magicPPP
High Precision and Safe GNSS Positioning System for Automotive Market

NAVISP Industry Days, ESTEC, January 2020
Round Table: “Solutions for Autonomous Road Vehicle”
Science Fiction in the 80s

KNIGHT RIDER (1982-1986)
And now…

Highly motivated and talented team!

R&D

> 30 years of experience in GNSS & 15 years in Automotive

magicPPP for Automotive
THE CHALLENGE

Classical PPP

Open Environment
- Agriculture, Off-shore, Mining...
Human Supervised
Low risk for human lives
THE CHALLENGE

Classical PPP
Open Environment
- Agriculture, Off-shore, Mining...
Human Supervised
Low risk for human lives

Automotive PPP
Harsh Environment
- Buildings, tree canopies, tunnels, underpasses...
Fast Convergence in hot and cold start
High Availability
Safety Critical
OVERALL SYSTEM ARCHITECTURE

On-board System:
- Positioning Engine SW
- GNSS Rx
- IMU

Correction Service (CS)

GNSS Station Network
Processing Centers
Regional Station Network
GNSS Products
Communication Link
End GNSS High Accuracy Users

Customer Backend System
ALGORITHMIC ENHANCEMENTS

Server Side

Accuracy

- Integer Ambiguity Fixing at Orbit Determination
- Phase biases estimation

Positioning Engine

- Zero-Difference Ambiguity Fixing
ALGORITHMIC ENHANCEMENTS

Server Side

Positioning Engine

Accuracy + Fast Convergence

• Integer Ambiguity Fixing at Orbit Determination
• Phase biases estimation
• Regional Ionosphere Estimation

• Zero-Difference Ambiguity Fixing
• Ionosphere correction
ALGORITHMIC ENHANCEMENTS

Server Side

Positioning Engine

Accuracy + Fast Convergence + Dead Reckoning

- Integer Ambiguity Fixing at Orbit Determination
- Phase biases estimation
- Regional Ionosphere Estimation
- Zero-Difference Ambiguity Fixing
- Ionosphere correction
- Sensor fusion
- Gap-bridging algorithms
ALGORITHMIC ENHANCEMENTS

Server Side

Positioning Engine

Accuracy + Fast Convergence + Dead Reckoning + Integrity

- Integer Ambiguity Fixing at Orbit Determination
- Phase biases estimation
- Regional Ionosphere Estimation
- Safety Processor

- Zero-Difference Ambiguity Fixing
- Ionosphere correction
- Sensor fusion
- Gap-bridging algorithms
- Threat Monitors
- KIPL Bounding
• High accuracy positioning system customized to the particular requirements of the automotive market.

• Two levels of service:

<table>
<thead>
<tr>
<th>Service Level</th>
<th>High Accuracy</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>QM</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>ASIL-B</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

• Solution based on Precise Point Positioning (PPP) technology:
  - Preferred over RTK due to proven PPP advantages:
    - Stability of solution, comms bandwidth minimization, network density minimization.
    - Nevertheless, the solution is compatible with RTK positioning engines as it can emulate virtual RTK stations.

• System designed to fulfil key requirements received from various customers.
# KEY CAPTURED CUSTOMER REQUIREMENTS

<table>
<thead>
<tr>
<th>#</th>
<th>Customer Requirements</th>
<th>magicPPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High accuracy</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Fast Convergence</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Full integration with IMU for dead-reckoning during GNSS outages</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>ASIL-B Safety</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>Protection to jamming and spoofing attacks</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>Flexibility to integrate with customer back-end services</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>Bandwidth minimization</td>
<td>✓</td>
</tr>
<tr>
<td>8</td>
<td>Robustness vs connection outages with correction service</td>
<td>✓</td>
</tr>
<tr>
<td>9</td>
<td>(Cyber-)security protection of system assets and communication links</td>
<td>✓</td>
</tr>
<tr>
<td>10</td>
<td>Service Areas: Initial service over Europe and North America, others regions under study</td>
<td>✓</td>
</tr>
</tbody>
</table>
# Key System Performance Requirements

<table>
<thead>
<tr>
<th>KPI</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Accuracy</td>
<td>&lt; 10 cm RMS</td>
</tr>
<tr>
<td>Integrity Risk (TIR)</td>
<td>Up to 10-7 per hour</td>
</tr>
<tr>
<td>Convergence Time</td>
<td>&lt; 30 sec</td>
</tr>
<tr>
<td>Service Availability</td>
<td>&gt; 99.9 %</td>
</tr>
<tr>
<td>Corrections Update Rate</td>
<td>1 sec – 1 min</td>
</tr>
</tbody>
</table>

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ISO 26262  
FULL SAFETY CASE AND ARTIFACTS PRODUCED IN ACCORDANCE WITH ISO 26262
EXAMPLE OF TESTING CASE

TRAJECTORY

Peripheral highway in Madrid (M40)
High multipath
Multiple overpasses
Max speed 100km/h
Medium-High level traffic during whole day
PERFORMANCE TESTING SET UP

Vehicle Equipment
- Amotech AGA556022
- uBlox ZED-F9P
- Xsens Mti-10

Constellations
- GPS
- Galileo

Ground Truth
- Novatel GNSS 850
- Novatel OEMV
- Imar FSAS
PERFORMANCE TESTING SET UP

GROUND TRUTH IMU

GROUND TRUTH ANTENNA

VEHICLE IMU

VEHICLE ANTENNA

XSENS IMU

UBX ANTENNA

ACC/GYROS 50Hz

GNSS 10Hz

UBX RX & PROCESSING CORE
TYPICAL ACCURACY - OPEN SKY

PPP Monitor Stats
PPP Position Error

North Error (RMS=3.63 cm | p95=4.54 cm | Ave=1.65 cm | Max=62.18 cm)
East Error (RMS=4.26 cm | p95=7.50 cm | Ave=2.91 cm | Max=47.26 cm)
TYPICAL PERFORMANCE – HIGH-WAY
COLD (INITIAL) CONVERGENCE

30 Secs

Positioning Error

30 cm
COLD (INITIAL) CONVERGENCE

3.88 seconds!

<table>
<thead>
<tr>
<th>Convergence tests</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS</td>
<td>3.88</td>
</tr>
<tr>
<td>P95</td>
<td>10.10</td>
</tr>
<tr>
<td>Average</td>
<td>1.69</td>
</tr>
<tr>
<td>Max</td>
<td>12.3</td>
</tr>
</tbody>
</table>

Position Error

- Vertical
- Horizontal

Open Sky

50 cm

20 cm

Time
HOT CONVERGENCE

Performance Recovery Time after short signal outages
Bridges, Tunnels, Tree Canopies...
DEAD RECKONING WITH IMU DATA

- GNSS Data Outage
- GNSS Data Recovery

Horizontal Hot Convergence Time
< 5 sec 99%

Calculated Protection Level
Actual Positioning Error
Thank you

Irma Rodriguez
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INTEGRITY PROCESSING

• Integrity assurance based on the calculation of real time Protection Levels (PLs):
  - PLs bound the positioning errors
  - Define the region where the car is contained with high probability
  - Probability of error bounding failure < TIR requirement

• Integrity concept:
  - In absence of failures (fault free condition) the integrity algorithms ensure that the Protection Levels bound the actual positioning error
  - Built-in integrity monitors in CS and PE check the presence of all potential failure conditions
  - Residual errors taken into account in the Protection Levels calculation