Parallel Matlab Computation for STAP Clutter Scattering Function Estimation and Moving Target Estimation

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Context

Problem: Detect ground moving targets in the presence of ground clutter
Context

- Wide-area surveillance airborne radar
- Arbitrary flight path
- Multiple sensors and Doppler pulses
- Space-time adaptive processing (STAP)
  - Better knowledge of the clutter covariance matrix gives better detection performance

Objective: Estimate the clutter covariance matrix and detect moving targets
Approach

• Ground subdivided into pixels or ground patches
• Known range and angle of each patch with respect to airborne platform
• Known illumination pattern
• Received data: sum of returns from targets and all patches on the ground
• Prior knowledge is available:
  – Digital Terrain Elevation Maps
  – Land use information
• Region of Interest
  • Lake of the Ozarks
  • 15 km diameter
  • 197,316 pixels
  • 30m resolution
Datasets

- Obtained from USGS Seamless Data Server
  - 30m resolution
- Digital Elevation Model
  - Used for modeling geometry
- Land Use
  - Scattering function based on 21 classes of land cover
    - 9 primary classes
      - Water, Developed, Barren, Forested Upland, Shrubland, Non-Natural Woody, Herbaceous Upland Natural/Semi-natural Vegetation, Herbaceous Planted/Cultivated, Wetlands
    - Each class contains one or more categories, e.g.
      - Open Water, High-Intensity Residential, Deciduous Forest, Row Crops
  - Scattering function chosen arbitrarily for simulation
Coordinate Systems

• Datasets referenced in spherical coordinates
  – Latitude, Longitude, Elevation

• Convert to Cartesian Coordinates
  – Simpler to use over small region
  – Computations can be made independent of Earth model
Coordinate Conversion

• First Stage
  – Origin at Earth’s center
  – Use Geodetic Reference System 1980 (GRS80)

• Second Stage
  – Move origin to center of region of interest
  – Elevation along Z-axis
  – North along positive Y-axis
Coordinate Systems

• Adjacent data samples grouped into patches
  – Each patch, or pixel, contains:
    • Location for each corner
    • Location of center
    • Scattering function
    • Normal vectors

• 197,316 pixels in all
• Platform moves around region of interest
  – Actual flight path is arbitrary
• Eight looks
## SIMULATION PARAMETERS

<table>
<thead>
<tr>
<th>Platform</th>
<th>Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flies in circular path around region</td>
<td>( f_c : 10 ) GHz</td>
</tr>
<tr>
<td>Radius 25 km</td>
<td>BW: 10 MHz</td>
</tr>
<tr>
<td>Altitude 7 km</td>
<td>PRF: 2 KHz</td>
</tr>
<tr>
<td>8 different viewpoints</td>
<td>Pulses per CPI: 38</td>
</tr>
<tr>
<td></td>
<td>ULA elements: 12</td>
</tr>
<tr>
<td></td>
<td>Range gates: 990</td>
</tr>
</tbody>
</table>
Geometry Parameters

- Geometry dependent parameters required for simulation
  - Range to each pixel
  - Projected area of each pixel
    - Incident energy incorporates range and projected area of patch
  - Occluded pixels
    - Patches hidden from radar are removed using Z-buffer algorithm
      - Patches sorted by distance from radar
      - Any patch facing backwards or directly behind another is removed
  - Angle between platform’s velocity vector and line of sight to each pixel
Datacube Generation

• Received data from a single patch

Return from $n^{th}$ path is a random variable

$$u_k(n) \sim \mathcal{CN} \left( 0, \lambda_k(n) \sigma_n \right)$$

$$z_k = \mathbf{s}_k + \mathbf{n}_k + \sum_{n=1}^{N} u_k(n) a_k(n)$$

Return from targets

$$n_k(n) \sim \mathcal{CN} \left( 0, \epsilon I_M \right)$$

• Response at a single range gate
  – Sum over all patches in range gate
ILLUMINATION

Illumination from different looks
Scattering Function Estimation

- Prototype designed and tested first
  - Implements EM algorithm
  - Uses a Small-Scale Dataset with 554 pixels
- EM algorithm requires response vector for each pixel, in each look
  - For Small-Scale Simulation
    - 2,020,992 complex doubles
    - 30.8 MB of data
- Large-Scale Simulation contains 197,316 pixels
  - 719,808,768 complex doubles
  - 10.73 GB
Memory Reducing Techniques

• Maintain only the Doppler and spatial vectors
  – Compute Kronecker product as needed
  – Reduces requirements to 1.17 GB

• Lookup Table
  – Finely sampled table containing Doppler and spatial vectors
  – Indexed by a single value
  – Further reduces memory requirements
    • 10.64 MB when using a 10,000 entry table
The Need For Parallelism

- The EM Algorithm can be parallelized in multiple ways
  - Across looks
  - Across range gates
- Parallelism improves the algorithm
  - Significant speedup in processing time
  - Additional physical memory available
    - Only 150 MB needed per look for the response vectors
      (250 MB when all other necessary data are included)
  - More effective cache
    - Possible gain when using a Lookup Table
Parallelism Using MatlabMPI

- MatlabMPI provides parallel interface
  - Allows passing of messages between multiple systems that share a file system
- Use 9 parallel threads (1 master, 8 slaves)
  - Slaves perform iterations of the EM algorithm on a single look
  - Master provides slaves with data and collects results from each iteration
- Messages only sent at beginning and end of each iteration
Results

- **Small-Scale Simulation**
  - Provides results identical to prototype version
  - Runs 4% slower than non-parallel version
    - Computation for a single look is too fast to gain from parallelism
    - Message passing overhead too large
    - Not a problem for full-scale simulation
Results

• Full-Scale Simulation
  – Does not use Lookup Table
  – To avoid large messages, some inputs are read from disk

• Execution Environment
  – 2.4 GHz Pentium IV processors w/ hyperthreading
  – 1 GB RAM each
  – 4 nodes
Detection Example

• Two artificial targets
• In small-scale environment
• Binary detection problem
  \[ z_k = \begin{cases} 
  s_k + A_k u_k + n_k & H_1 \\
  A_k u_k + n_k & H_0 
\end{cases} \]
• Use adaptive matched filter
Adaptive Matched Filter Detector
Current and Future Work

- Completing the Full-Scale Simulation
  - Long runtimes are still a problem

- Moving Target Estimation on Full-Scale System