Small-Scale DIAL for Methane Detection

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Main Objective

This project was awarded to the University of Colorado in order to create a design for an airborne differential absorption lidar (DIAL) system that can be used to remotely detect leaks emanating from pipelines that transport natural gas. This system will be miniaturized so that it can fly upon a medium-sized unmanned aerial vehicle (UAV).

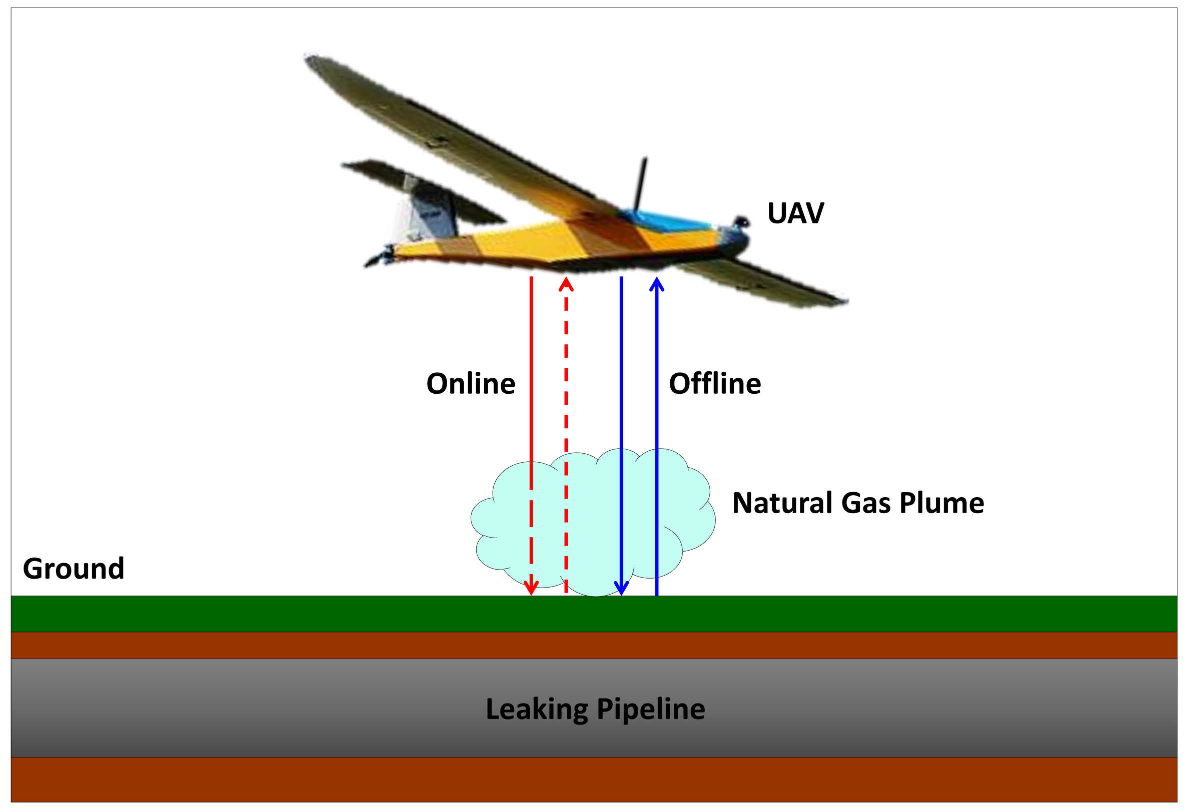

Figure 1. Airborne methane DIAL operation.

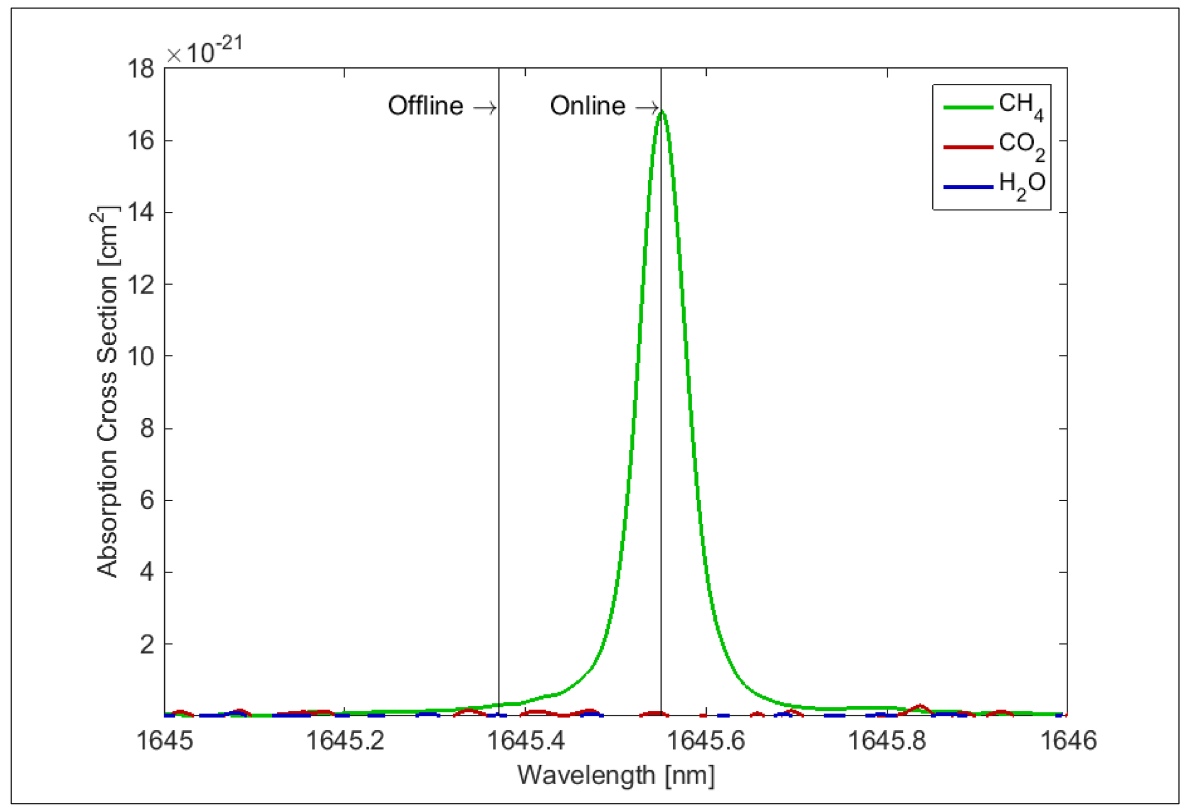

Figure 2. Methane absorption.

Project Approach/Scope

- Develop a mathematical model based in lidar theory to estimate the accuracy and precision of a hypothetical airborne DIAL system.
- Explore hardware options that would allow a UAV-based DIAL system to be implemented practically.
- Study actual data collected by other airborne methane DIAL systems to identify the many subtle factors that influence actual DIAL measurements.

$$N_S(\lambda) = N_L(\lambda) \cdot \frac{\rho}{\pi} \cdot \frac{A_{Rx}}{z^2} \cdot \mathcal{T}^2(\lambda) \cdot \eta$$

$$\mathcal{T}(\lambda) = exp\left(-OD_{\mathrm{CH_4}}(\lambda)\right)$$

$$OD_{\mathrm{CH_4}}(\lambda) = \int_0^z \chi_{\mathrm{CH_4}}(r)\, n_{\mathrm{air}}(r) \sigma_{\mathrm{CH_4}}(\lambda, r) dr$$

$$SNR = \frac{GN_S}{\sqrt{G^2F\left({N_{S,n}}^2 + {N_{B,n}}^2 + {N_{D,n}}^2\right) + {N_{th,n}}^2}}$$

$$\bar{\chi}_{\mathrm{CH_4}} = \frac{1}{n_{\mathrm{air}} z\left[\sigma_{\mathrm{CH_4}}(\lambda_{\mathrm{on}}) - \sigma_{\mathrm{CH_4}}(\lambda_{\mathrm{off}})\right]} \cdot \frac{1}{2}\left[ln\left(\frac{\lambda_{\mathrm{on}}}{\lambda_{\mathrm{off}}}\right) - ln\left(\frac{N_{S,\mathrm{on}}}{N_{S,\mathrm{off}}}\right)\right]$$

$$\frac{\delta\bar{\chi}_{\mathrm{CH_4}}}{\bar{\chi}_{\mathrm{CH_4}}} = \frac{1}{2\left[OD_{\mathrm{CH_4}}(\lambda_{\mathrm{on}}) - OD_{\mathrm{CH_4}}(\lambda_{\mathrm{off}})\right]} \sqrt{\frac{{SNR_{\mathrm{on}}}^{-2} + {SNR_{\mathrm{off}}}^{-2}}{m}}$$

Figure 3. DIAL equations.

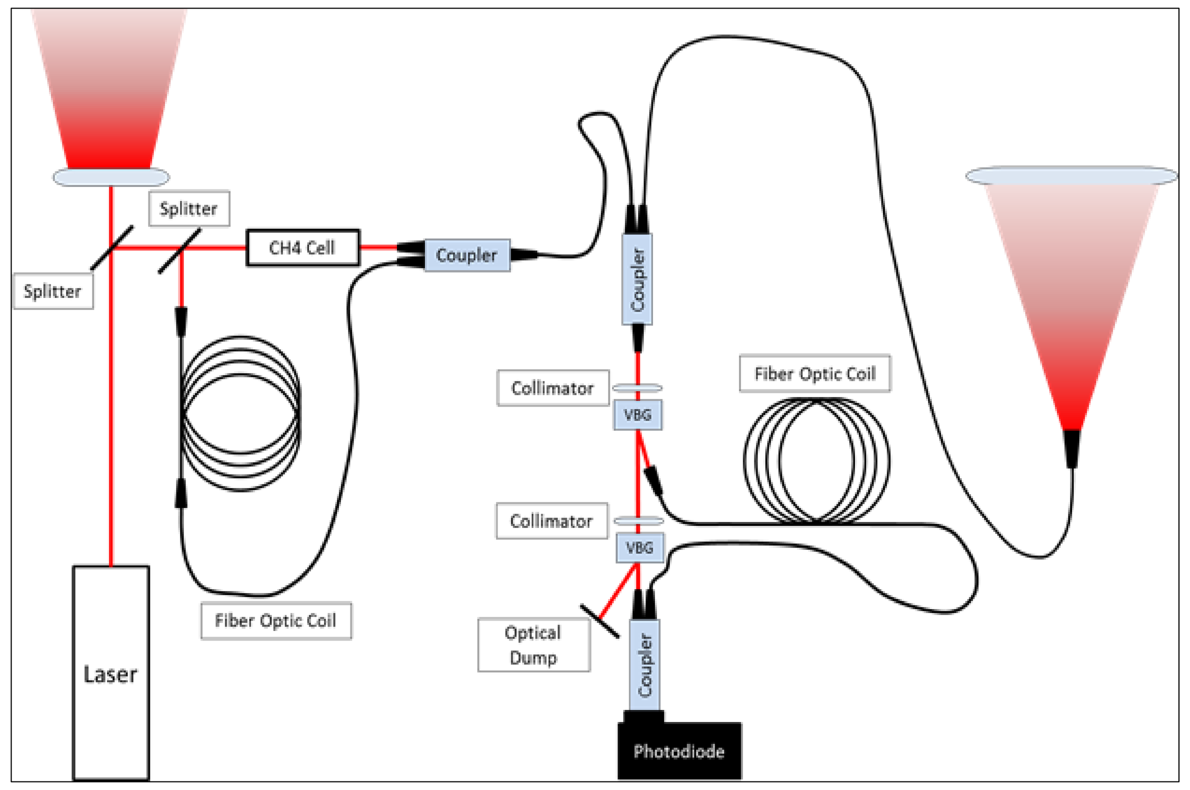

Figure 4. Hardware configuration.

Expected Results or Results to Date

- A laser trade study was conducted and it was decided that the DIAL system should operate near 1.65 µm.
- A DIAL system with the design characteristics listed in Figure 5 should theoretically be able to measure the background methane concentration of ~1.8 ppm with an uncertainty of ~10%.
- Data from other airborne methane DIAL systems is currently being investigated.
  - Advanced Leak Detector Lidar – Natural Gas (ALDL-NG) by Ball Aerospace.
  - Airborne Lidar Pipeline Inspection System (ALPIS) by LaSen.
- Hardware tests to assess the feasibility of compactly generating laser beams at the desired wavelengths and linewidths are underway.

Term	Value
Online Wavelength	1645.55 nm
Offline Wavelength	1645.37 nm
Laser Linewidth (Each Signal)	0.1 nm
Average Transmit Power (Each Signal)	50 mW
Pulse Repetition Frequency (Each Signal)	4000 Hz
Transmitted Pulse Length (Each Signal)	30 ns
System Bandwidth	20 MHz
Receiver Telescope Diameter	6 cm
Receiver Efficiency	55%
Detector Quantum Efficiency	70%
Optical Filter Bandwidth	1 nm
Receiver Field-Of-View	2°
Dark Current	30 nA
Load Resistance	50 Ω
Load Temperature	320 K
Detector Gain	10
Detector Excess Noise Factor	2
UAV Altitude	100 m
Number of Samples per Measurement	25

Figure 5. Potential DIAL system characteristics.

Figure 6. Methane maps created from ALDL-NG (left) and ALPIS (right) data.

Acknowledgments

This project is funded by DOT/PHMSA's Competitive Academic Agreement Program. The authors would also like to acknowledge the Ball Aerospace & Technologies Corp. and LaSen, Inc. for providing DIAL data and technical assistance.

References

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