Power Variable Training STAP

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Current GMTI Issues

Current GMTI System Performance Limitations

- Heterogeneous clutter
- Clutter discretes
- Dense target backgrounds
- Low Doppler targets
- Area coverage rate
- Lack of “smart” radar system adaptivity

Scheduling, waveforms, algorithms, processing, \textit{a priori} knowledge

Problems can be addressed with simple, logical ideas that utilize external knowledge
Outline

• Current STAP challenges
• Power variable training with excision algorithm
• Detection and angle estimation
• Tuxedo data results
• Conclusions
Desirable Features for STAP Training

- Training statistics must match the cell under test
  - Angle/Doppler relationship
  - Clutter type (vegetation / mountain / desert)
  - Power

- The training set should **NOT** include targets or other moving objects

Train STAP in Range

```
Train

Range
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Localized Training Impact

- Overnulled clutter degrades MDV
- Undernulled clutter degrades $P_D$ and increases $P_{FA}$
- Targets in training set degrades $P_D$
- Windblown clutter degrades MDV
SINR Loss in 50% Wind-Blown Clutter

Target in the clear (no foliage)
Train with 50% wind blown clutter from foliage

Platform velocity = 150 m/sec
Altitude = 10 km
CNR = 35 dB
f0 = 10 GHz
PRF = 2 kHz
50% mixture (wind-blown & stationary)

Wind blown foliage training degrades performance in clear
Distributed Training

Random Training
- Undernulls strong clutter
- Training samples

Power Selective Training
- Overnulled clutter degrades MDV
- Training samples

Locus of Constant Cone Angle
- Clutter steering vector changes with range

STAP Training Issues:
- Windblown clutter
- Angle/Doppler relationship
- Targets included in training
- Correct power

Neither localized nor distributed training address these issues which affect MDV, $P_D$, and $P_{FA}$
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Regionalized Training

TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power

- Classify ground swath regions
  - Foliage
  - No foliage
  - Urban

- Apply STAP separately for each region
Doppler Warping and Power Selected Training

Doppler Warping Aligns Clutter

\[ e^{j2\pi f(\rho)t} \]

Range varying phase ramp in pulse dimension

Locus of Constant Cone Angle

\[ \rho = \text{Range} \]

\[ \text{Clutter Doppler} \]

\[ f(\rho) \]

Power Selective Training

TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power
Mapped Discretes and Tracker Feedback

- Don’t train or detect on problematic clutter discrete range gates
  - High Doppler sidelobes
- Clutter discretes may be provided by tracker or external NGA map data

- Tracker predicts where targets will exist in future CPIs
- This knowledge is utilized to prevent known targets from being included in STAP training data

TRAINING SAMPLES
- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power
Target Excision

Power Selective Training

- Select strongest clutter returns as candidate training samples

Excision

- Excise samples away from clutter ridge (potential targets)

TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power
Power Variable Training with Target Excision

**Power Selective Training**
- Select strongest clutter returns as candidate training samples

**Excision**
- Excise samples away from clutter ridge (potential targets)

**Adjust Clutter Power**
- Scale training samples to estimated CNR for Tile

**Training Samples**
- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power

Mathematical Expression:

\[ R_M = \beta \left( \frac{1}{K} \sum X_i X_i^H \right) + \lambda I \]

\[ \beta = \frac{\text{Tile M power}}{\text{Training power}} \]

\[ \beta < 1 \]
Power Variable Training for STAP

Covariance Matrix: \[ R_S = \frac{1}{K_S} \sum x_i x_i^H \]

Tile Power: \[ e_M = \frac{1}{K_M} \sum x_i^H x_i \]

Estimate Pure Clutter Covariance Matrix
\[ R_C = R_S - \lambda I \]
\[ \lambda = \text{Estimated Noise Floor} \]

Covariance Matrix for Tile “M”
\[ R_M = \beta R_C + \lambda I \]
\[ \beta = \frac{e_M - N\lambda}{\text{tr}[R_S] - N\lambda} \]

Diagonally Loaded Covariance for Tile “M”
\[ R_M = \beta R_C + (\lambda + \delta)I \]
\[ \delta = \text{Diagonal Load Level} \]

Adaptive Weight for Tile “M” with AMF Normalization
\[ w_M = \frac{R_M^{-1} v}{\sqrt{v^H R_M^{-1} v}} \]
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Lesser-Of CFAR Target Detection with ACE

- Choose *lesser of* training window means for noise estimate
  - Stencil with lesser mean will be least likely to include targets
- Two pass architecture
  - First pass identifies targets
  - On second pass, exclude first-pass targets from stencils
- Small ACE values implies target is better suited by another beam or is associated with sidelobes
- Targets must satisfy CFAR threshold and ACE threshold for detection

\[ \frac{w^H x_i}{x_i^H R_M^{-1} x_i} \geq \chi_{\text{ACE}} \]
Knowledge Aided Detection Management

- Estimate arrival angle for each detection:

  Spatial Steering Vector:

  \[ a(\theta) = \begin{bmatrix} 1 \\ e^{j\theta} \\ \vdots \\ e^{j(N-1)\theta} \end{bmatrix} \]

  Apply linear transformations to match STAP output:

  \[ h(\theta) = W(Fb \otimes a(\theta)) \]

  Find angle that maximizes inner-product:

  \[ \angle = \arg \max_{\theta} |h(\theta)^H x_{STAP}| \]

- Delete or flag detections with angle estimates that closely match clutter ridge location
- Use knowledge of road locations to discriminate angle ambiguities
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Tuxedo Data
Recorded Data

System Parameters for GMTI Mode

- Center Freq.: 9.6 GHz
- Bandwidth: 66 MHz
- PRF: 1,400 Hz
- Tx Apertures: 1
- Rx Apertures: 3
- Horiz. Aperture: 1.83 m
- Vert. Aperture: 0.18 m
- Az BW: 3.6 deg
- El BW: 9.1 deg
- Polarization: HH
- A/C Heading: 290 deg
- Depr. Angle: 15 deg
- Recorded Time: 40-60 sec

Limited targets in data (up to 5) and uniform terrain type (desert)
Demonstrated GMTI Enhancements

**Demonstrated:**
- Power Variable Training with Excision
- Tracker feedback of target locations
- Doppler Warping to account for aircraft crab
  - Near broadside collection
- Angle estimation rejection of clutter discretes
- Prior knowledge of problematic clutter discrete locations
- Use of platform inertial data to estimate clutter ridge location
- Use of road locations to discriminate angle ambiguities

**Not Demonstrated:**
- Separate training for windblown clutter
  - No significant foliage present in data
- DTED enhanced clutter ridge estimation
  - Flat terrain
Range-Doppler Image

(map cropped and stretched to match data)

Railroad track

(Railroad train (wheels))

Strong clutter discretes
Power Variable Training Comparison: STAP Output

Locally Trained STAP

Knowledge Aided Power Variable Training

Railroad train self-nulled with localized training
Power Variable Training Comparison: Detector Output

Power variable training dramatically reduces false alarm rate
SINR Loss
Simulation and Data Results

Simulation

Clutter Ridge

Normalized Spatial Frequency

Radial Velocity (m/s)

-10 dB Null Width = 2.26 m/s

SINR Loss (dB)

Radial Velocity (m/s)

Knowledge Aided Power Variable Training
Power Variable SINR Loss Effects

- Tile SINR loss approaches 0 dB as tile power decreases
- Significantly improved MDV for lower power range gates
ROC Comparison

- Overall ROC curve illustrates performance increase
- Significant $P_{FA}$ benefits demonstrated
- Performance gain primarily from $P_{FA}$
Comparison Movie

Detection
Angle Localization
Conclusions

• Use of internal and external knowledge improves performance
  – Tracker feedback
  – External data maps

• Simple, “smart” enhancements significantly improve overall performance
  – Validated improvements with tuxedo data

• Enhanced algorithm data results
  – Probability of false alarm significantly decreased
  – SINR Loss closely matches predicted performance
  – Targets of interest consistently detected
  – Low MDV observed
  – “Convoy-like” railroad train easily detected and not self-nulled