RAIM for Ship and Rig Management

Maritime Applications

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Peking, China
7 November 2012
Presentation Overview

- Motivation & Objectives
  - Present eNavigation
- Receiver Autonomous Integrity Monitoring (RAIM)
  - Horizontal Protection Levels (HPL)
  - RAIM Availability
- Simulation Performances
  - HPL Values for the Harbor in Hamburg
  - RAIM Availability Over the Globe
- Threats & Alternative Systems
Motivation & Objectives

- What benefits does Receiver Autonomous Integrity Monitoring (RAIM) offer to marine navigation?

- Can multi-constellation dual frequency GNSS RAIM meet Arctic challenges and provide integrity for the safety, reliable and cost-effective oil transport and exploitation?

- Can classical RAIM extended to operate with dual frequency and dual constellation GNSS achieve 99.8% of IMO future GNSS availability requirements A 22/Res. 915?
  - Availability of RAIM is the percentage of time that provides usable navigation service within a specified coverage area.
**Present eNavigation**

**Mix of AtoN (Aids to Navigation)**

- **Augmentation** through IALA\(^1\) DGPS
- **e-Navigation** elements
  - AIS\(^2,3\) (Automatic Identification System)
  - ECDIS (Electronic Chart Display and Information System)
  - GNSS/DGNSS (Global Navigation Satellite Systems/ Differential GNSS)
  - Radars (X-Band or S-Band)
  - eLORAN (enhanced LOng RAne Navigation)
  - other radio navigation means

\(^1\) International Association of marine aids to navigation and Lighthouse Authorities

\(^2\) [http://www.marinetraffic.com](http://www.marinetraffic.com)

\(^3\) possible integration of position integrity enhanced by RAIM (Receiver Autonomous Integrity Monitoring)

**e-Navigation** is the collection, integration and display of maritime information onboard and ashore by electronic means to enhance berth-to-berth navigation and related services, safety and security at sea and protection of the marine environment

**IALA e-navigation definition**

**RAIM**\(^3\) is a vital technology and an easy way to provide a GNSS integrity monitoring solution
**RAIM**

**Receiver Autonomous Integrity Monitoring (RAIM)** is a technique that uses an *overdetermined* solution to perform a consistency check on the satellite measurements.

- The **output** of the algorithm is the **Horizontal Protection Level (HPL)**, which is the radius of circle, centered at the true user position that is assured to contain the indicated horizontal position with the given probability of false alarm ($P_{FA}$) and missed detection ($P_{MD}$).

**ISTSAR (Integrity Simulation Tool for Advanced RAIM)** allows to estimate Horizontal Protection Levels based on the various GNSS constellations and multiple frequencies.

- **Ref.: MultiRAIM** Project, founded by the Bundesministerium für Wirtschaft und Technologie (BMWi), administered by the Agency of Aeronautics of the DLR in Bonn (FKZ 50NA1004)
Summary of Major Steps

RAIM Availability

1. Determine the **number of satellites** (Note: affects the *Threshold TH*)

2. Calculate **Observation Matrix (G)**

3. Variance of the **User Range Error** (diagonal weight matrix W)

4. Calculate **HPL** for the given geometry

5. Determine the availability of the algorithm (**HPL < HAL**)

6. Proceed to the next sample point in time, and repeat steps (1) – (5)

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1 Horizontal Alert Limit (HAL)
Horizontal Protection Level (HPL)

\[ HPL1 = \max \{ \text{Slope}_i, i = 1 \ldots N_{\text{sat}} \} \cdot \sqrt{p_{\text{bias}}_B} \]

where \( \max \{ \text{Slope}_i, i = 1 \ldots N_{\text{sat}} \} \) is a linear relationship between position error and the test statistics for the largest satellite range error. \( p_{\text{bias}}_B \) is the non-centrality parameter of the non-central chi-square density function.

\[ HPL2 = \max \{ \text{Slope}_i, i = 1 \ldots N_{\text{sat}} \} \cdot \sqrt{TH + K_H} \cdot \sqrt{\left( G^TWG \right)^{-1}}_{1,1} + \left( G^TWG \right)^{-1}_{2,2} \]

where \( TH \) is the threshold for the sum of the squared measurement residuals (chi-square distribution with Degrees of Freedom of \( [N_{\text{sat}}-5] / 2 \) is applied). The second term is a measure of confidence of the horizontal accuracy. \( K \) factor is based on the worst case assumptions (Gaussian) error function.

- Ref.[1]: Kaplan, p. 353
- Ref.[2]: J.E.Angus, RAIM with Multiple Faults.
HPL over 10 Sidereal Days

Hamburg harbour

HPL$^2$ values for LatN53LonE10

**System Level Parameters**

<table>
<thead>
<tr>
<th>Absolute accuracy</th>
<th>Integrity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (Meters)</td>
<td>Alert Limit (Meters)</td>
</tr>
<tr>
<td>Port approach and restricted waters</td>
<td>10</td>
</tr>
</tbody>
</table>

IMO GNSS performance requirements for general navigation according to Res. A.915(22) on future GNSS

- **GPS 27 Sat**
- **GAL 27 Sat**

Time period: 10 Days,
Time step: 600 s

$Pmd = 10^{-4}$
RAIM Availability (HPL$_2$)

**HPL$_2$ values (Pmd = 10e-3)**

Grid: 5° x 5°
Time period: 10 Days
Time step: 600 s

GPS 27 Sat
GAL 27 Sat

**URA = 1.2 m**
**SISA = 1.2 m**
**Pfa = 2.1 \cdot 10^{-5}**
**P_{apriori\_sat} = 10^{-4}**

Mask angle: 10°

**Service Level Parameters** | **Availability % per 30 days** | **Continuity % over 3 hours** | **Coverage** | **Fix interval (s)**
---|---|---|---|---
Port approach and restricted waters | 99.8 | N/A | Global | 1

IMO GNSS performance requirements for general navigation according to Res. A.915(22) on future GNSS
RAIM Availability

<table>
<thead>
<tr>
<th>Constellation</th>
<th>( P_{md} = 10^{-3} )</th>
<th>( P_{md} = 10^{-4} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS 27 GAL 27</td>
<td>95%</td>
<td>99.8%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>GPS 24 GAL 24</td>
<td>99.9</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>99.7</td>
<td>100</td>
</tr>
<tr>
<td>GPS 24 GAL 18</td>
<td>96.2</td>
<td>98.1</td>
</tr>
<tr>
<td></td>
<td>94.6</td>
<td>96.9</td>
</tr>
</tbody>
</table>

The percentage of the globe between 70°S and 70°N that has 95% and 99.8% RAIM availability.

INTEGRITY REQUIREMENTS

- \( \text{HAL} = 15 \text{ m} \)
- \( \text{Pfa} = 2.1 \cdot 10^{-5} \)
- \( \text{URA} = 1.2 \text{ m} \)
- \( \text{SISA} = 1.2 \text{ m} \)
- \( \text{Mask angle} = 10° \)
- \( P_{apriori\_sat} = 10^{-4} \)

Dual Frequency GNSS RAIM

With the 15m Horizontal Alert Limit the simulation results meet the required availability.
Threats

- **GNSS-Weakness**
  - Large Distance to Satellites
  - Low GNSS-Signal Power
  - Space Weather

- **Spoofing**
  - Simulation and Transmission of fake GNSS-Signals
  - Manipulate NPT-Solution

- **Denial of Service**
  - Intentional Jamming
  - Unintentional Radio Interference
## Alternative Systems

<table>
<thead>
<tr>
<th>Navigation Parameter</th>
<th>Measurement Principle</th>
<th>Accuracy</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heading</strong></td>
<td>Mechanical Gyroscope</td>
<td>0.1 deg</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td>FOG (Fiber Optic Gyroscope)</td>
<td>&lt; 0.5 deg</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td>THD (Transmitting Heading Device)</td>
<td>&lt; 1.0 deg</td>
<td>&lt;100 %</td>
</tr>
<tr>
<td></td>
<td>Magnetic (Compass)</td>
<td>&lt; 5 deg</td>
<td>100 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Position</strong></td>
<td>GNSS</td>
<td>4.5 – 25 m</td>
<td>≈100% (for 2 GNSS)</td>
</tr>
<tr>
<td></td>
<td>DGNSS</td>
<td>0.1 – 25 m</td>
<td>Station dependent</td>
</tr>
<tr>
<td></td>
<td>LORAN C</td>
<td>&lt; 450 m</td>
<td>Chain dependent</td>
</tr>
<tr>
<td></td>
<td>eLORAN</td>
<td>&lt; 20 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Doppler Speed Log</td>
<td>&lt; 0.2 kn</td>
<td>Depth 80 – 400 m</td>
</tr>
<tr>
<td></td>
<td>Electromagnetic Log</td>
<td>&lt; 0.5 kn</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Satellite Log</td>
<td>&lt; 0.1 kn</td>
<td>≈ 100%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>Echo Sounder</td>
<td>&lt; 1 m</td>
<td>&lt;300 m</td>
</tr>
</tbody>
</table>

*Ref.[1]: Dr. v. Koehler, Integrated Navigation Systems for Commercial Shipping, CCG e.V. Oberpfaffenhofen, 2010*
Summary & Conclusions

- **Dual Frequency Dual GNSS constellation RAIM** Algorithms can achieve **99.8%** of IMO future GNSS availability requirements A 22/Res. 915
  - Ships have to carry a **GNSS receiver** (AIS). RAIM could be **integrated**
  - Moreover RAIM can be supported by **additional INS or augmentation system information**

- **Multi-constellation GNSS RAIM** can support in demanding applications such as navigation in Arctic

- The **RAIM** already used in **aviation** is fairly **efficient against** a large number of threats (including **spoofing**)

- Future GNSS systems & increased number of satellites will allow **best selection of the NPT information** in order to provide integrity to the user’s position; achieve safety and cost-effective navigation solution
Questions and Discussion

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Phone: +49-89-6004-2588

Thank you for your attention!
### RAIM Availability

<table>
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<tr>
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<td>100</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
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<td>100</td>
<td>100</td>
<td>1</td>
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<td>99.6</td>
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- $HAL = 25$ m
- $P_{fa} = 2.1 \cdot 10^{-5}$
- $URA = 1.2$ m
- $SISA = 1.2$ m
- $Mask$ angle: $10^\circ$
- $P_{apriori\_sat} = 10^{-4}$

**Dual Frequency Dual GNSS RAIM**

with 2 simultaneous failures.