

Inertial positioning for autonomous vehicles

Teknologia 19 – Uudet paikannusteknologiat

Anssi Blomqvist

Murata Electronics Oy



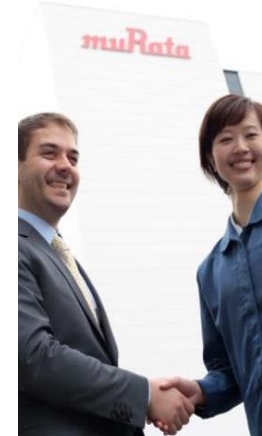
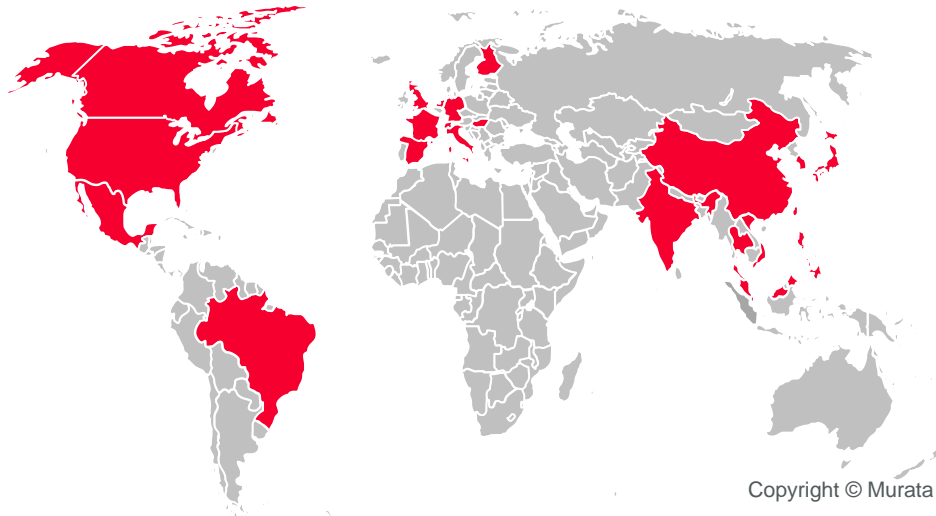
Murata – Innovator in Electronics

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



Murata components all around you



~ 1,000



~ 900



~ 4,000



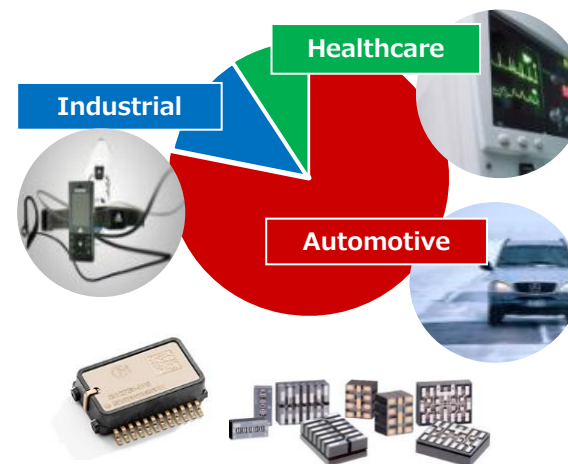
~ 250

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



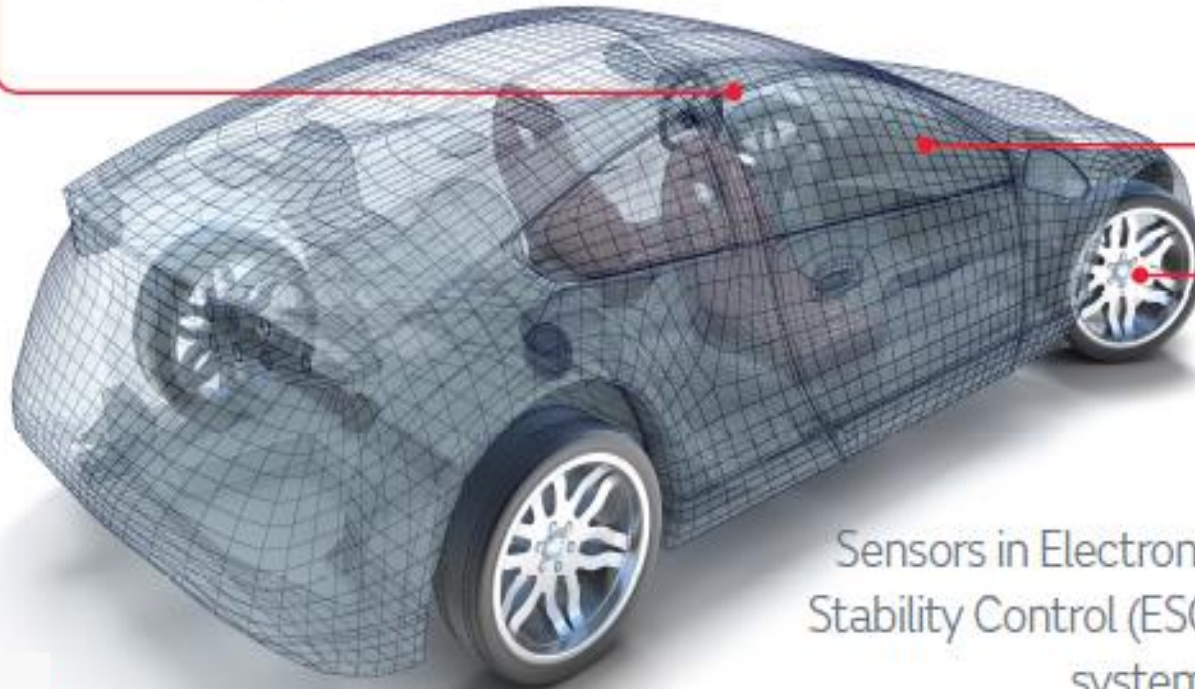
- Vehicle Dynamics**
 - Electronic Stability Control (ESP/ESC)
 - Roll Over / Roll Stability Control (RO/RSC)
 - Electronically Controlled Suspension (ECS)
- Vehicle Inclination**
 - Electric Parking Brake (EPB)
 - Hill Start Assistance (HSA)
 - Headlight leveling
 - Transmission control (TCM)
- Emerging Applications**
 - Navigation and Dead Reckoning
 - ADAS applications



Where Are Inertial Sensor Already Used?

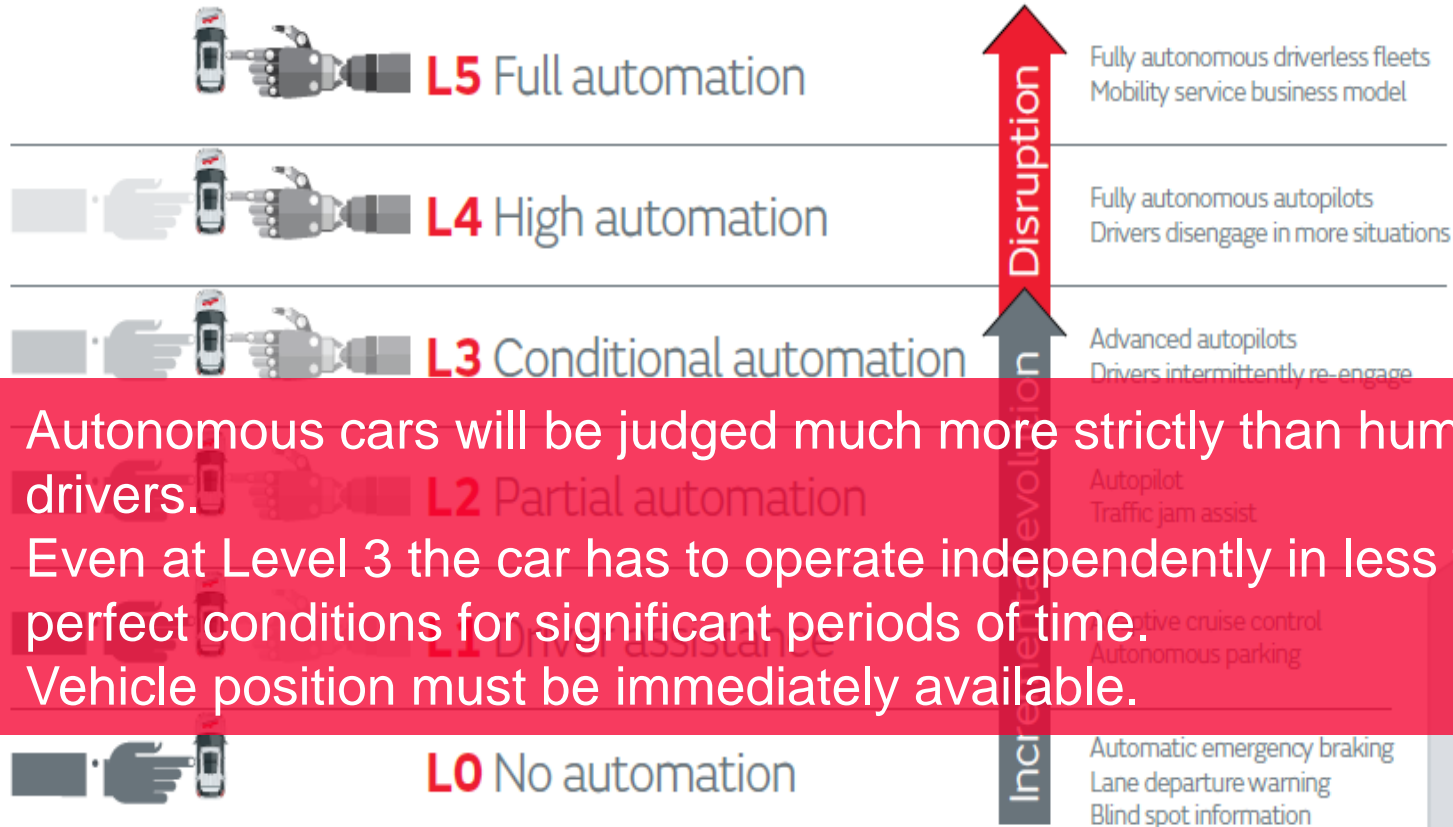
Supporting IMU for
in-dash navigation

Acceleration/crash
sensors for airbag
systems



Sensors in Electronic
Stability Control (ESC)
systems

Automation levels

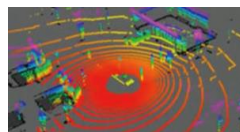


- Autonomous cars will be judged much more strictly than human drivers.
- Even at Level 3 the car has to operate independently in less than perfect conditions for significant periods of time.
- Vehicle position must be immediately available.

Why Inertial Sensor in AD?

Accurate positioning requires fusion of multiple sensors

Image based

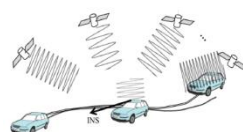


Lidar/Radar



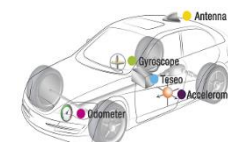
Camera

Satellite based



Multi band GNSS

Inertia based



IMU / Vehicle Speed

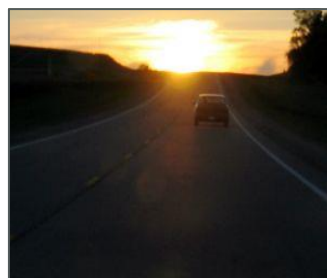


GNSS ❌

Image



IMU



GNSS

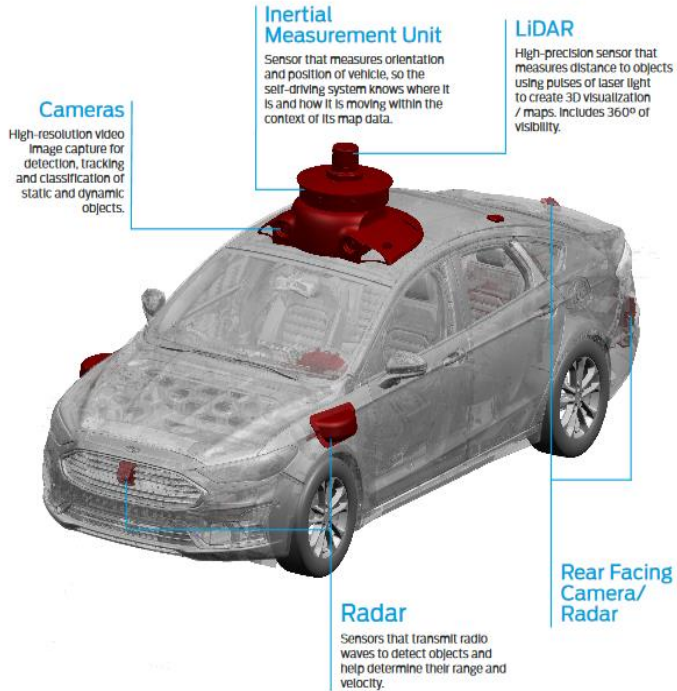


Image ❌

IMU



Safety report examples



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

Our Vehicles' Redundant Safety-Critical Systems

Backup Computing
A secondary computer running in the background brings the vehicle to a safe stop in the event of a failure of the primary system.

Redundant Inertial Measurement Systems for Vehicle Positioning
Redundant inertial measurement systems help the vehicle accurately track its motion along the road. These two systems cross-check each other and assume control from one another, if a fault is detected in either system.

Backup Power System
Independent power sources for each of the critical systems ensure that our vehicles' critical systems remain online during system or circuit interruptions.

Independent drive controllers ensure that one can fail without affecting the other.

Systems help ensure that one system can fail without affecting the other.

the rare event that the primary system does not detect or respond to objects in the path of the vehicle.

*<https://waymo.com/safety/>

SAFETY FIRST FOR AUTOMATED DRIVING

2019

3.6.2 Localization (Including GNSS)

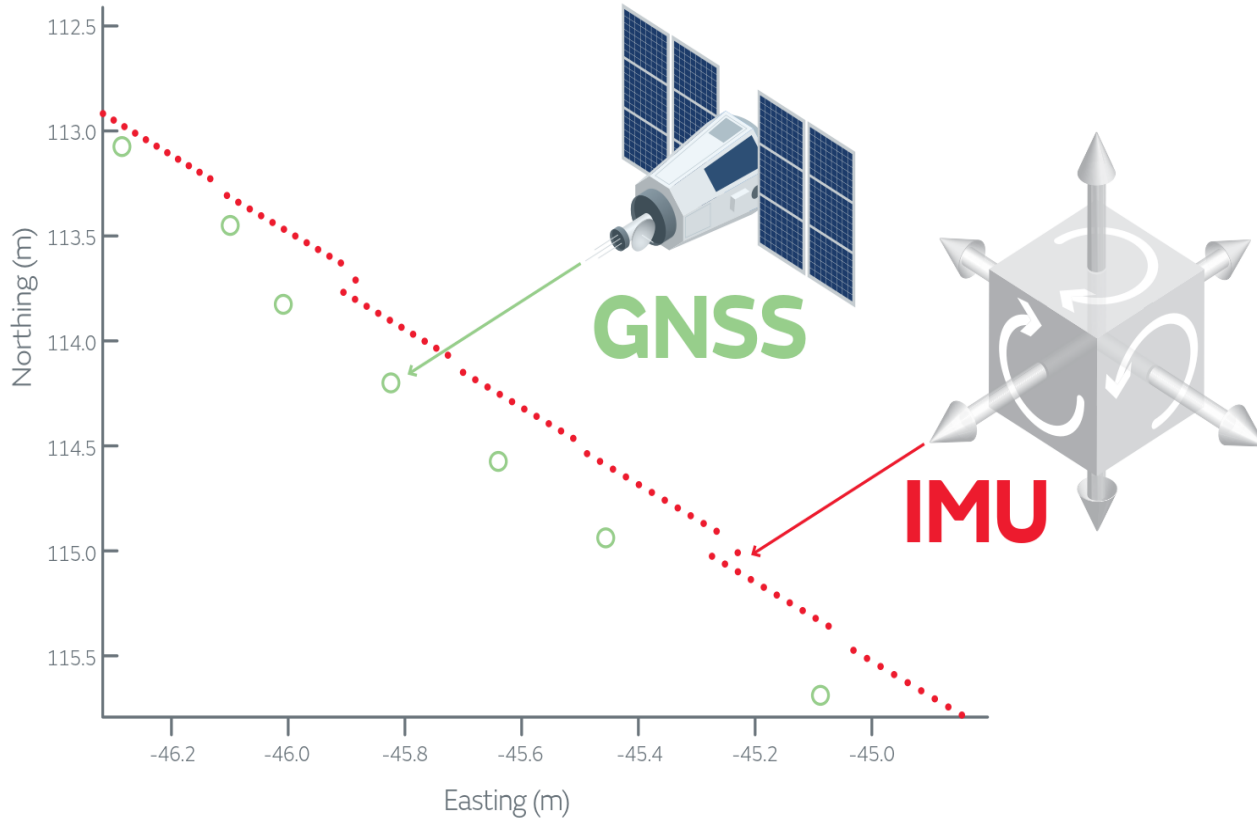
This section pertains to devices for determining the position of the vehicle relative to Earth surface coordinates. The input to the location system of the vehicle may comprise direct observation of global position (e.g. from the global navigation satellite system (GNSS)), local landmarks or information from V2X. This data is used in conjunction with other egomotion sensor data on the vehicle to ensure that the vehicle is positioned in an appropriate lateral position on the roadway and that curves on the roadway are appropriately anticipated with corresponding longitudinal speed adjustments. This is referred to as localization. The devices use GNSS. When the satellite system is not available, the vehicle systems defer to an inertial measurement unit (IMU) capable of measuring accelerations that are doubly integrated with respect to time to render position vs time. The IMU error is an error in acceleration. Thus, doubly integrating the error causes it to grow with the square of time. For this reason, IMU data is used briefly before it is reset. The error of satellite-based GPS data is generally time-independent, except for brief randomly distributed infrequent events for which the coordinate data are vastly incorrect. The sensors on the vehicle compare contextual information with the localization provided from map/Earth surface coordinates, which are imposed on map data, to determine whether localization from map/Earth surface coordinates

localization. The devices use GNSS. When the satellite system is not available, the vehicle systems defer to an inertial measurement unit (IMU) capable of measuring accelerations that are doubly integrated with respect to time to render position vs time. The IMU error is an error in acceleration. Thus, doubly

In terms of V&V for the localization system with respect to functional safety and safety of the intended functionality, dedicated testing is needed to ensure that the vehicle's behavior is safe on the roadway. For instance, functional safety testing includes fault injection on the IMU or GNSS system.

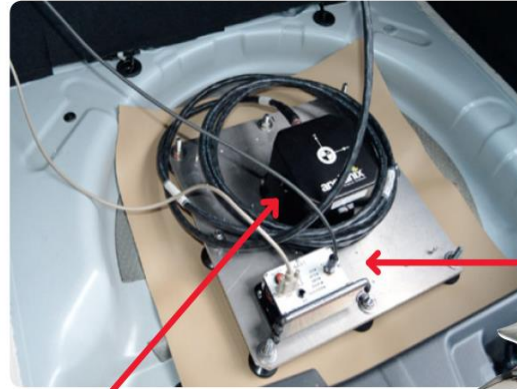
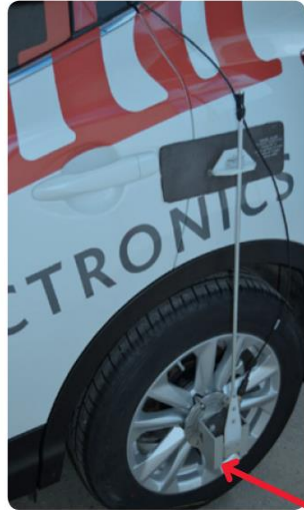
*<https://www.daimler.com/innovation/case/autonomous/safety-first-for-automated-driving-2.html>

Inertial Navigation System



High Performance IMU covers the gaps caused by missing GNSS data

Murata Test Vehicle



Murata IMU



Applanix POS LV 420 reference

Inputs

- 6DOF IMU
- external speed input

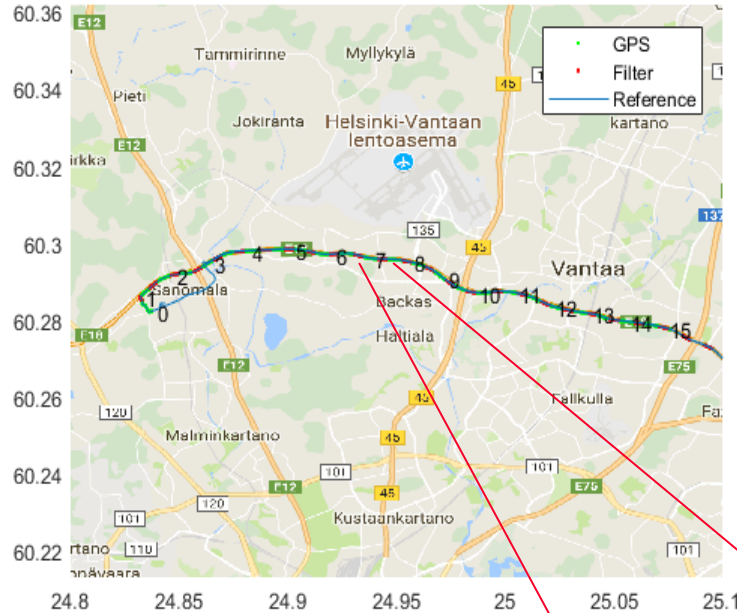
Outputs

- Vehicle Position
- Velocity
- Orientation

Components of inertial navigation solution

- Murata IMU
- Any GPS
- Wheel speed sensor output from OBD2

Case: Highway 80 km/h = 50 mph

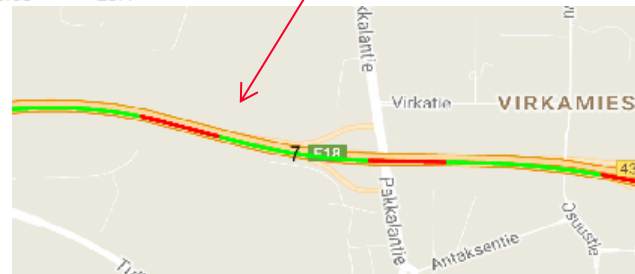


IMU + OBD (speed) + GPS

- 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

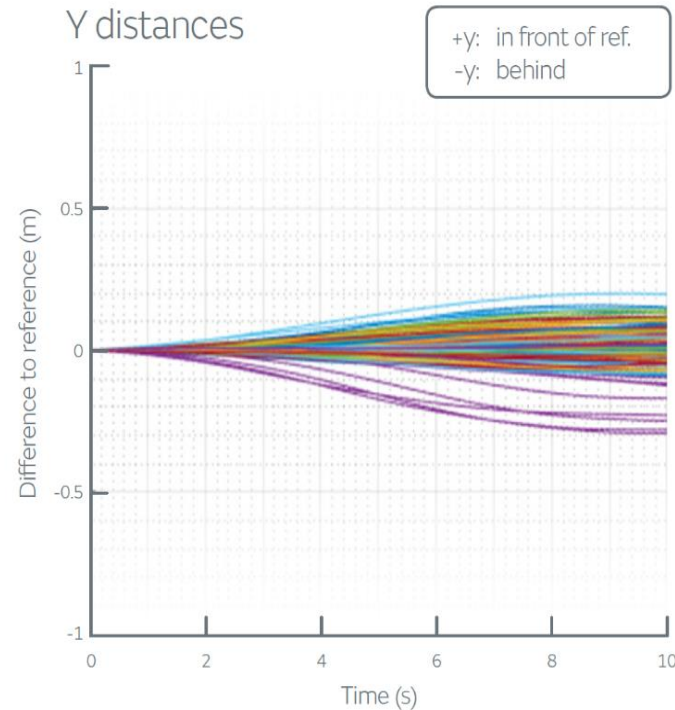
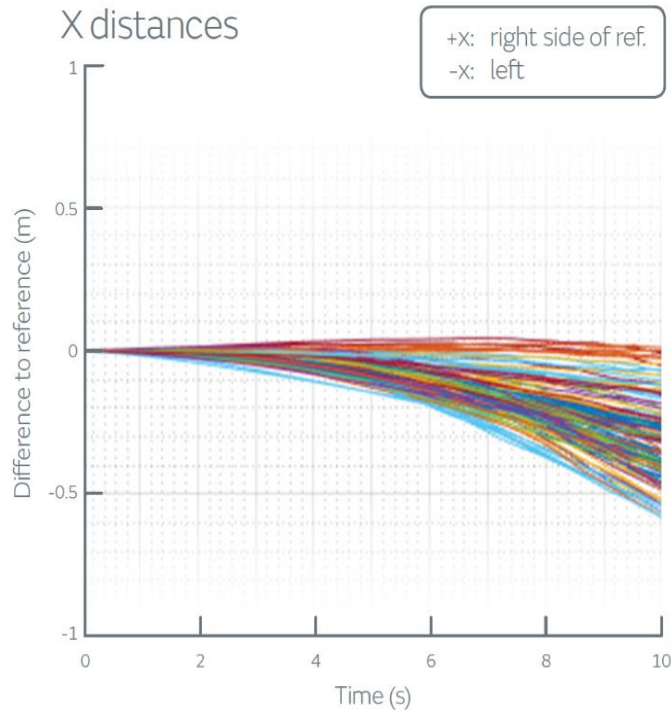
GPS off 10 sec
IMU + OBD



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

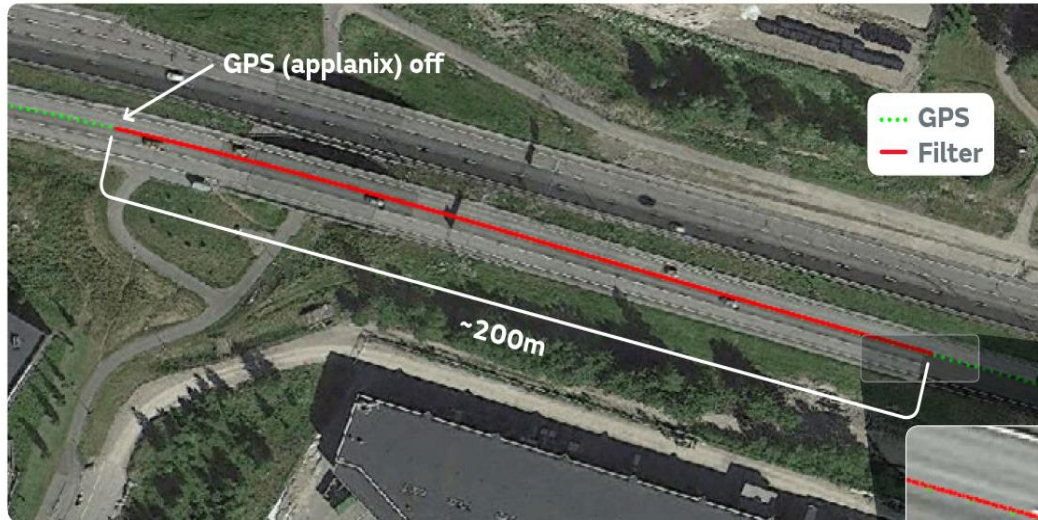


- Drive segments with GPS off for 10 sec stacked
- Lateral error (X): max 60 cm → MEMS IMU can keep car on lane for 10 sec.
- Longitudinal error (Y): max 30 cm

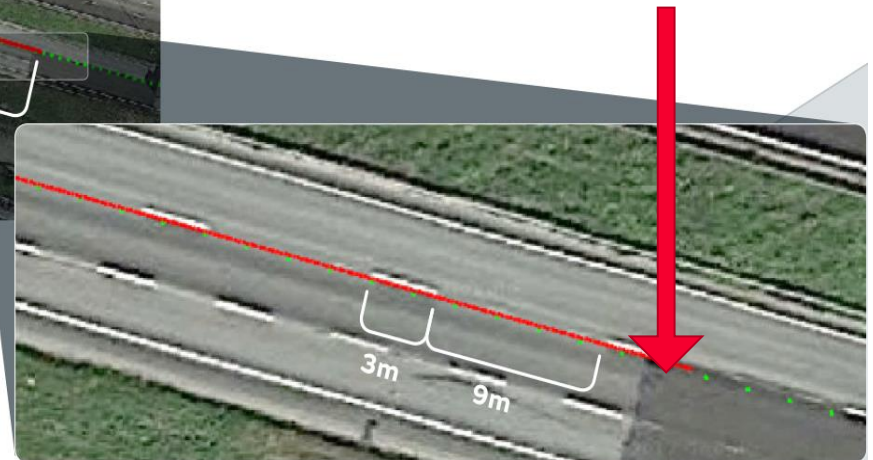


Closer Look (Highway 80km/h)

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

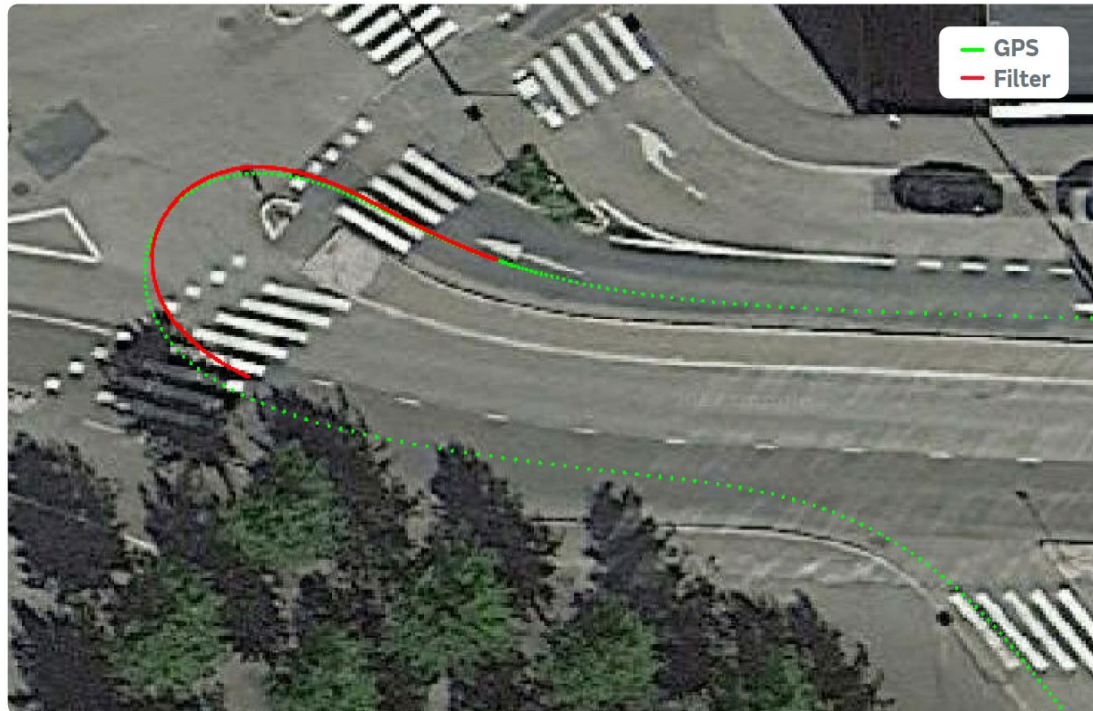


*Discrepancy between Google map coordinates and ref. GPS.
(We did driving in the center of the lane)*



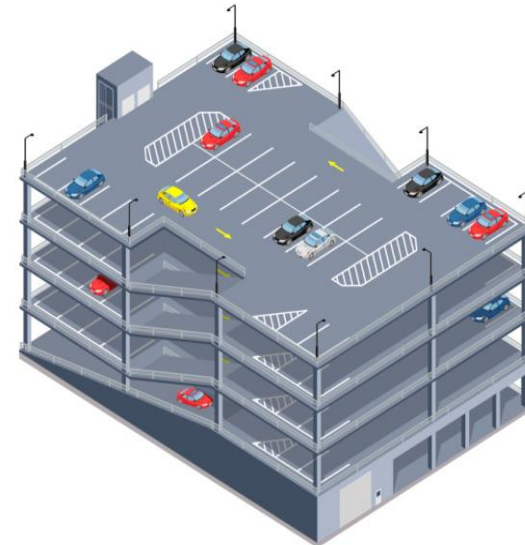
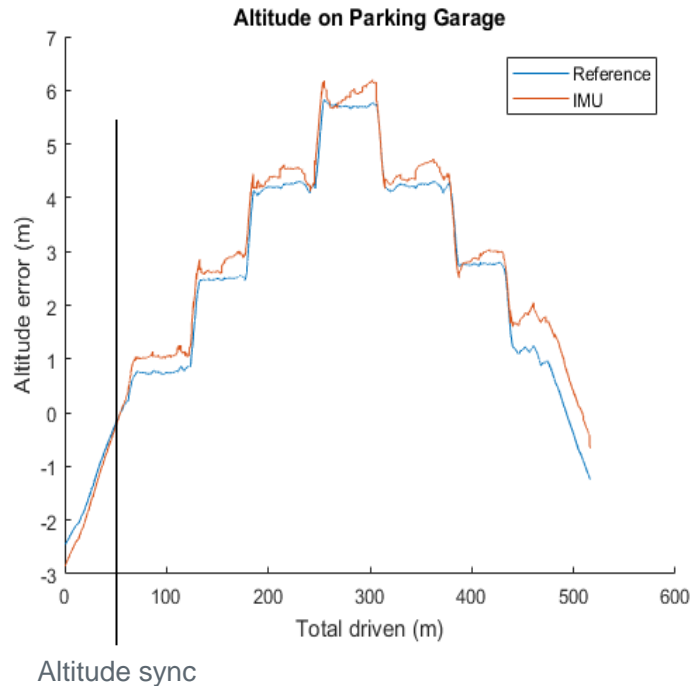
Case U-turn

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



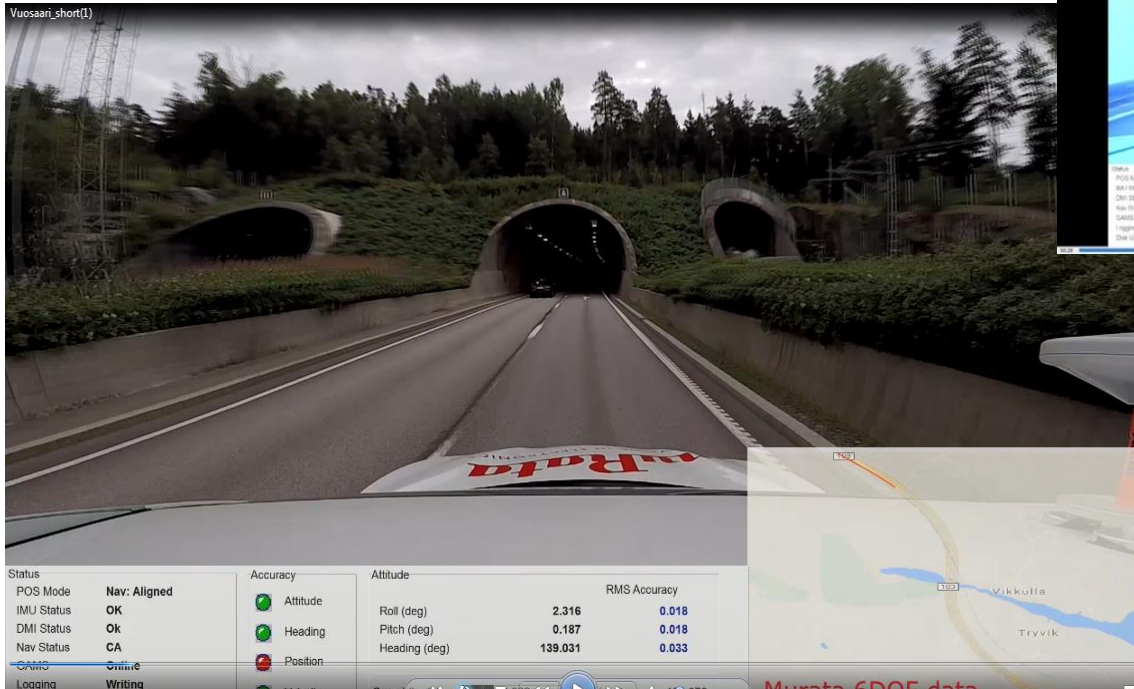
Case: Parking Garage, Altitude Detection by IMU

- 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



Case: Tunnel Drive

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

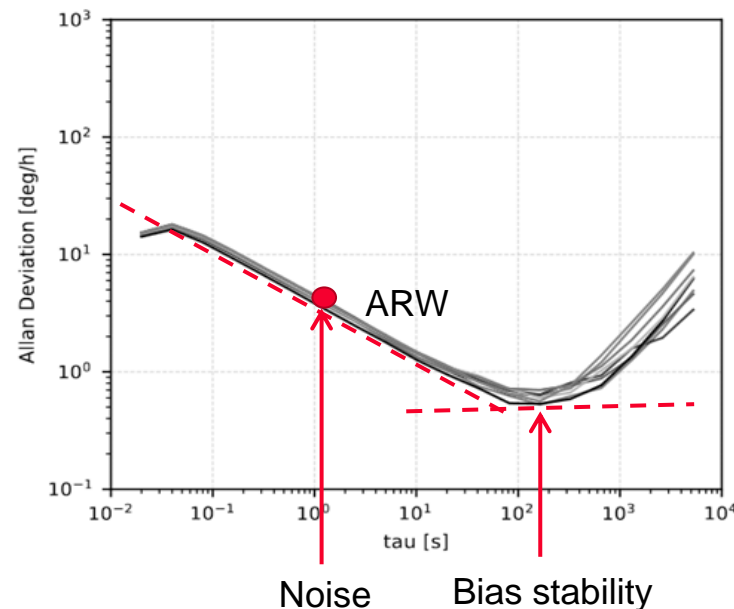


Urban canyon



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

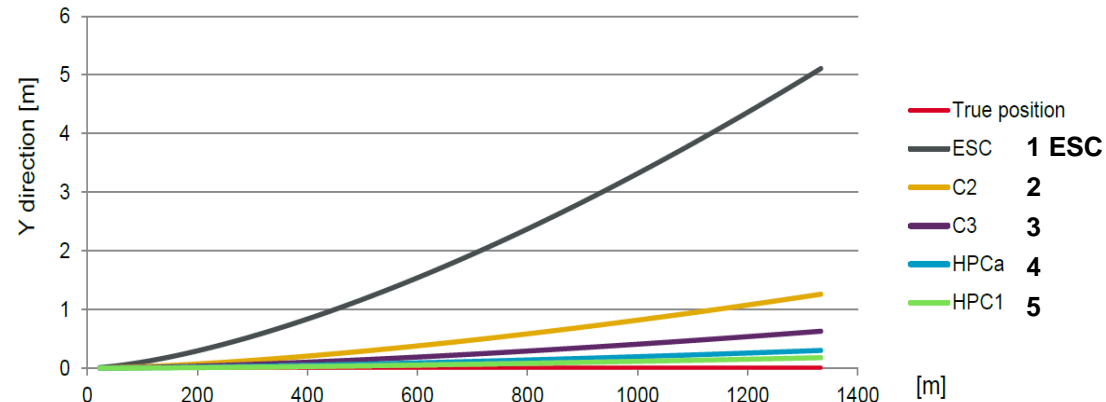
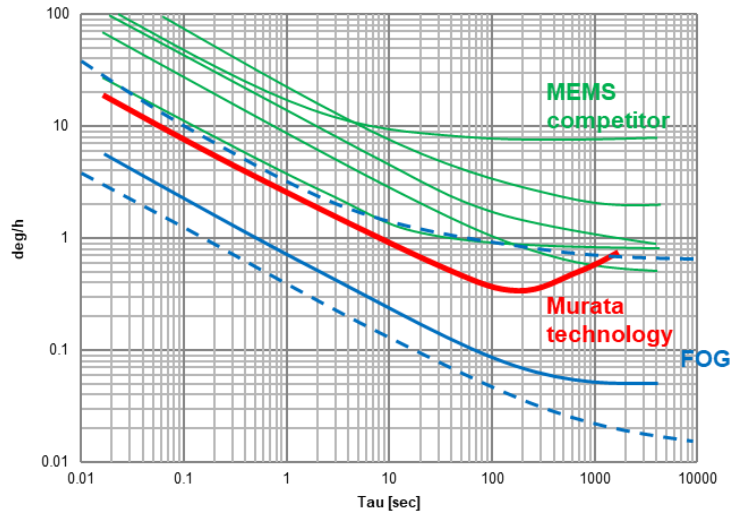


*ARW= Angular Random Walk

The Effect of ARW in Vehicle Positioning

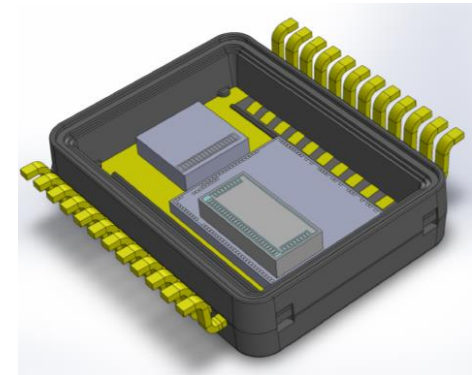
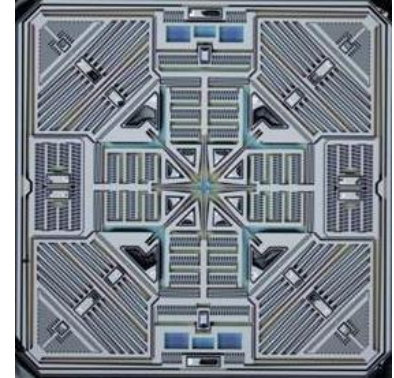
- IMU usage in navigation requires continuous error correction by the system based on GPS position.
- **The performance limit there is set by the gyro angular random walk (ARW) which is directly related to gyro white noise level.**
- Calculated errors in case of 80km/h 1 min driving
 1. ESC standard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

| | |
|----------------------|----------------|
| ARW 1.7deg/sqrt(h) | → error 5 m |
| ARW 0.4 deg/sqrt(h) | → error 1.2 m |
| ARW 0.2 deg/sqrt(h) | → error 0.6 m |
| ARW 0.1 deg/sqrt(h) | → error 0.3m |
| ARW <0.1 deg/sqrt(h) | → error < 0.3m |

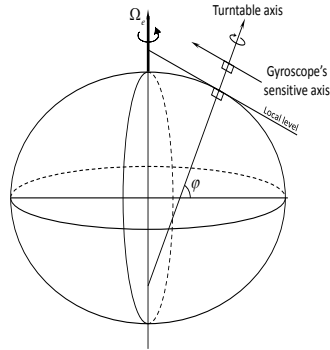


1st High Performance IMU Component w/ 4-ax MEMS gyro

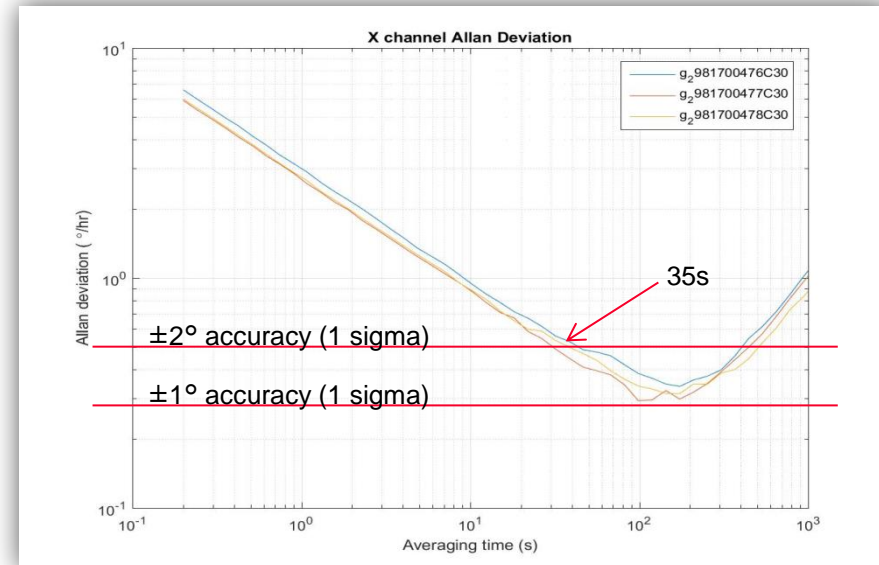
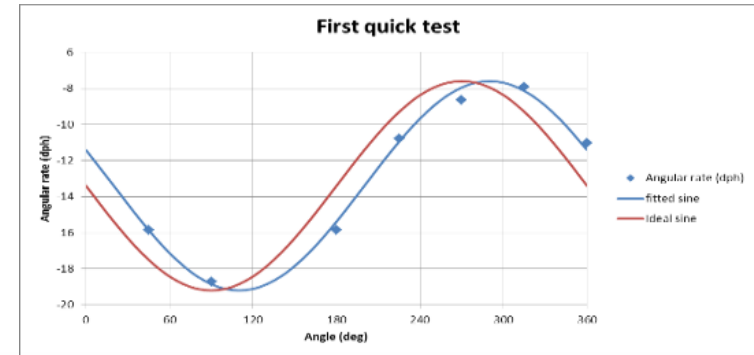
- HPC1
 - First true 6dof version for ADAS/AD
 - Several versions optimized based on application needs, e.g. industrial.
- Technical solution
 - 2 robust Z-gyros combined and XY gyros built on same structure (stability, noise, functional safety)
- Vision of future Combos, “true inertial navigation”
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



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 $\pm 180^\circ$) offset error can be cancelled



THANK YOU!

