Inertial positioning for autonomous vehicles

Teknologia 19 – Uudet paikannusteknologiat

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Murata Electronics Oy

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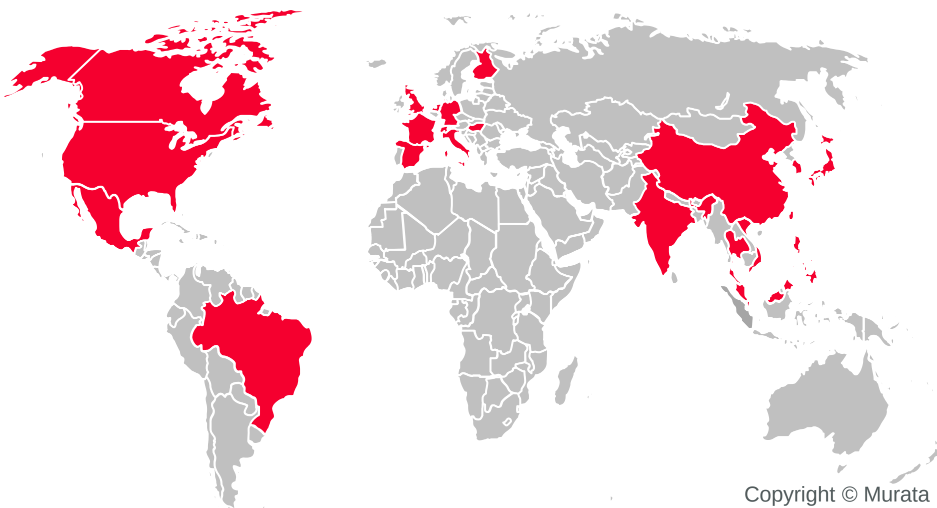
Murata – Innovator in Electronics

Our Business

We are worldwide leaders in **electronic components, wireless modules and solutions**, based on unique technologies.

Our Figures

- **1944** Established in 1944, Kyoto Japan
- **13** Net sales 13 billion €
- **80 000** Employees Globally
- **1200** Employees In Murata Finland



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Murata MEMS Sensors in Automotive Applications

- In House 3D MEMS technology, designed and manufactured by Murata Finland (MFI)
- MFI is Global leader in low-g MEMS sensors for **automotive**, healthcare and industrial applications, providing accelerometers, gyros and combined sensors for a wide range applications
- Leading position in MEMS sensors for automotive safety systems

Vehicle Dynamics

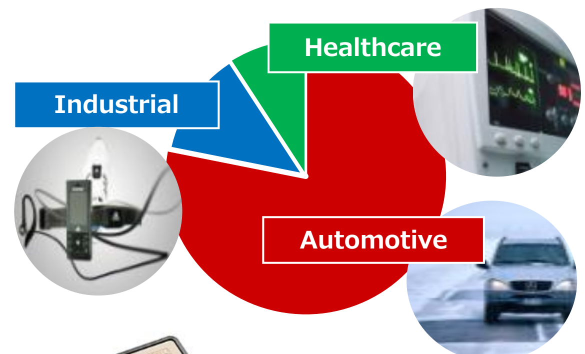
- Electronic Stability Control (ESP/ESC)
- Roll Over / Roll Stability Control (RO/RSC)
- Electronically Controlled Suspension (ECS)

Vehicle Inclination

- Electric Parking Brake (EPB)
- Hill Start Assistance (HSA)
- Headlight leveling
- Transmission control (TCM)

Emerging Applications

- Navigation and Ded Reckoning
- ADAS applications



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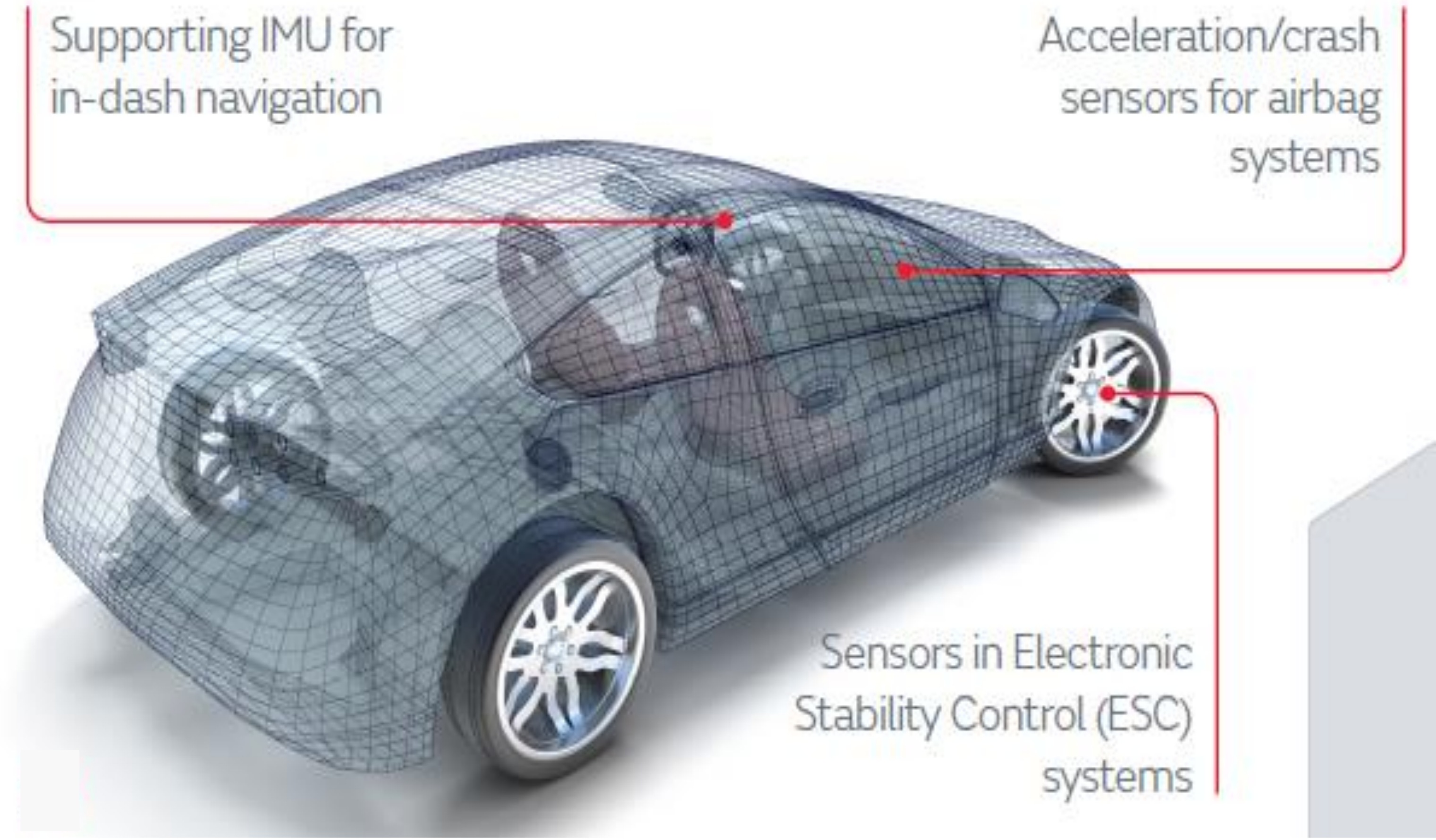
Where Are Inertial Sensor Already Used?



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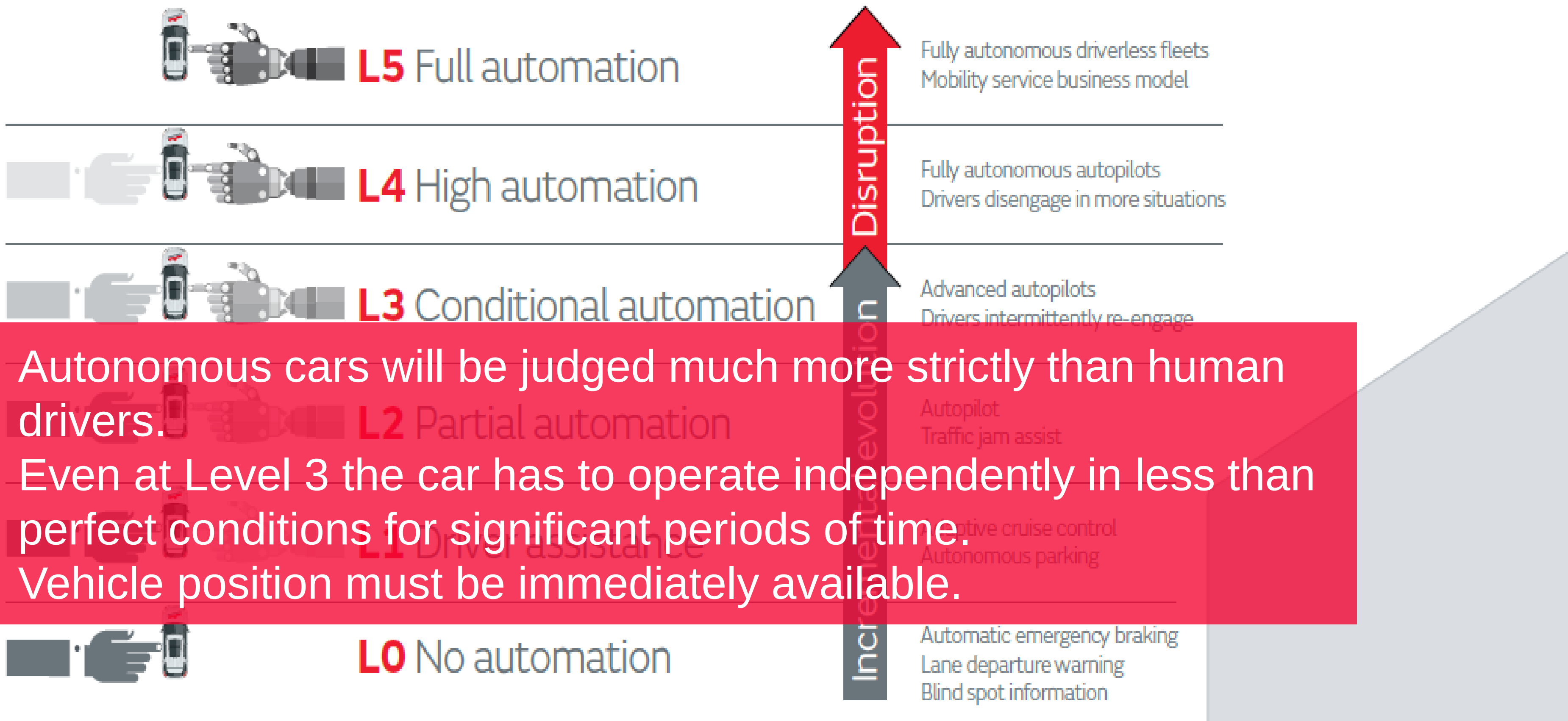
Automation levels



- Autonomous cars will be judged much more strictly than human drivers.
- Even at Level 3 the car has to operate independently in less than perfect conditions for significant periods of time.
- Vehicle position must be immediately available.

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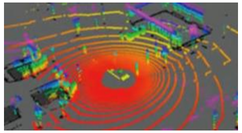
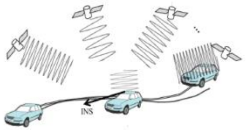
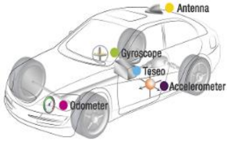
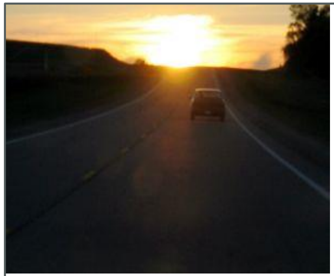
Why Inertial Sensor in AD?

Accurate positioning requires fusion of multiple sensors

Image based		Satellite based	Inertia based
 Lidar/Radar	 Camera	 Multi band GNSS	 IMU / Vehicle Speed


GNSS ✗ Image ✓ IMU ✓



GNSS ✓ Image ✗ IMU ✓

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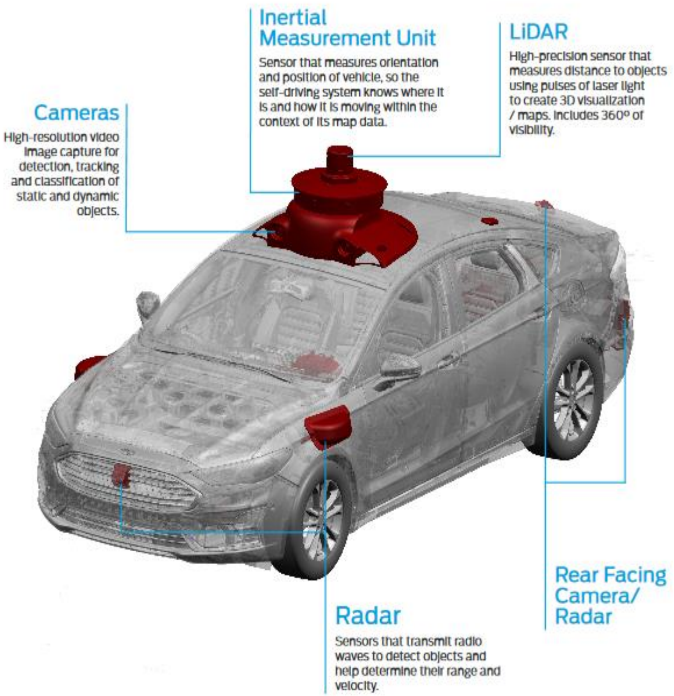
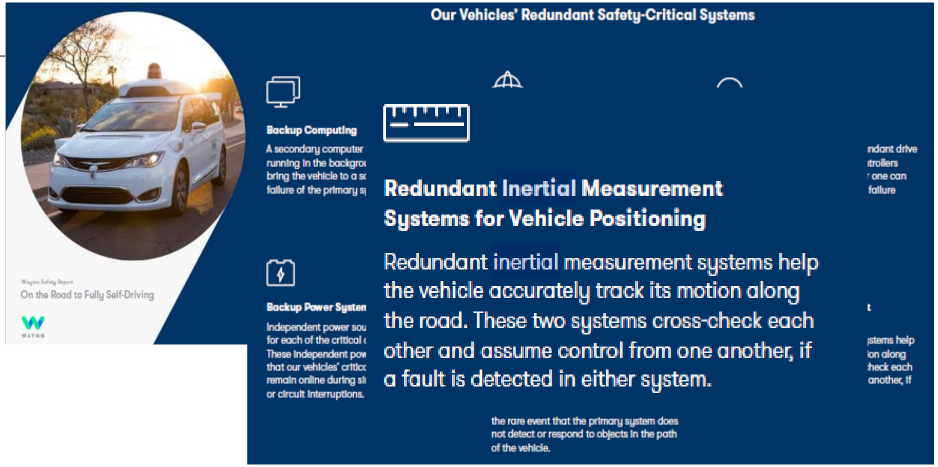
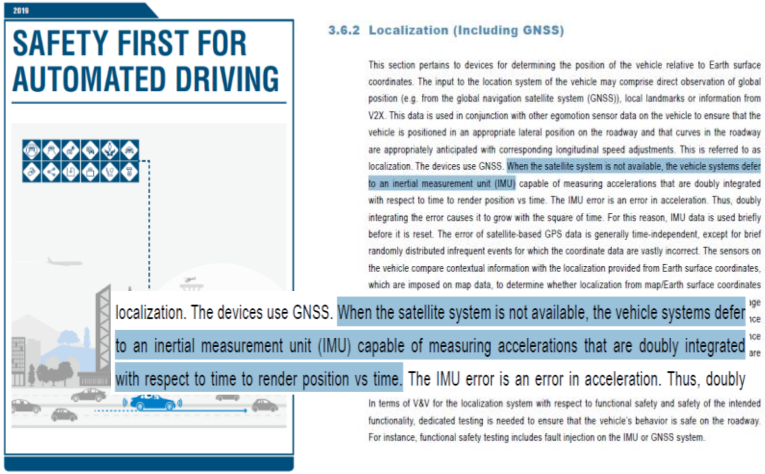
Safety report examples



*https://media.ford.com/content/dam/fordmedia/pdf/Ford_AV_LLC_FINAL_HR_2.pdf

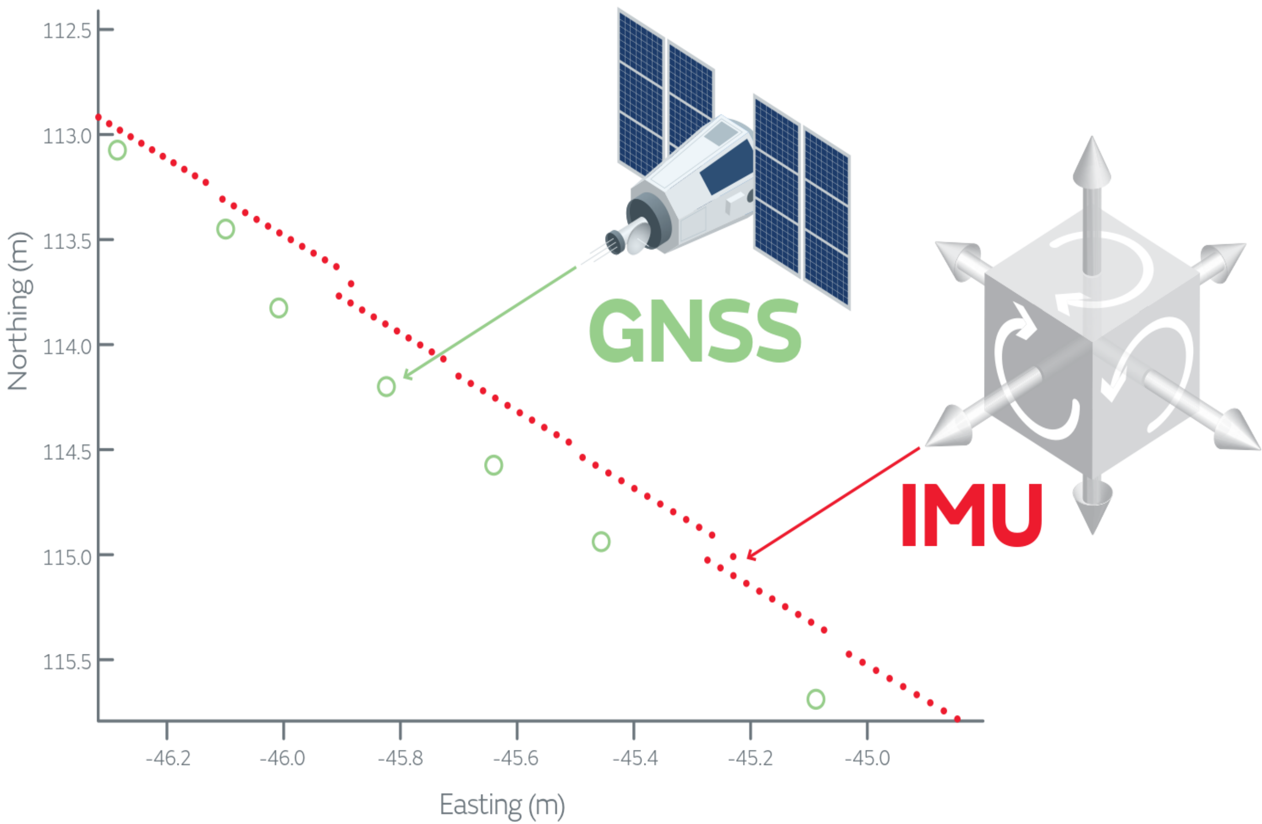


*https://waymo.com/safety/



*https://www.daimler.com/innovation/case/autonomous/safety-first-for-automated-driving-2.html

Inertial Navigation System



High Performance IMU covers the gaps caused by missing GNSS data

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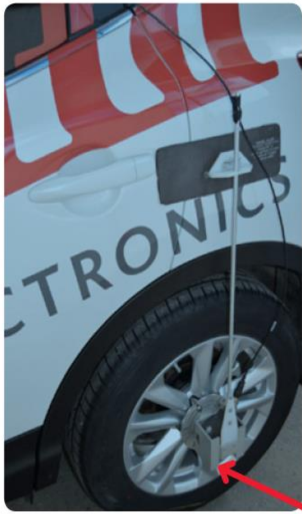
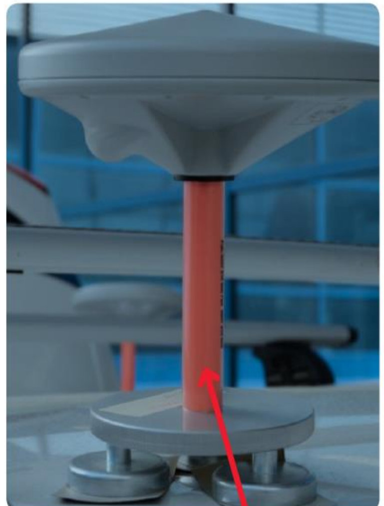
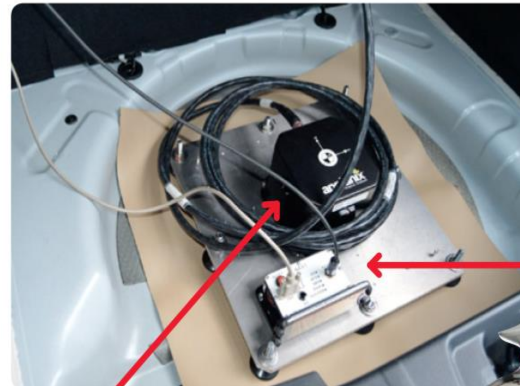
Murata Test Vehicle







Murata IMU

Applanix POS LV 420 reference

Inputs
- 6DOF IMU
- external speed input

Outputs
- Vehicle Position
- Velocity
- Orientation

Components of inertial navigation solution
- Murata IMU
- Any GPS
- Wheel speed sensor output from OBD2

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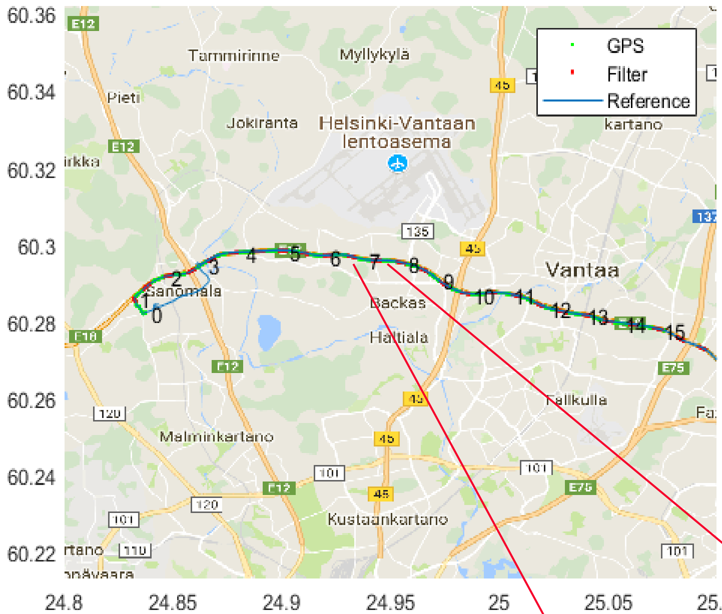
Case: Highway 80 km/h = 50 mph

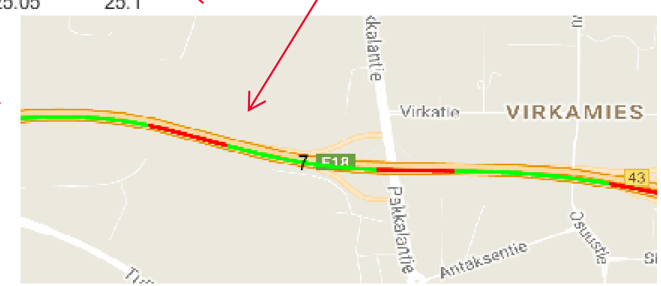


IMU + OBD (speed) + GPS

- Applanix as GPS and ref
- Assume we have cameras/lidar etc. (= GPS on) and then other than IMU and OBD fails (= GPS off)

GPS on 20 sec
GPS (applanix) + IMU + OBD

GPS off 10 sec
IMU + OBD



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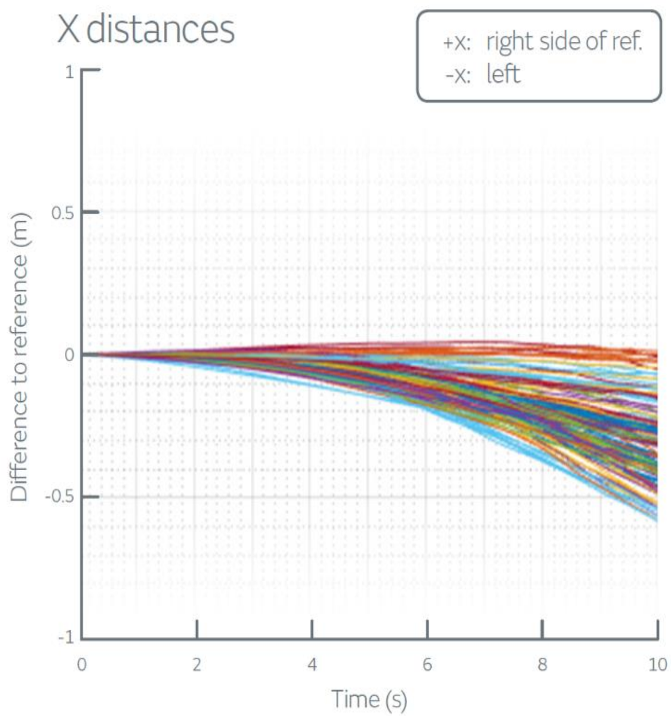
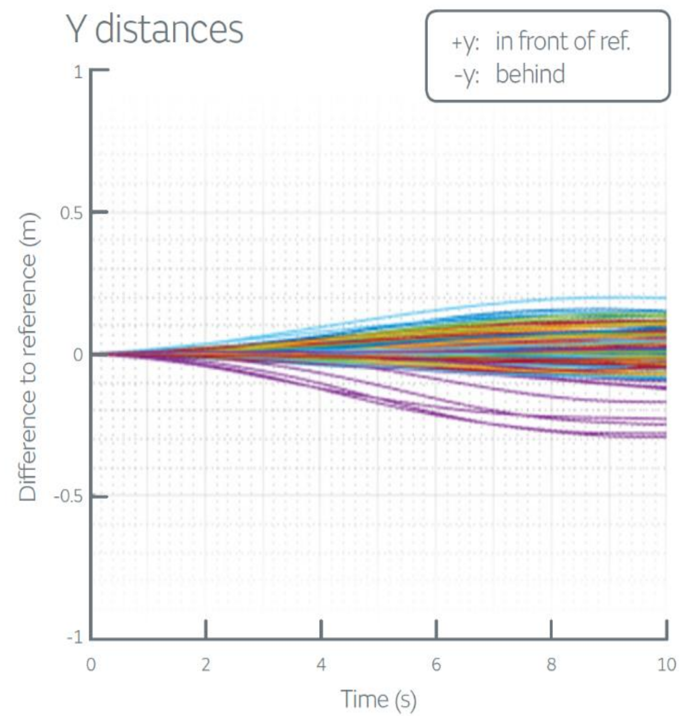
Distance Between Filter Output and Reference GPS (Highway 80km/h)

- Drive segments with GPS off for 10 sec stacked
- Lateral error (X): max 60 cm → MEMS IMU can keep car on lane for 10 sec.
- Longitudal error (Y): max 30 cm





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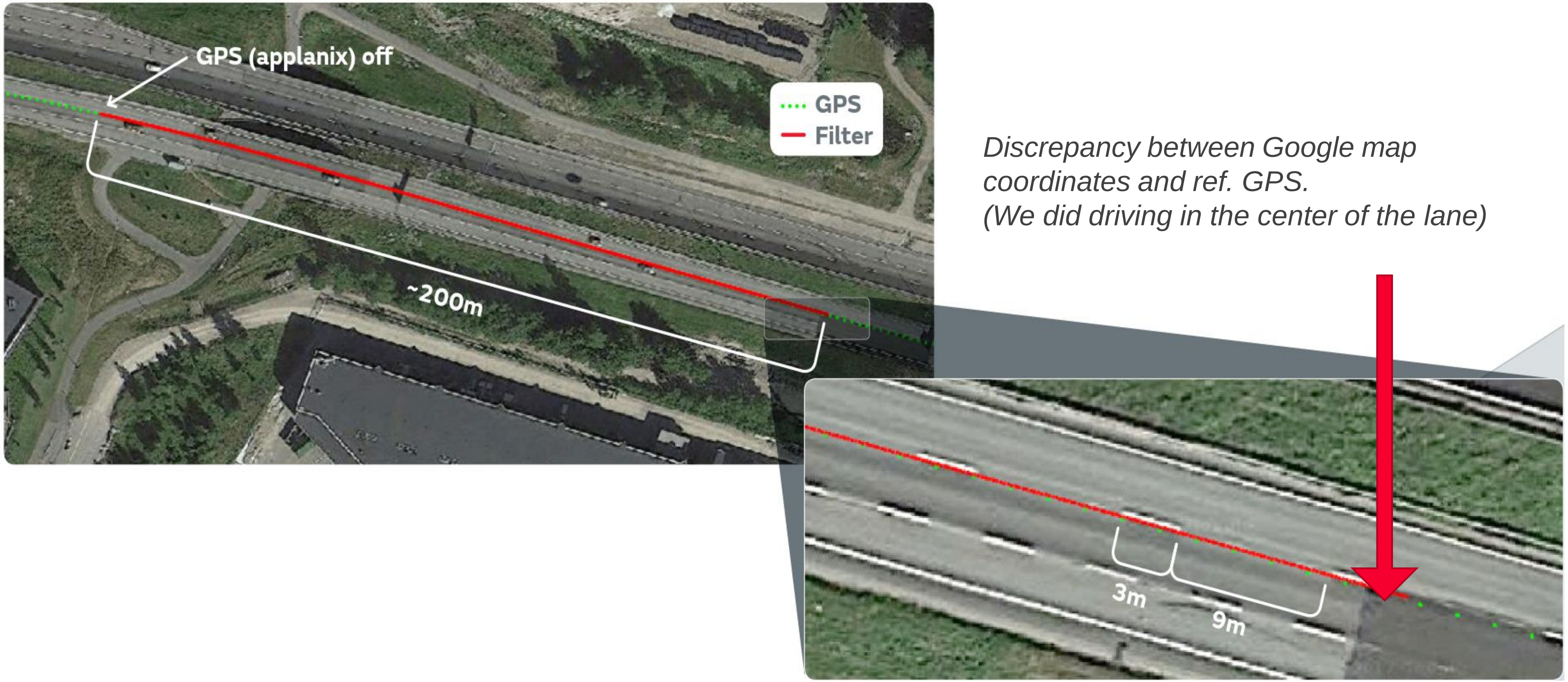
Closer Look (Highway 80km/h)

- Red line: position calculation by IMU
- Green dots: ref GPS



Discrepancy between Google map coordinates and ref. GPS.
(We did driving in the center of the lane)

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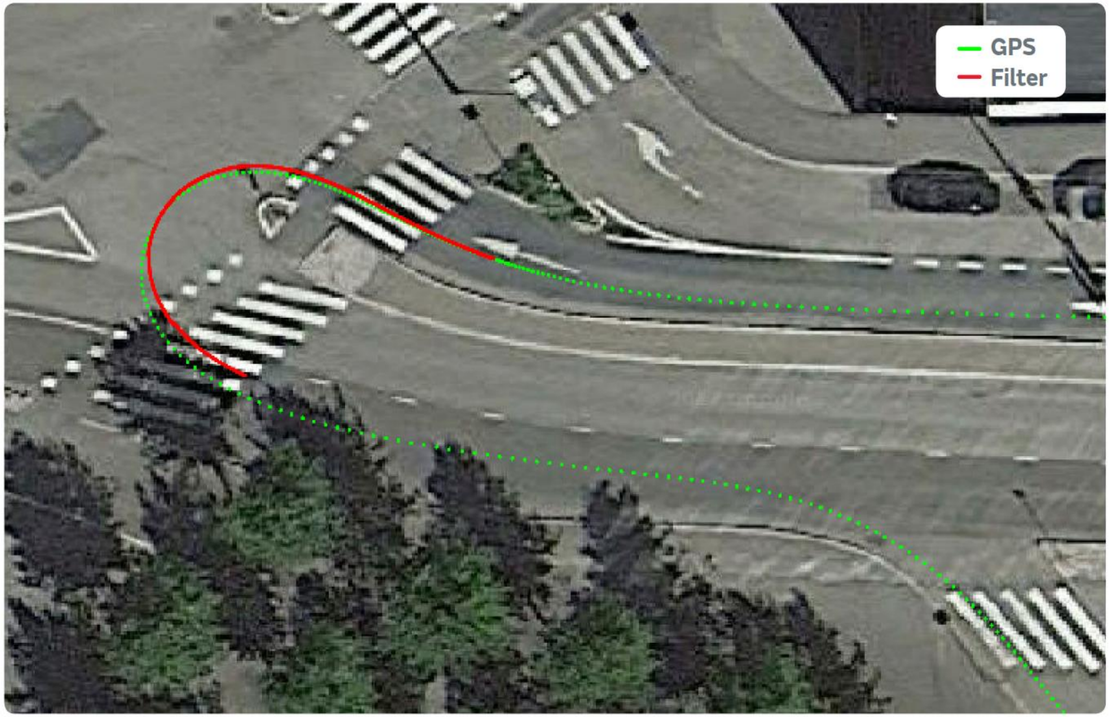
Case U-turn

- Junction area has limited landmarks but IMU can handle.
- Standard GPS would not be useful due to low speed.



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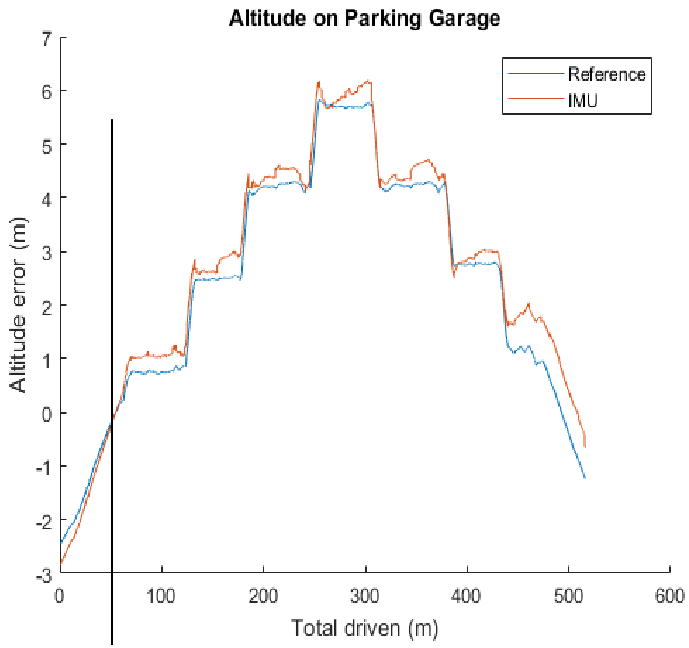
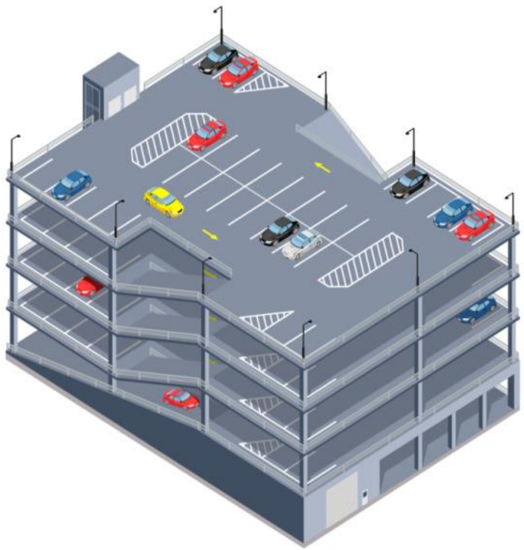
Case: Parking Garage, Altitude Detection by IMU

- IMU can be also used for vertical location (in which floor we are)
- Only IMU used (kalman filter but no GPS) ➔ 0.5 m error after 500 m of driving



Altitude sync



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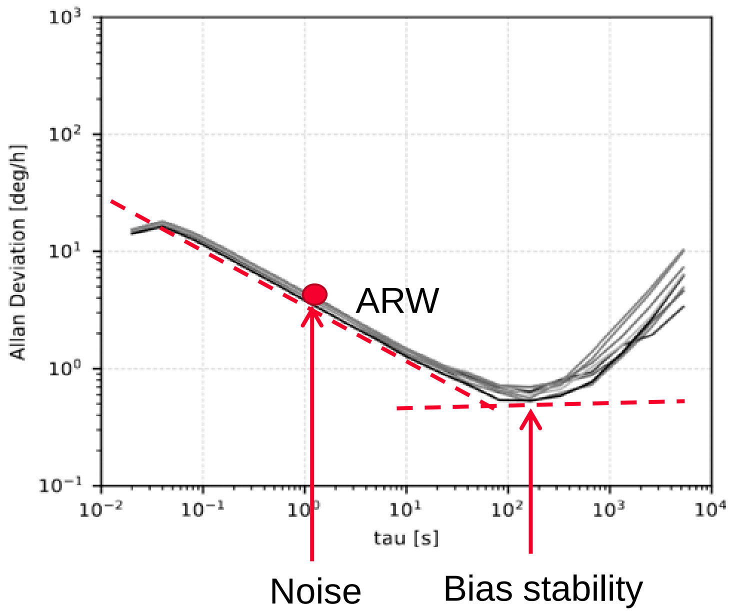
Case: Tunnel Drive

- No GPS inside tunnel
- Cameras can be used, but they may become blinded momentarily

Urban canyon

Important Sensor Performance Parameters in AD?

- Typically gyro sensor quality have been compared with parameters like **bias stability**
- In Autonomous **driving relative positioning** becomes more important
- For example safety stop requires very high precision localization where vehicle position is mainly calculated based on inertial and wheel speed sensor data.
- Short term stability = **noise** and **ARW *** become more important



*ARW= Angular Random Walk

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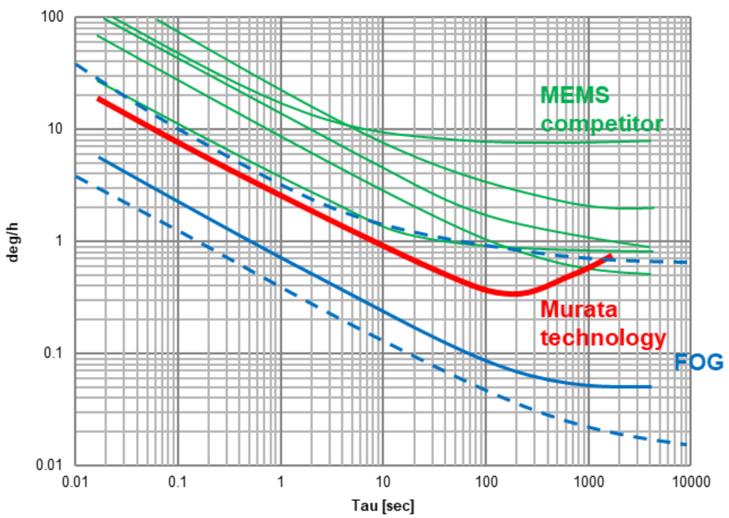
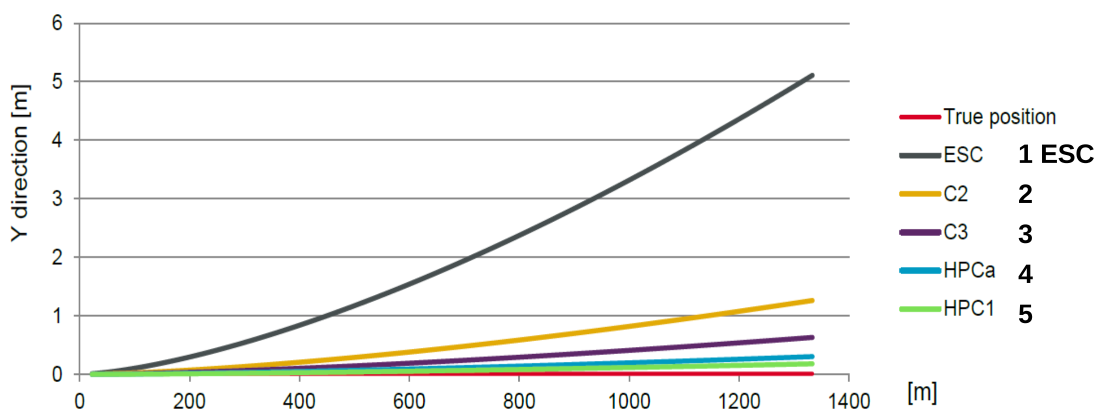
The Effect of ARW in Vehicle Positioning

- IMU usage in navigation requires continuous error correction by the system based on GPS position.
- **The performance limit there is set by the gyro angular random walk (ARW) which is directly related to gyro white noise level.**
- Calculated errors in case of 80km/h 1 min driving
  1. ESC standard spec performance — ARW 1.7deg/sqrt(h) → error 5 m
  2. Murata current best in class ESC sensor — ARW 0.4 deg/sqrt(h) → error 1.2 m
  3. Murata next gen high performance ESC sensor — ARW 0.2 deg/sqrt(h) → error 0.6 m
  4. Murata first gen AD/ADAS 6DOF sensor — ARW 0.1 deg/sqrt(h) → error 0.3m
  5. Next level 4/5 6DOF MEMS sensor — ARW <0.1 deg/sqrt(h) → error < 0.3m





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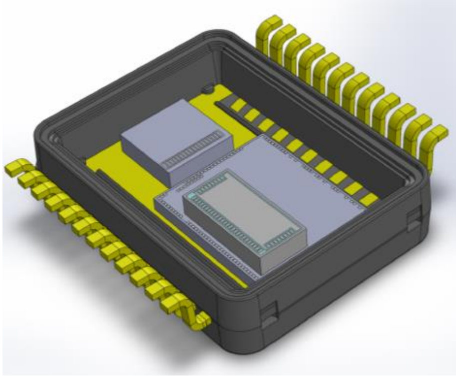
1st High Performance IMU Component w/ 4-ax MEMS gyro

muRata
INNOVATOR IN ELECTRONICS

- HPC1
  - First true 6dof version for ADAS/AD
  - Several versions optimized based on application needs, e.g. industrial.
- Technical solution
  - 2 robust Z-gyros combined and XY gyros built on same structure (stability, noise, functional safety)
- Vision of future Combos, “true inertial navigation”
  - 6dof North finding level gyro + Geophone level accelerometer



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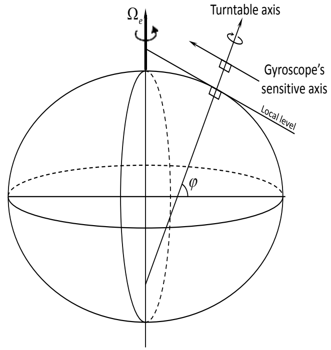
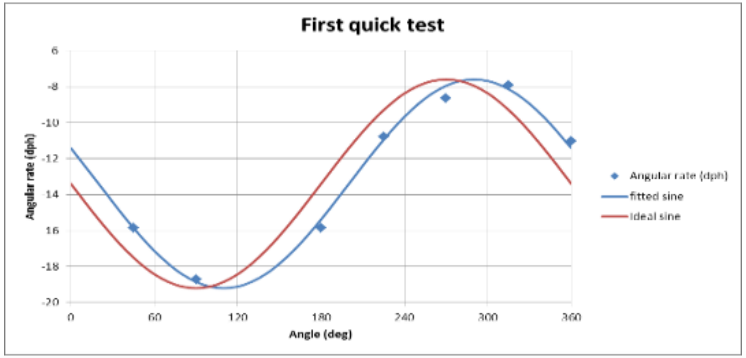
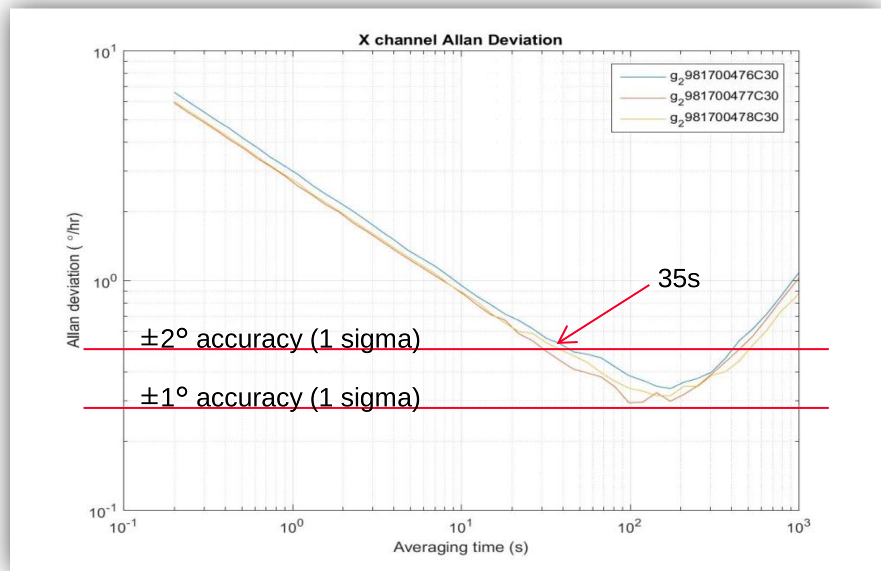
Gyro Performance Requirements for Northfinding







- Signal dependent on latitude
  - Earth rotation rate = 15 °/h
  - Component to horizontal plane ~ 7.5 °/h in Finland
- Way too small for current MEMS gyro stability
- By turning gyro to different orientation (Maytagging ± 180°) offset error can be cancelled

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THANK YOU!

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