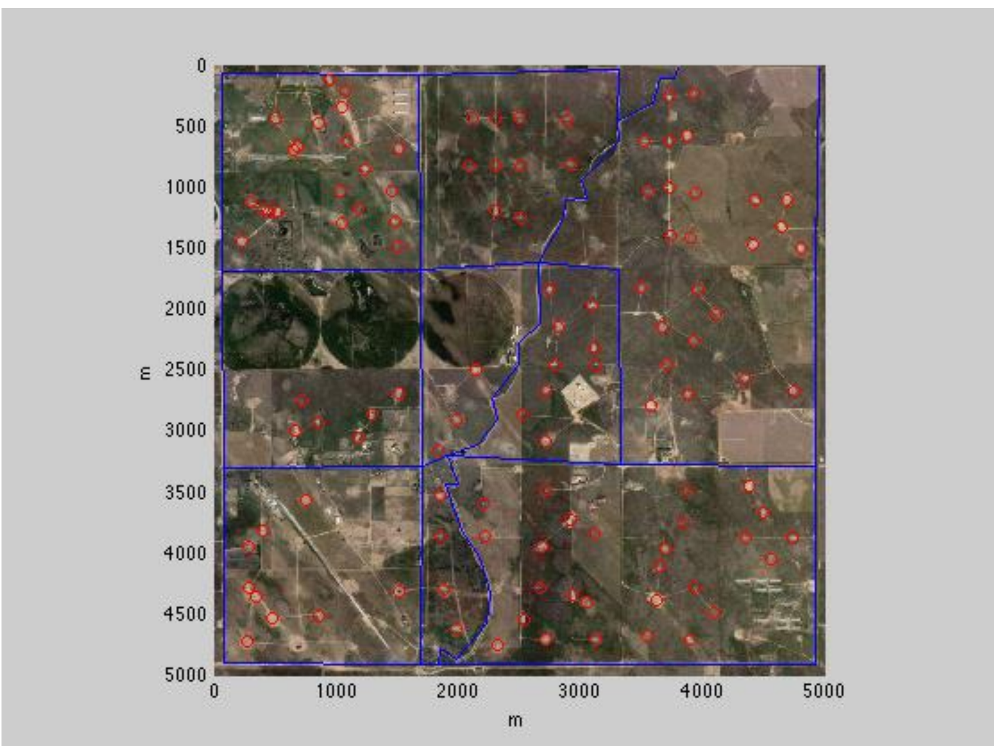

Figure 1. Illustrative example of oil fields and roadmap.

Problem Formulation and Assumptions

This project addresses the problem of detecting methane emissions from distributed natural gas and oil field production sites using a mobile sampling vehicle that can measure methane concentrations along public roadways over a desired region of interest (ROI). Using a methodology of your choice, determine a path for the vehicle that obeys the road system illustrated in Fig. 2, and that can help identify leaking wells by maximizing the measurement value for the estimates of methane concentrations in Fig. 3.

For simplicity, it is assumed that the vehicle obeys the unicycle dynamics,

$$\dot{\mathbf{q}}(t) = \begin{bmatrix} \dot{x}(t) \\ \dot{y}(t) \\ \dot{\theta}(t) \end{bmatrix} = \begin{bmatrix} v(t)\cos\theta(t) \\ v(t)\sin\theta(t) \\ \omega(t) \end{bmatrix} \tag{1}$$

where v and ω are the control inputs, and $\mathbf{x} = [x\ y]^T$ is the sensor position. The initial position of the vehicle, is illustrated by the red dot in Fig. 1, where $x_0 = 0$ [m], and $y_0 =$ 5000 [m]. You may choose the initial vehicle orientation as you please.

Assume a perfect measurement model by which the sensor measures the exact concentration of methane at every position, $\mathbf{x}$, visited by the vehicle over time.

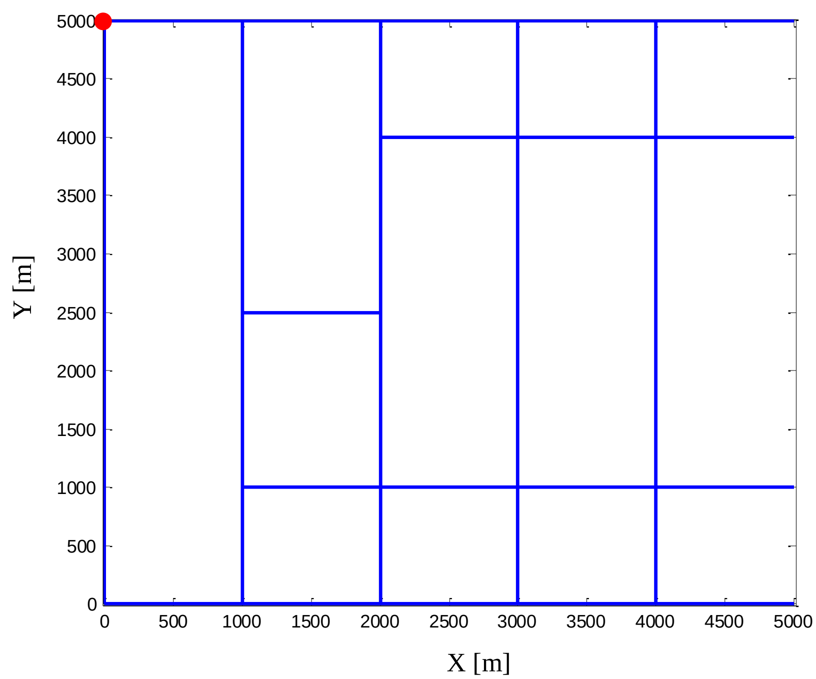

Figure 2. Road map for ROI (roads are shown in blue solid lines), and initial vehicle position (red dot).

Let C denote the CH_4 concentration in parts-per-million [ppm]. Because, in this case, the sensor is deployed to determine methane leaks, the instantaneous measurement benefit can be assumed equal to C, and, thus, it is a function of $\mathbf{x}$ and t. Assuming all wells are leaking at the same high rate, the concentration field in Fig. 3 can be determined using a forward Gaussian dispersion model. The instantaneous cost of operating the mobile sensor can be assumed proportional to the linear speed, v, which could be a function of $\mathbf{x}$, as per a feedback control law, and is typically a function of time. If the concentration field can be assumed to remain constant over a period of time $[t_0, t_f]$, the sensor objective function can be written as,

$$J = \int_{t_0}^{t_f} \{ w_c C[\mathbf{x}(t), t] + w_d v[\mathbf{x}(t), t] \} dt \qquad (2)$$

where, w_c and w_d are two constant weights of your choice that indicate the desired tradeoff between measurement value and cost.

The maximum speed of the vehicle is $v_{\max} = 10$ Km/hr, such that $v(t) \leq v_{\max}$, at all times. **(Q1)** Find the path that offers the best tradeoff of energy and measurement value, for the roads and concentration field in Figs. 2-3, assuming the vehicle has (i) $t_f = 30$ [min], (ii) $t_f = 45$ [min], (iii) $t_f = 2$ [hr], and (iv) $t_f = 4$ [hr] to explore the ROI.

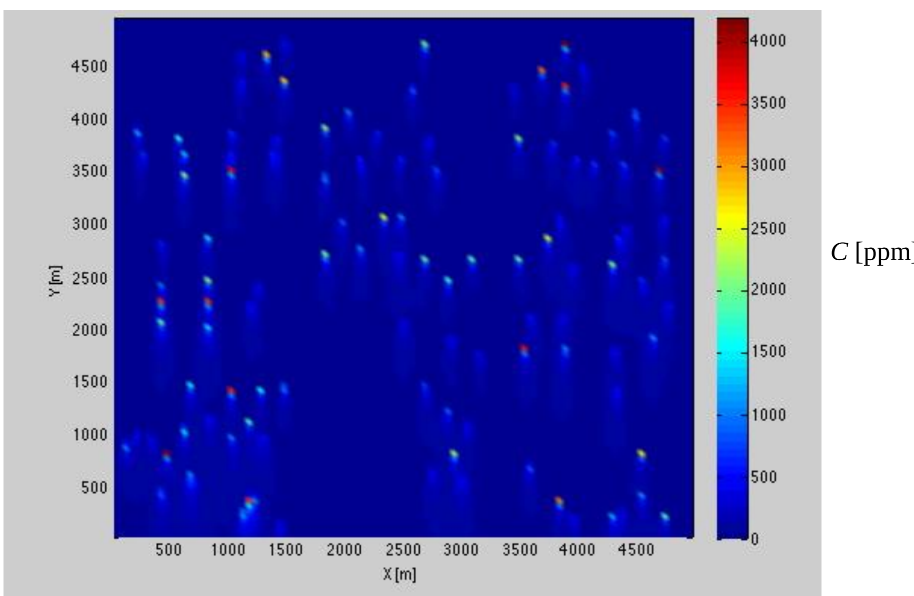

Figure 3. Concentration field over the ROI in Fig. 2, assuming all wells leak at the same high rate.

Now, **(Q2)** use the paths you determined in (Q1) to obtain methane measurements from the new concentration field in Fig. 4, which represents the methane concentration when only 10% of the wells are leaking, and the leaking wells are selected at random. Compare the performance of each optimal path under the conditions in Fig. 4, to its performance when all wells are leaking (Fig. 3). Plot the concentration levels measured over time along all four optimal paths you determined, using both concentration fields(Figs. 3 and 4). **(Q3)** Then, consider other (sub-optimal) paths (e.g. obtained using random, grid, or lawnmower algorithms), and show whether your method attains better concentration levels, for the same energy consumption (or distance traveled). **(Q4)** How does the final time affect the results? **(Q5)** How could you improve the path performance, and what new information would you need?

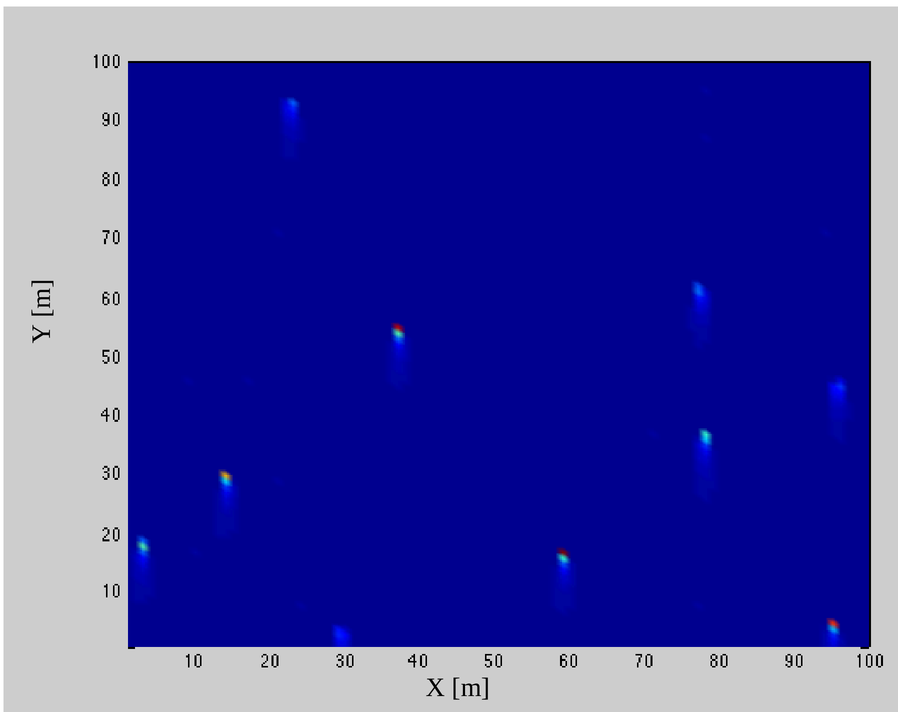

Figure 4. Concentration field over the ROI in Fig. 2, assuming a random 10% of the wells leak at the same high rate, where the same color map in Fig. 3 expresses *C* in [ppm].

Final Report:

a) All results must be presented using a technical-report style, using Word or Latex.

b) Use consistent section headings and subheadings, type equations, results, and discussions in a word processor (preferably Latex), and produce figures using a compatible software.

c) The report must include the following: title page, abstract, introduction, body of the paper, conclusions, references and, possibly, appendices.

d) Poorly written or incomplete reports will be penalized in the grading.

e) Send your report in PDF via email to ferrari@cornell.edu and sc2892@cornell.edu with “MAE6790 – Final Project” in the subject line.

References

[1] J. Albertson, T. Harvey, G. Foderaro, P. Zhu, X. Zhou, S. Ferrari, S. M. Amin, M. Modrak, H. Brantley, E. Thoma, “A Mobile Sensing Approach for Regional Surveillance of Fugitive Methane Emissions in Oil and Gas Production,” *Environmental Science and Technology*, 50.5 (2016): 2487-2497.

[2] V. Hernandez Bennetts, A. J. Lilienthal, P. P. Neumann and M. Trincavelli. Mobile Robots for Localizing Gas Emission Sources on Landfill Sites: Is Bio-Inspiration the Way to go? *Frontiers in Neuroengineering*, 4, 2012, pp. 1 - 12.

[3] A. J. Lilienthal, A. Loutfi and T. Duckett. Airborne Chemical Sensing with Mobile Robots. *Sensors*, 6, 2006, pp. 1616-1678.