Investigation of Noise and Dimensionality Reduction Transforms on Hyperspectral Data as Applied to Target Detection

Brian Staab
Emmett Ientilucci

Digital Imaging and Remote Sensing Laboratory
Center for Imaging Science
Rochester Institute of Technology
Overview

Background

- Dimension & Noise Reduction Transforms
  - Principal Components Analysis (PCA)
  - Maximum Noise Fraction (MNF)
- Target Detection Algorithms
  - Spectral Angle Mapper (SAM)
  - Orthogonal Subspace Projection (OSP)

Experiment

Results
- A small sample

Conclusions
The Transforms

Too Much Data
- Simplify and Speed up Analysis

*Without Throwing Away Information?*

Principal Components Analysis (PCA)
- Compress Variance to Few Bands
- De-correlation via linear transforms

![Graph showing variance decay over PCA/MNF bands](image)
The Transforms

PCA maximizes variance of bands
  - Signal & **Noise** Maximized

Maximum Noise Fraction (MNF)
  - Attempt to “separate” Noise and Signal
  - Maximize Signal to Noise Ratio
  - Requires Estimate of Noise
**Dimension Reduction**

- Only use the First Few PCA/MNF Bands
  - Contains the Most Variance or Information (compressed)
  - Remaining Bands = Noise (Low Variance)

**Noise Reduction**

- PCA/MNF Space
  - Zero the Noise Bands

- Inverse Transform to Original Space
  - “Noise Cleaned Data”
Consider

How many dimensions do you keep?

How will it affect target detection performance?
Target Detection Algorithms

Spectral Angle Mapper – SAM

\[ \cos(\theta) = \frac{t^T x_{i,j}}{||t|| \cdot ||x_{i,j}||} \]

Detection Statistic = Angle
Target Detection Algorithms
Orthogonal Subspace Projection (OSP)

- Geometrical Approach

- Matrix operator
  - Eliminate undesired spectral signatures (background) contribution
  - How unlike the Background

- Vector operator
  - Maximizes the contribution of desired target spectra
  - How Target-Like
Hypothesis

- Dimension and Noise reduction transforms on hyperspectral imagery have no effect on target detection performance

- Testing an Assumption that there is no Effect
Experiment

Hyperspectral Image Cube

Radiance or DC Space

Atmospheric Compensation

ELM

Reflectance Space

PCA

MNF

145 Bands

PCA/MNF Space
Experiment: Band Reduction

Trim PCA/MNF Data

PCA/MNF Space

PCA/MNF same transform

Target Detection -SAM -OSP

Record Detection Statistic

Iterate Number of Dimensions Trimmed

Target Reflectance
Experiment: Noise Reduction

Zero PCA Data → Inverse PCA → Noise Reduced Reflectance

Target Reflectance → Target Detection -SAM -OSP

Iterate Number of Bands Zeroed → Record Statistic
Experiment: Band/Noise Reduction

- Vary No. Bands Kept or Zeroed
- Examine Trends:
  - Low and High Contrast Targets
  - SAM & OSP

Detection Statistic $\theta$

Number of Dimensions Kept
Or % Variance Kept

Reference: Detection using all bands

Less % or Bands

100 % = All Bands
Hydice Forest Radiance Scene

**High Contrast**
30 Fully Resolved pixels

**Low Contrast**
15 Fully Resolved pixels

**Zoom**

- 141 x 116 Subset
- 145 Bands
- .4 to 2.4 μm
- ELM Applied
- 9 mb
Noise Estimate

- Needed for MNF Transform
- 20x17 pixel calibration panel
  - Homogeneous Region
- Difference of Original and Spatially Shifted Version = Noise

Noise Covariance Matrix

Noise Std. Dev.
Vs. Band
Results

8 Graphs per Experiment: Dimension and Noise Reduction
- PCA & MNF
- SAM & OSP
- High & Low Contrast Targets

To compare with the trends of target pixels
3 background classes were used as test pixels
High Contrast
- Very Little Effect
- Mean of 30 Pixels

Background
- Grass
- Road
- Dirt

Results: PCA Band Reduction

PCA Band Reduction: SAM: Mean High Contrast

<table>
<thead>
<tr>
<th>Angle (Radians)</th>
<th>Number of Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>0.15</td>
<td>10</td>
</tr>
<tr>
<td>0.2</td>
<td>15</td>
</tr>
<tr>
<td>0.25</td>
<td>20</td>
</tr>
</tbody>
</table>

% Variance Kept
- Mean Target: 94.6%
- Grass: 99.15%
- Road: 99.6%
- Dirt: 99.69%
Results: MNF Band Reduction

- High Contrast
  - More Separation with Background Classes
  - Mean of 30 Pixels

![Graph showing MNF Band Reduction: SAM: Mean High Contrast]

<table>
<thead>
<tr>
<th>Angle (radians)</th>
<th>Target Mean</th>
<th>Grass</th>
<th>Road</th>
<th>Rock/Dirt</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Variance Kept</td>
<td>73.6%</td>
<td>97.99%</td>
<td>99.37%</td>
<td>99.89%</td>
</tr>
</tbody>
</table>
Results: MNF Noise Reduction

- Low Contrast
- Improvement in Angle
- Increase in background separation
- Ideal

MNF Noise Reduction: SAM: Mean Low Contrast

<table>
<thead>
<tr>
<th>% Variance Kept</th>
</tr>
</thead>
<tbody>
<tr>
<td>73.6%</td>
</tr>
<tr>
<td>97.99%</td>
</tr>
<tr>
<td>99.37 %</td>
</tr>
<tr>
<td>99.89%</td>
</tr>
</tbody>
</table>

Number of Bands Kept

Angle (radians)
## Summary: SAM

Target relatively constant till significant band/noise reduction then:

<table>
<thead>
<tr>
<th>Band Reduction</th>
<th>PCA</th>
<th>MNF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Contrast</strong></td>
<td>+ Improves target angle - Improves background angles</td>
<td>+ Improves target angle + Improves separation from background</td>
</tr>
<tr>
<td><strong>Low Contrast</strong></td>
<td>+ Improves target angle and + Improves separation from background slightly</td>
<td>- Worsens target angle - Confusion with background</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Noise Reduction</th>
<th>PCA</th>
<th>MNF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Contrast</strong></td>
<td>- Worsens target angle</td>
<td>+ Improves / Better target angle till significant noise reduction then: + Improves separation from background slightly - Improves background angles</td>
</tr>
<tr>
<td><strong>Low Contrast</strong></td>
<td>+ Target angle improves + Improves separation from background</td>
<td>+ Improves / Better target Angle till significant noise reduction then: ++ Improves separation from background (Target Improves/Background Worsens)</td>
</tr>
</tbody>
</table>
## Summary: OSP

<table>
<thead>
<tr>
<th>Band Reduction</th>
<th>PCA</th>
<th>MNF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Contrast</strong></td>
<td>+ Improves target slightly + Improves separation from Background till significant band reduction</td>
<td>+ Improves target slightly + Improves Separation from Background till significant band reduction</td>
</tr>
<tr>
<td><strong>Low Contrast</strong></td>
<td>+ Improves Target and + Improves Separation from background till significant band reduction then: - Background Increase but at lower rate</td>
<td>- Confusion with background • Target relatively constant till significant band reduction then: - Worsens Target Angle</td>
</tr>
<tr>
<td><strong>Noise Reduction</strong></td>
<td>PCA</td>
<td>MNF</td>
</tr>
<tr>
<td><strong>High Contrast</strong></td>
<td>• Target Relatively Constant till significant noise reduction then: - Worsens Target statistic</td>
<td>- Worsens target statistic + Small area of improvement of target &amp; background separation</td>
</tr>
<tr>
<td><strong>Low Contrast</strong></td>
<td>• Constant target/backgrounds till significant noise reduction then: - Worsens target statistic + Small area of improvement of target &amp; background separation</td>
<td>- Worsens target till 99.8% variance (~110 bands) kept then:</td>
</tr>
</tbody>
</table>

Endmember changes cause drastic fluctuations, some cause background confusion
Conclusion

**Band Reduction**
- Detection statistic remains relatively constant or improves
- Some cases: Increase in separation

**Noise Reduction**
- SAM angle constant or improves
  - Background Separation increases
- OSP statistic constant or deteriorates
  - Drastic fluctuations (Endmembers)
Conclusion

Future Considerations:

- Use of varying
  - Data sets
  - Target Detection Algorithms
  - Targets
- Better Noise Estimates
Questions