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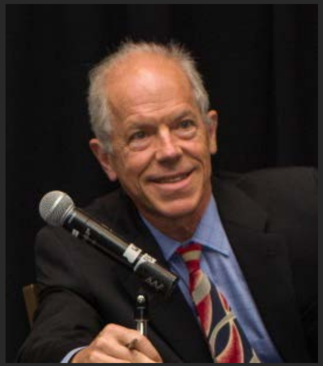
Wed, February 12, 2020

10 a.m.-11:30 a.m. PST • 11 a.m.-12:30 p.m. MST
12 p.m.-1:30 p.m. CST • 1 p.m.-2:30 p.m. EST

AUTOMOTIVE-GRADE GNSS + INERTIAL
FOR ROBUST NAVIGATION

WELCOME TO

Automotive-Grade GNSS + Inertial for Robust Navigation



Alan Cameron
Editor in Chief
Inside GNSS
Inside Unmanned Systems

Andrey Soloviev
Principal
QuNav

Philip Mattos
GPS/GNSS
Positioning/Navigation Expert
u-blox

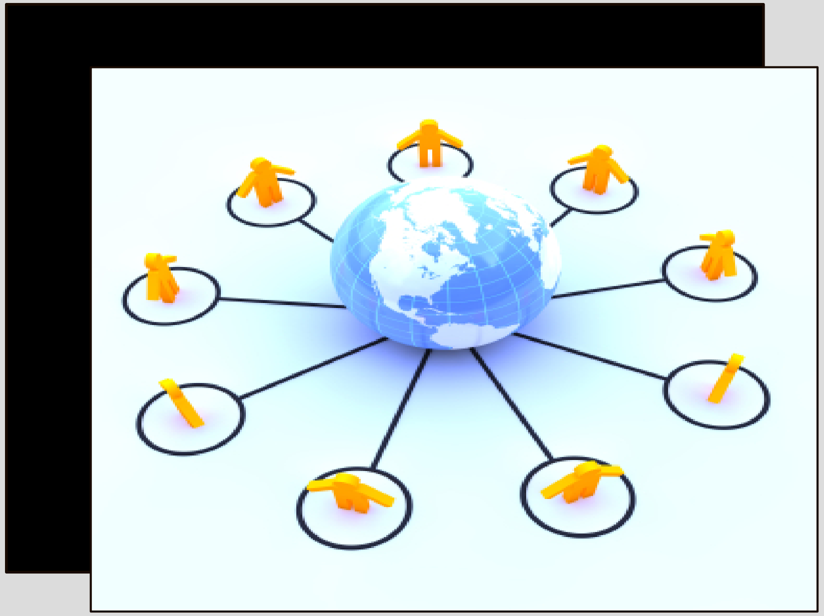
Jussi Collin
CEO Nordic Inertial
Adjunct Professor Tampere University Finland

Co-Moderator: Lori Dearman, Executive Webinar Producer

Who’s In the Audience?

A diverse audience of over 325 professionals registered from 45 countries, representing the following industries:

- 27% Automotive
- 11% Military and defense
- 8% Transportation/logistics/asset tracking
- 5% Precision agriculture
- 4% Machine control/mining/construction
- 45% Other



Today's Moderator

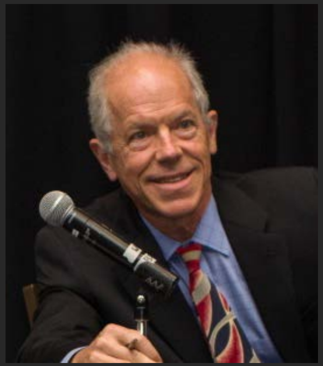
Alan Cameron
Editor in Chief
Inside GNSS
Inside Unmanned Systems

A word from the sponsor

Ananth Vadlamani
Systems Engineer
QuNav

Today's Panel

Automotive-Grade GNSS + Inertial for Robust Navigation



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QUICKPOLL

What are your accuracy requirements for harsh environments (urban canyons, tunnels, parking garages)?

Poll Results (single answer required):

10 centimeters	51%
1 meter	39%
5 - 10 meters	9%
greater than 10 meters	1%

GNSS/Inertial Vehicular Engine

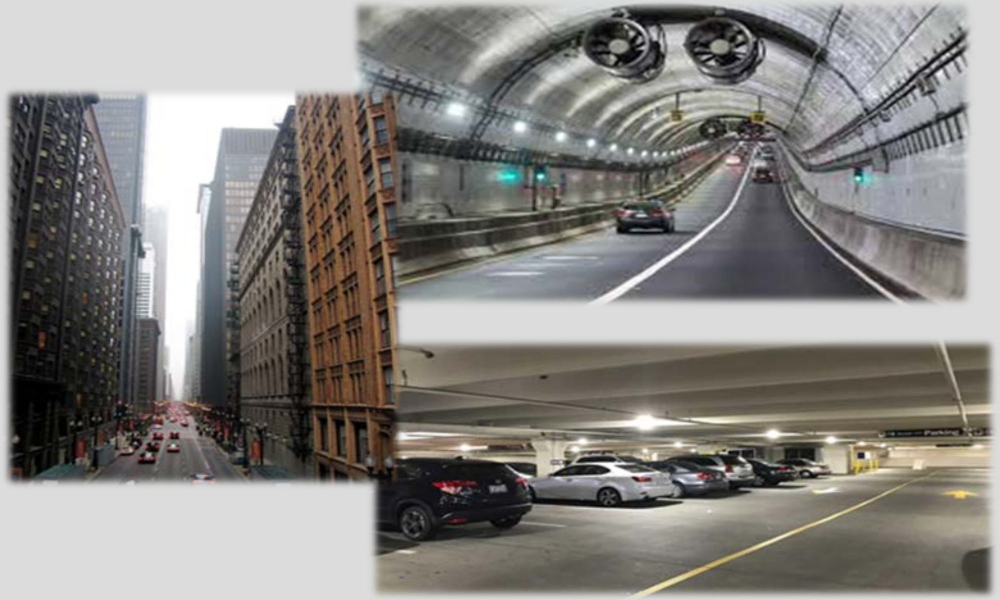
GIVE

for Automotive Navigation

Andrey Soloviev
Principal
QuNav

Motivation

- ***Low-cost*** augmentation of GNSS chipsets with MEMS inertial sensors (automotive and cell phone quality);
- ***Vehicle tracking*** in ***GNSS-challenged environments*** (urban canyons, tunnels, parking garages);



- ***Self-contained*** solution (without connecting to car sensors) for ease of operation

Key Features

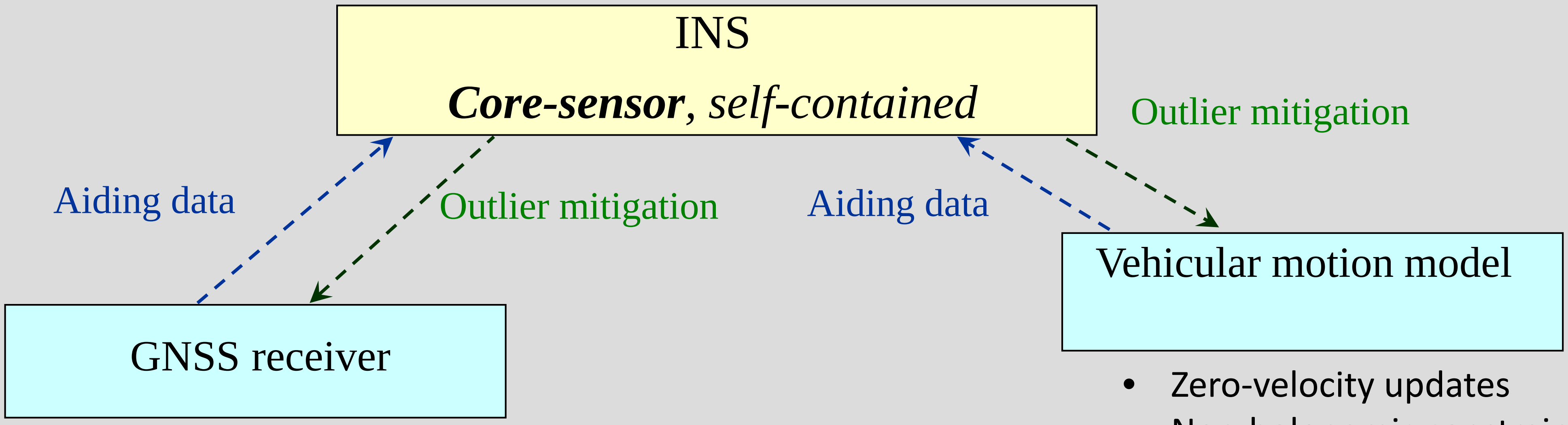
- Integration of ***consumer-grade GNSS*** and ***consumer-grade MEMS*** ($2-3) inertial sensors;
- ***Self-contained solution:*** No need for odometer connectivity;
- ***Sensor-agnostic*** system mechanization: software-based solution that can be ported to different implementation platforms;

Key Features

- ***Tight coupling*** of ***carrier phase GNSS*** with ***inertial*** measurements and vehicle ***motion model;***
- Software-based ***multipath mitigation;***
- ***Reliable and consistent navigation performance*** (position, velocity and attitude) in GNSS-challenged and denied environments (*urban canyons, tunnels and parking garages*).

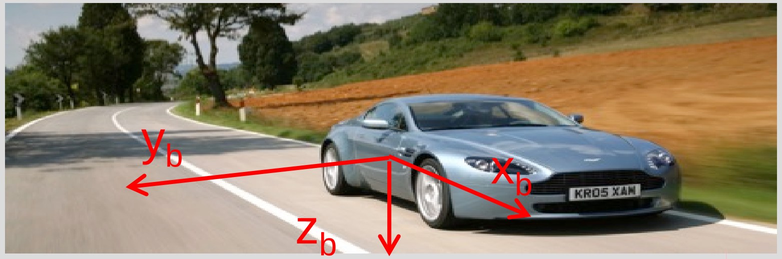
Navigation Solution

Tight coupling of *Inertial, GNSS* and *vehicular motion model*



- Pseudoranges
- ***Carrier phase***

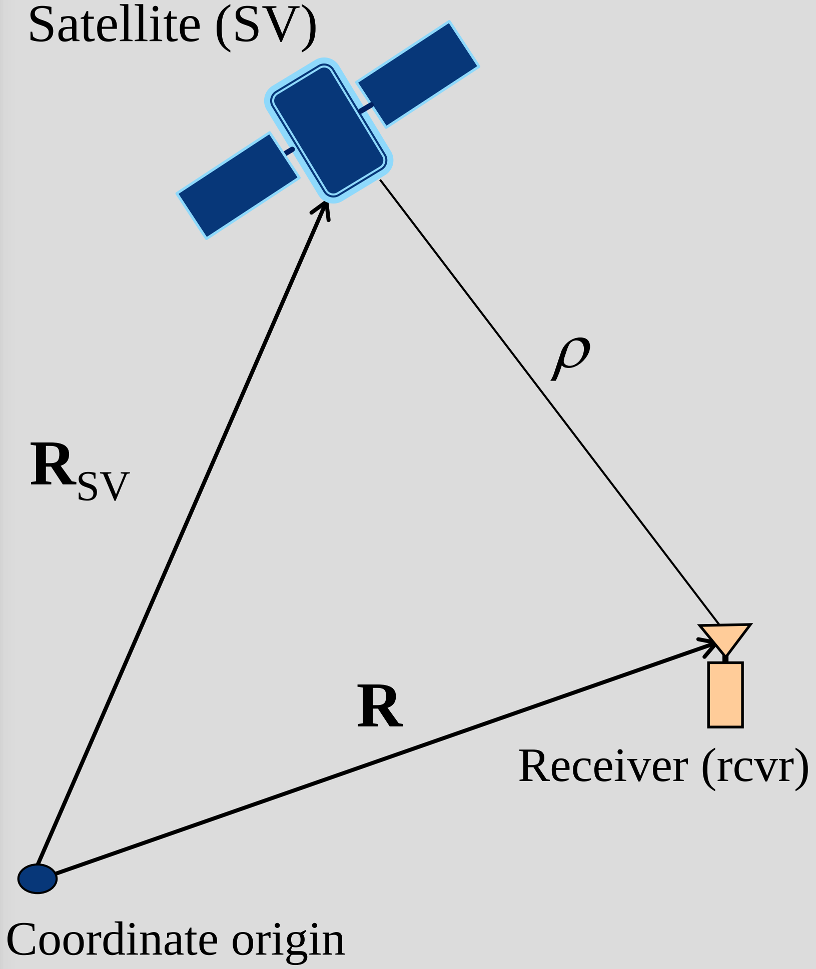
- Zero-velocity updates
- Non-holonomic constrains



$$V_{y_b} = 0$$

$$V_{z_b} = 0$$

Use of GNSS Carrier Phase



Carrier phase measurement

$$\varphi = \rho + \lambda N + \delta t_{rcvr} + \varepsilon + \eta$$

- λN → Integer ambiguity
- δt_{rcvr} → Clock bias
- ε → Atmospheric delays & SV clock
- η → Noise & multipath

- ***Resolving integer ambiguities*** can be ***challenging:***
  - Need for correction services;
  - Limited number of SVs

- Therefore, ***temporal phase changes*** are used as ***GNSS observables:***

$$\Delta\varphi = \varphi(t_n) - \varphi(t_{n-1}) = \Delta\rho + \Delta\delta t_{rcvr} + \Delta\varepsilon + \Delta\eta$$

$\Delta\rho$ → ***Position change***

↓

Full observability of INS error states

- Two levels of mitigation:
  - *Step 1*: ***INS-based statistical gating:*** residual screening of the tightly coupled Kalman filter
  - *Step 2*: Probabilistic data association filtering (PDAF): ***adaptive de-weighting*** that incorporates probability of missed-detection

GIVE Evaluation Kit

- Consumer grade GNSS (Ublox M8T);
- Consumer-grade MEMS IMU (STMicro iNEMO);
- Real-time navigation and data logging software running on an ARM processor;
- Extendable to other sensor-fusion augmentations (lidar, vision)

Test Environments

Real-time solution was tested in a variety of GNSS-degraded and GNSS-denied environments

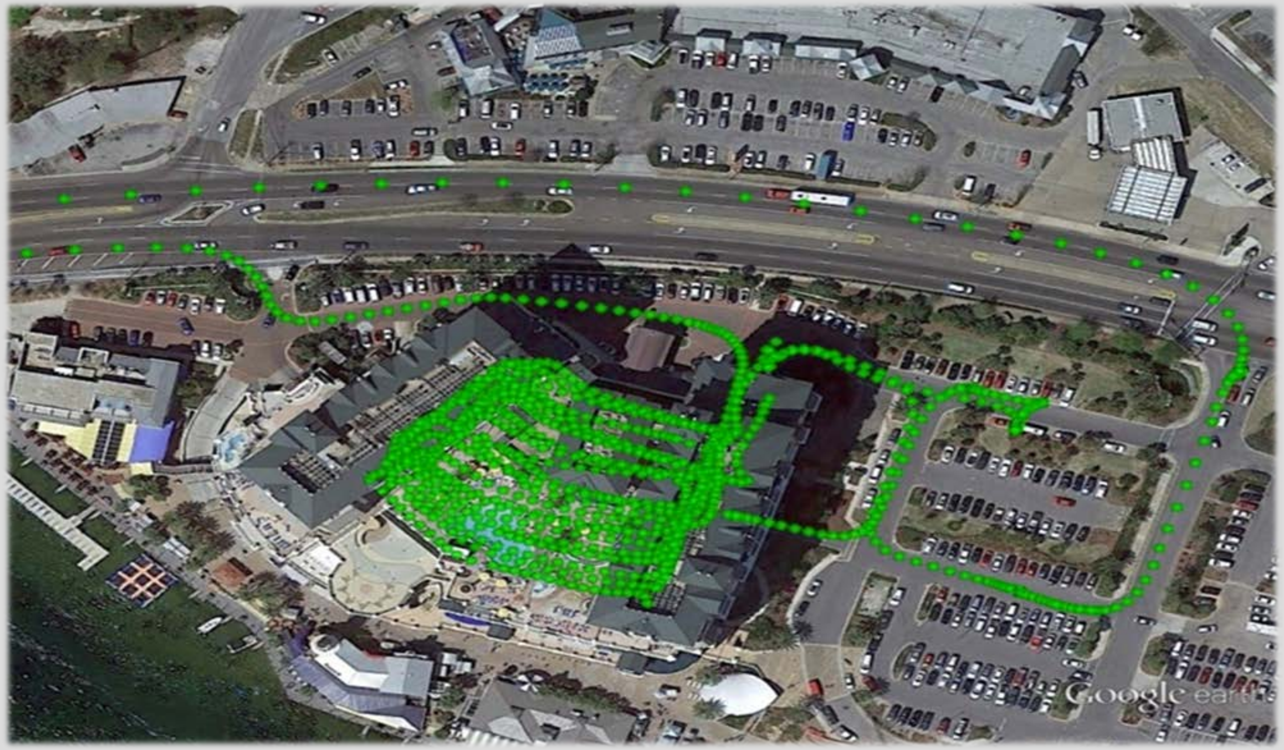




Real-time performance in ***harsh GNSS environments***

Parking garages:

- Two loops inside a completely enclosed parking garage;
- GNSS outage duration is 5 minute of each loop



Consistent navigation performance over long GNSS outages

Real-time performance in ***harsh GNSS environments***

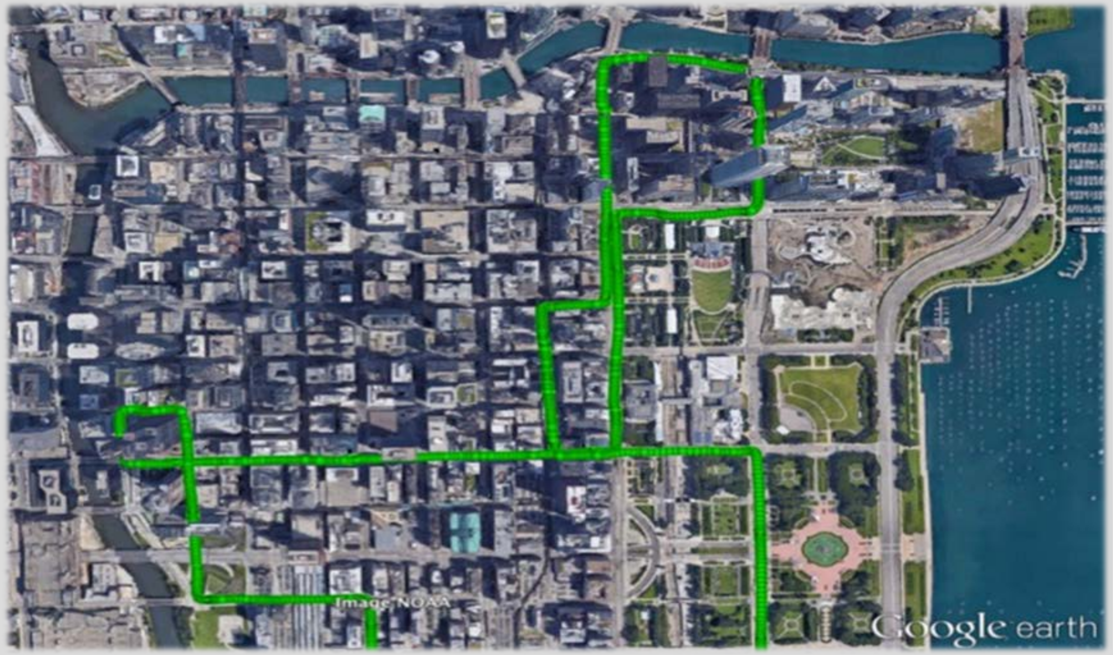
Atlanta, GA

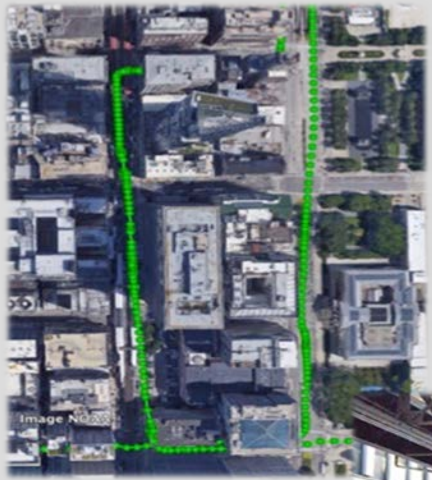
Consistent navigation performance in downtown environments and parking garage

Example Test Results

Real-time performance in ***harsh GNSS environments***

Chicago, IL

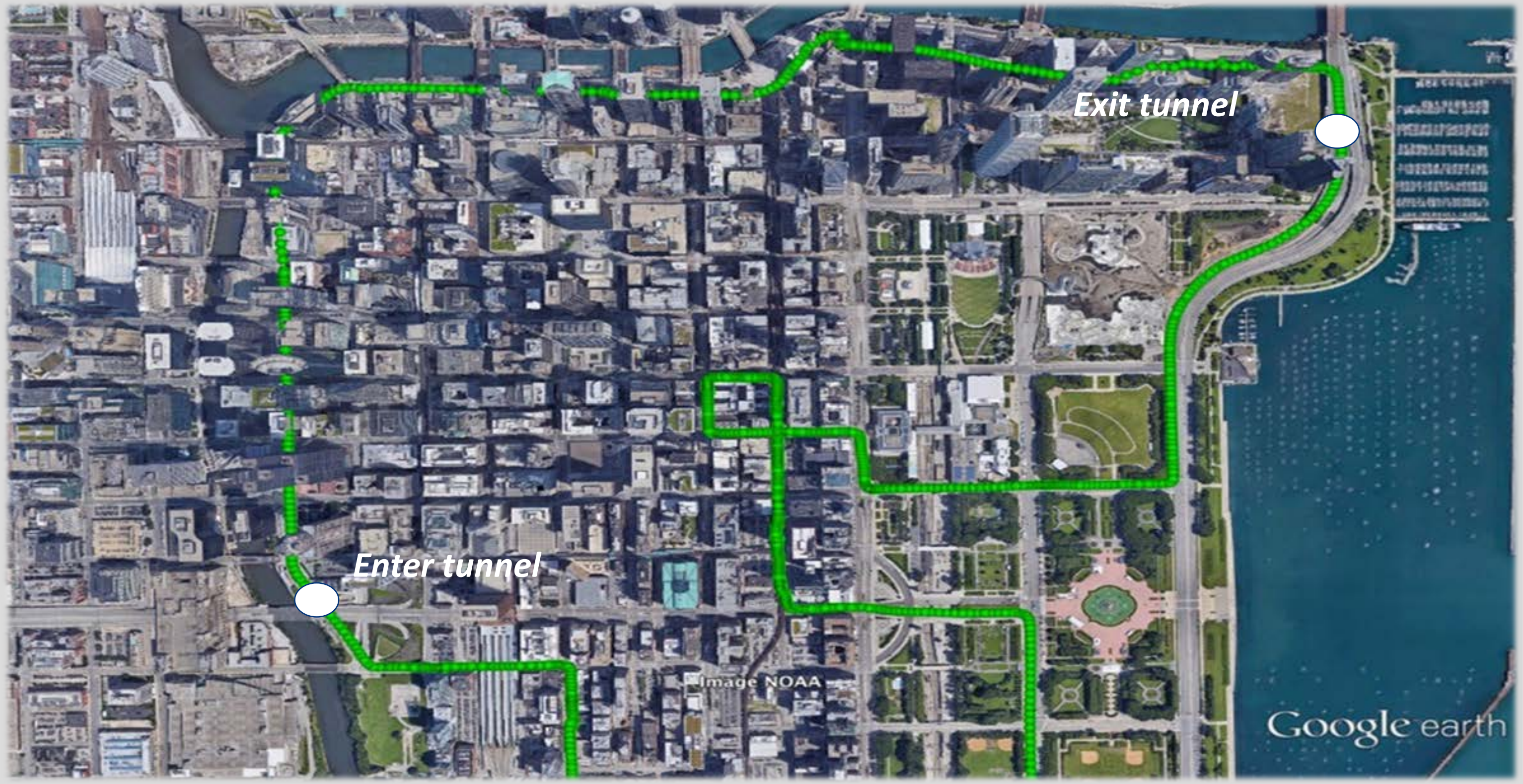




Consistent navigation performance in dense urban canyons

Real-time performance in *harsh GNSS environments*

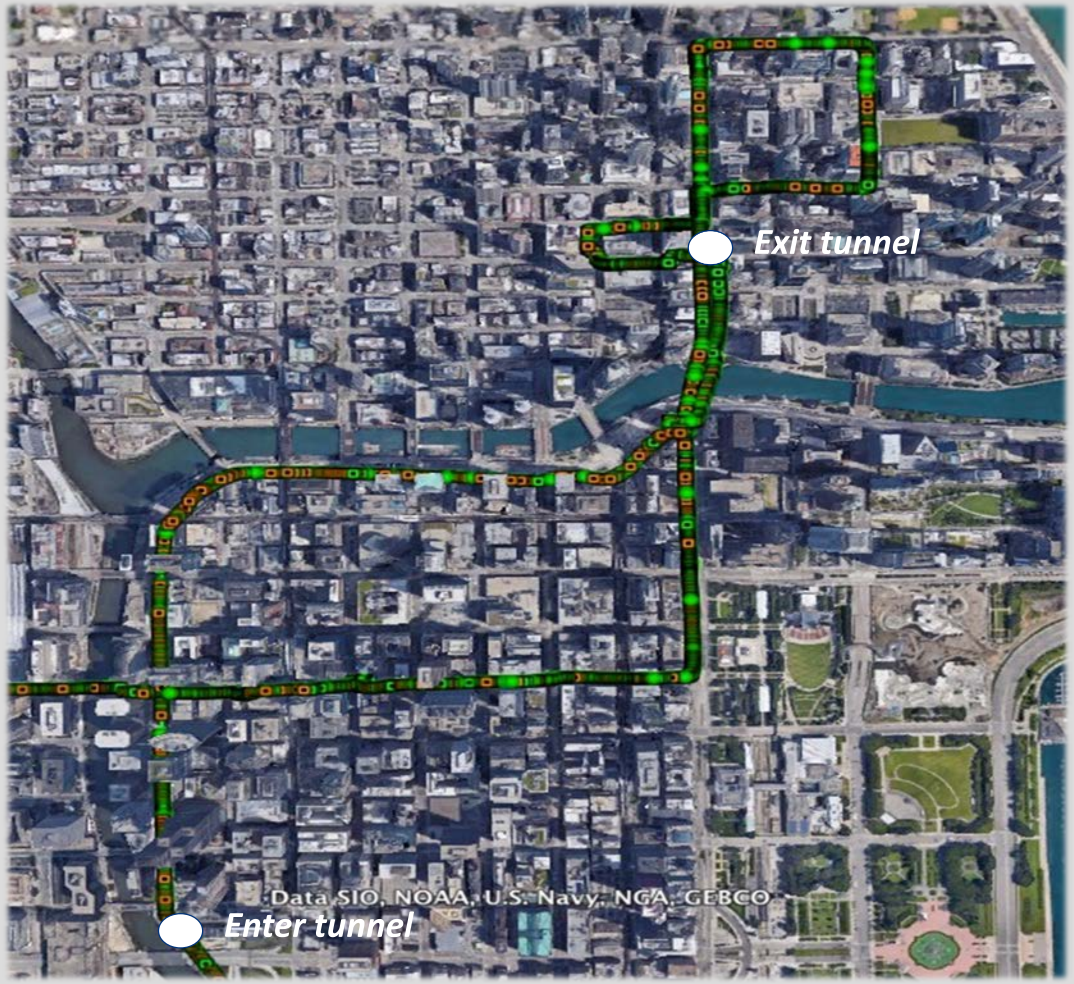
Chicago, IL

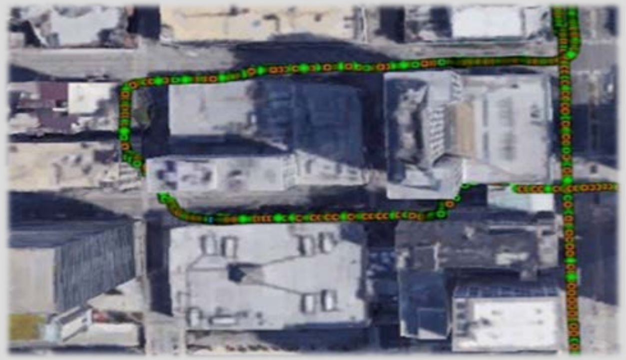


Consistent navigation performance in long tunnel (Lower Wacker drive)

Real-time performance in ***harsh GNSS environments***

Chicago, IL



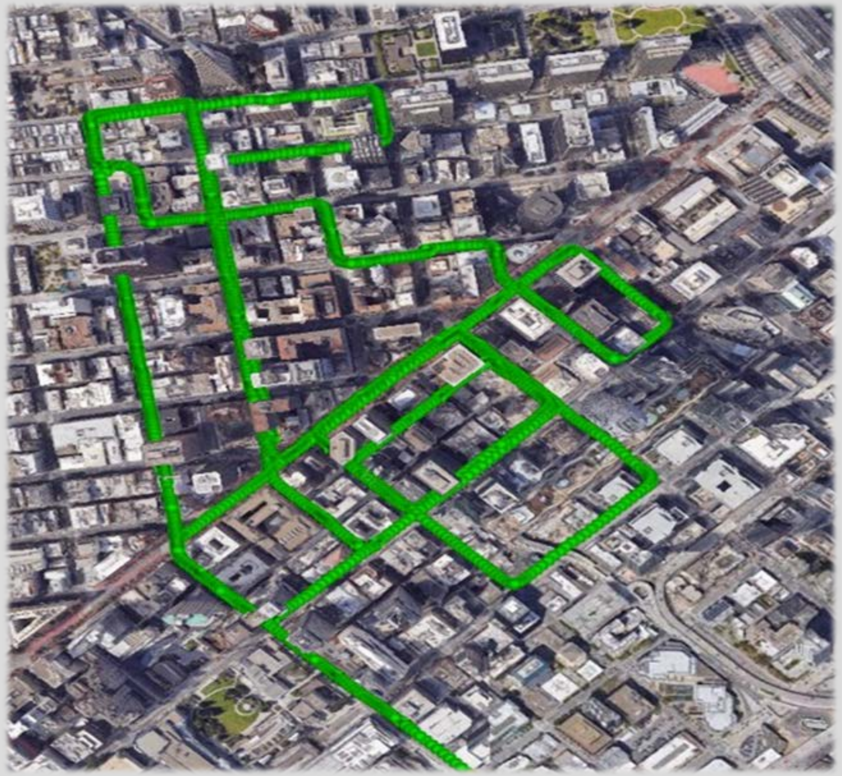


Seamless transition from a tunnel into an urban canyon

Example Test Results

Real-time performance in ***harsh GNSS environments***

San Francisco, CA



Consistent navigation performance in dense urban canyons

Example Performance on Android Phone

- Xiaomi Mi 8
- GNSS and inertial data were logged and post-processed with GIVE software
- Long tunnel example (lower Wacker drive in downtown Chicago)

Xiaomi position output

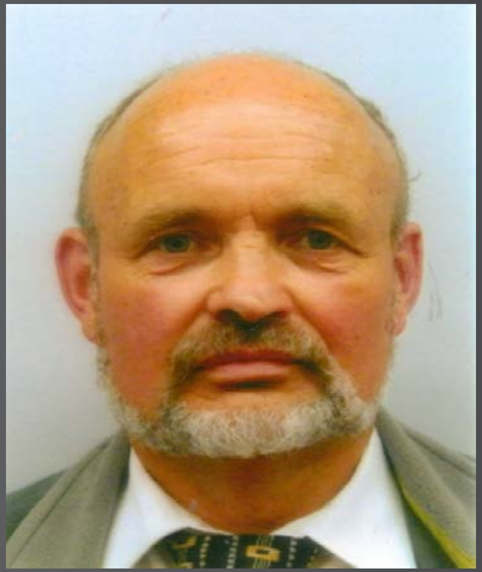
GIVE solution

No availability in the tunnel

Consistent navigation performance is maintained for the entire test

Self-contained integration of ***low-cost GNSS*** and ***inertial*** sensors enables ***consistent and reliable navigation performance*** for ***the most challenging automotive scenarios*** (urban canyons, tunnels, parking garages)

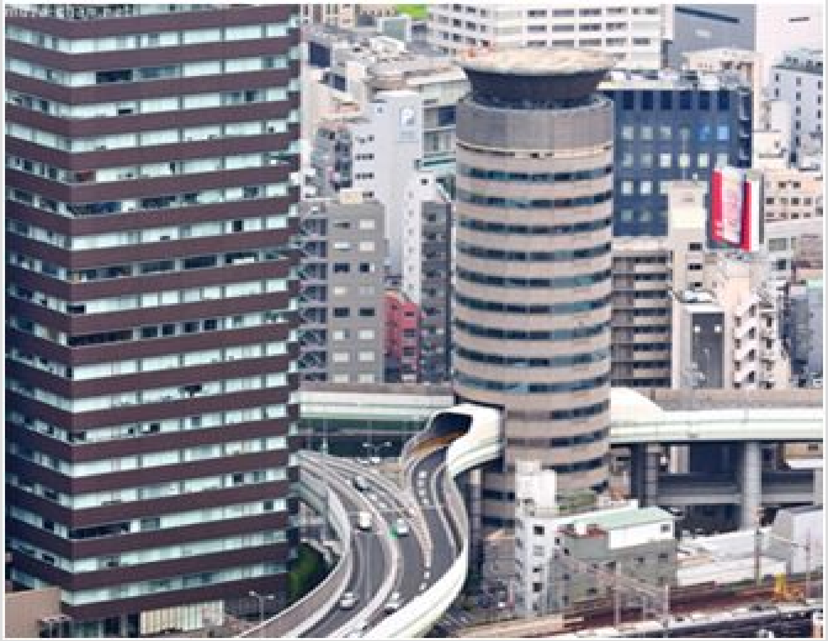
GNSS and Inertial, Fused for Accuracy and Robustness



Philip Mattos
Positioning Technology Expert
u-blox

The navigation challenge in the 21st century

- Position accuracy is key factor in automotive applications
- City and roadway environments can interfere with GNSS reception
  - Deep urban canyons
  - Multi-level roads
  - Indoor driving
- Wrong or no position calculations due to
  - Lack of satellite visibility
  - Poor satellite geometry (DOP)
  - Multi-paths

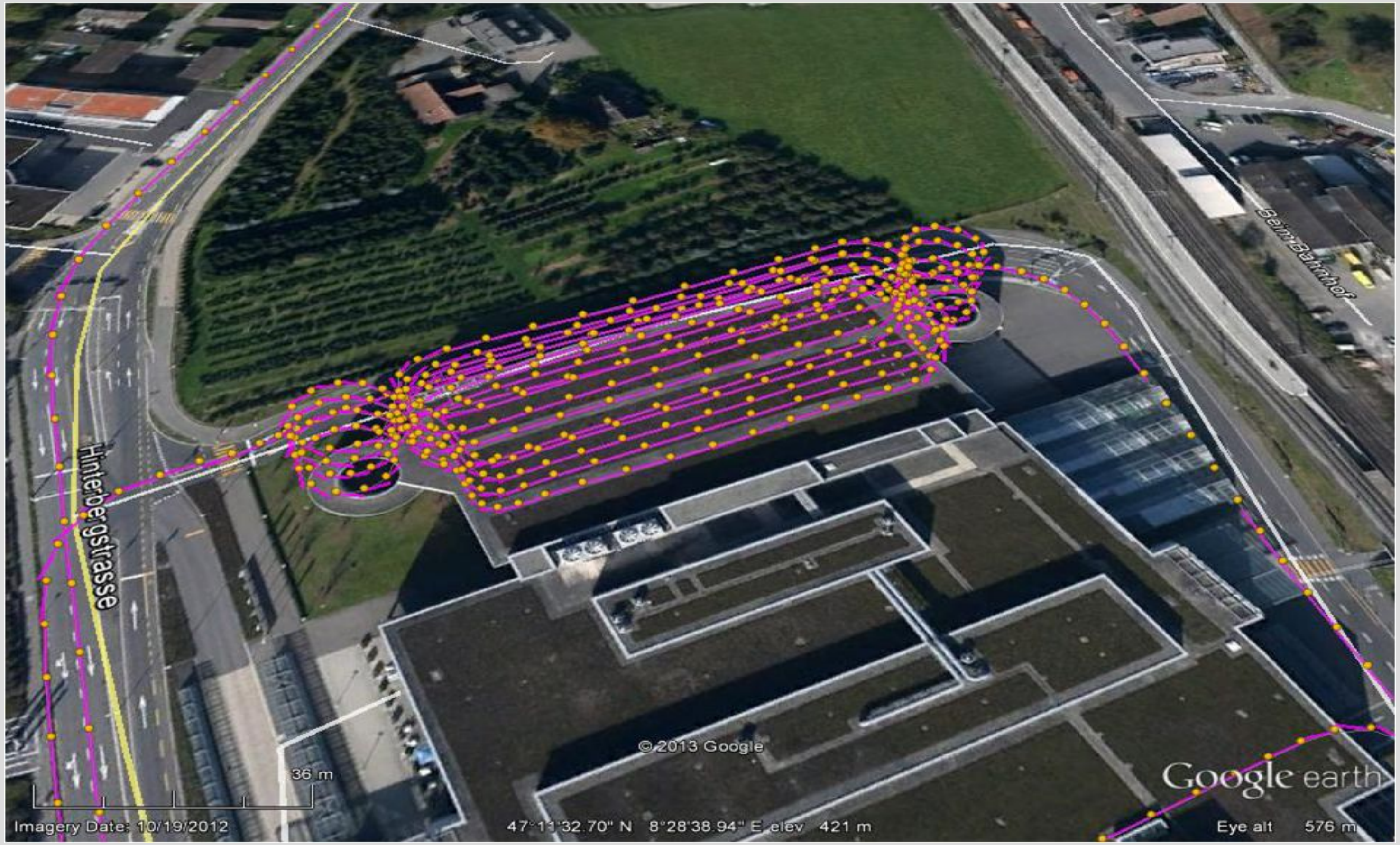


* Global Navigation Satellite System

u-blox M8 3D-ADR - Solution

- Support of concurrent GNSS reception (GPS,Galileo,QZSS,GLONASS, BeiDou)
  - High Sensitivity, excellent accuracy and fast TTFF
- Sensor support (**D**ead **R**eckoning) for various sensor combinations
  - DWT (Differential Wheel Tick): enables 2D ADR
  - GWT (Gyro & Wheel Tick): enables 2D ADR
  - GAWT (Gyro, Accelerometer & Wheel Tick): enables 3D ADR
- High navigation update rate
  - >= 30Hz update rate enables Lag-free display
  - Configurable
  - Low Latency for real-time applications such as V2X

Multi Story - Parking Garage (3D)



With no GNSS reception, the ADR solution continues to operate, including altitude determination for best position.

Leading performance under poor signal conditions

- Better navigation performance at weak signals (~20-25 dBHz) vs. GNSS only

Possible location of the device, which may be placed anywhere in the vehicle.

UDR+GNSS

GNSS only

UDR applications examples

- Designed for applications mounted in a road vehicle looking for:
  - Differentiation over GNSS only
  - Enabling new markets through:
    1. Enhanced GNSS performance in most conditions
    2. Cost/size reduction thanks to extra performance

- Typical industrial vehicle based tracking solution:

Examples

Security – car alarm

Insurance telematics

Navigation (aftermarket)

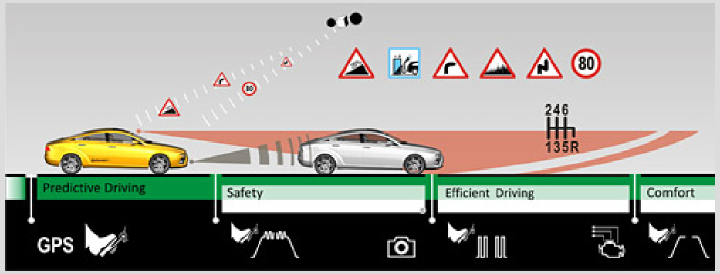
Road tolling

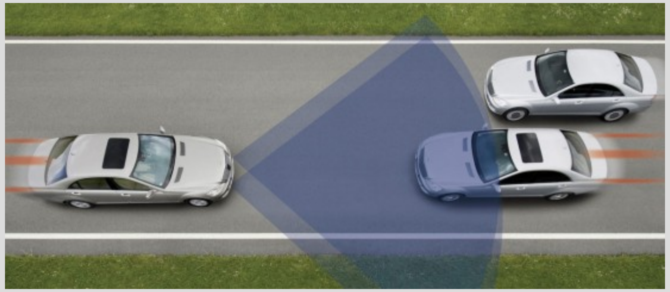
OBD-retail

Fleet management

Lane Accuracy for ADAS / Autonomy

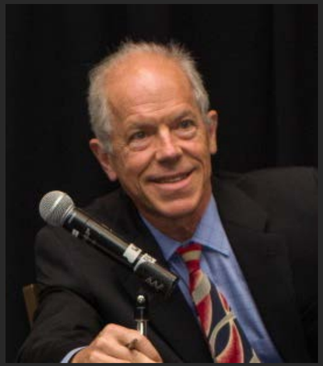
- SSR/RTK solution incorporating ADR specifically for lane accuracy
  - ADAS
  - autonomous driving applications
- Integrity
- Functional safety





Ask the Experts Part I

Automotive-Grade GNSS + Inertial for Robust Navigation



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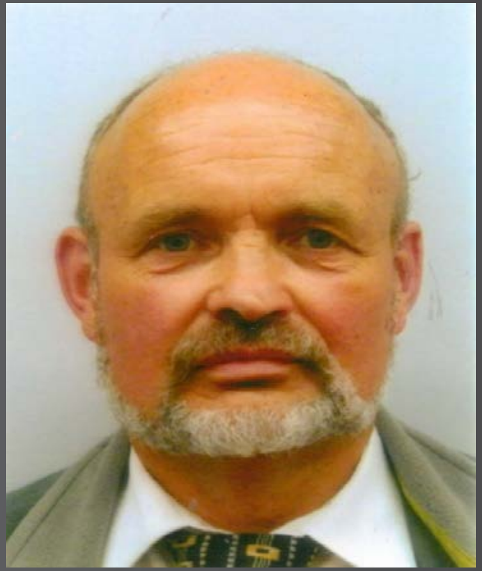
QUICKPOLL

In which problem scenarios are low-cost inertial solutions most useful? (Select two)

Poll Results (multiple answers allowed):

Typical urban environment	74%
Tree canopies	24%
Tunnels and parking garages	60%
Multi level interchanges	28%

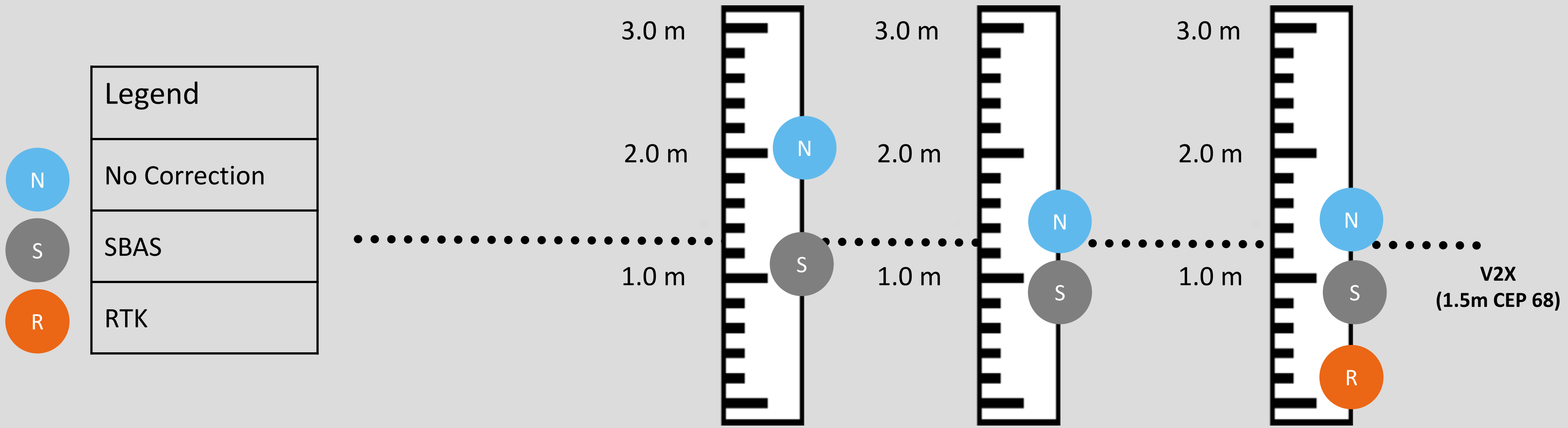
GNSS and Inertial, Fused for Accuracy and Robustness (Part 2)



Philip Mattos
Positioning Technology Expert
u-blox

CEP50 accuracy performance

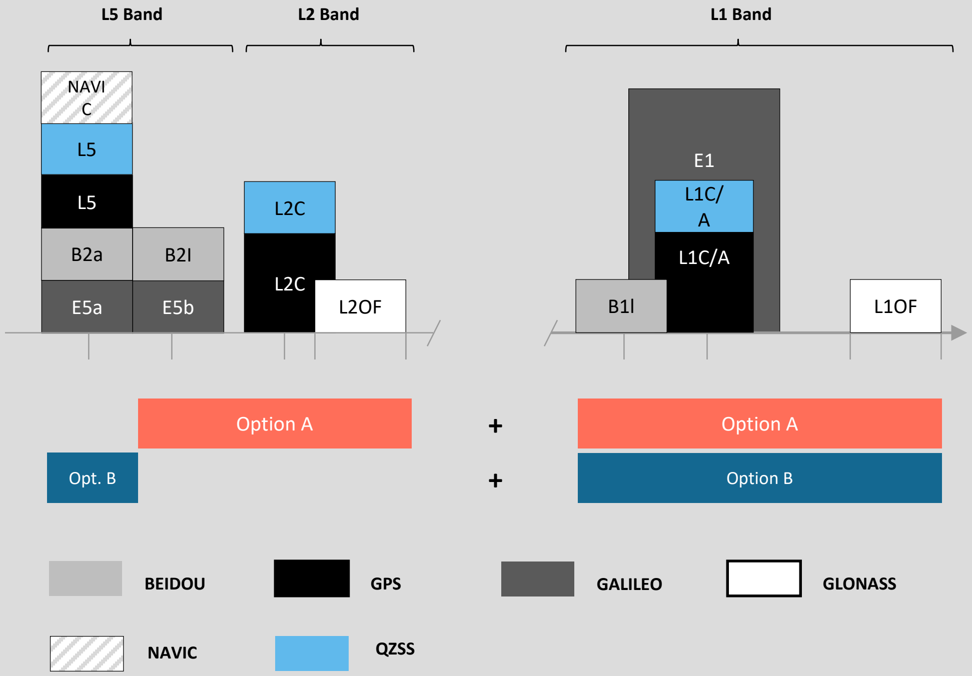
Under open sky, static conditions



	Single Band + DR	Multi-band + DR	Multi-band + DR + SSR-RTK
Bands	L1	L1/L2/L5	L1/L2/L5
Constellations	4	4	4
Applications	eCall, Navigation, V2X	eCall, Navigation, V2X	Advanced Navigation, ADAS

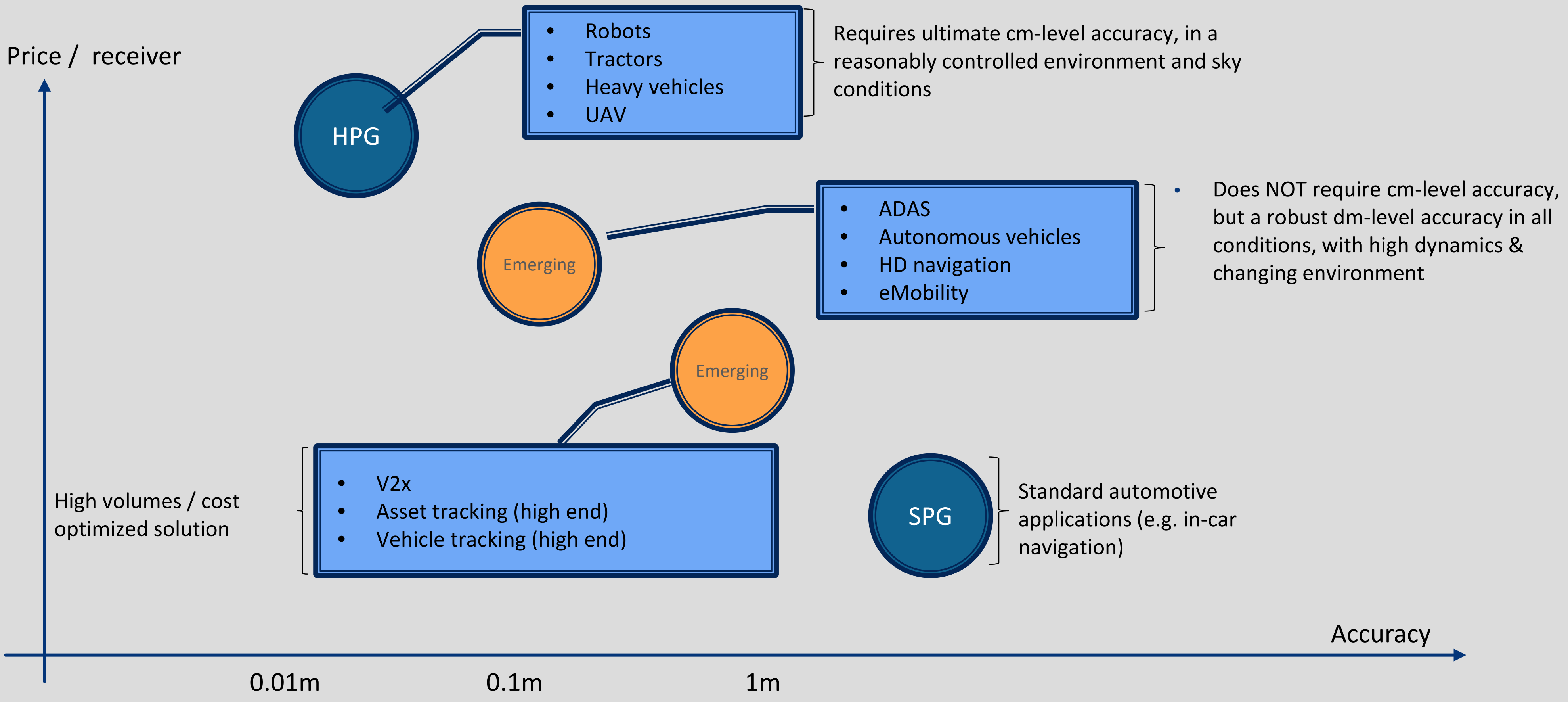
u-blox F9

- Multi-band, multi-constellation capabilities
  - u-blox F9 capable of tracking all civil GNSS signal bands
  - Multi-band enables fast time to first ambiguity fix and robust performance
  - Multi-constellation enables receiver to track a high number of GNSS observations
  - u-blox F9 comes with two band options:
    - GPS L1/L2C, Galileo E1/E5b, Glonass L1/L2, BeiDou B1I/B2I, QZSS L1/L2C, SBAS L1
    - GPS L1/L5, GAL E1/E5a, GLO L1, BDS B1I/B2a, QZSS L1/L5, NAVIC



Overview of main vehicle applications

Requirements differ depending on applications

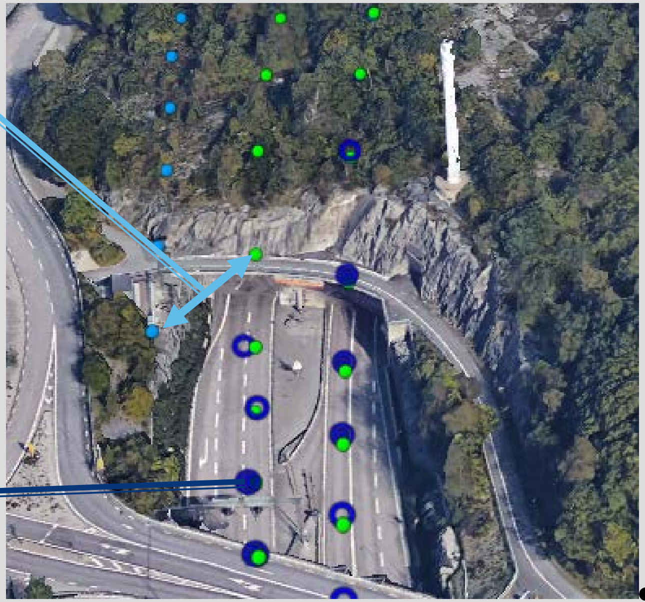


Performance data in tunnel scenario

Fast recovery to lane accuracy

1% of distance travel

Quick 2 sec convergence to lane



2 km tunnel in Gothenburg

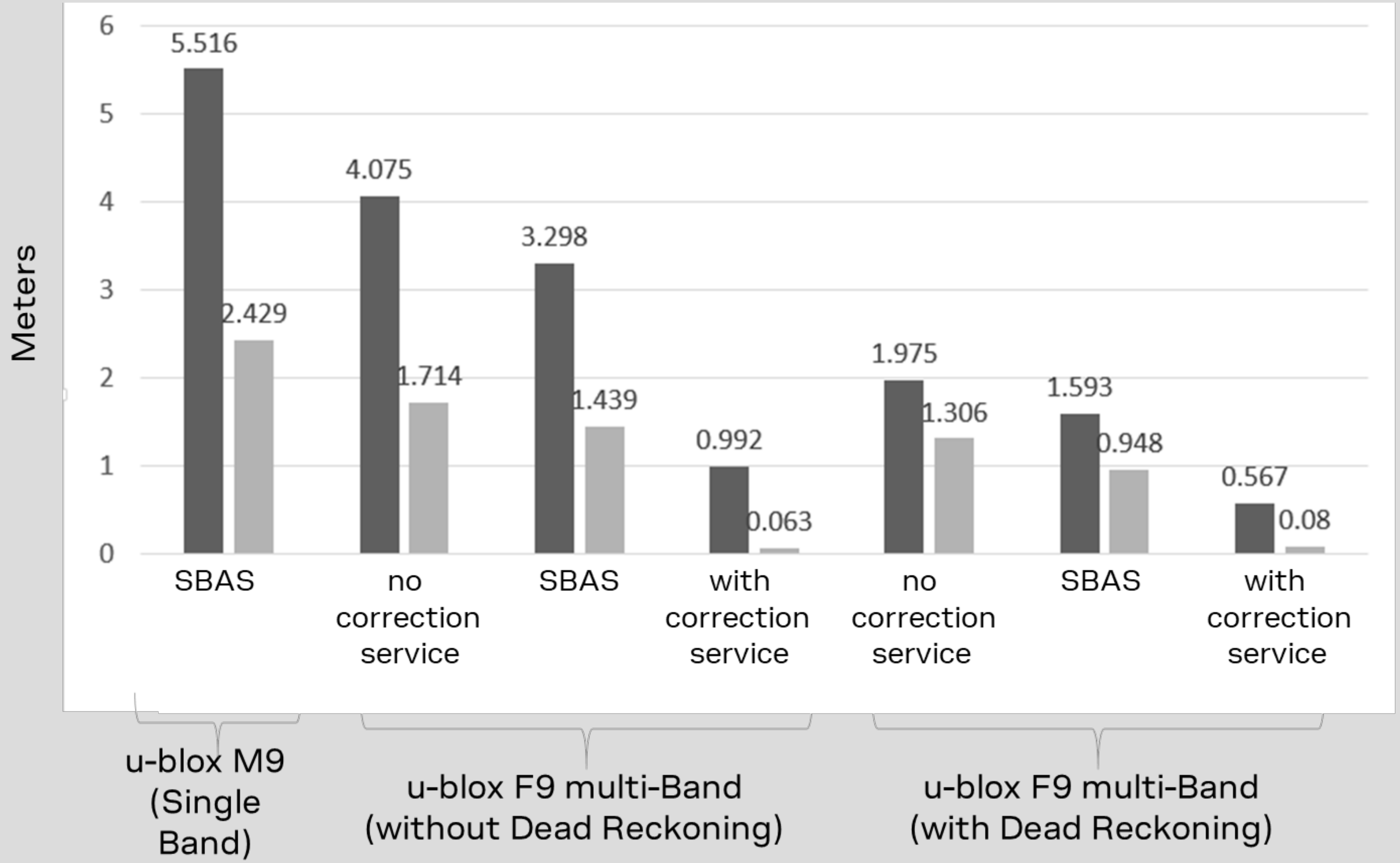
Dead Reckoning only

Fused Solution

Truth

Urban Scenario

DR improvements in urban conditions



Summary

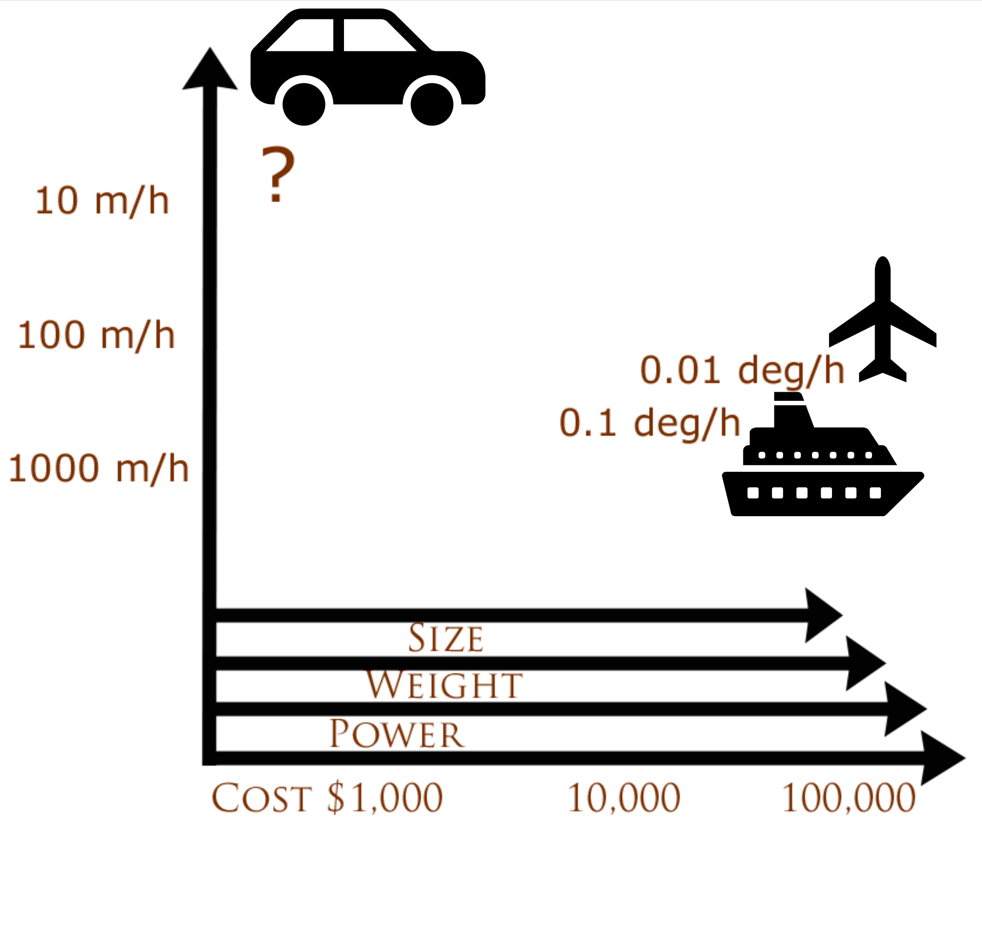
- 3D ADR brings reliable positioning even in case of outage, jamming, reflected or weak signals
- UDR does not require a connection to vehicle data and can be installed in any vehicle without extra cost
- ADAS applications using carrier phase GNSS via SSR/RTK
- Highly Automated applications require integrity and functional safety

Wheel-Mounted Inertial Navigation

Jussi Collin
CEO
Nordic Inertial

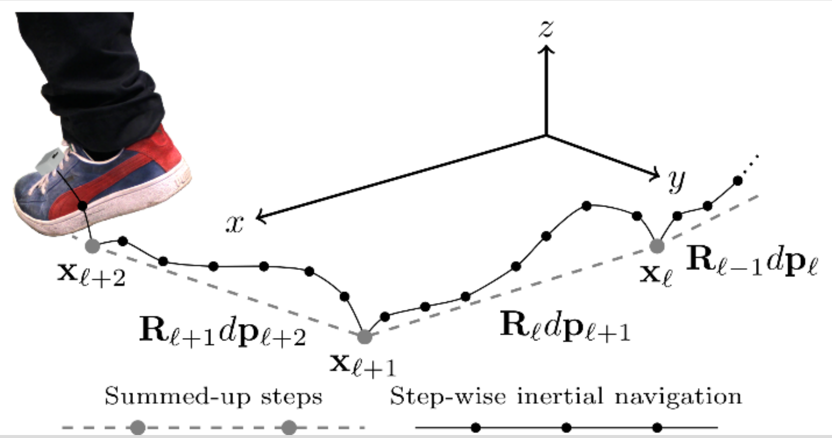
Background

- Inertial sensors provide observations **everywhere**
- Pure inertial challenging in terms of size, power, and cost
- GNSS or odometry may not be available
- Solution:
  - Add constraints
  - Calibrate the units for the specific application



Constrained Inertial Navigation

step-wise inertial → continuous inertial



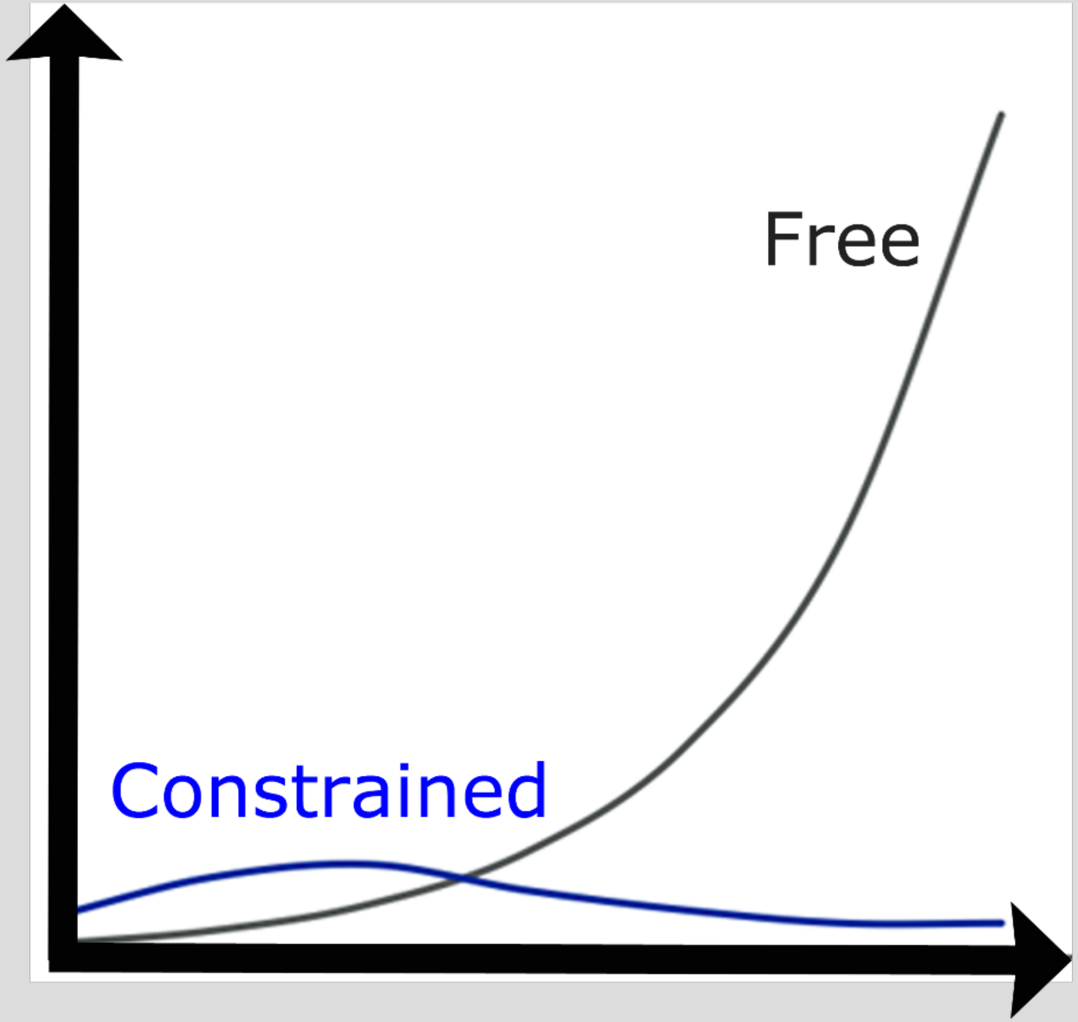
openshoe.org

Continental Shoe Bike

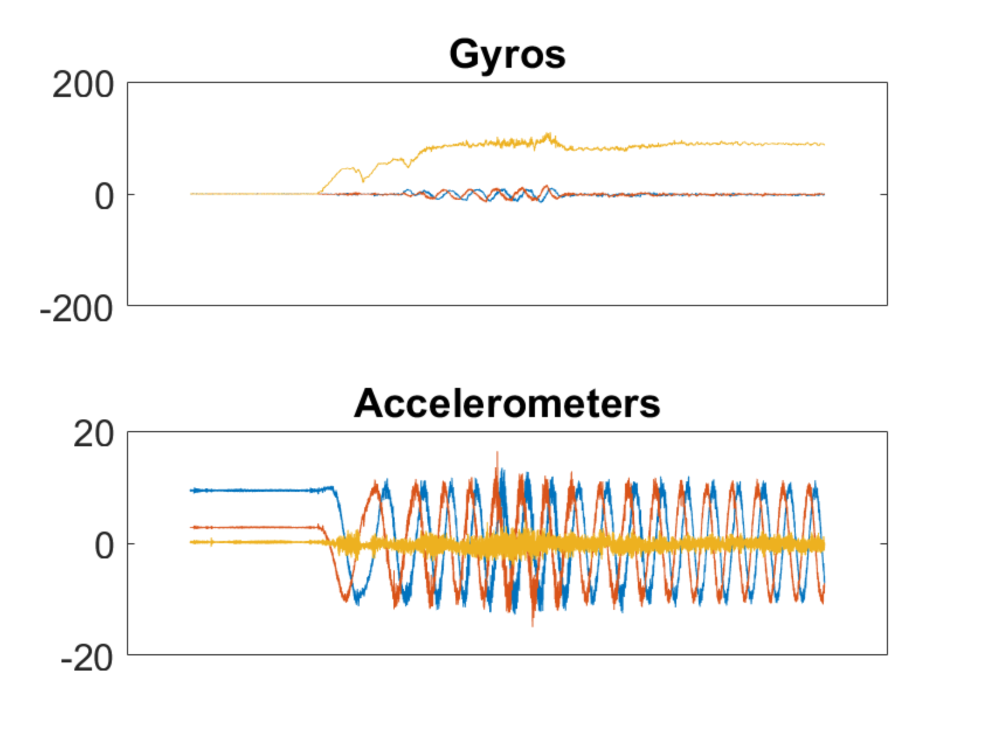
Position & Heading Drift

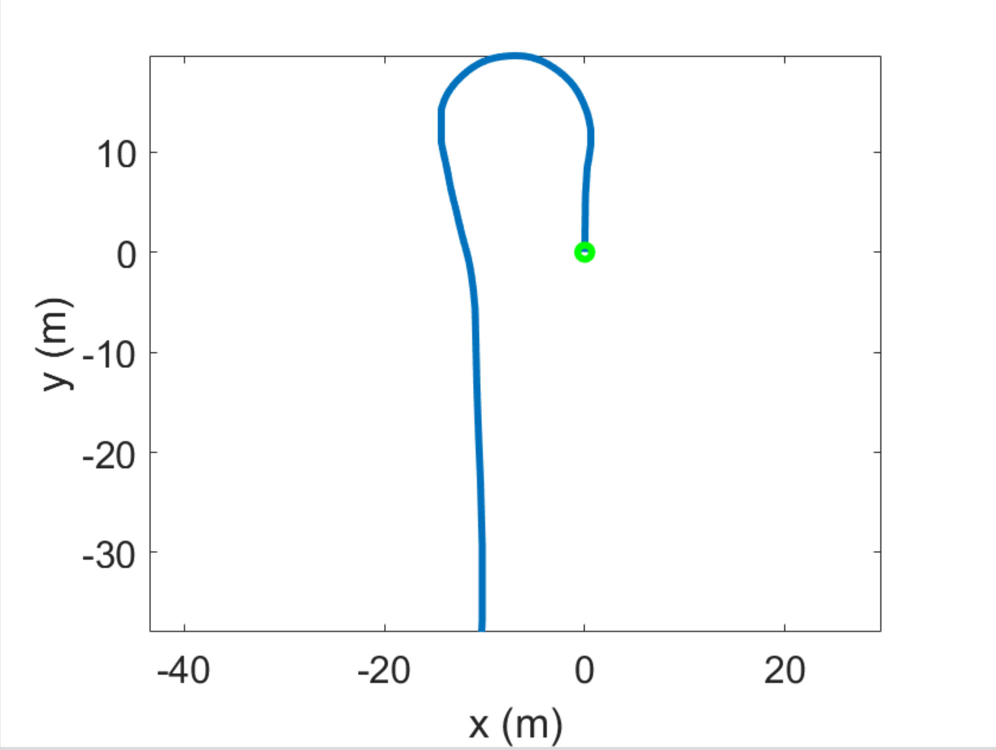
$$\iint_0^T \ddot{x} = f(\theta)$$

$$\int_0^{2\pi} \sin(t)dt = 0$$

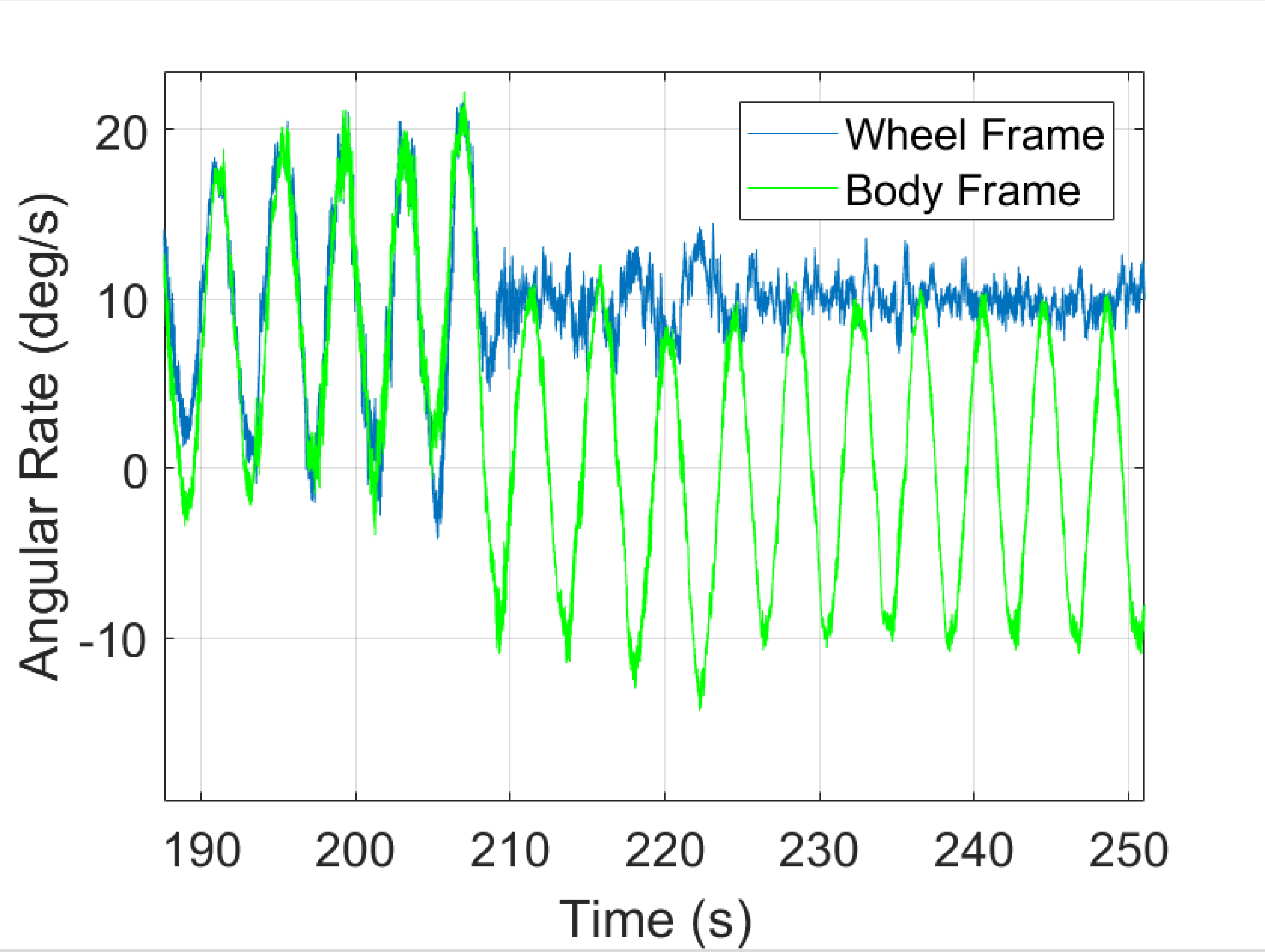


Does it work?

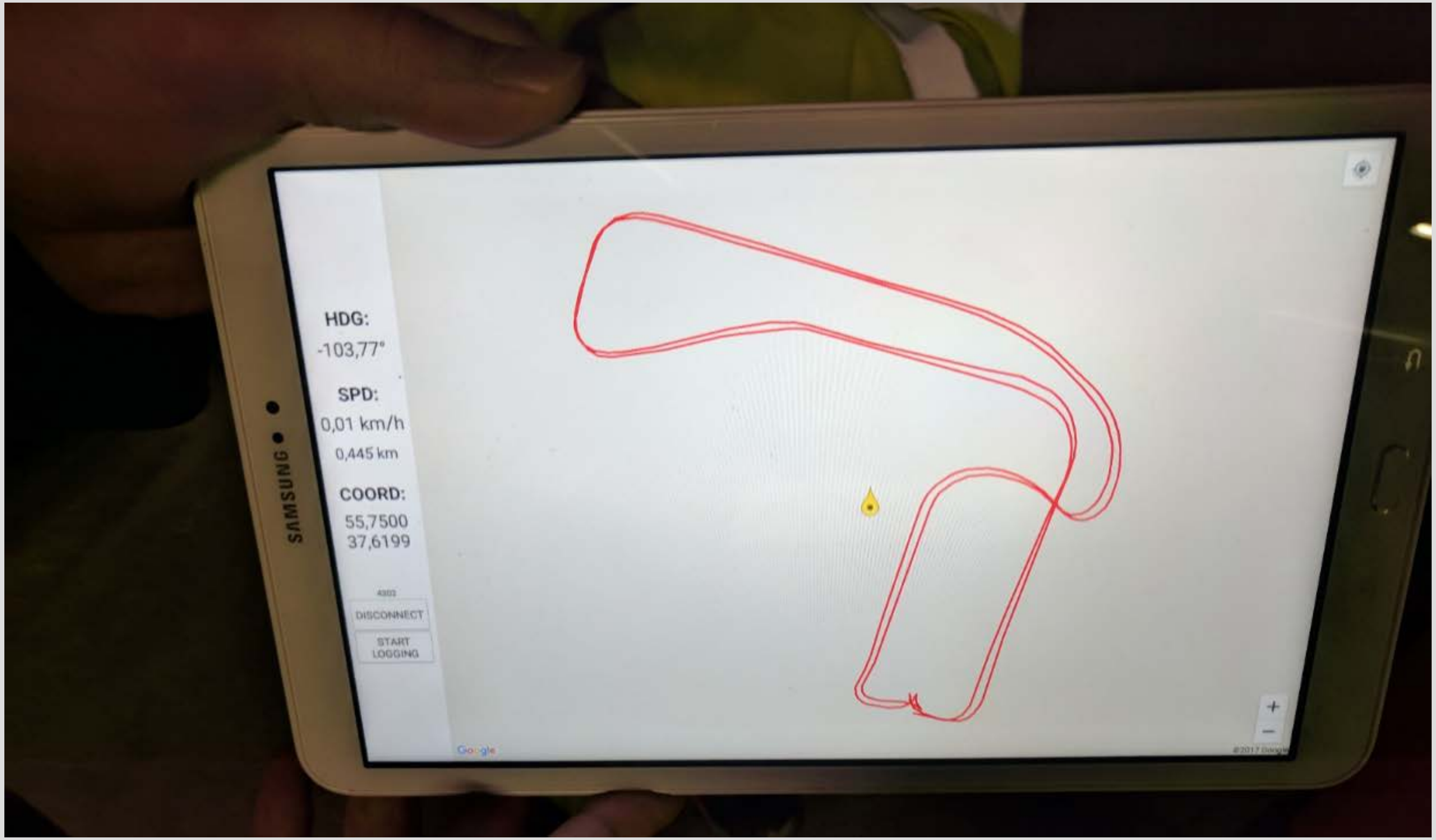

Gyros
200
0
-200
Accelerometers
20
0
-20


10
0
-10
-20
-30
y (m)
-40
-20
0
20
x (m)

Bias Modulation



Results: Underground 20 minutes



Data Conversion for Fusion Filters

- Output can be converted to dead reckoning format (wheel-tick + yaw rate) or in-car inertial (specific force + angular rate)
- Robot Operating System (ROS) etc. tools available

- Customization often necessary:
  - Extended battery (1 month)
  - Slip-ring version
  - Rugged for harsh usage environments

www.pacificinertial.com

- Extension to manipulators straightforward

Conclusions

- Constrained inertial systems provide fully inertial solution with reduced SWaP-C
  - Examples: foot-mounted inertial, wheel-mounted inertial, manipulator arm positioning
  - Both position and heading drift can be reduced, subject to pitch&roll dynamics

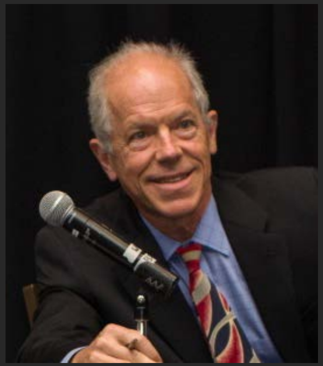
QUICKPOLL

In what platforms are low-cost inertial solutions best suited? (select two)

Poll Results (multiple answers allowed):

Car	71%
Machine control - Tractors and heavy machinery	29%
Drone / UAS	45%
Pedestrian	36%
Truck	23%

Ask the Experts



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