Why can’t road positioning and integrity be friends?

Invited talk Session I: Path Planning & Navigation Systems

Rafael Toledo-Moreo
Integrity concept

- **Integrity** is a measure of the degree of trust that can be placed in the correctness of the navigation information [ICAO International Civil Aviation Organization]

- **RAIM** (Receiver Autonomous Integrity Monitoring) detects faults thanks to redundant GPS pseudorange measurements coming from more satellites than needed to compute the position
  - 4 satellites for 3D position determination
  - 5 satellites to detect a fault
  - 6 for fault detection and exclusion (with 1 fault at a time)
Integrity concept

- Calculate the difference between the expected measurements and the observed ones: residuals
- Calculate the **Sum of the Squared Errors (SSE)** of the residuals
- Comparison of this value with a **threshold** determined based on requirements of false alarms ($P_{fa}$) and missed detections ($P_{md}$) (assuming Gaussian distribution)
Integrity concept

- Integrity depends on the geometry of the satellites
  - Bad geometry leads to poor \textit{Dilution Of Precision (DOP)} values
**Integrity concept**

- HPL **Horizontal Protection Level** represents the radius of a circle centered on the GPS position and **guaranteed** to contain the true position of the receiver according to the specifications of the RAIM ($P_{fa}$ and $P_{md}$).

- HPL is calculated from the RAIM threshold and the DOP value at any time.

- If HPL > HAL (Horizontal Alert Limit) an alarm is launched.
Differences between road navigation and aviation

The integrity concept comes from the aerial domain

- Vehicle’s environment

It is not the same problem this..
Differences between road navigation and aviation

The integrity concept comes from the aerial domain

- Vehicle’s environment
  
  .. than this

- Even with enough satellites in view their signals are affected by
  - multipath propagations
  - distortions
  - attenuations
Differences between road navigation and aviation

Integrity depends on the geometry of the satellites

- DOP grows
- HPL grows
- More difficult to detect faulty measurement
- Integrity falls

Bad geometry
Differences between road navigation and aviation

- **SBAS Satellite Based Augmentation System** based on geostationary satellites but these are also vulnerable to interference, blockage and jamming

- **Aiding sensors** (affordable cost)

- Intended **applications**: the needs of the specific applications cause different interpretations of the concept of integrity. e.g.
  - Integrity for Road User Charge
  - Integrity for lane-level positioning-based services
Maps

Do maps make things simpler or more complex?

* The number of **choices** is limited

* Map-matching may correct and **bound** positioning errors

* Map model errors

* Map creation errors

* Map-matching errors

* Updates

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A village of 16,000 inhabitants in the South of Spain
Do maps make things simpler or more complex?

Maybe maps make positioning more simple
but integrity more complex
Against maps and map-matching

An onboard GNSS navigation device guides our vehicle nicely over country roads and in open sky until the long driveway through the woods. When the vehicle leaves the mapped road, the navigation device keeps correcting the vehicle’s position back onto the road just exited. Some distance into the wooded property, the navigation position is suddenly snapped to the road on the other side of the cottage. This makes sense since the vehicle had just then become closer to that second road. Comically, there is an impassable river between the vehicle and the second road.

Against maps and map-matching

Maps make things worse because their errors are impossible to handle and predict.

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**Concept**

**Air vs. Road**

**Maps**

**Emaps**

**Aiding sensors**

**Definitions**

**Benefits**
In favor of maps and map-matching

Quddus M. et al. Integrity of map-matching algorithms

A quality indicator representing the level of confidence (integrity) in map-matched locations is essential for some Intelligent Transport System applications and could provide a warning to the user and provide a means of fast recovery from a failure.

- The issue is to find the proper metrics

\[ \frac{1}{\sigma_e^2} = \frac{1}{\sigma_{\text{map},e}^2} + \frac{1}{\sigma_{\text{gps},e}^2} \]

- Based on the error sources associated with the positioning data and the map data.
In favor of maps and map-matching

Toledo-Moreo R. et al. Integrity Provision for Map-Matched Positioning of Road Vehicles at Lane Level. IEEE ITSC 2009

Sensor data fusion

GNSS sensor

Proprioceptive sensor 1

Proprioceptive sensor 2

Position on the map

Relevant attributes of the road segment

Map-matching

Digital road database

You are here, on this segment, at this abscissa!
In favor of maps and map-matching

Eventually there’s the need of some kind of map to link an absolute reference to real objects

- For route navigation and guidance
- ADAS support
- Intelligent Speed Adaptation
- Preview curve information
Enhanced maps (Emap)

If maps are not complete and accurate enough

**Emaps (Enhanced maps)**

- More detailed description
- More parameters to be stored (sometimes)

*D. López and R. Toledo-Moreo. Example of Emap for cities*
**Elevation-Enhanced maps (EEmaps)**

An **EEmap** contains:

- Roads
- Building location
- Building height

Elevation-Enhanced maps (EEmaps)

An EEmap contains:

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- Building height

Elevation-Enhanced maps (EEmaps)

Simple maps

More simple maps, such as areas or virtual gantries for road user charge

R. Toledo-Moreo et al. Why is so difficult to find the proper OBU for Automated Road User Charging? ESA NAVITEC Conference. Noordwijk. 2004
Aiding sensors and integrity

Aiding sensors can improve the quality of the positioning output in terms of

- **Accuracy**: correcting wrong GPS updates thanks to the redundancy measurements
- **Availability**: giving updated positions where there is no GPS coverage
- **Continuity**: during GPS outages and with higher PVT output frequencies capable of modeling the vehicle’s dynamics
- Consequently they must also affect the **integrity**
Aiding sensors and integrity

- In a GPS-aided navigation system, integrity **cannot** come only from the GPS device.

- Inputs coming from aiding sensors must be included in the calculation of integrity parameters even though the incorporation of the aiding sensors error models into a integrity index may be complex.

- **Sensor-level integrity monitoring** is advisable: sensor measurements must meet sensor models.
# Aiding sensors and integrity

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Measurement</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odometer</td>
<td>Travelled distance</td>
<td>Quite reliable</td>
<td>Non-modeled errors: slides and slippages.</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>Acceleration</td>
<td>No subject to the terrain</td>
<td>At affordable prices performance is still poor</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Angular rate</td>
<td>No subject to the terrain</td>
<td>At affordable prices performance is still poor</td>
</tr>
<tr>
<td>Wheel encoders</td>
<td>Wheel velocities</td>
<td>Speed and orientation information</td>
<td>Often taken from ABS: values are not reliable</td>
</tr>
<tr>
<td>Steering encoder</td>
<td>Wheel direction</td>
<td>Quite reliable</td>
<td>Incorporation of the error model in the overall integrity index</td>
</tr>
<tr>
<td>Electronic compass</td>
<td>Heading</td>
<td>Absolute reference</td>
<td>Unpredictable errors due to power lines, metal structures and magnetic fields</td>
</tr>
</tbody>
</table>
The number of possibilities regarding sensors, maps, etc. has as a consequence that there are different definitions of integrity in road navigation.
Integrity for road navigation 1

- **Monitoring** the input measurements used to calculate the position of the vehicle for fault detection, isolation and removal [Bhatti U et al]
  - Fault detection for **error-free** positioning
  - Fault isolation and removal for more **availability**
  - **Provision of** Horizontal Protection Level
  - **Map-matching not considered**
Integrity for road navigation 2

- Continuous real-time provision of a confidence index of the map-matched position [Quddus M et al]
  - It overcomes previous problems in cases where applications need confidence on map-matched position
  - Applications that require HPL values to run not covered

Integrity for road navigation 3

- Continuous real-time provision of confidence indicators of the final system positioning outputs [Toledo-Moreo R et al]
  - Covering both HPL and map-matched-based applications
  - Lane Position Protection Level
  - Probability of Lane Occupancy
  - Indexes are complementary

Integrity for road navigation 4

- A verified certainty of the error in statistical terms
  - Valid for Road User Charge, not for real-time monitoring
  - Integrity is the probability that the (charging) error is not over an upper limit, protecting users of overcharges.
  - Acceptable for service providers and users if general terms are accepted
  - Potential systematic errors for a user whose daily trajectory falls into the 0.00001 percentage of charging error that is accepted

## Positioning with integrity

<table>
<thead>
<tr>
<th>Application</th>
<th>No integrity</th>
<th>With integrity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road user charge</td>
<td>More redundancy (investment) is needed</td>
<td>Lower costs in maintenance</td>
</tr>
<tr>
<td>Collision avoidance support</td>
<td>Difficult penetration due to reluctance from manufacturers and users</td>
<td>Support</td>
</tr>
<tr>
<td>Lane-level navigation</td>
<td>Too many mistakes make users reluctant</td>
<td>Feasible</td>
</tr>
<tr>
<td>Location-based-services in cities</td>
<td>Many inaccuracies. Loss of user’s confidence</td>
<td>More services available</td>
</tr>
<tr>
<td>GPS-based traffic priority control (for buses)</td>
<td>Faulty</td>
<td>Minimum number of false alarms</td>
</tr>
<tr>
<td>Automated positioning of accidents</td>
<td>Feasible in convenient scenarios</td>
<td>Better information for emergency services</td>
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Thank you very much for your attention

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