Trustworthy Positioning: Why We Need To Take It Seriously

Chris Rizos
Positioning and Mapping needs to address the advanced ITS challenges...

- Performance specifications are very tight
- Highly Automated Driving (HAD) is going to become a reality very soon
- GNSS (or other sensor technologies) is not reliable enough
- *Mass market* in Precise Positioning has different drivers to *professional market*
- *If we don’t, who will?*
What are we talking about?

Positioning in vehicles is going from **Passive** to **Active**...
From simple navigation to information about traffic, to warnings about hazards, to actively avoiding hazards, to supporting **HAD modes**
HAD... Utopia 1958
HAD... now, everyone wants in

There are non-technical concerns:
What are the design & performance specs? Who certifies these? Who is responsible for insurance cover? What about other road users?...
Australian govts agree on provisional driverless car rules

Fully autonomous vehicles not expected until after 2020.

Australia’s federal, state and territory transport ministers have agreed to a suite of national policies that will guide Australian road rules through the journey to the widespread adoption of fully driverless cars.

The National Transport Commission is not expecting driverless cars to hit the mainstream until after 2020.

Australian governments have been waiting on the opinion of the NTC – which has been conducting a comprehensive review of road rules and stakeholder concerns over the past year – before they start amending their driving regulations, so as to avoid patchwork approach to traffic legislation.

The commission has now received the green light from federal, state and territory ministers to go ahead with 24 new policies that iron out some of the legal shortcomings with driverless cars.

For the time being, Australian governments have jointly committed to an existing policy consensus that a human driver has full legal liability for a vehicle, even if it is “partially or conditionally” automated.

Human drivers must also not undertake in-car activities currently banned under Australian road rules, like speaking on a mobile phone, even when a car is effectively driving itself.

Under the NTC’s rationale, this buys road authorities a few more years to nut out a new regime before fully automated vehicles become commonplace.

It has identified a raft of legal grey areas that will need to be tackled before this time, including:
Tesla driver dies in first fatal crash while using autopilot mode

The autopilot sensors on the Model S failed to distinguish a white tractor-trailer crossing the highway against a bright sky

Joshua Brown, the first person to die in a self-driving car accident. Photograph: Facebook

The first known death caused by a self-driving car was disclosed by Tesla Motors on Thursday, a development that is sure to cause consumers to second-guess the trust they put in the booming autonomous vehicle industry.

The 7 May accident occurred in Williston, Florida, after the driver, Joshua Brown, 40, of Ohio put his Model S into Tesla's autopilot mode, which is able to control the car during highway driving.
Trustworthy Positioning... lots of technology

Need **Precise** & **Reliable** positioning, as well as **Robust** positioning...

But how to define performance specifications, SARPs, etc?
Levels of positioning accuracy required...

- **road-level** - which road is the vehicle on?
- **lane-level** - which lane is the vehicle in?
- **where-in-lane-level** – where within the lane is the vehicle?

**Positioning includes V2V (relative) and V2I (absolute)**


## ITS positioning requirements…

<table>
<thead>
<tr>
<th>Type</th>
<th>Level</th>
<th>Accuracy Requirement</th>
<th>Research prototype</th>
<th>Communication Latency (second)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V2I: absolute</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V2I = \text{Vehicle to Infrastructure} )</td>
<td>Road-level</td>
<td>5.0</td>
<td>Metre</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Lane-level</td>
<td>1.1</td>
<td>Sub metre</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Where-in-lane-level</td>
<td>0.7</td>
<td>Decimetre</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>V2V: relative</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( V2V = \text{Vehicle to Vehicle} )</td>
<td>Road-level</td>
<td>5.0</td>
<td>Meter</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Lane-level</td>
<td>1.5</td>
<td>Sub metre</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Where-in-lane-level</td>
<td>1.0</td>
<td>Decimetre</td>
<td>0.01-0.1</td>
</tr>
</tbody>
</table>


Trustworthy Positioning... new design paradigm

We want more accuracy, but also more integrity…

Accuracy

Old design space

Surveying, mapping

New design space

Advanced ITS - HAD

Integrity

Aviation, marine navigation
Required Navigation Performance Parameters (1)

No uniform performance standards for advanced ITS with respect to positioning have been established. The preferred technological solution should not be specified.

The following RNP parameters need to be considered:

• **Accuracy** – the degree of conformance of an estimated or measured position at a given time wrt a defined reference value:
  – *Absolute vs Relative* is important
  – Confidence level is important, e.g. RMS at 68% vs 95% as in ISO GUM vs 99.9% vs 99.999999%

• **Integrity** – the ability of the positioning system to identify when a pre-defined alert limit has been exceeded, and to then provide timely and valid warnings to driver systems
Required Navigation Performance Parameters (2)

- **Continuity** – the ability of the system to provide a navigation output with the specified level of accuracy and integrity throughout the intended period of operation

- **Availability** – percentage of time during which the service is available and satisfying all of the accuracy, integrity and continuity requirements

- **Interoperability** – the ability of different vehicle positioning systems with different absolute positioning capabilities to be used on the road network, and still meet the RNP specs

- **Timeliness** – the ability of the system to update position solutions at the required rates or on an event basis

(Source: Feng, Higgins and Millner for ARRB, April, 2013)
ICAO aviation performance specifications

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>ACCURACY (95%)</th>
<th>AVAILABILITY</th>
<th>CONTINUITY</th>
<th>INTEGRITY</th>
<th>TIME TO ALERT</th>
<th>COVERAGE **</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceanic</td>
<td>10 or 4 nmi***</td>
<td>N/A</td>
<td>0.99 – 0.99999</td>
<td>1-1x10⁻⁷/hr to 1-1x10⁻⁹/hr</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Enroute</td>
<td>2 nmi</td>
<td></td>
<td></td>
<td></td>
<td>5 min</td>
<td>N/A</td>
</tr>
<tr>
<td>Terminal</td>
<td>1 nmi</td>
<td></td>
<td></td>
<td></td>
<td>15 s</td>
<td>N/A</td>
</tr>
<tr>
<td>Non Precision Approach</td>
<td>≤ 20 m</td>
<td>N/A</td>
<td>0.99 – 0.99999</td>
<td>1-1x10⁻⁷/hr</td>
<td>10 s</td>
<td>N/A</td>
</tr>
<tr>
<td>APV-I</td>
<td>16 m</td>
<td>20 m</td>
<td>0.99 – 0.99999</td>
<td>1-2x10⁻⁷ in any approach</td>
<td>10 s</td>
<td>N/A</td>
</tr>
<tr>
<td>APV-II</td>
<td>16 m</td>
<td>8 m</td>
<td>0.99 – 0.99999</td>
<td>1-2x10⁻⁷ in any approach</td>
<td>6 s</td>
<td>N/A</td>
</tr>
<tr>
<td>CAT I</td>
<td>16 m</td>
<td>6 – 4 m</td>
<td>0.99 – 0.99999</td>
<td>1-2x10⁻⁷ in any approach</td>
<td>6 s</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* From ICAO Annex 10 Vol 1 Table 3.7.2.4-1. ICAO is in the process of changing approach definitions of the APV classification and including LPV-200 as a precision approach.
** Not Specified by ICAO, Annex 10, Vol. 1, Table 3.7.2.4-1, Signal-in-Space Performance Requirements.
*** Depends on the navigation specification (RNP 10 or RNP 4) employed in the oceanic area.

Behind these are a HUGE volume of SARPs...

## Highway Performance Specs (US FRP2014)

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>ACCURACY (meters, 2 drms)</th>
<th>AVAILABILITY</th>
<th>CONTINUITY</th>
<th>INTEGRITY (Alert Limit)</th>
<th>TIME TO ALERT</th>
<th>COVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigation and route guidance</td>
<td>1 – 20</td>
<td>&gt;95%</td>
<td>*</td>
<td>2 – 20 m</td>
<td>5 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Automated vehicle monitoring</td>
<td>0.1 – 30</td>
<td>&gt;95%</td>
<td>*</td>
<td>0.2 – 30 m</td>
<td>5 s – 5 min</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Automated vehicle identification</td>
<td>1</td>
<td>99.7%</td>
<td>*</td>
<td>3 m</td>
<td>5 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Collision avoidance</td>
<td>0.1</td>
<td>99.9%</td>
<td>**</td>
<td>0.2 – 30 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Geophysical survey</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>0.2 – 1 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Geodetic control</td>
<td>0.01</td>
<td>**</td>
<td>**</td>
<td>0.2 – 1 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Accident Survey</td>
<td>0.1 – 4</td>
<td>99.7%</td>
<td></td>
<td>0.2 – 30 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Emergency Response</td>
<td>0.1 – 4</td>
<td>99.7%</td>
<td></td>
<td>0.2 – 30 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
<tr>
<td>Intelligent Vehicle Initiative</td>
<td>0.1</td>
<td>99.9%</td>
<td></td>
<td>0.2 – 30 m</td>
<td>2 – 15 sec</td>
<td>Nationwide / Surface Coverage</td>
</tr>
</tbody>
</table>

* Continuity applies to phases of operations. For highway applications.
** In these instances, availability of a real-time solution is not needed.
*** This is typically done using post-processing techniques. While it cannot be provided after data is collected.

Note: the technological solution is not specified...

Moving forwards...

- **GNSS** is the primary navigation technology for “absolute positioning”
- **Other sensing/imaging technologies** used for “relative positioning”... essentially collision avoidance systems
- **Mapping data** used for ancillary purposes... “global situation awareness”, “around-corners” capability, POIs, etc
- **Biggest challenge** is ensuring 100% availability and very high integrity... correctly identified degraded performance is not critical, but HMI is
- **Complexity of multi-sensor systems**, coupled with AI, operating in a **highly dynamic environment**, is a huge challenge... **compared with Aviation systems**
- **Many players, many solutions, many standards**... **what could Australia do (in a meaningful way)**?
Positioning... more than meets the eye

1: “I can see clearly now...” sensing the world

2: “I know where I am...” everything in its place

Each technology/approach has its strengths & weaknesses...

3: “With a little help from my friends...” cooperative approaches
## Five-tier GNSS-based techniques

<table>
<thead>
<tr>
<th>Tier</th>
<th>Technique Option</th>
<th>Status</th>
<th>Accuracy range</th>
<th>Cost</th>
<th>ITS applications</th>
<th>Source: Feng, Higgins and Millner for ARRB, April, 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A Standalone GPS (SPS)</td>
<td>Standalone multiple GNSS</td>
<td>10-20m</td>
<td>Low</td>
<td>Vehicle navigation, personal route guidance and location based services (LBS)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A Standalone GNSS (DF), Code DGPS</td>
<td>Standalone multi-GNSS positioning</td>
<td>1-10m</td>
<td>Low</td>
<td>Vehicle navigation, LBS, road traffic management</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>B Current WAAS Commercial WADGPS</td>
<td>Future SBAS design for multi-GNSS</td>
<td>0.1-1m</td>
<td>Low</td>
<td>ITS safety applications: lane-level positioning, lane-level traffic management and where-in-lane-level applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C Smoothed DGPS</td>
<td>Smoothed DGNSS</td>
<td>0.1-1m</td>
<td>Medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>D RTK</td>
<td>Combined PPP and RTK (seamless)</td>
<td>0.01-0.1m</td>
<td>Medium to High</td>
<td>Research prototype ITS safety systems, offering bench mark solutions for testing low-cost units</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Advanced D and E Static positioning</td>
<td>Sub-cm RTK with multi-GNSS signals</td>
<td>0.001-0.01m</td>
<td>High</td>
<td>Geosciences and geodynamic studies. Not recommended for ITS applications</td>
<td></td>
</tr>
</tbody>
</table>
M-GNSS visibility: Sydney
10deg elev, 7 December 2016

This is about 4x number used for standard GPS positioning...

http://www.taroz.net/GNSS-Radar.html
But GNSS was never designed to be a Ubiquitous Positioning technology... Signals are too weak & vulnerable

GNSS is like Swiss cheese... ... it’s full of holes”

Nunzio Gambale
Locata Corp
GNSS positioning: the reality

- In some environments (such as tunnels, built up urban areas, or in the presence of signal interference or spoofing) GNSS performance deteriorates rapidly.
- GNSS on its own cannot satisfy the “high performance positioning” needs of applications that are liability-critical or life-critical.
- Positioning for advanced ITS apps is not an “off-the-shelf” solution... state-of-the-art fusion of sensor outputs blended with machine-based reasoning.
- Multiple approaches likely to be used... variety of R&D, commercialisation and implementation challenges to be addressed.
A simplified taxonomy of man-made RF threats to GNSS

- Denial of Service (Interferences)
  - Deliberate (Jamming)
    - Multipath
    - Unintentional
      - Others RFI
    - Forged signal generation
      - Data Bits Generation
      - Spreading Sequence & Carrier Generation
  - Replay attacks (Meaconing)
    - Real-Time Replica
    - Record and Replay
- Deception of Service (Spoofing)
Known Unknowns…

1. What level of HAD do we focus on?
2. Which “school” of HAD will prevail?
3. What can we learn from Aviation?
4. Who will provide the positioning/navigation solutions?
5. How to make GNSS-based positioning more trustworthy?
6. What could we do with SBAS in Australia?
7. What is the optimal mix of positioning technologies?
8. What test or certification processes will Australia insist on?
9. Who will drive the introduction of HAD systems in Australia?
10. How will we cope with mix of HAD and traditional driver behaviour?

ARC project “Trustworthy Positioning for Next Generation ITS” (2017-2019)…
Where do we start?

Task 1: Foundation for Integrity Monitoring for C-ITS
Task 2: Dealing with Critical Issues Causing Significant Interruption to Positioning Services
Task 3: Building a Robust Integrity Monitoring Scheme for Reliable Positioning in C-ITS

What sort of Integrity Monitoring is appropriate for positioning to support HAD?...
Concluding Remarks...

- GNSS (both augmented & unaugmented) will have to be monitored... *at system provider, service provider & user level*
- HAD proponents are sceptical of PNT technology... *Navigation community must start promoting Trustworthy Positioning*
- HAD is much more than GNSS or PNT technology... *but we have to start defining RNPs*
- We need holistic solutions, need awareness raising, need test beds, need alternative technologies...