UNDERWATER CHANNEL CHARACTERIZATION FOR SHALLOW WATER MULTI-DOMAIN COMMUNICATIONS

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Funded by:
Problem definition for research project

• Simulation of an underwater acoustic channel with environmental parameters supplied to Bellhop to predict performance of an underwater channel, simulations focussed on Bedford Basin, Canada - shallow water with muddy bottoms at various water depths.

solution: Bellhop modeling

• Provides an estimated operating range and depth for UUV+ deployment for simulations on multi-domain marine robots communications for above and below-water surveillance and characterization of floating marine objects.¹

¹ unmanned underwater vehicle

Figure 1: Robotic multi-vehicle collaboration – above and below water [7]
Simulation objectives (1 / 2)

• concept of operation: heterogeneous marine robots (unmanned underwater vehicle (UUV), unmanned surface vehicle (USV), and unmanned aerial vehicle (UAV)) collaboratively acquire situational awareness on a floating target

• analyze impact of channel characteristics on underwater communications

Figure 2: Bathymetry of Bedford Basin - Halifax, Canada
Simulation objectives (2 / 2)

• prior to deploying robots, predict communication system performance

• provide guidance on best physical layout to deploy underwater vehicles

• provide estimates on parameters for link budget calculation

Figure 3: sound-speed profile of Bedford Basin used for simulation test cases
Bedford Basin bathymetry used for simulation cases

Figure 4: Detailed Bathymetry of Bedford Basin - Halifax, NS, Canada
# Relevant References from Literature Survey

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Title</th>
<th>Authors</th>
<th>Published in</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
<td>Simulation and experimentation platforms for underwater acoustic sensor networks: Advancements and challenges(^1)</td>
<td>Hanjiang Luo, Kaishun Wu, Rukhsana Ruby, Feng Hong, Zhongwen Guo, and Lionel M. Ni.</td>
<td>ACM Comput. Surv. 50, 2, Article 28 (May 2017), 44 pages</td>
</tr>
</tbody>
</table>
Methodology (1 / 3)

• Custom MATLAB based GUI+ is being used collaboratively for simulation of various test cases.

Figure 5: Heterogeneous marine sensor network architecture

Figure 6: Software framework
Methodology (2 / 3)

• GUI used MATLAB App building Toolbox, planning to open source it soon to the community.

Figure 7: Ray Tracing from Underwater Ray Tracing Toolbox – MATLAB custom GUI

Figure 8: Transmission loss from Underwater Tracing Toolbox – MATLAB custom GUI
Methodology (3 / 3)

• GUI used MATLAB App building Toolbox, planning to open source it soon to the community.

Figure 9: Ray Plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox

Figure 10: TL plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox
Figure 11: File structure of Underwater Ray Tracing Toolbox

Figure 12: File structure of Underwater Plotting Toolbox
Bellhop Simulation Results (1 / 3)

Table 2: System parameters to simulate

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
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<tr>
<td>frequency</td>
<td>25 kHz</td>
</tr>
<tr>
<td>water depth</td>
<td>50, 100 m</td>
</tr>
<tr>
<td>range</td>
<td>0-6 km</td>
</tr>
<tr>
<td>USV uw modem depth</td>
<td>1.8 m</td>
</tr>
<tr>
<td>UUV depth</td>
<td>10 m</td>
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</table>

- from predicted transmission loss to determine the optimal range (function of water depth, UUV depth = 10 m)

Figure 9: Ray Traced and TL with water depth = 50 m

Figure 10: Ray traced and TL with water depth = 100 m

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Table 3: System parameters to simulate

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<tbody>
<tr>
<td>frequency</td>
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<tr>
<td>water depth</td>
<td>150,200 m</td>
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<tr>
<td>UUV-USV range</td>
<td>0-6 km</td>
</tr>
<tr>
<td>USV uw modem depth</td>
<td>1.8 m</td>
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<td>UUV depth</td>
<td>10 m</td>
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- from predicted transmission loss can determine the optimal range (function of water depth, UUV depth = 10 m), 0 – 6 km range)
Bellhop Simulation Results (3 / 3)

Table 4: System parameters to simulate

<table>
<thead>
<tr>
<th>parameter</th>
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<tr>
<td>frequency</td>
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<tr>
<td>water depth</td>
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<td>UUV-USV range</td>
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<tr>
<td>UUV depth</td>
<td>3 m</td>
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</table>

- from predicted transmission loss can determine the optimal range (UUV depth = 3m, UUV-USV range = 0 – 2.2km)

Figure 13: Transmission loss at water depth = 200 m starting from top left corner - for ranges: i) 100 m; ii) 200 m; iii) 500 m; iv) 1 km; v) 1.5 km, and vi) 2.2 km
More test cases explored using ARLPY toolbox (1 / 5)

Figure 14: For water depth = 20 m; Tx=5m; Rx= 10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) coherent TL [9]

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More test cases explored using ARLPY toolbox (2 / 5)

Figure 15: For water depth = 20 m; Tx=3m; Rx=10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]
More test cases explored using ARLPY toolbox (3 / 5)

Figure 16: For water depth = 20 m; Tx=3m; Rx= 6m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]
More test cases explored using ARLPY toolbox (4 / 5)

Figure 17: For water depth = 20 m; Tx=3m; Rx=10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL \(^9\)
Figure 18: For water depth = 20 m; Tx=3m; Rx= 3m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL \[9\]
Conclusion (1 / 2)

- simulating several underwater networks test case, it was observed that for the given environmental conditions, feasible range between UUV and USV as less than or equal to 1.3 km.

- this tools were important part of any project in-which a real time uw-network operational range are critical parameter of the mission.

Video 1: Gazebo simulations experimental validation of all 3 marine robots in the.
Integration of hardware-in-loop simulator for multi-domain marine robots may increase the complexity.

Figure 18: All 3 marine robots in the experimental validation. The USV is left in the foreground. The surfaced UUV is right in the foreground. The barge is behind both. The UAV is left of the barge. On the wall, the red LED rings are 3 of the 8 motion capture cameras installed in the Aquatron Pool tank. [6]

Figure 19: starting from left (a) Flexview sonar imaging of the barge underside from the IMOTUS UUV, (b) Optical camera photogrammetry reconstruction of the barge topside with the Pelican UAV on top of the bottom-side sonar (isometric view). [6]
Questions?

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References


References


