Direct Imaging of Shale Gas Leaks Using Passive Thermal Infrared Hyperspectral Imaging

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About Telops

- Established in 2000 in Quebec City.
- About 50 employees (Ph.D., M.Sc., Eng.).
- Privately owned and profitable since its creation.
- Worldwide network with distributors around the globe.
- Established as a world leader in thermal infrared imaging solutions.
Methane

- Among the most infrared-active naturally occurring molecules
- Important greenhouse gas
- Major component in
  - Landfill Gas (LFG)
  - Natural Gas, including shale gases
  - Bacterial decomposition products
- Flammable/Explosive
- Naturally present at low concentration (1.79 ppm) in the atmosphere

The 2 main vibrational modes of methane
Under ambient conditions, methane self-emission is much higher in the thermal infrared (TIR) spectral range (7.65 $\mu$m) than in the midwave infrared (MWIR) spectral range (3.3 $\mu$m).
Methane Imaging

- Passive infrared hyperspectral imaging of methane:
  - Spectroscopic confirmation from high-resolution spectra
  - Methane quantification
  - 2D spatial resolution for surveying large areas
  - Temporal resolution


*Supplementary Figure 6.* Mapping and quantification of the CH₄ gradient above the nutrient poor lake Lillsjön, having the lowest CH₄ emissions among the boreal lakes studied in (28) (14 cubes, acquisition time 11.2 min). The calculated column density map (a) shows the total amount of CH₄ along all lines of sight in the image. Background distances range from 120 to 350 meters (resulting in increasing amounts of CH₄ per lines of sight from left to right due to increasing background distance) with a field of view of 25 x 9.4°. After division with distances, a map of mixing ratios shows areas with excess CH₄ (b). The squares marked with numbers in panel a mark the locations of the two selected spectra shown in Supplementary
Shale Formations

- Very common porous mineral formations found in eastern Canada regions
- Energy reservoir: methane bubbles trapped in the shale formation

A Tricky Geological Survey

- The drill digs into a natural shale gas reservoir
- Survey carried out in a residential area in the parking of a hospital
- Winter conditions (-20 °C)
Experimental Parameters

- Distance: 50 m
- Instrument
  Hyper-Cam Methane
- Spectral range:
  7-8 µm (LWIR)
- Spectral resolution:
  2 cm\(^{-1}\) (85 bands)
- Image size
  128 x 256 (50 cm\(^2\)/pixel)
Typical Measurements
Radiative Transfer Model

\[ L_{\text{tot}} = \left[ L_{\text{bkg}} \tau_{\text{plume}} + L_{\text{plume}} (1 - \tau_{\text{plume}}) \right] \tau_{\text{atm}} + L_{\text{atm}} (1 - \tau_{\text{atm}}) \]

Sky radiance or other objects

Self-emission from the gas plume

Gas plume transmittance

Atmospheric transmittance

Self-emission from the atmosphere
Algorithm Scheme

Temperature-Emissivity Separation (TES)

Clustering → Atmosphere estimate → Downwelling radiance → Background emissivity

Gas plume temperature different than atmospheric temperature

Good

Repeat iteration using diffuse emission model

Fit with a gas plume
Assuming a cylindrical geometry of the gas plume next to the drill, the methane concentration is on the order of 6-7%
Velocity Estimation using Optical Flow

- Telops Hyper-Cam is a 2-in-1 camera collecting broadband-like frames at high-velocity
Velocity Estimation using Optical Flow

- Gas cloud velocity is estimated using spatio-temporal correlation algorithms

By combining column density values (ppm×m) and speed (m/s), information about the depth of the gas cloud, i.e. the path (m), is no longer needed.
Mass Flow Rate

- By combining column density values (ppm×m) and speed (m/s), information about the depth of the gas cloud, i.e. the path (m), is no longer needed.
- By summing all linear velocities across a selected slice, a mass flow rate is obtained.

Slice 1: 43 g/s

Slice 2: 40 g/s

Estimated CH₄ Column Density in Gas Plume

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The methane gas cloud is significantly driven by cross-wind that keep changing orientation as a function of time.

- Net mass flow rate of about $27 \pm 15$ g/s
- Corresponds to $\sim 2000$ L/min of methane
Conclusion

- High spectral resolution provides selectivity for methane detection
- High sensitivity due to the stronger self-emission signal in the thermal infrared spectral range
- Quantitative chemical imaging can be carried out as a function of time
- The combination of high-speed broadband-like frame imaging and spectral information allows mass flow rate estimations
- Information obtained from a safe location

Methane concentration above the lower explosion limit (LEL) was measured from a 2-meter distance from the drill.
Questions?

- A rescue flare was installed for safety purposes ...