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Buried Target Detection using a 3-band LWIR Airborne Sensor
Three-Band Data from SCISSOR (Shadow-Class Infrared Spectral SensOR)

- Three bands chosen within and just outside the Restrahlen band.

- SCISSOR data collected using a helicopter flyover.

- Buried targets marked by fiducials including pressure plates, 155 rounds, and empty holes.

Flight path
Area of study

Set of fiducial marked targets, including 14 pressure plates

Closer view of data

Image: scan_1500_20_off_cm_EW_run1_090723_063623_rad_m filt_median_3band_12600-14700_TRIGEO_rotreg_merge_geomerge.xv
Scatter Plot of Whitened Radiance Data

Spectral features are not enough to clearly separate targets from background.

Pressure Plate Distribution
Targets
Clutter
Objectives

- Maximize detection of buried targets while minimizing false alarms.

- Explore a variety of RX-family detectors that could be useful for buried target detection within varying background complexities.

- Provide an overall framework for buried target detection using a combination of anomaly detection followed by spectral and spatial feature classification.
Overall Approach

• Features: Spectral and relative spatial information

• Image segmentation to find regions of interest (ROIs) using a variational Bayesian Gaussian mixture model.

• Classification of each ROI as a target or clutter using a relevant vector machine (RVM).
Overall Process

Spectral and Spatial Features

ROI Features

Target classification using RVM

RX or GMMRX

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Spectral Features

2 Bands of emissivity and temperature (emissivity normalization method)

\[ T = \frac{C_2}{\lambda_j \ln \left( \frac{\varepsilon_j C_1}{L_j \lambda_j^5 \pi} + 1 \right)} \]
A Sobel operator is used on the spectral data to find edges within the image, revealing the buried targets as rings. An annular template, the size of the target rings, is applied to the Sobel image, providing a final image displaying where the centers of the rings are (likely target locations).
Spatial Anomaly Measure: RX family

- Standard RX anomaly detector assumes that points in context region are from a multivariate Gaussian density

\[ RX = (\bar{X}_{inner} - \bar{X}_{context})^T \Sigma_{context}^{-1} (\bar{X}_{inner} - \bar{X}_{context}) \]

- This assumption is violated when the local context region is abruptly changing or composed of multiple types of background signals

- **NEW APPROACH**: Model context region pixels with a Gaussian mixture model using local and global context
  - Use a variational Bayesian Gaussian mixture model (GMMRX) to learn clusters globally for an entire image
  - Use globally learned clusters to create local GMMs (local GMMRX) for each context region
## Comparison of approaches

<table>
<thead>
<tr>
<th></th>
<th>RX</th>
<th>GMMRX</th>
<th>Local GMMRX</th>
<th>Min Local GMMRX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
<td>Detecting anomalies in relatively smooth, well-behaved regions (usually)</td>
<td>Detecting anomalies in smoothly varying background</td>
<td>Detecting anomalies in smooth regions</td>
<td>Detecting anomalies in smooth regions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detecting anomalies in rapidly varying background</td>
<td>Detecting anomalies in rapidly varying background</td>
<td>Detecting anomalies that differ from all local context clusters</td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td>Detecting anomalies in rapidly varying background</td>
<td>Detecting anomalies that do not differ substantially from globally-learned parameters (even if they are noticeably different from local context pixels)</td>
<td>May detect more unwanted anomalies since any anomaly that differs from at least some local context clusters will be detected</td>
<td>Detecting anomalies that differ from some local context clusters but not all (can cause a problem when trying to detect anomalies in rapidly varying background)</td>
</tr>
</tbody>
</table>
Spatial Features: RX family

RX

GMMRX

Local GMMRX

Min Local GMMRX
RX Performance

RX detector only, not with the comprehensive detection process.

All Target Types

Pressure Plates Only

Since they perform the best, the standard RX and the Min GMMRX are both used as features in the overall target detection process described. Min GMMRX is referred to as GMMRX in the remainder of the slides for convenience.
Unsupervised clustering using VBGMM

- The number of clusters is determined by the algorithm.
- Complex models are penalized, guiding the algorithm to choose the best fit using the least number of clusters.

\[ F_m[q] = \int d\theta q(\theta) \log \frac{p(D,k|\theta)}{q(\theta)} = \langle \log \frac{p(D,k|\theta)}{q(\theta)} \rangle_{q(\theta)} - KL[q(\theta)||p(\theta)] \]
Features used for VBGMM image segmentation

- **Spectral Features** (E2, E3, T)

- **Spatial Features** (Sobel with Template Matching, RX)

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Image segmentation using VBGMM

Groups of brown pixels designated as regions of interest (ROI).
Relevance Vector Machine

- RVM functional form is *kernel-space hyperplane classifier*: \( f(x) = w^T \phi_n(x) \)

- Bayesian learning: *prior on weights to induce sparse solution (i.e., most weights driven to zero)* - *learn weights by maximizing posterior*

\[
p(w \mid f, y) \propto p(y \mid f, w) p(w)
\]

\[
p(w_i \mid \gamma) = \frac{1}{\gamma} \exp\left\{-\frac{\gamma}{2} w_i^2\right\}
\]

- Example - Automatic relevance determination (ARD)
  - Adopt hierarchical Bayes model – *zero-mean Gaussian prior with exponential hyper-prior on independent variances, \( t_i \)*
    \[
p(w_i \mid \tau_i) = N(w_i \mid 0, \tau_i) \quad p(\tau_i \mid \gamma) = (\gamma/2) \exp\{-\gamma \tau_i/2\}
\]
  - Integration with respect to \( t_i \) recovers *Laplacian form*
    - Allows for expectation-maximization (EM) iterative optimization
    \[
p(w_i \mid \gamma) = \int_0^\infty p(w_i \mid \tau_i) p(\tau_i \mid \gamma) d\tau_i = (\gamma/2) \exp\{-\sqrt{\gamma} |w_i|\}
\]
ROI Features used with RVM

2-Dim. RVM classification map (White areas are regions of low uncertainty)
ROI classification using RVM

Each ROI is classified as target or clutter by the RVM.
Results on pressure plate detection
Results on 155 round detection

Image: scan_1500_20_off_cm_EW_run1_090723_063623_rad_mfilt_median_3band_12600-14700_TRIGEO_rotreg_merge_geomerge.xv

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Results empty hole detection

![Graph showing empty hole detection](image_url)

Image: scan_1500_20_off_cm_EW_run1_090723_063623_rad_mfilt_median_3band_12600-14700_TRIGEO_rotreg_merge_geomerge.xv

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Results on pressure plate, 155 round, and empty hole detection

Image: scan_1500_20_off_cm EW_run1_090723_063623_rad_mfilt_median_3band_12600-14700_TRIGEO_rotreg_merge_geomerge.xv
Summary

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Follow On Work

- Improve target detection by representing spatial pixel blocks of spectral data as a mixture of base distributions, and performing unsupervised clustering using the Dirichlet process.

- Develop a fully Bayesian approach to emissivity and temperature extraction from multiband radiance data.

- Consider a noise model in buried target detection within a fully Bayesian setting.