Bistatic STAP for Airborne Radar

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Bistatic Radar

Motivation
Future radar systems are strongly considering the bistatic option

Benefits of bistatic radar
• Receiver is not broadcasting its location
• Use as adjunct to monostatic radar to enhance detection range

Challenge: Complicated nature of bistatic clutter due to transmitter motion effects
Outline

• Background
  STAP for Monostatic Radar
  – Bistatic Clutter

• Pulsed Bistatic STAP

• CW Bistatic STAP

• Summary
## Analysis Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar Frequency</td>
<td>435 MHz</td>
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<tr>
<td>Bandwidth</td>
<td>5 MHz</td>
</tr>
<tr>
<td>PRF</td>
<td>300 Hz</td>
</tr>
<tr>
<td># elements</td>
<td>18</td>
</tr>
<tr>
<td># pulses</td>
<td>18</td>
</tr>
<tr>
<td>Receiver velocity</td>
<td>100 m/sec</td>
</tr>
<tr>
<td>Transmitter velocity</td>
<td>100 m/sec</td>
</tr>
<tr>
<td>Receiver altitude</td>
<td>10 km</td>
</tr>
<tr>
<td>Transmitter altitude</td>
<td>10 km</td>
</tr>
</tbody>
</table>

* J. Ward MIT/LL Technical Report 1015
Bistatic STAP
Mitigation of Bistatic Interference

Monostatic STAP

Bistatic Jamming

- Hot clutter or terrain scattered interference
- Extensive modeling of hot clutter exists through Mountaintop program
- Hot clutter mitigation conclusions:
  - stationary bistatic jammer easy to cancel
  - moving bistatic jammer hard due to non-stationarity in range
Monostatic Clutter
No Array Rotation

Monostatic Doppler
Velocity = 100 m/sec

Clutter Ridges

- Common reference point for Doppler and cone angles (Rx/Tx)
- Iso-Dopplers and Iso-Cones align

Effective reduced dimension STAP algorithms exist
Monostatic Clutter
Array Rotation = 45 degrees

Monostatic Doppler
Velocity = 100 m/sec

Clutter Ridges

- Clutter ridge is non-stationary in range
  - near range varies rapidly
  - far range approximately stationary
    (common reference for iso-Dopplers and iso-cones)

- Iso-Dopplers and Iso-Cones do not align

Must compensate for non-stationarity in range to effectively null clutter
Doppler Warping*

- Makes clutter ridge approximately stationary across range (over region of interest)
- Simplifies the training of STAP weights (all range gates have same clutter characteristics)
- Implemented using a range-dependent Doppler shift (phase ramp across pulses)
- Same STAP weights applied to all range gates

* Borsari 1998, IEEE Radar Conference

MIT Lincoln Laboratory
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Bistatic Clutter Doppler
Stationary Transmitter

- Clutter Doppler identical to the monostatic case
  - Doppler results from receiver motion only (same reference for array cone angles)
  - Doppler warping may be used to compensate for any rotation or tilt of the receive array

Traditional, monostatic STAP techniques effective
Bistatic Doppler
Sum of Receiver and Transmitter Doppler

- Two independent sources of Doppler
- Transmitter Doppler originates from a different point than the cone angle reference point (Receiver)
Bistatic Clutter Ridges
Transmitter Moving ‘South West’

Bistatic Doppler
Rx, Tx Velocity = 100 m/sec

- Clutter ridges non-stationary at all range
- Non-stationarity cannot be well approximated by a common Doppler shift at all angles

Complicated clutter structure due to independent transmitter motion
Outline

• Background

Pulsed Bistatic STAP
  – Compensation with Doppler Warping
  – Range-varying STAP weights

• CW Bistatic STAP

• Summary
Bistatic Clutter Ridges
STAP Example over 12 km Training Region

This scenario produces challenging signal processing problem
– Doppler warping can only work over limited ranges
– Only solution is to have range-varying weights

- Clutter ridges vary significantly over a small range extent
STAP Performance with Training
No Doppler Warping

• STAP uses training data to estimate the clutter statistics
  – Clutter nulling filter is formed from the statistics estimated from the data

• Complex non-stationary clutter degrades STAP performance
  – Poor minimum detectable velocity and usable Doppler space

Target Bistatic Range = 250 km

SNR Loss (dB) vs. Velocity (m/s)

- Ideal
  6 km training
  12 km training

Training ranges
(Typically 100s range gates)

Hypothesized target range
STAP Performance with Doppler Warping
Target Bistatic Range = 250 km

- Doppler warping improves STAP performance, but MDV is still impacted
  - Clutter ridges are not exactly parallel - even in the mainbeam region
  - Cannot use a common Doppler shift at all angles to align clutter ridges
Derivative-Based Updating*

- Power series expansion of instantaneous weight vector
- Sample and ignore higher order terms
- Both $w_0$ and $\dot{w}_0$ must be estimated from the data

$w(t) = w_0 + t\dot{w}_0 + \frac{t^2}{2} \ddot{w}_0$

$w(k) \approx w_0 + k\dot{w}_0$

Calculation of STAP Weights with Derivative-Based Updating

Range-Varying STAP Weights
\[ w(k) = w_0 + k\dot{w}_0 \]

STAP Output (kth snapshot)
\[ y(k) = w_0^H x(k) + k\dot{w}_0 x(k) = \ddot{w}^H \ddot{x}(k) \]

Augmented Data Vector
\[ \ddot{x}(k) = \begin{bmatrix} x(k) \\ kx(k) \end{bmatrix} \]

Form Augmented Covariance Matrix
\[ \ddot{R} = \begin{bmatrix} \sum_k R(k) & \sum_k kR(k) \\ \sum_k kR(k) & \sum_k k^2 R(k) \end{bmatrix} \]

Augmented STAP Weights
\[ \ddot{w} = \begin{bmatrix} w_0 \\ \dot{w}_0 \end{bmatrix} = \ddot{R}^{-1} \begin{bmatrix} v \\ 0 \end{bmatrix} \]

Need to compute 2*DOF weights
- Increased computation
- Increased sample support required
STAP Training Performance
Doppler Warping vs. Derivative-Based Updating (DBU)

12 km Training
Target Bistatic Range = 250 km

Derivative based weight updating algorithm restores near ideal STAP performance but is computationally more expensive
Performance of the algorithm degrades as the training region grows, and appears to fail at a 90 km training window.
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Waveform Ambiguity Surfaces

Pulsed Waveform

- Doppler
- Az. Beamwidth
- Elev. Beamwidth

Continuous Waveform

- Doppler
- Range

Resolution Cell

- CPI length
- Bandwidth

Resolution Cell

- CW possible because of bistatic radar
- PN sequences can be used for CW waveform:
  - easily generated
  - low range sidelobes (when matched in Doppler)
  - non-repeating over coherent processing interval
Post- Doppler STAP for PN Waveforms

Spatial Channels

Matched Filter Doppler #1

Matched Filter Doppler #2

\( e^{-j\omega n} \)

Matched Filter Doppler #M

Doppler Dependent Matched Filter

Doppler Match

\( X \)

Matched Filter

N Beams
M Doppler bins

STAP

Post-Doppler STAP Algorithm

Matched Filter Doppler #1

Matched Filter Doppler #2

\( e^{-j\omega n} \)

Matched Filter Doppler #M
• Range/Doppler combined sidelobes

\[
\text{SLL} \sim \frac{1}{\text{Time-Bandwidth}}
\]

• Long matched filters to reduce sidelobes

• Integration times limited by
  – target coherence times (motion)
  – computations

• Integrated Sidelobe Ratio (ISLR) will limit performance

• Put STAP degrees of freedom on regions of high combined sidelobes
  – e.g., Receive/Transmit Mainbeam
CW STAP SINR Performance

CPI Length = 0.06 sec (Length of non-repeating PN sequence)

Only one Blind Velocity Zone due to Doppler Unambiguous Waveform
Summary

• Bistatic clutter cancellation is a “new frontier” for STAP
  – creative solutions required to handle complex clutter characteristics

• Complicated and non-stationary clutter leads to:
  – multiple SINR loss blind regions
  – difficult training problem for STAP

• STAP algorithm must address non-stationarity of clutter
  – Doppler warping is ineffective against rapid variation in range
  – Derivative-based updating weight algorithms can extend the range interval for STAP training

• CW waveforms offer a potentially, attractive alternative
  – Range and Doppler unambiguous
  – Integrated range sidelobe clutter limit performance
  – Same weight training issues as pulse-Doppler STAP