Real-time detection of methane plumes by AVIRISng

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Agenda

- Why real-time?
- Prior studies
- Our approach
  - Comparison of methods
  - Operational application
- Future directions
Why real-time remote sensing?
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**In flight:** Provide tactical feedback to pilots

[Image of oil pumpjack and CH₄ plume]
Post-flight trace gas detection

Unambiguous source attribution

Reveal plume structure

CH$_4$ signal (SNR)
Some prior work in real-time remote sensing

- Cloud detection [Thompson et al., *TGRS 2014*, Altinok et al. (in review)]
- Endmember detection [Thompson et al., *TGRS 2013*]
- Spectral band ratios by EO-1 [Chien et al., 2005]
Some prior work in trace gas detection

- Trace gas detection in marine seeps [Thorpe et al., *RSE* 2013, Roberts et al., *RSE* 2010]
- CO₂ [Dennison et al., *RSE* 2013]
- Band Ratios [Bradley et al., *GRL* 2011]
- ... and many others

Thorpe et al., SPIE 2012
Agenda

• Why real-time?

• Prior studies

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• Future directions
Target CH$_4$ signal

CH$_4$ transmittance (modeled)

Transmittance

Wavelength (microns)
Kern River Oil Field, Bakersfield
Three detection methods

Continuum-Interpolated Band Ratio  
Matched filter  
Columnwise matched filter  

Increasing computational complexity
Continuum Interpolated Band Ratio (CIBR)

Calculate for each absorption "spike"

$$R_{CIBR} = \frac{L_m}{\omega_r L_r + \omega_r \omega_r L_r}$$

Transmittance

Wavelength (microns)
In-flight detections (examples)
Validation methods

(in plume) / (out of plume) ratio vs. modeled transmittance

Ratio vs. modeled transmittance
Can we do better?
Matched filter detection

• Decide between hypotheses:

  \( H_0 \) : \( x \sim N(\mu, \Sigma) \)
  \( H_1 \) : \( x \sim N(\mu + \alpha t, \Sigma) \)

• Optimal decision rule:

\[
\alpha(x) = \frac{(t - \hat{\mu})^T \hat{\Sigma}^{-1} (x - \hat{\mu})}{\sqrt{(t - \hat{\mu})^T \hat{\Sigma}^{-1} (t - \hat{\mu})}}
\]
A columnwise matched filter

Buffer blocks of 2000 lines, Apply one matched filter per column

Advantages
• Completely removes striping

Challenges
• Just 2000 samples to estimate the 100x100 covariance matrix
• We must invert the matrix once per column
Dominant mode suppression
[Manolakis et al., 2009]

1. Decompose covariance matrix (SVD)

\[ \Sigma = \sum_{i=1}^{p} \lambda_i q_i q_i^T \]

Advantages: few parameters, stable, fast.

Regularized versions use diagonal loading

2. Approximate the inverse using just the top \( d \) eigenvalues

\[ \tilde{\Sigma}^{-1} = \frac{1}{\alpha} \left[ I - \sum_{i=1}^{d} \left( \frac{\lambda_i - \alpha}{\lambda_i} \right) q_i q_i^T \right] \]

\[ \alpha = \frac{1}{p - d} \left( \text{tr}\Sigma - \sum_{i=1}^{d} \lambda_i \right) \]

Advantages: few parameters, stable, fast.

Regularized versions use diagonal loading
Real time implementation

- Recording process
  - SSD RAID
    - Raw instrument data
    - CH4 data
  - Master CPU process
    - Radiance spectra
    - Combine columns
- Parallel Multicore Detection (CPU)
  - Signal library
    - Matched filter, column 1
    - Matched filter, column 2
    - Matched filter, column 600

- Matched filter, column 600
- Spectrometer
- Direction of flight
Example

Before

After
Conclusions

• We demonstrated detection of methane plumes in real time
• A columnwise matched filter performs real time CH$_4$ detection at 500MB/s
• Next steps:
  – Refine target signature (use Jacobians?)
  – Automatic geolocalization
  – Quantify sensitivity?
Thanks!

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