Performance Comparison of Hyperspectral Target Detection Algorithms in Altitude Varying Scenes

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Outline

- Overview / Intro
- Target Detection Algorithms
- Comparison Metrics
- Data Set
- Results
- Conclusions

Recent Work
  - Intro
  - Results
  - Conclusions
Overview / Intro

- Hyperspectral target detection algorithms are used to locate predefined target pixels in a data set.
- Numerous algorithms exist and have been developed, tested, and compared.
- This project performs this analysis over multiple:
  - Algorithms
  - Backgrounds
  - Targets
  - Image altitudes
- Multiple comparison metrics are used to differentiate performance.
- Conclusions are drawn from these results.
Target Detection Algorithms

- Three algorithms chosen to examine.
  - SAM
  - ACE
  - CEM

- Only matched filter algorithms were examined.

- SAM algorithm included as a baseline for comparisons.

- ACE and CEM algorithms are statistical matched filters utilizing a background covariance matrix.

\[
T_{SAM}(x) = \frac{s^T x}{(s^T s)^{1/2}(x^T x)^{1/2}}
\]

\[
T_{ACE}(x) = \frac{(s^T \Sigma^{-1} x)^2}{(s^T \Sigma^{-1} s)(x^T \Sigma^{-1} x)}
\]

\[
T_{CEM}(x) = \frac{s^T \Sigma^{-1} x}{s^T \Sigma^{-1} s}
\]
Comparison Metrics

Quantitative Metrics - developed from ROC curves

• **DR @ FAR**
  - Dependent on user defined threshold

• **AFAR/ADR**
  - Complimentary metrics

\[
AFAR = \frac{1}{N} \sum_{i=1}^{N} FAR_i
\]
Comparison Metrics

Visual Metrics

• Experiments with small target sets are ill suited for computing ROC curves

• Visual metrics can better illustrate algorithm performance
Data Set

- **Forest Radiance I**
  - HYDICE data
  - US Army Aberdeen Proving Grounds, Maryland
  - August 17-31, 1995
  - 6 runs (2 runs/altitude)
  - 3 altitudes (ft)
    - ~5000
    - ~10000
    - ~20000
  - Atmospheric Correction
  - Ground Truth Data
  - Target Truth Maps
Data Set – Targets

Targets

- Searching for 4 man-made targets in FR1 scene
  - 2 Larger targets groups
    » 2 locations for each
  - 2 Smaller targets groups
    » 3 objects in one group
    » 4 objects in other group

- Multiple measurements made for each target.
- Mean reflectance data used as target signature.
## Data Set – Target Truth Maps

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>Pixel contains only or mostly the target.</td>
</tr>
<tr>
<td>Sub</td>
<td>Pixel contains both target and background in some combination.</td>
</tr>
<tr>
<td>Shadow</td>
<td>Full pixel targets that exhibit shadowing.</td>
</tr>
<tr>
<td>Glare</td>
<td>Full pixel target that appear to be reflecting something else.</td>
</tr>
<tr>
<td>Guard</td>
<td>Pixels not to be examined for detection results.</td>
</tr>
<tr>
<td>Background</td>
<td>Pixels that do not contain any of the target.</td>
</tr>
</tbody>
</table>
Full scene covariance calculation yields less than desirable results.

- Non gaussian distribution
- Contains target pixels

Solution:

- Calculate covariance matrix over smaller target free data section
  - Grass, tree, and road regions each exhibit a more gaussian distribution than the full data set.
  - *a-priori* knowledge of target free section eliminates worries about including target pixels in calculations
Data Set - Covariance

- Covariances calculated over red (tree), green (grass), and blue (road) regions.
- No target pixels are included in any region.
## Results

<table>
<thead>
<tr>
<th>Altitude</th>
<th>SAM</th>
<th>ACE</th>
<th>CEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grass</td>
<td>Tree</td>
</tr>
<tr>
<td>5000</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10000</td>
<td>X</td>
<td>X</td>
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<tr>
<td>20000</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

- SAM, ACE, and CEM algorithms were run on three runs of the FR I data set.
- Road covariance not computed for Run 9 due to fewer road pixels at higher altitude.
# Results

## Detection Rate at False Alarm Rate = 10^{-3}

<table>
<thead>
<tr>
<th>Algorithm (background)</th>
<th>Run 5 C5</th>
<th>Run 5 C6</th>
<th>Run 5 V</th>
<th>Run 5 VF</th>
<th>Run 7 C5</th>
<th>Run 7 C6</th>
<th>Run 7 V</th>
<th>Run 7 VF</th>
<th>Run 9 C5</th>
<th>Run 9 C6</th>
<th>Run 9 V</th>
<th>Run 9 VF</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAM</td>
<td>.557</td>
<td>.270</td>
<td>.324</td>
<td>.384</td>
<td>.526</td>
<td>.335</td>
<td>.323</td>
<td>.518</td>
<td>.681</td>
<td>.328</td>
<td>.587</td>
<td>.571</td>
<td>.462</td>
</tr>
<tr>
<td>ACE (Grass)</td>
<td>.973</td>
<td>.924</td>
<td>.691</td>
<td>.767</td>
<td>.993</td>
<td>.920</td>
<td>.912</td>
<td>.776</td>
<td>1.00</td>
<td>.953</td>
<td>1.00</td>
<td>.034</td>
<td>.679</td>
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<tr>
<td>ACE (Tree)</td>
<td>.937</td>
<td>.897</td>
<td>.686</td>
<td>.540</td>
<td>1.00</td>
<td>.964</td>
<td>.922</td>
<td>.758</td>
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<td>1.00</td>
<td>1.00</td>
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<tr>
<td>ACE (Road)</td>
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<td>.988</td>
<td>.734</td>
<td>.583</td>
<td>1.00</td>
<td>.920</td>
<td>.943</td>
<td>.601</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.845</td>
</tr>
<tr>
<td>CEM (Grass)</td>
<td>.946</td>
<td>.745</td>
<td>.540</td>
<td>.004</td>
<td>.909</td>
<td>.738</td>
<td>.697</td>
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<td>.619</td>
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<td>.775</td>
<td>.722</td>
<td>.524</td>
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<td>.894</td>
<td>.724</td>
<td>.681</td>
<td>.006</td>
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<tr>
<td>CEM (Road)</td>
<td>.961</td>
<td>.866</td>
<td>.713</td>
<td>.026</td>
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<td>.784</td>
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</table>

## ADR

<table>
<thead>
<tr>
<th>Algorithm (background)</th>
<th>Run 5 C5</th>
<th>Run 5 C6</th>
<th>Run 5 V</th>
<th>Run 5 VF</th>
<th>Run 7 C5</th>
<th>Run 7 C6</th>
<th>Run 7 V</th>
<th>Run 7 VF</th>
<th>Run 9 C5</th>
<th>Run 9 C6</th>
<th>Run 9 V</th>
<th>Run 9 VF</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAM</td>
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<td>.884</td>
<td>.952</td>
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<td>.887</td>
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<td>.987</td>
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<td>ACE (Tree)</td>
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<td>.769</td>
<td>.807</td>
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<td>.999</td>
<td>.990</td>
<td>.982</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>.958</td>
</tr>
<tr>
<td>ACE (Road)</td>
<td>.999</td>
<td>.999</td>
<td>.855</td>
<td>.952</td>
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<tr>
<td>CEM (Grass)</td>
<td>.995</td>
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<td>.995</td>
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<tr>
<td>CEM (Tree)</td>
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<td>CEM (Road)</td>
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<td>.983</td>
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<td>.980</td>
</tr>
</tbody>
</table>
Results - Bar Charts

Grass

C5

Tree

C6
Results - Histograms

Run 5

Run 7

Run 9

C5

C6
Results - Target Distribution

C5

Run 5

C6

Run 7

Run 9
Conclusions

- Both ACE and CEM outperformed SAM
  - ACE performed best across range of targets.
- Quantitative metrics can be used to make broad comparisons over a wide range of data.
- Visual metrics can be used for more in depth analysis:
  - Smaller data sets
  - Trends
- Detection improved as spatial information decreased.
  - Target pixels at low spatial resolution are more similar to target vector used.
  - Target variability decreased at lower spatial resolutions.
Recent Work - OSP

- Geometric Algorithm - OSP
- Calculate endmembers using MAXD
- Calculate on portion of scene containing no man-made objects (eliminates man-made objects including target from being selected as endmembers)
- MaxD code uses MNF image as an input.
  - Why?
  - Is it necessary?
  - Better results using original image?
- Calculate MNF image in ENVI
  - Keep all bands
  - Calculate using uniform region and scene wide stats.
- Using modified maxd code calculate endmembers from data sets
  - Range of endmembers examined - (5, 10, 15, 20, 25, and 30 endmembers)
ROC Curves - Ref

Reflectance image target C5 OSP results

Detection Rate

False Alarm Rate

10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0
ROC Curves - MNF (Full)
ROC Curves - MNF (uniform)
# Metric Summary - C5

<table>
<thead>
<tr>
<th># Endmembers</th>
<th>Ref Image</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFAR</td>
<td></td>
<td>.0263</td>
<td>.0199</td>
<td>.0133</td>
<td>.0190</td>
<td>.0121</td>
<td>.0063</td>
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<tr>
<td>ADR</td>
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<td>.9737</td>
<td>.9801</td>
<td>.9867</td>
<td>.9810</td>
<td>.9879</td>
<td>.9937</td>
</tr>
<tr>
<td>PD @ PFA</td>
<td></td>
<td>.6288</td>
<td>.7778</td>
<td>.7141</td>
<td>.6960</td>
<td>.8764</td>
<td>.9340</td>
</tr>
</tbody>
</table>

## MNF - Full image

| AFAR         |          | .0239 | .0207 | .0091 | .0021 | .0213 | .0113 |
| ADR          |          | .9761 | .9793 | .9909 | .9979 | .9787 | .9887 |
| PD @ PFA     |          | .7784 | .9020 | .8667 | .9394 | .9142 | .9188 |

## MNF - Uniform region

| AFAR         |          | .0330 | .0239 | .0144 | .0044 | .0075 | .0095 |
| ADR          |          | .9670 | .9761 | .9856 | .9956 | .9925 | .9905 |
| PD @ PFA     |          | .6415 | .8358 | .9072 | .8924 | .9108 | .9431 |
Conclusions - Recent Work

• MNF is used to reduce noise in images therefore improving endmember extraction.
  – FR1 images have high SNR and I do not have noise data.
  – “Uniform” region in images contain variability not associated with sensor noise.
  – MNF still improves results
  – Next step:
    » Need further examination of how to calculate MNF
    » Examine the effect of # MNF bands kept

• # Endmembers used affects the detection algorithm results
  – More endmembers does not equal better results.
  – Next step:
    » Examine ideal # of endmembers for algorithm performance
    » Method to determine the ideal # of endmembers