Acoustically Aided Inertial Navigation – Proven, Robust and Efficient Positioning Systems

James Titcomb
iXBlue
Acoustically Aided Inertial Navigation - Proven, Robust, and Efficient, Positioning Solution

MTS DP Conference, 10th October 2012, Jim Titcomb
Inertial Navigation Track Record.

- 1944  German V2 hitting London and Antwerp
- 1950’s Atlas ICBM
- 1958  USS Nautilus to North Pole
- 1961  Apollo program
- 1969  Commercial Navigation Boeing 747
- 1980’s Practical ring laser gyro systems
- 1985  Development of FOG starts at iXBlue (then Photonetics)
- 2011  High performance Earth-observation Pléiades satellites
- 2011  iXBlue MARINS chosen for Royal Navy nuclear attack submarines.
What is an Inertial Navigation System (INS)?
An instrument (electronic + sensors) which is using its initial state (position) and internal motion sensors (gyroscopes + accelerometers) to measure and calculate its subsequent positions in space with high accuracy, stability and update rate.
What makes an INS good.. or not?
- Internal sensors (gyroscopes & accelerometers) are never perfect, bias and scale factors accumulate over time
- Navigation is mostly about Gyroscopes

Gross figures:
- Accelerometers errors are not heavily involved in the position drift – 4m – Schuller period
- Gyroscope are heavily involved in the drift – 400 m

Drift is directly related to gyro performance.
- INS drift Nmi/hr = 60 x Gyro Bias in deg/h
- 0.01deg/h gyro = 0.6Nmi/h drift rate.
Dealing with Drift.

- GPS, DVL, LBL, USBL, EM Logs, etc. Are all routinely used for aiding an inertial navigation system.
- The classic example when discussing INS aiding is GPS.
The Problem with GPS aiding

- GPS can be unreliable for significant periods of time.
  - Next to structures – multipath
  - Scintillation effects
  - System Failures
- GPS can drift before failure.
  - Scintillation can cause ranges to increase slowly leading to incorrect positioning prior to a total failure.
  - INS will tend to follow a drifting aiding sensor.

Conclusion
- INS aided GPS can only be good for a few moments of GPS outage.
- INS aided GPS can be severely effected by scintillation.
### Acoustic Aiding

<table>
<thead>
<tr>
<th>Acoustic</th>
<th>Noise</th>
<th>Update rate</th>
<th>Drift</th>
<th>Robust</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>No</td>
<td>No</td>
<td>Range Angle</td>
</tr>
<tr>
<td>Inertial</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Attitude Speed</td>
</tr>
<tr>
<td>SYSTEM approach</td>
<td>Low</td>
<td>High</td>
<td>No</td>
<td>Yes</td>
<td>Attitude Position</td>
</tr>
</tbody>
</table>

- **Noise**: High
- **Update rate**: Low
- **Drift**: No
- **Robust**: No
- **Measurements**: Range Angle
- **Attitude Speed**
- **Attitude Position**
Acoustic Aiding Examples

- ROV on Seabed.
- 850m water depth
- Well calibrated USBL
- About as good as it gets with USBL

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
</tbody>
</table>
**INS Aided with USBL**

- Spikes in USBL rejected Automatically.
- Much higher update rate.
- Smoother positioning.
- Reduced spread of positions.

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
<tr>
<td>INS</td>
<td>0.16</td>
<td>0.2</td>
<td>0.26</td>
</tr>
</tbody>
</table>

- 5 X improvement with INS
INS aided Acoustics - Conclusions

- INS improves acoustics
- Acoustics improve INS
- We still have a single point of failure
  - INS will drift quickly if the acoustics fail.
    - 3m in 2 min,
    - 20m in 5 min.
    - 0.6Nmi in an hour.
- INS can make acoustics almost as good as GPS.
- Adding INS alone does not increase redundancy.
- What else is available?
What about LBL?

- At least three ranges are required for LBL positioning.
Pure LBL

- With only two ranges positioning is not possible

- There are two possible locations which match the received ranges.
INS aided by LBL

- Station keeping with only two ranges is possible with INS and LBL combined.

- The system must be initialised to the correct position first.

- The two ranges will constrain the INS drift.

- Positioning accuracy is directly related to the range measurement accuracy.
INS LBL Accuracy and Geometry

- Accuracy of results is dependant on a combination of geometry and range measurement accuracy.
- If the beacons are “in line” with the vessel results will be poor.
- But accuracy will be good if there is a high “Angle of cut”
LBL Trials

- Barge Moored in Loch Linnhe
- Anchors fore and aft.
- Barge drifting across the loch with the tide

- Red Track is GPS
- Blue Track is PHINS aided with only two acoustic ranges.
- Note the spread of the INS LBL data is narrower than that of the GPS
INS Velocity Aiding

- INS measures rotation rate and acceleration.
- First integration produces heading and velocity
- Second integration produces position

- USBL aids INS at the second integration level
- DVL aids INS at the First integration level.

- INS aiding data is used to estimate errors. The errors are fed back in to the calculation in order to correct at a low level.
- Aiding at the first integration level has more effect than aiding at the second integration level.
Effect of Velocity Aiding

- INS free inertial specification is based on time. The more time, the greater the drift.
- DVL aided INS specification is based on distance travelled. If you don’t move the error can’t grow (as much).
The problem with DVL

- Deep water.
  - DVL is only available in water depths up to around 1,000m.
  - In deeper water DVL update rate will be slow.
- Remember DVL aids INS at a more fundamental level than other sensors.
- The INS only needs a velocity aiding input infrequently in order to correctly estimate the error on the sensors.

<table>
<thead>
<tr>
<th>DVL Update Rate</th>
<th>Error, % distance travelled</th>
<th>Drift speed m/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1s</td>
<td>0.03%</td>
<td>0.18</td>
</tr>
<tr>
<td>2s</td>
<td>0.13%</td>
<td>0.82</td>
</tr>
<tr>
<td>3s</td>
<td>0.26%</td>
<td>1.67</td>
</tr>
<tr>
<td>4s</td>
<td>0.27%</td>
<td>1.77</td>
</tr>
<tr>
<td>6s</td>
<td>0.32%</td>
<td>2.08</td>
</tr>
<tr>
<td>8s</td>
<td>0.30%</td>
<td>1.98</td>
</tr>
</tbody>
</table>
Acoustic Aiding Examples - Recap

- ROV on Seabed.
- 850m water depth
- Well calibrated USBL
- About as good as it gets with USBL

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
</tbody>
</table>
INS Aided with USBL - Recap

- Spikes in USBL rejected automatically.
- Much higher update rate.
- Smoother positioning.
- Reduced spread of positions.

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
<tr>
<td>INS</td>
<td>0.16</td>
<td>0.2</td>
<td>0.26</td>
</tr>
</tbody>
</table>

- 5 X improvement with INS
INS Aided with USBL & DVL

- DVL update only every 3 seconds
- Positioning now better than high accuracy GPS even in 850m

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
<tr>
<td>INS</td>
<td>0.16</td>
<td>0.2</td>
<td>0.26</td>
</tr>
<tr>
<td>With DVL</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

- 17 x Better than raw acoustics.
What if we lose acoustics?

- DVL update only every 3 seconds
- Positioning now better than high accuracy GPS even in 850m

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>X</th>
<th>Y</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>USBL</td>
<td>1.03</td>
<td>0.86</td>
<td>1.34</td>
</tr>
<tr>
<td>INS</td>
<td>0.16</td>
<td>0.2</td>
<td>0.26</td>
</tr>
<tr>
<td>With DVL</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>INS DVL</td>
<td>0.04</td>
<td>0.02</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Conclusions

- INS is a proven technology on Land, Under water, in Space, why not in DP?
- INS has a long track record, Modern FOG based systems bring extreme robustness and reliability.
- INS can produce heading and attitude data as well as positioning.
- INS Should not be aided just by GPS for DP applications.
- INS can make your acoustics as good as high accuracy GPS.
- The biggest benefits can be obtained by combining aiding sensors.
- With the addition of DVL, INS can now be considered a stand alone PME for a significant period of time.
Announcement

- IXBLUE is proud to announce DP-PHINS.
  - World class PHINS inertial navigation system.
  - DP specific interface unit.
  - Aiding from typical DP acoustics, GPS, DVL, and any other PMEs.
  - Outputs tailored for compatibility with typical DP systems.

- Now delivering to select customers.
- Ready to discuss your requirements.