Performance assessment of sensors for maritime surveillance using sea trial data.

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Outline

- Maritime Surveillance program at the NATO Undersea Research Centre (NURC)
- Recent experiments
  - HF-Radar09
  - MS09
- SAR ship detection performance evaluation
The Maritime Surveillance (MS) program at NURC
Tasks & dates

- **Project tasks (started in 2007)**
  - Sensor performance assessment
  - Multi-sensor data fusion and tracking
  - Simulation, sensor suite optimization (OR study)
  - Anomaly detection

- **Characterization of sensors for MS (started at the end of 2008)**
  - Synthetic aperture radar ship detection performance evaluation
  - HF radar ship detection performance evaluation and improvement
Sensor performance assessment: goals

- Provide ship detector performance parameters to the fusion and tracking engine ($P_d$, $P_{fa}$ and positioning error)

- Provide realistic radar detection simulation to the MS simulator and help the OR study on MS

- Integrate improved and optimized ship detectors into the MS prototype system
Sensors

- **SAR:**
  - ENVISAT, ERS-2,
  - TerraSARX,
  - RADARSAT1/2

- **HF Radar:**
  - *Two WERA systems located in Palmaria Island and San Rossoree Park, Italy*
HF radar Ligurian Sea experiment
HF-radar experiment in the Ligurian Sea

- **HF radar set up**
  - Two WERA HF-radar systems operating at 12.5 MHz (~120 km range)

- **Data collection**
  - AIS
  - Acquisition of SAR images from Envisat, ERS-2, Radarsat-2 and TerraSAR-X
  - Nautical radar
  - Environmental parameters (waves, currents, wind)

- **Goals**
  - Investigation of ship detection and tracking performance
  - Testing new algorithms
HF-radar setup for ship detection in the Ligurian Sea

Operating since May 2009
HF-radar retrieved ship detections in the Ligurian (Preliminary results)
MS09: Multi-Sensor Surveillance for Op Active Endeavor and AIS Range Prediction
October 17-21: Continuous tracking in the Eastern Mediterranean

- Confirm feasibility of Multi-Sensor Tracking and Fusion
- Validation of AIS Range Prediction Tool
- Operational Assessment of Capability
Live Data Feed to MCC Naples

MS09 Viewer used for live feed to Maritime Ops Centre at MCC Naples via NURC Data Fusion Center
Persistent Tracking and Anomaly Detection

Data Collected by Alliance from 06 Oct – fused tracks for entire period

Course over Ground Anomaly

Route Anomaly
SAR ship detections of RADARSAT1
Oct20 @ 1610UTC

KANAWHA – two false detects (wake)

P230 – double collect due to vessels displacement (Doppler shift) and detecting wake
AIS Range Prediction Calibration

AIS Range Prediction for 20 Oct AM with overlay of actual Alliance AIS and entire AIS network in white.
SAR Ship Detection Algorithms

A Mathematical Morphology Detector
Algorithm

Basic Detector

- Hypothesis on input signal
  - Unknown target stats and geometry
  - Unknown clutter stats
  - Spatially variant clutter
Morpho Processing

2D Closing → 2D Opening → Background estimation

**Morphological filtering:** preservation of spatial edges

\( W \): size of filtering window (square structural element)
Test Statistic

Input Image → log

Estimated clutter level → log

Local Signal Clutter Ratio (LSCR)

Clutter is now stationary: CFAR is possible
Examples

ENVISAT-ASAR and TerraSAR-X
ENVISAT ASAR Data (I)
ENVISAT ASAR Data (II)

Basic Detector ($\alpha = 3.3$, $W = 13$)
Detected target: 9/9
False alarms: 47

Post-processing
Detected target: 9/9
False alarms: 1
SAR ship detection performance assessment

A methodology based on AIS data comparison
Methodology

AIS contact tracks → AIS contact selection → SAR Azimuth Doppler Shift Correction → SAR-AIS time shift Correction (actualization) → AIS-SAR contact association → Performance estimation

- Position error ($\varepsilon_r$)
- Detection Probability ($P_d$)
- False Alarm Probability Bound ($P_{fa}$)

SAR Bounding Box, acquisition time → SAR acquisition parameters → SAR contacts
AIS data correction and SAR contact association
Data Set

- Number of images: 120
- Images covered by AIS data: 60
- Satellite: Radarsat 2 (different acquisition modes)
### Data set acquisition mode

<table>
<thead>
<tr>
<th></th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
<th>Cluster 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampled Pixel Spacing [m]</td>
<td>12.5</td>
<td>12.5</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Beam Mode</td>
<td>EH 1-6</td>
<td>S7</td>
<td>SCN A-B</td>
<td>SCW A</td>
</tr>
<tr>
<td>Acquisition Type</td>
<td>High Incidence</td>
<td>Standard</td>
<td>Scan SAR Narrow</td>
<td>Scan SAR Wide</td>
</tr>
<tr>
<td>Polarizations</td>
<td>HH</td>
<td>HH HV</td>
<td>HH HV</td>
<td>HH HV</td>
</tr>
</tbody>
</table>
Average position error

<table>
<thead>
<tr>
<th></th>
<th>Average CEP 99% [m]</th>
<th>Mean Position Error [m]</th>
<th>Mean Standard Deviation [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Correction</td>
<td>1713</td>
<td>707</td>
<td>790</td>
</tr>
<tr>
<td>After Correction</td>
<td>425</td>
<td>175</td>
<td>92</td>
</tr>
</tbody>
</table>
$P_{fa} - P_{d}$

Data set average performance
- $PFA$ bound: 7e-005 %
- $PD$: 82 %
### Average cluster performance

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</tr>
</thead>
<tbody>
<tr>
<td><strong>Pfa Bound %</strong></td>
<td>13.7e-005</td>
<td>9 e-005</td>
<td>2.7 e-005</td>
<td>8 e-006</td>
</tr>
<tr>
<td><strong>Pd %</strong></td>
<td>92</td>
<td>79</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td><strong>Average CEP 99% [m]</strong></td>
<td>325</td>
<td>580</td>
<td>525</td>
<td>470</td>
</tr>
<tr>
<td><strong>Mean Position Error [m]</strong></td>
<td>138</td>
<td>239</td>
<td>218</td>
<td>194</td>
</tr>
<tr>
<td><strong>Mean Standard Deviation [m]</strong></td>
<td>72</td>
<td>125</td>
<td>113</td>
<td>102</td>
</tr>
</tbody>
</table>
Conclusions

- **Data acquisition during the NURC HF radar experiment in the Ligurian Sea**
  - A set of radar data, AIS and environmental parameters is available to learn, test and improve detection schemes.

- **MS09 successful in demonstrating multi-sensor data fusion in an operative scenario**

- **SAR ship detection algorithm evaluation: improve performance assessment by expanding the image database, including other sensors and acquisition modes, comparing different algos.**