Final Presentation
Thursday, July 28, 2011
Week 8

Sensor and Technology Applications in Port Security Team

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Daniel Reynolds    Samuel Otu-Amoah
Tyler Hee Wai      Enrique Questell
Presentation Outline

• SRI Objectives and Architecture
• Technology Overview
  – Near Shore Systems:
    • Acoustics, Optical with Image Processing
  – Long Range Systems
    • Satellites, AIS, HF Radar
• Data Collection Process
• Tracking Examples & Exercise
• Decision Support
  – User Interface & Resources
  – Layered Architecture
  – BOOM: Interactive Bay and Ocean Observation Management System

Stevens’ Research Vessel, RV Savitsky

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SRI Objective and Architecture

To study and address the threat of pirated ships in the MTS being used as a weapon of terror

Define the strengths and limitations of sensor technologies to detect, classify, and track vessels in, near, and approaching the urban port environment

- Satellites, HF Radar, AIS
- Acoustics, Electro-optics
- Vessel categorization, threat assessment
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Acoustic Data Collection and Processing
Stevens Passive Acoustic Detection System (SPADES)

In Water System
- Passive Acoustic Detection with four hydrophones
- Data from hydrophone acquired and recorded
- SPADES GUI
- Spectral Analysis
- Cross-Correlation Analysis
- Data pre-processed in underwater system and transmitted digitally

Land based system
- Frequency (Hz)
- Time (s)
- Boat Signal
DEMON Analysis

- **Detection of Envelope Modulation on Noise**
- Allows for classification by demodulating vessel specific noise
- Demonogram (top) shows how the spectral density of a vessel characteristic signal varies with time
- Demon Spectrum (bottom) shows the time averaged (60 s) representation of a vessel's signal in the frequency domain
Infrared vs. High-resolution video

Video taken on July 4, 2011 from Maritime Security Laboratory

**Infrared Image**
- Thermal image does not change
- Vessels can be tracked independently of light source

**Optical Image**
- Vessels are hard to track as natural light decreases (use their self lightening)
- Vessels are impossible to track w/o own light
Introducing Digital Image Processing

• Set of computational techniques for analyzing, enhancing, compressing and reconstructing images

• Applications:
  – Image Subtraction: pixel by pixel intensity subtraction between two images to form a better contrast image with the potential target
  – Image Overlay: Alignment of overlapping HR and IR images to construct one seamless composite image with more detail
  – Noise and glare reduction
  – Edge and corner detection
Image Subtraction

**Goal:** contrast enhancement (for edge detection)

Image of interest (1) is subtracted from a time averaged reference image.

Resulting image (2) is the contrast enhanced image:
- eases operator decision
- further processing
Image Processing

• Conclusions
  • Image subtraction was established as a viable surveillance technology
  • You can detect things better & nice for further processing
  • Suggests automation

• Recommendations
  • Create a database of background images sorted by significant changes in the environment
  • Fully automate the algorithm so it continually analyzes IR images
  • Make the algorithm do successful image vessel classification
  • Create a fully-functional GUI that could be integrated into a surveillance system such as BOOM
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Satellites - Introduction

**Early detection**
- Low to high resolutions
- Monitor environmental conditions
- Limited availability
- Required trained personnel to operate
- High operational cost
- Processing time depends on orbit, post-processing, and image download time

TerraSAR-X-Satellite (EADS-Astrium)

SAR image of NJ, Manhattan and Brooklyn
Types of Satellite Imaging

**Optical**
- Uses visible and infrared light
- Passive detection
- No image distortion

**Synthetic Aperture Radar (SAR)**
- Uses radio waves
- Active detection
- Higher resolution images, covering larger areas
- Flight path simulates large antenna
- Images are distorted
- Can look through clouds
- Ship wakes are more easily visible
Satellite image comparison: Optical vs. SAR

EROS-B at 18:57:00 GMT on 7/11/2011
- Clouds covering bridge
- Wakes of vessels barely visible

- No clouds
- Wakes of vessels visible
- Buildings leaning to right
Automatic Identification System (AIS)

- Tracks time and location of vessels
- Provides name, type of vessel, MMSI #, country of origin
- Class A and Class B
- Stevens, Rutgers, and Coast Guard receivers
- Compatible with Google Earth
- Only effective when AIS transmitter is turned on in vessels
Ship Identification-AIS

- Comparison of SAR Satellite image and AIS Google overlay
- SAR image taken by TerraSAR-X on 10:56:19 GMT on 7/12/2011
- Vessel's Details
  - Speed recorded (Max): 10.2 knots

Source: marinetracking.com
Vessel Detection
- Detection range: 0 to 70 km
- Detects vessels trajectory, distance and velocity
- Effective in fog and rain
- Cannot characterize type of vessel
- Requires surface disturbance
- Strong winds and lightning can damage radar
**Cross Spectral Image**
- Three plots show 2 directional loops and monopole
- Doppler spectrum determines vessels direction and speed
- Bragg Waves: ⭐ A measure of radar signals scattered by waves

**Range Cell Image**
- 95 range cells with each range cell being ~3 km long
- Three colors represent three loops, or antennae on the radar
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Data Collection Process

- AIS
- RADAR
- SPADES
- HF Radar
- Satellite

- Record and review

- Optical and IR Camera

- NYHOPS

- AIS, Radar, and Spades Map

- HF Radar Map (Google Earth)
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22:49:02 GMT on 7/12/2011
Pacific Huron

- Example of acoustic layered architecture
- AIS ID: 305535000
  - Ship Type: Cargo
  - Length x Breadth: 190 m X 25 m
  - Flag: Antigua Barbuda [AG]

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Time (GMT)</th>
<th>Distance* (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic detection</td>
<td>22:41</td>
<td>2023</td>
</tr>
<tr>
<td>Video detection</td>
<td>22:46</td>
<td>872</td>
</tr>
<tr>
<td>Satellite</td>
<td>22:49</td>
<td>646</td>
</tr>
<tr>
<td>Video loses contact</td>
<td>22:52</td>
<td>944</td>
</tr>
<tr>
<td>Acoustic loses contact</td>
<td>22:55</td>
<td>1475</td>
</tr>
</tbody>
</table>

*Distance measured from SPADES
Tracking Redundancy: Pacific Huron

Ferry Signal

Pacific Huron

SPADES

Video

COSMO SkyMed, 20110712 224902 GMT w/ Google Overlay

135 Hz 22:49:00
Detection Distances

- Acoustic detection depends on several factors
  - background noise (bridges, rain)
  - interferences from other targets (coherent noise)
- Maximum detection distance for SPADES bounded by two ferry terminals (2.5 km N, 750 m S)

Carnival Miracle: Cruise Ship
Detection: 1200 m, Loss: 1200 m

Robert Fulton: NY Ferry
Max Detection Distance: 2500 m

Thomas D. Witte: Tug Boat
Detection: 550 m, Loss 1000 m

Small Pleasure Craft
Detection: 450 m, Loss 800 m
Simulation Results - GPS Tracking route

- Pin ups represent Savitzky’s positions at time of Satellite images
- Routes also confirmed with SPADES and Video

- Savitsky confirmed with satellite image
- Savitsky not confirmed on satellite image
- Savitsky’s explosion site (confirmed)
Acoustic detection distance: 550 m at 22:48:00 GMT
Acoustics loses contact: 460 m at 22:50:50 GMT due to ferry noise from the north
Stability of Demonogram

Abraham Lincoln Ferry 7/11 19:04

Savitsky 7/11 11:51

Douglas B Guarin Ferry 6/30 20:34

Savitsky 7/11 11:59
# DEMON Spectra Classification

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Fundamental Frequency range [Hz]</th>
<th>1st Harmonic [Hz]</th>
<th>2nd Harmonic [Hz]</th>
<th>3rd Harmonic [Hz]</th>
<th>Other frequency [Hz]</th>
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<tr>
<td>Small cruise</td>
<td>5-6</td>
<td>10-12</td>
<td>15-18</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Tanker</td>
<td>4-6</td>
<td>8-12</td>
<td>n/a</td>
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</tr>
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<td>Tugboat</td>
<td>14-20</td>
<td>28-40</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Pleasure boat</td>
<td>88-97</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>154-172</td>
</tr>
<tr>
<td>34 foot Zurn</td>
<td>81</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>141,222</td>
</tr>
<tr>
<td>Jet Ski</td>
<td>26</td>
<td>53</td>
<td>79</td>
<td>105</td>
<td>n/a</td>
</tr>
</tbody>
</table>

![Small cruise](image1.png)

![Tugboat](image2.png)
Engine Speed Effects on DEMON Signature

- DEMON analysis gives us a signal which is dominated by the engine and propellers
- As the engine speed changes, the DEMON spectra will as well
- Signatures show that the vessel dependent frequencies change proportionally when the engine speed changes

Unknown Boat 6/30 18:57.
Peaks change by a factor of .72

Unknown Boat 6/30 18:42.
Peaks change by a factor of 1.08
Near Shore Technologies

• Conclusions
  – SPADES is a reliable system in tracking vessels of interest (real time!) in the absence of dominant noise (i.e. other vessels or rain)
  – Successful in detection, tracking and classification

• Recommendations
  – Add 2nd set of hydrophones to obtain distance information
  – Assess accuracy of system (w/ known vessel positions)
    • Variations in Sound Speed, Positioning of the Array
  – Detailed study of DEMON stability (separate a particular signal in the presence of other signals)
Long Range Tracking: HF Radar

Cross-spectra, 10:10:59 GMT on 7/19/2011

Ship Detection GUI, 10:20:00 GMT to 11:10:00 GMT on 7/19/2011
Long Range Tracking: AIS and Satellite (SAR)

AIS data overlaid onto Google Earth, 10:13:45 GMT on 7/19/2011

Satellite image taken by COSMO-SkyMed, 10:13:06 GMT on 7/19/2011

Joan Moran (MMSI # 368669000)  Miss Gill (MMSI# 367122680)
Long Range Tracking: Complimenting HF Radar with AIS

Cross-spectra, 18:24:58 GMT on 7/26/2011

AIS data overlaid onto Google Earth, 18:26:59 GMT on 7/26/2011
Long Range Technologies

• Conclusions
  – Best used in a layered approach
  – Successful in detection, not identification
  – Good for port security because:
    • Satellite gives a large overview of the area
    • Good tools to display post effects (i.e. oil spill)
    • HF Radar can see over the horizon, “eyes”

• Recommendations
  – Add higher frequency HF RADARs to the area of interest
  – Make the technology real time
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Putting It All Together
How To Make Sense of Sensor Information

Common Operational Picture

Inform The User
Who Uses Sensor Networks?

Law Enforcement:
United States Coast Guard

Problem:
Vessels without AIS

Needs:
- Tracking
- ID or Classification

Emergency Response:
OEM & First Responders

Problem:
No Modeling Input Data

Needs:
- Visual Information
- Vessel Information

CLASSIFICATION
Contact ID and Assessment Process

CONTACT!

Classify Vessels Without AIS

Vessels With AIS

Threat ID
How do you get from this...

Multisource Data Interpretation:

Demon Spectrum

Blurry Camera

HF Radar Screen

HF Radar, Speed and Range

Vessel Specifics

...to This?
Process Breakdown:

**Contact:**
- Fundamental Frequency: -88Hz

**Small Recreational Vessel**
- Length: 20-50’
- Draft <4’
- Beam: 6’

**Suspicious:**
- Should It be Broadcasting AIS?
- Is it Where Expected?
- Is it Acting as Expected?
Decision Support

• Conclusions
  – Generated BOOM as a GUI that allows the user to select which technologies to integrate into an interactive map
  – Decision Support Database providing consistent vessel classification and target identification

• Recommendations
  – Continue to define the operational boundaries of each type of vessel
  – Ensure that there is a ‘memory’ of the work conducted this year to provide a foundation for future research programs
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Bay and Oceanographic Observation Management System (BOOM)

Integration of sensor displays

Law enforcement official

BOOM

Acoustic
HD cameras
CODAR
RADAR

DETECTION SYSTEMS

Data Fusion

Laboratory setting

Single Integrated display
Layered Architecture

- **SPADES**
  - max detection range: 2.5 km
  - usual detection range: 1.2 km

- Coverage hole in the layer between SPADES and HF Radar

**Satellite Overlay**

**RADAR coverage**

**HF Radar coverage**

**HD Camera coverage**
BOOM!: Interactive Bay and Oceanographic Observation Management System

- AIS
- SPADES
- NYHOPS
- MACOORA
- RADAR
- Satellite
- Coverage Zones
- Live Feeds
Thank you for your time!

Are there any questions?

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Example Image Overlay

Original HR Image

Overlaying Image

Original IR image
IR Imaging Overview

- All objects radiate thermal energy
  - As the temperature increases, the amount of thermal energy increases while the peak wavelength of the radiated energy decreases

- IR cameras detect radiated energy, NOT Temperature
  - Heat energy is emitted by the object so no light or heat source is needed
  - Emissivity is a characteristic of the material. Two objects at the same temperature can emit a different amount of energy and thus appear different on an IR image

Aluminum emissivity of 0.1, Electrical tape emissivity of 0.95.

IR represents the wavelengths slightly longer than visible
Image Processing for Detecting Multiple Targets
Acoustic Data Collection & Processing

**SPADES**
Stevens Passive Acoustic Detection System

Data from hydrophone acquired and recorded

Data pre-processed in underwater system and transmitted digitally

**NEW BUOY**
Graphical User Interface

**Spectral Analysis**

**Cross-Correlation Analysis**

**Signature Analysis**

**Demon Spectrum**

**Cross-Correlogram**

**Circular Cross-Correlation**
## DEMON Spectra Classification

### Circle Line Cruise Ship

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<td>95-109</td>
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## Appendix 2: Stability of Savitsky Signal

<table>
<thead>
<tr>
<th></th>
<th>Peak</th>
<th>49.8 Hz</th>
<th>99.1 Hz</th>
<th>148.9 Hz</th>
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<tbody>
<tr>
<td>Savitsky 1</td>
<td>Relative Intensity</td>
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## Appendix 3: Engine Speed Effects

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<th>1st Frequency (Hz)</th>
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<th>3rd Frequency (Hz)</th>
<th>4th Frequency (Hz)</th>
<th>5th Frequency (Hz)</th>
<th>6th Frequency (Hz)</th>
<th>7th Frequency (Hz)</th>
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<th>9th Frequency (Hz)</th>
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<td>1</td>
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<td>25</td>
<td>100</td>
<td>175</td>
<td>83.5</td>
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<td>78</td>
<td>137</td>
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## Ten Satellite Flyovers

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<td>COSMO-SkyMed</td>
<td>SAR</td>
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<tr>
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<td>11:13:25</td>
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</table>
SAR: Image Distortion

- Beam reaches top of target before it reaches its bottom
- Image appears compressed
Ship Identification-Wakes

- Large vessels are easy to see
Types of Satellite Imaging

- Optical
  - Passive
  - Uses visible and Infra-Red light

- Synthetic Aperture Radar (SAR)
  - Active
  - Flight path simulates large
Long Range Flow Chart

- AIS
  - Transas AIS
  - USCG AIS
  - Rutgers AIS
  - Google Earth
  - Ship Detection GUI

- CODAR
  - Surface Velocities and Vessel Detection
  - Microwave signals hit water surface and ships
  - Seabright Website
  - Tools for viewing raw data
  - Tools for interpreting processed data
  - Range Cells
  - Spectral Images
  - Timbuktu

- Bearing, Velocity and Range
  - SNR
  - Manipulating SNR that can be viewed by tools
  - Filters
  - Threshold
Threat ID: Check For Normal Behavior
User Information Tools

How do you get from this…

89 Hz

Demon Spectrum + Blurry Camera Image + HF Radar Screen

HF Radar – Speed and Range

…to This?
Bay and Oceanographic Observation Management System (BOOM)

Integration of sensor displays

Law enforcement official

Laboratory setting

Acoustic HD cameras

CODAR RADA R

DETECTION SYSTEMS

Data Fusion

Single Integrated display