Anomaly Detection in Hyperspectral Images

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Anomaly – a man-made object surrounded by natural clutter
Adaptive Anomaly Detection

Hyperspectral image

Pre-processing

Parameter estimation

decision rule

Post-processing

A-priori knowledge

Parametric Clutter model
Local Anomaly Detectors

- After local mean removal, clutter is spatially-stationary within a small-enough processing window.

Parameter estimation:

- Using reference data
- Binary Hypothesis approach
Global Anomaly Detectors

Gaussian Mixture Model (GMM)

- Clutter is spatially-stationary within each cluster
- Parameter estimation employing the entire image, neglecting the effect of anomalies
Iterative Clustering Algorithms

- Maximization of an optimality function
- Fuzzy clustering: fractional degrees of membership
- Criteria for optimal number of clusters
Main clustering algorithms

Algorithm is determined by the calculation of pixel-cluster membership degree

- Euclidian distance from centroids (K-means, fuzzy K-means, ISODATA)
- A-posteriori probability (EM, CEM, SEM, ICM)

Parameter estimation:

- Maximum likelihood (ML)
- Fuzzy maximum likelihood (FML)
Split & Merge

Splitting Criteria:

- Kurtosis
- Fourth moment
- First moment
- Major axis length
- Condition number
Performance Evaluation

Receiver Operation Characteristics (ROC):

• Detection and false-alarm probabilities ($P_D$, $P_{FA}$)
• Theoretical vs. Empirical performance evaluation
Constant False Alarm Rate (CFAR)

Prior to threshold-comparing:

After threshold-comparing:

• More reliable detection and performance evaluation
• Non-trivial property
Utilizing a-priori knowledge

Binary Hypothesis (BH) detector:

- Parametric target model: known shape and/or spectrum
- Generalized likelihood ratio test (GLRT)

\[
\max_{S, \theta} P(X \mid S, \theta, H_1) \overset{?}{>} \eta > \max_{\theta} P(X \mid \theta, H_0)
\]

Pre-processing: band reduction
Post-processing: morphological operations
Incorrect Shape Assumption

(various sizes)  (size of 5x5)

5x5 Gaussian  5x5 square  7x7 square  11x11 square
Band Removal Methods

• After clustering, the number of bands may be reduced.
• Several methods exist: Averaging, PCA and more.
• We proposed the DCT, which has an advantage when the Global BH detector is used.
Survey of Detection Algorithms

- RX [Yu and Reed, 1990]
- Local GMRF [Schweizer and Moura, 2000]
- Global Single-Hypothesis
- Global Binary-Hypothesis
- Single-Hypothesis RX
- Fuzzy detection
An Example
Main Conclusions

• If target’s size is known approximately, a BH approach is recommended

• If the picture has several distinct clusters, the detector should possess the CFAR property

• If the picture is known to be piecewise smooth, use clustering which prefers homogenous clusters, e.g. ICM

• One cannot detect all types of anomalies at once, since each detector has its own model. Combining several approaches may increase performance
Our Contributions

• Developing a Global BH detector with the CFAR property.

• Theoretical performance evaluation of the Global BH detector with known spectral signature.

• Theoretical performance evaluation of the Global SH detector with a smoothing filter.

• Introducing the DCT transform as a band reduction method, which can outperform the PCA method.

• Introducing and implementing a Fuzzy detector.
The End