Optimal Detection of Surface Drifting Mine with Navy Ocean Model

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Purpose

• To provide methodology for optimizing locations of stationary sensors and UUV path planning intended for drifting mine detection using Navy ocean model
Specific Requirements

- Estimations of target movement

- Optimal sensor numbers (or number of UUVs)

- Optimal sensor locations (or UUV locations)
Hampton Roads Inlet

- Within 3nm of Norfolk Naval Base
- Hampton Roads—world’s leading bulk cargo harbor.
  - 150,000 – 500,000 barrels of petroleum in and around Hampton Roads biweekly
- Six military tankers (7.5 million gallon capacity) home-ported in Norfolk
Physical Processes in Hampton Roads Inlet

- Tides
- Freshwater
- Surface Winds
- Water Levels
- Waves
- Water Temperature
- Salinity
- Currents
River-Estuary-Ocean (REO) Interactions
Prediction of Mine Drifting

6 DOF Model

\[ m \frac{dV}{dt} = (\rho \Pi - m) g \mathbf{k} + f_{\text{drag}} \mathbf{e}_d + f_{\text{lift}} \mathbf{e}_l \]

\[ \mathbf{I} \cdot \frac{d\Omega}{dt} = r_v \times f_b + r_f \times (f_{\text{drag}} + f_{\text{lift}}) + \mathbf{M}_r \]

\( \mathbf{V} \rightarrow \text{Mine Drifting Velocity} \)

\( \mathbf{\Omega} \rightarrow \text{Mine Angular Velocity} \)
Definition of \((f_{\text{drag}}, f_{\text{lift}}, M_r)\)

\[
f_{\text{drag}} = \frac{1}{2} C_d \rho A_w (V - V_o)^2
\]

\[
f_{\text{lift}} = \frac{1}{2} C_l \rho A_w (V - V_o)^2
\]

\[
M_r = \frac{1}{2} C_m \rho \Pi_w (V - V_o)^2
\]

\(V_o \rightarrow \) Ocean Velocity (from Navy Ocean Model)

\(\Pi_w \rightarrow \) Underwater volume

\(A_w \rightarrow \) Underwater area
Ocean Modeling

Observations → Global → Regional → Coastal

3D, Full Physics, Data Assimilating, Dynamic, Forecast Models

COAMPS

NOGAPS

Global NCOM

Delft3D

NCOM

US-East NCOM

Water Temperature at 0m for 03 Mar 2009 00:00 Z
Real-time

• Current
• T & S
• Waves
• Surface Elevation

NAVO Coastal Model - Delft-3D

MIW – EXW – HLS: Port & Estuarine Modeling

Horizontal resolution 10-100 m or less
Delft3D - Chesapeake Bay

- Operational Model at NAVO
- Acting as a nested model, its flow forced at open boundaries by:
  - Temperature
  - Salinity
  - Velocity
  - Water level
  Provided by the USEAST Regional NCOM
- Local wind stress input forces flow at the free surface: COAMPS
- Tidal forcing
Ocean Velocity
Prediction of Mine Drift Trajectory

• July 28 – August 30, 2011

• Delft3D $\rightarrow$ Ocean Velocity $(u_o, v_o)$

• Mine Drift Model $\rightarrow$ Mine Position $(x, y)$
  $\rightarrow$ Mine Trajectory
Optimal Sensor Grid - Formation

Sensor Grid Location, Sensor Index Numbers, and Drifter Start Box

Uncertain Mine Location Inside the Box
Monte-Caro Simulation of Mine Trajectories
Procedures of the Monte-Carlo Simulation

- All drifters started with randomly selected position (Normal Distribution, Matlab) within 2 x 1.6nm (3.7 X 3 km) box

- Box located 0.75nm (1.4 km) east of Fort Wool

- 10,000 simulated drifters permitted to run at beginning of flood tide each day

- Flood period ~3hrs
# Flood Period

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<th>Flood Time Period</th>
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<td>19Z – 22Z</td>
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Trajectories of Drifting Mines
Optimal Sensor Grid

• Sensors are hypothetical and ideal:
  – Modeled as perfect upward looking sonar systems
  – Circular detection footprint on the surface (radius = 100 m)
  – Drifting mines will be called if they enter the footprint

• Each drifter will only be called once
Probability of Detection
Probability of Detection - Assumptions

• Positive detection if drifter within radius for 5 seconds or more

• Based solely upon the three hour flood period
Probability of Detection – Ranking Sensors

• After 3hr flood period, ranking process of sensors
  – Sensor with the highest number of detections, “lead sensor” (or “best location” for UUV)
  – 2nd highest detections, not called by the lead sensor, “second place sensor”...
  – continued until all drifters that flowed through the grid were counted
Probability of Detection – Sensor Detection Probability

• number of drifters each sensor called, not previously called by other sensors, divided by 10,000

• Equaled zero if:
  – All of the drifters were previously called
  – Not a single drifter flowed through its radius
Optimal Deployment of Stationary Sensors – Results
Optimal Deployment of Stationary Sensors – Sensor Location*

Sensor Detection Probability (28JUL2011) - Normal
Optimal Deployment of Stationary Sensors – Sensor Number*

*Optimum sensor number – average value for 99% of total probability

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• 8 sensors for Normal (99% of total prob)
Conclusions

• Navy ocean model → methodology for optimizing stationary sensor employment in an inlet

• The results can be used for UUV path planning to get optimal detection
QUESTIONS?