Passive Standoff Detection of Solid Explosive Residues on Soil via Infrared Hyperspectral Imaging

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Objective

- Detection of explosive residues on, and possibly under, soil at standoff distances using hyperspectral imaging

\[ L = \varepsilon B(T) + (1 - \varepsilon)L_d \]

Pixels → Spatial Information
Spectral → Chemical Information

- Imaging spectrometer
- Down-welling \( L_d(\nu) \)
- Reflected down-welling \( (1 - \varepsilon(\nu))L_d(\nu) \)
- Ground radiance \( \varepsilon(\nu)B(\nu, T) \)
<table>
<thead>
<tr>
<th>Image</th>
<th>Date</th>
<th>Time</th>
<th>Amb. (K)</th>
<th>(mg/cm²)</th>
<th>Image</th>
<th>Temp.</th>
<th>Target</th>
<th>Distance</th>
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<tbody>
<tr>
<td>a</td>
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<td>5:11 PM</td>
<td>313</td>
<td>blank</td>
<td></td>
<td></td>
<td></td>
<td>3.25 m</td>
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<td>b</td>
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<td>2:45 PM</td>
<td>308</td>
<td>NaClO₃ 37</td>
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<td>c</td>
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<td>310</td>
<td>NaClO₃ 37, NH₄NO₃ 55</td>
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<td>312</td>
<td>NaClO₃ 37, NH₄NO₃ 55, 1 mm of soil deposited over targets</td>
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- NaClO₃ was a very fine powder with a strong reflectance in the measured range
- NH₄NO₃ was clumpy and had only minor reflectance in the measured range
- ~3 mm of soil covered the majority of the targets
- only the largest clumps are visible

- 1 m x 1 m x 4 cm
- cool sky-shine
  - no active illumination
- 3x3 pixel spatial median filter and imputation
  - remove bad pixels / channels
- pan tilted ~ 4° toward spectrometer
- spectrometer at 34° from

Quincy soil (high quartz)
NaClO₃ cross
NH₄NO₃ circles
Aluminum Pan
NH₄NO₃ has very little signal in the measured range: reststrahlen shoulder in the 1300 to 1250 cm⁻¹ range and a minor peak at 1094 cm⁻¹.

NaClO₃ has strong reststrahlen feature over the entire measured range. Peaks observed at 972, 939 and 1005 cm⁻¹.

Water is present for >1300 cm⁻¹.
End-Member Extraction

- Four end-members were selected from Image $c$ using the DISTSLCT geometric-based method.
- Data from all images were fit in a least-squares sense to the normalized end-members (classical least squares for target detection).
- Images have *not* been contrasted.
Comparison of End-Members to Laboratory Spectra

\[ \begin{align*}
L &= \varepsilon B(T) + (1 - \varepsilon)L_d \\
(1 - \varepsilon) &= \frac{(L - B(T))}{(L_d - B(T))} \\
&\approx \frac{L_{x,y} - B(T_{b,\text{max}})}{(L_d - B(T_{b,\text{max}}))} \\
L_d &= \frac{(L_{1,1} - \varepsilon_{Al} B(T))}{(1 - \varepsilon_{Al})} \\
&\approx \frac{L_{1,1} - 0.05 B(310K)}{(1 - 0.05)}
\end{align*} \]
• PCA suggested 5 major factors and perhaps 2 very minor factors.
  - no centering or scaling was used.
• MCR (least squares) with 7 factors and non-negativity constraints on both C and S.
  - show contribution (C) images
• Two factors have high contributions on the aluminum pan and show distinct ozone features in the 1070-1010 1/cm range
  - reflection of sky shine
  - “two” might be due to differences in phase correction.
• Two factors have high contributions on the aluminum pan (reflection of sky shine).
  • Factor 1 (blue) also shows contributions on the Quincy soil
    • appears to be glint off soil
    • NH$_4$NO$_3$ circles have low reflection
• Factor 2
  • may be off scratches on aluminum pan (¿).
Three factors are directly related to soil and the two targets.

Factor 1 (blue) shows distinct features from NaClO₃ and the cross pattern.

Factor 2 (green) shows the four circles from NH₄NO₃.

Factor 3 (red) is related to the soil.
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- RGB image of the three factors directly related to soil and the two targets.
- Targets are visible even with a 1-3 mm coating of Quincy soil.

![RGB image of the three factors directly related to soil and the two targets.](image)
Laboratory Spectra with Polarization

R/R₀ measured using a specular reflection accessory for NaClO₃ buried 0.5 mm below Quincy soil surface (R₀) corresponded to bare Quincy soil.

Target was not apparent for >0.5 mm depths with laboratory spectra. p-polarized light appeared to penetrate deeper than s-polarized light.

Incident lighting in the lab was directed. Field soil was exposed to an ~entire hemisphere of sky radiance and may also be more influenced by temperature differences w/in the sample (e.g., aluminum pan sitting on warm asphalt).
Conclusions

- Sodium chlorate and ammonium nitrate were detected using hyperspectral imaging at a distance of 3.25 m.
  - visible in images at selected wavenumbers, anomaly detection methods and using multivariate curve resolution
- Detection was made for compounds on, and below the soil surface for depths ~1-3 mm
  - the detected signal for sodium chlorate compared well with specular reflectance of the corresponding laboratory spectrum
- $p$-polarized light penetrated more than $s$-polarized light
  - although the mechanism is unclear, results suggest reflection of sky-shine is possible
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Related References
