Combining High Dynamic Range Photography and High Range Resolution RADAR for Pre-discharge Threat Cues

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The objective of this project is to develop a joint high dynamic range photography and high range resolution RADAR system on mobile platforms to provide pre-discharge threat warning in urban and mountain environments.
Approach:

- Expand upon the sensor and processing concepts of MTRI Counter RPG and Counter Sniper programs.
  - The expansion of the system will be in the areas of
    - rural, mountainous terrain and threats
    - incorporating cued high dynamic range imagery to the warfighter.
    - Clutter rejection and target detection algorithm variants will be developed
    - develop a parallel aperture high dynamic range optical system along with its attendant signal processing
      - provide confirmatory images of the threat as cued by the RADAR.
      - high dynamic range optical system will be cued by the RADAR in operation
  - Deploy our instrumentation RADAR and optical system at mountainous sites for empirical collections to verify performance
  - Provide a near real-time demonstration of the system.
Optical Difficulty: Find the Shooter
Radar Locates Potential Threat

* Chart is Animated in Slide Show Mode
Shooter is Located
Impacts of Mountain/Rural Clutter

- Moving from “Sniper in Building” to “Sniper in Mountainous Terrain” – significant differences

<table>
<thead>
<tr>
<th>Urban</th>
<th>Mountainous</th>
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<tbody>
<tr>
<td>Bright and more localized discretes</td>
<td>Diffuse and distributed scatters</td>
</tr>
<tr>
<td>Fast changes in spatial clutter</td>
<td>Slow to moderate changes in spatial clutter</td>
</tr>
<tr>
<td>Predominance of flat surfaces (walls/furniture)</td>
<td>Distribution of rocks and vegetation</td>
</tr>
<tr>
<td>More control of incident angles</td>
<td>Wide variety of incident angles</td>
</tr>
<tr>
<td>Clutter = combination of several discretes</td>
<td>Clutter = variety of distribution of scatterers (moderate to heavy-tailed)</td>
</tr>
<tr>
<td>Polarimetric – known distinct differences between targets/clutter</td>
<td>Polarimetric – expect differences but less distinct between targets/clutter</td>
</tr>
<tr>
<td>Weapon variety – mod variability</td>
<td>Weapon variety – more variable</td>
</tr>
<tr>
<td>Focused Scan Area (windows, roofs, edges of buildings)</td>
<td>Larger Scan Area (more possible locations)</td>
</tr>
</tbody>
</table>
Ft. Pickett Collection Campaign

March, April 2008
W and Ka bands collected
Ave Pd=.95 at Pfa=.05
Blind Test Results Show Detectable Signatures in Clutter

- Radar scanned across building with blind target deployment
  - Complex clutter in room including holes in walls, steel furniture and large wooden ladder
  - Deployed behind fully open, half open windows and “kill hole”
- System correctly identified all threats without false alarms

Null-to-Null Beam Locations During Sweep of Building: W-Band

Real Threats:
- AK-47
- Dragonov
- Sniper Rifle
- RPG-7

False Threats:
- Broom
- Shovel
- Ladder

*Animated GIF plays in “SlideShow” mode*
Scan set #1
  - False alarm testing
    • Scan #1: building with confuser targets
      - Empty rooms, people, people with implements
        » Positioning of people determined on site with government
    • Scan #2: completely empty building, shutters open
    • Scan #3: empty building with shutters closed

Inspection of processing results

Scan set #2
  - Detection testing
    • 3 Scans
    • 4 Weapons
      - RPG-7, Dragunov, AK-47, AR-10
    • Positioning of target determined on site with government
    • Confusers added as resources permit
Scenario

Munitions
• Dragunov
• AK47
• RPG
• AR10

Confusers
• Person with Tripod
• Person with Broom

Results
• Dragunov, AK47, RPG, and AR10 detected as weapons
• Person+Tripod declared as clutter
• Person+Broom declared as clutter

Notes
• AK47 and Dragunov in same room
Summary: Algorithm Declarations

- All weapons within search range of system were detected
- No false alarms
- Automated algorithm used 4 minutes for declarations (non-real time code)

<table>
<thead>
<tr>
<th></th>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
<th>Window 4</th>
<th>Window 5</th>
<th>Window 6</th>
<th>Window 7</th>
<th>Window 8</th>
<th>Window 9</th>
<th>Window 10</th>
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<tr>
<td>Clutter Test, Windows Open</td>
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<td>Person</td>
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<td>Clutter Test, Windows Open</td>
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<td>Person</td>
<td>Person</td>
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<td>Clutter Test, Windows Closed</td>
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<td></td>
<td>Person</td>
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<tr>
<td>Detect Test 1</td>
<td>Dragunov</td>
<td>RPG</td>
<td>Person + Tripod</td>
<td>AK47</td>
<td>AR10</td>
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<td>Detect Test 2</td>
<td>RPG</td>
<td>Person + Tripod</td>
<td>AK47</td>
<td>AR10</td>
<td>Dragunov</td>
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<tr>
<td>Detect Test 3</td>
<td>AK47 + Dragunov</td>
<td>RPG</td>
<td>Person + Tripod</td>
<td>Person + Broom</td>
<td>AR10</td>
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Detection | Missed Detection/Outside Search Area | False Alarm | Confuser | Correct Declaration | Incorrect Declaration

- Confuser
- Correct Declaration
- Incorrect Declaration
Nonparametric Boosting Classification: Discrimination of Output Cues

- Nonparametric boosting-based rule ensembles
  - Flexible to new operating conditions
  - Doesn’t assume Gaussianity
  - Needs relatively moderate amounts training data
  - Robust to over fitting
  - Computationally efficient
  - Approximately optimal (Bayesian Neyman-Pearson Detector)
Mountainous Surrogate: Quarry at Ft. Pickett, VA
Mountainous Surrogate: Ft. Pickett, VA
Algorithm Declaration After SAR Processing

- Algorithm searched for target over all ranges
- Azimuth compression eliminates false alarm (clutter is localized in azimuth)
Quarry Clutter Scans Processed Using Training Sets

- Training sets created from urban target and quarry clutter
  - Training sets are HV, so testing sets are also HV
- Test data was quarry clutter scans
- Expectation that false alarms would decrease with better clutter match was verified
High Dynamic Range Photography

Combination of 4 moderately exposed images

Camera metered as ‘normal’ exposure

Vs.

Significantly overexposed image (no context)

+2 stops

+1 stop

-1 stop
High Dynamic Range Photography

- Linear Combination of over/under exposed images to increase dynamic range
  - Maximum likelihood
- Tone mapping optimally maps high dynamic range data onto display
  - Local operator using the zone method (local dodging and burning)

\[ L_d(x, y) = \frac{L(x, y)}{1 + V(x, y; s)} \]

\[ V(x, y, s) \] - local average over scale s
Fattal (2002) – Localized gradient based method
[1 alpha, .8 beta, 1 saturation, no noise reduction]
Mountainous Site: Ft. Carson, CO
Ft. Carson Site 1

Site 1: Broadside
300m view

Site 2: Off Center
500m view
Summary

- Initial results from Ft. Pickett are very promising
  - With minimal training on new data, detection/FA results are quite good
    - $P_d=1, P_{fa}<5\%$

- Including EO imagery provides actionable imagery to commander
  - RF provides cues
  - HDR alleviates shadowing while maintaining context

- Ft. Carson campaign to commence in early August
  - Much larger data set
  - True mountainous terrain
  - Using both EO and Radar in the collection

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