Integrating Autonomous Underwater Vehicle Capability into Hydrographic Operations

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Canadian Hydrographic Conference

18 May 2016

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1. **Introduction to the Littoral Battlespace Sensing-Autonomous Underwater Vehicle (LBS-AUV)**

2. Operational methods required to meet hydrographic standards

3. **Understand the function of the onboard sensors**

4. **Horizontal and Vertical accuracy methods**

5. **Calibration and Mission Planning**

6. **Overall process flow**

7. **Conclusions**
Emphasize bathymetric data collection to support hydrographic and mine warfare survey requirements

**REMOTE ENVIRONMENTAL MONITORING UNITS (REMUS) 600**

Developed with the shallow water Kongsberg EM3002 multibeam sonar and positioning capability to meet stringent accuracy requirements
Survey Operation

- Ship Survey Area
- REMUS600 Mission with 7 Sorties
- HSL Survey Area

SURVOP
Mission Planning Parameters

Parameters to consider include:

• the sortie duration (in time and distance)
• vehicle altitude and swath width
• number of lines and turns
• where and how many UTP transponders are needed (for position updates)
• orientation of lines
• frequency of position updates
• speed of advance
• water depth
• vehicle altitude
• maximizing swath width, and other factors
Acoustic Positioning

• Long Baseline multiple transponders of known locations are pinged and those slant ranges are used to triangulate the vehicle position

• Ultra-Short Baseline (USBL) range and bearing measurements are obtained between a single transducer on a surface vessel, such as the High Precision Acoustic Positioning System (HiPaP) and the vehicle multi-element transducer
**Underwater Transponder Positioning**

- **Complement to USBL acoustic positioning**
- **Key:** tight integration between the range measurements and the inertial navigation system significantly improves the real-time accuracy
- **As few as one UTP transponder can be deployed, centrally located**
- **Deploy multiple transponders to increase range of survey area**
- **Position error increases between position updates; drift limit controls line length**

*Covariance ellipse of position error compresses in vicinity of UTP transponder*

Inertial navigation degrades, or drifts, very rapidly with distance from the last known location.

Inaccurate vehicle velocity and heading are the primary obstacles to position accuracy.

Doppler Velocity Log provides an independent and reliable measurement of the vehicle velocity to aid the INS in detecting and mitigating the inertial measuring unit (IMU) velocity error.

http://www.rdinstruments.com/navigator.aspx
• Vehicle must encounter a position update BEFORE exceeding the allowable cross-track error

• Max. *drift limit is primary parameter affecting length of the lines* and transponder placement
Mission Pattern

- Maneuvering has a significant impact on the drift error
- Velocity error in the IMU becomes observable when the measured acceleration can be compared to the predicted centripetal acceleration
- Cancelling effect increases for shorter lines with turns

<table>
<thead>
<tr>
<th>Position error drift (%) of traveled distance</th>
<th>Straight line</th>
<th>Straight line with 360° turns every 5 km</th>
<th>Lawn mower pattern with 1 km lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Along track</td>
<td>0.11%</td>
<td>0.05%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Across track</td>
<td>0.03%</td>
<td>0.02%</td>
<td>0.001%</td>
</tr>
</tbody>
</table>


Testing has demonstrated position drift of 0.1% of distance travelled or 1m per kilometer! Remember this number!
• Ensure 2km position update radius is commensurate with the specific environmental conditions
• The transponders positioned with the HiPaP
• Position drift error bounds the survey line length (0.1% dist. travelled, or 1m/km)
Real Time Position Accuracy: NavP

- Rigorous real-time navigation solution provided by Kongsberg Navigation Processing Suite (NavP)
- Provides complete time synchronization and integration of onboard navigation and environmental sensors
- NavP can be remotely initialized, monitored, and supplied with surface position via modem
- Uses the tight coupling between the INS with the UTP as well as all navigation and environmental sensor inputs
- Real-time Kalman filter improves the best accuracy for position

Backward/forward processing can significantly improve the final solution.

Navigation Laboratory (NavLab) is a powerful and versatile tool to estimate the vehicle’s position, attitude and velocity.

NavLab uses all measurements and applies the optimal smoothing algorithm in the NavLab Kalman filter.

Position accuracy data from the 2011 test period in Sidney, Canada show DVL-aided INS (without UTP) before and after post-processing.

Saw tooth pattern of error (blue line) is typical where position error ramps up rapidly from known positions, and then falls sharply when an updated position is obtained or as a result of vehicle maneuvers.

[3] Cronin, Doug, Dave Small, Shannon Byrne, 20-24 February 2012, New Zealand
GPS Buoy: records changes in water levels relative to the ellipsoid; tide data must be continuous throughout AUV operations

Liquid Robotics Wave Glider SHARC (Sensor Hosting Autonomous Remote Craft): long-duration Unmanned Surface Vehicle (USV) that utilizes wave energy for propulsion and solar panels for energy; in addition to sending position updates to AUV, can act as a GPS buoy

Virtual Tide Corrector (VTC) from nearby vessel: promising technique under development


Challenge: Measure tides without land-based tide gauge!
**Cal1:** Bias in pressures between vehicle and deck-mounted barometer

Barotroll mounted at deck level

Weatherpak mounted on mast

**Cal2:** Multibeam Patch Test for sensor alignment error

Calibrations required prior to data collection!
Advantage of the AUV data collection

- Vehicle stays at constant height
- Swath width remains the same whether the depths grow deeper or shallower.
- Up and down slope vice parallel to depth contours
- No data gaps between swaths; very efficient

Entire swath constant 120m
Vehicle stamina: 24 hours
During 20 hours on-line, six lines of data can be acquired each sortie
Multiple sorties may be stacked to reduce the amount of transponder repositioning
• Cross-line data should be the most accurate available

• QC tool: collect first so routine processing of main-line data is evaluated as the mission progresses

• Cross-line placement near the transponder(s) is the obvious location
Increased survey manning to 3 Lead Positions from Hydrographic Department
Conclusions

1. NAVOCEANO is flagship for implementing US Navy unmanned capabilities

2. UTP tightly coupled with the DVL-Aided inertial allows required position accuracy for hydrographic standards

3. Ellipsoid-referenced survey techniques show promise in extracting the needed water level corrections

4. Large strides have been made and operational use now needed to further define process and realize capability

5. LBS-AUV operations is an exciting new area for hydrographic and mine warfare applications
Questions?
Cited References


