Modeling the Interaction of a Laser Target Detection Device with the Sea

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Low Level & Embedded Threats

- Threat proximity to sea surface a challenge for the TDD
  - Sea skimming missiles close to sea clutter
  - Fast Inshore Attack Craft (FIACs) embedded in sea clutter
- Clutter reflections difficult to differentiate from target
  - Can be similar range and amplitude
- Analysis of TDD performance requires representative models of sensor interaction with the sea surface

![Diagram of Sea Skimming Missile and Boston Whaler with rocket launcher]
TDD Sensor Options for Low Level Threats

- TDDs for low level applications have historically employed Radar and/or Passive IR sensor technologies
  - Mature and validated models have been developed for simulation of the interaction of these sensors with the sea surface
- Active IR (laser) sensors offer an attractive alternative for reasons of detection precision and cost
  - Semiconductor laser sources in near IR
  - To date have not been employed in low level roles due to the uncertainty of their response to the sea surface
  - Absence of validated models with which to quantify the interaction
Multiple Fan Beam Laser Sensor TDD

- Multiple fan beams provide full azimuth coverage
  - Beam geometry approximates to a hollow cone
    - Forward looking with a semi angle to ~60°
    - Good match fragmenting warhead dynamics
  - Each fan a miniature Lidar able to measure range (time of flight)
    - Based on near IR pulsed semiconductor laser emitter technology and silicon pin diode receivers
  - Emphasis on use of low cost COTS opto-electronic components

Example 8 beam configuration

Side view

Nose on view
Multiple Fan Beam Laser Sensor TDD

- Part of the Thales ‘Modular Vision for Future Target Detection Device Technology’ briefed last year
  - Re-use of common signal processor and other key components
- TRL5/6 hardware demonstration of fan beam laser TDD
  - Subject of UK research over past 5 years

Product now in full development
- Body mounted configuration (ϕ<80mm)
- Designed for volume manufacture
- Extensive use of low cost moulded optical elements and mechanical parts
- Light weight
- Fully re-programmable
- Development and qualification planned to complete by end 2010
Laser Sensor Interaction with the Sea

- Operating at near IR wavelength ($\lambda \sim 0.9\mu m$)
  - Imaginary component of refractivity ($k$) very small
  - Bulk absorption high hence volume backscatter can be ignored
  - Real component of refractivity ($n$) $\sim 1.33$ can be used to estimate surface reflectivity ($\rho$) using Fresnel
  - Only incident angles close to normal are of interest
    - Small sensor bistatic angle
    - Fresnel equations simplify
    - Reflectivity $\sim 2\%$

\[
\rho \approx \left( \frac{(n - 1)}{(n + 1)} \right)^2 \approx 0.02
\]
Laser Sensor Interaction with the Sea

- **Active IR (laser) sensor response to sea ‘intermittent’**
  - Sea surface behaves like a rippled mirror with a 2% reflectivity
    - Strong reflection if surface elements intersect beam near normal
    - Very low response if illuminated surface not close to normal
    - Response depends upon complex geometry of beam and rippled shape of sea surface
  - White caps can present a diffusely scattered signature
    - Detected over a broad range of illumination angles

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*Image: Diagram showing the interaction of laser beams with the sea surface.*
Modelling the Sea Surface

Sea surface modelled as an array of small 2% reflectors
- Contiguous surface comprising non planar facets
  - 5mm x 5mm (or smaller)
- Arranged to represent 3D geometry of sea surface
- Model shares origins with existing radar TDD interaction model
  - Smaller facets due to much shorter wavelength (~1\(\mu\)m versus ~10cm)
  - 64bit PC with large memory capacity used to run analyses (slowly)

TDD sensor interaction model
- Multiple fan beam geometry modelled
- Defined engagement trajectories
- Intersection of beams with 3D sea model
- ‘Pulse by pulse’ response modelled
- Summation of reflected pulse components from multiple facets computed
Modelling the Sea Surface

- Model uses wave spectrum proposed by Elfouhaily
  - Both gravity & surface capillary waves modelled
  - Capillary waves (e.g. $\lambda <$25mm) significant at laser wavelengths

- Parameters adjusted to vary sea conditions
  - Fetch
  - Wind speed & Direction
  - Resolution (e.g. 5mm)
  - Patch Size

- Wide variety of sea conditions modelled
  - Case shown a 80m by 80m patch, 12m/s wind, 500km fetch
Modelling Sensor Response to the Sea

- Sea surface modelled as a regular grid of heights
  - Height at each vertex derived using the Elfouhaily spectrum
  - Characteristics of each element calculated from adjacent vertices
    - Normal vector of each element
    - Radii of curvature in two orthogonal axes

- Intersection of beams with grid
  - Shot lines calculated to each element
  - Occurrences of surface normals found
  - Incremental contributions to pulse responses determined from:
    - Sensor parameters (e.g. power, etc)
    - Element radii of curvature
  - Repeated at Pulse Repetition Rate
Initial Pencil Beam Laser Sensor Trials

- **Pulsed laser sensor**
  - Narrow beam width <1°
  - Sensitivity calibrated
- **Mounted on bows of vessel**
  - Beam viewing sea surface ahead of wake
  - Adjustable pitch & roll angles
  - Adjustable height
  - Vessel speed ~13 knots
  - Wind speed/bearing recorded
- **Threshold crossings recorded**
  - Fair correlation with model
  - Provided initial validation

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<thead>
<tr>
<th>Metric</th>
<th>Trials Value</th>
<th>Model Value</th>
<th>Comment</th>
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<tbody>
<tr>
<td>Detection rate %</td>
<td>~30%</td>
<td>~34%</td>
<td>~ 6kt wind</td>
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</table>
Model Validation – Sea Data Gathering

Multiple Fan Beam Laser Sensor Trials

- Experimental form of future TDD
  - Four 30° contiguous fan beams
  - Partial azimuth coverage (only downward beams see reflections)
  - Received pulse waveforms digitised
  - Data recorded for various sensor orientations and sea conditions

Example of Sector 3 pulse responses
Model Validation – Analysis

Detection rate (%) Averaged over Multiple Cases

<table>
<thead>
<tr>
<th>Sensor Height</th>
<th>Fan Beam Angle from Vertical (°)</th>
<th>0°</th>
<th>10°</th>
<th>20°</th>
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<tbody>
<tr>
<td></td>
<td>Trial</td>
<td>Model</td>
<td>Trial</td>
<td>Model</td>
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<tr>
<td>3.4 m</td>
<td>89</td>
<td>93</td>
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<td>5 m</td>
<td>80</td>
<td>91</td>
<td>83</td>
<td>39</td>
</tr>
</tbody>
</table>

- Fair agreement between Model and practise
- Good comparison between modelled and observed detection rates
- Fair comparison between predicted and observed pulse amplitude distributions

Example of observed peak amplitude response (Sector 3)
Model Applications – Anti FIAC Algorithms

- **FIAC targets modelled**
  - 3D facet models
    - Diffuse Lambertian reflectors
  - Embedded in sea clutter models
  - Various dive angles modelled
  - Combined response to target and clutter modelled

- **Algorithm development**
  - Sea clutter rejection
  - Reliable target detection
  - Initial algorithms constructed and tested
  - Initial results encouraging
  - Validation in progress
Example Model Output – Case of Horizontal Trajectory

- Sector 1 - Red
- Sector 2 – Green
- Sector 3 – Cyan
- Sector 4 – Magenta
- Sector 4 – Black

- Sea Surface Only
- Target Present

First target facet enters beam
Target detection
Model Applications – Anti FIAC Algorithms

Example Model Output – Case of Diving Trajectory

Sector 1 - Red
Sector 2 – Green
Sector 3 – Cyan
Sector 4 – Magenta
Sector 4 – Black

Sea Surface Only
Target Present

Range from Missile (m)

Time in Flight (ms)

First target facet enters beam
Target detection
Recent ‘AFIAC’ Sea Data Gathering Trial

- Sensor deployed on boom to one side of vessel
- Rib ‘target’ travelling at speed under / to one side of sensor
  - Provides representative wake data
  - Data to be used for validating models and developing algorithms

30 knots

15 knots

30 knots

Land Defence

THALES
A model for the response of a multiple fan beam laser TDD to the sea surface has been developed

Initial data gathering and model validation performed
- Received signal levels estimated by the model compare favourably with those of the trials data
- The predicted variability of the signal returns from the sea appears to be confirmed by the trials

Facility to embed targets in scene
- e.g. FIACs and sea skimming missiles
- Supports the development of a lidar sensor TDD for Anti FIAC and anti Sea Skimmer missile applications
Any Questions ?