Cooperative Mid-Depth Navigation Aided by Ocean Current Prediction
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ABSTRACT
A current-aided inertial navigation framework is proposed for small autonomous underwater vehicles in long-duration (>1 hour), mid-depth operations; this strategy mitigates dead-reckoning uncertainty of an inertial navigation system by comparing the estimate of local, ambient flow velocity with preloaded ocean current forecast maps; this navigation system is implemented through a marginalized particle filter; opportunistic information fusion among neighboring vehicles is achieved through covariance intersection to further improve the navigation accuracy.

KEY RESULTS

<table>
<thead>
<tr>
<th>Flow Field Type (simulated / real)</th>
<th>Navigation Duration</th>
<th>INS Grade</th>
<th>Uncertainty per Distance Traveled</th>
<th>Number of Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double-gyre</td>
<td>6 hours</td>
<td>Industrial</td>
<td>3.0 %</td>
<td>1</td>
</tr>
<tr>
<td>Meandering-jet</td>
<td>6 hours</td>
<td>Industrial</td>
<td>7.3 %</td>
<td>1</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>6 hours</td>
<td>Industrial</td>
<td>8.0 %</td>
<td>1</td>
</tr>
<tr>
<td>Multi-gyre</td>
<td>25 hours</td>
<td>Tactical+AHRS</td>
<td>25.0 %</td>
<td>1</td>
</tr>
</tbody>
</table>

PROBLEM STATEMENT
Mid-depth navigation techniques for long-range AUVs are much less developed.

FLOW-AIDED NAVIGATION
- Preload ocean current forecast maps before deployment of the vehicle;
- Vehicle estimates position and velocity using an inertial navigation system (INS);
- Vehicle estimates flow velocity with an acoustic Doppler current profiler (ADCP);
- Compare local flow velocity estimate against preloaded forecast current maps;
- Vehicle updates the likelihood of position hypotheses to correct navigation error.

EXPERIMENTAL ANALYSIS
- Simulated experiment based on field test data from survey project GOMECC-2;
- The survey vessel was equipped with an ADCP (Ocean Surveyor 75 kHz);
- Ocean current estimates were produced by the HYCOM + NCODA Gulf of Mexico 1/25 degree Analysis (GOM0.04/ exp 31.0);
- INS samples were generated based on industrial/tactical-grade INS;

MARGINALIZED PARTICLE FILTER
- Particle filter (PF) state: $x_k^{PF} \equiv [x_k^{PF}, \dot{x}_k^{PF}, \theta_k] \in \mathbb{R}^{3}$ (location)
- Extended Kalman filter (KF) states: $x_k^{KF} \equiv [x_k^{KF}, \dot{x}_k^{KF}] \in \mathbb{R}^{3}$ (INS)

SIMULATION RESULTS
- A turbulent multi-gyre flow field was created to simulate the ocean current field;
- The turbulent component was generated through Kinematic Simulation (KS);
- Four vehicles followed prescribed trajectories while performing flow-aided navigation and opportunistic information fusion.

EXPERIMENTAL RESULTS
- Navigation performance for longer duration with tactile-grade INS and AHRS:

COOPERATIVE NAVIGATION
- Flow-aided navigation was implemented on the individual level;
- Opportunistic information fusion among AUVs by Covariance Intersection (CI);
- Relative locations were measured based on Time of Arrival (TOA) and phase shift.

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